Sweet Disposition:
Individual, population and global positionings of sweet taste

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Copyright statement

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Abstract

The narrative that a greater exposure to sweet taste would increase the preference for sweet taste and consequently, increase sugar intake and lead to a higher prevalence of negative health outcomes, remains unproven and unclear; even though it sets the parameter for numerous sugar reduction recommendations. This thesis, therefore, aimed to explore the entirety of sweet taste in dietary intake and health outcomes, at the individual, population, and global levels. A randomised controlled trial was designed to assess the adaptability of sweet taste preference through dietary intervention with varied sweet taste exposures. Dietary sweet taste exposure at baseline showed no association with sweet taste preference, nor with indicators of obesity and Type 2 diabetes.

Notwithstanding, focus groups identified possible attitudes towards sweet-tasting foods, sugar, and sweeteners, towards their consumptions and towards related policies, in a small sample of the general public in the United Kingdom (UK). Individuals varied in their perceptions, motivations, and concerns towards these food items. A structured questionnaire was then developed to assess associations between attitudes and intakes, and to identify individual characteristics that may influence the prevalence of attitudes. Individual variations in attitudes remained in this larger sample of consumers. Individuals who felt they could manage their intakes, added sugar and consumed sugar food groups and total sweet-tasting food groups more frequently; individuals who felt they were unaffected, also consumed sugar food groups and total sweet-tasting food groups more frequently. Three latent sub-populations with distinct combinations of attitudes of different strengths were identified: feeling ill-equipped, actively engaged or unopinionated.

Moreover, approaches to quantify sweet taste exposure in the diet, amongst other tastes, were evaluated for their suitability and feasibility to characterise dietary taste exposure patterns in and across populations. These taste exposures and patterns were subsequently compared between Australia, France, the Netherlands, the UK, and the United States (US). While the diets within the countries mostly had similar taste combinations, they differed in the percentage contributions from these clusters to total energy intake. They also differed in their absolute dietary taste exposure, although some of their patterns displayed similarities, such as dietary sweet taste exposure contributing the most to total exposure in the diets of Australia, the UK, and the US.

This thesis challenged the common narrative of ‘sweet taste exposure – preference – sugar intake – health’, by looking at the direct relationship between exposure and preference, and health. It provided insights into individual, population and global variations in dietary sweet taste exposure and attitudes towards and intake of sweet taste. While further investigation into the adaptability of sweet taste preference and the aforementioned associations in more representative samples is required, this thesis highlighted the value for segmentation and prioritisation of specific sugar reduction strategies in distinct sub-populations.

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Author's declaration

I hereby declare that the work presented in this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

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Summary of completed courses and activities

Discipline-specific courses and activities

2019	Ambition to Results Workshop	Top Institute Food and Nutrition
2020	Psychological Perspectives on Obesity - Addressing Policy, Practice, and Research Priorities	British Psychology Society
2020	Nutrition 2020 Live Online	American Society for Nutrition
2020	A Review of the Science of Sweetness and Its Potential Impacts on Health	American Society for Nutrition
2021	Food Psychology and the Role of Low-Calorie Sweeteners in Appetite and Weight Control	International Food Information Council
2021	British Feeding and Drinking Group (BFDG) 45th Annual Meeting	BFDG
2021	Psychobiology of Eating Behaviours Course	WUR
2021	Sensory Perception and Food Choice into the Future Course	WUR
2022	Exposure Assessment in Nutrition Research Course	WUR
2022	British Feeding and Drinking Group 46th Annual Meeting	BFDG
2022	10th European Conference on Sensory and Consumer Research	European Sensory Science Society

General courses and activities

2019	Advanced Literature Search Techniques	BU
2019	Ethics - Values, Practice and Standards	BU
2019	Good Clinical Practice	NIHR
2019	Research Design and Analysis	BU
2019	SPSS Statistics Workshop	BU
2019	Interviews and Focus Groups	BU
2020	Creating Academic Posters	BU
2020	Writing a Literature Review	BU
2020	Planning and Writing a Food Science and Technology Thesis	BU
2020	Effective Postgraduate Researcher	BU
2020	Introduction to General Risk Assessment	BU
2020	Academic Writing	BU
2020	Critical Thinking in Writing	BU
2020	Questionnaire Design	BU
2020	Introduction to R	WUR
2021	BFDG 45th Annual Meeting Organising Committee	BFDG
2021	Café Scientifique Presentation	BU
2021	Tasty Talks Presentation I	WUR
2021	Mixed Methods Research	BU
2021	Seven Secrets of Highly Successful Research Students	BU
2021	Socio-Emotional Approach to my Doctoral Journey	BU
2021	Critical Appraisal of Qualitative Research Papers	BU
2021	Postgraduate Researcher Teaching Course	BU
2021	Un-box Your PhD Process & Take Charge of Your Performance	WUR
2021	Tasty Talks Presentation II	WUR
2021	Critical Thinking and Argumentation Course	WUR
2021	Masterclass on Habits	WUR
2022	Productive Writing Workshop	BU
2022	Scientific Writing Course	WUR
2022	Understanding and Planning for a Research Career	BU
2022	Understanding and Planning for a Career outside of Academia	BU
2019-2022	Health and Clinical Research Group Meetings	BU
2019-2022	Sensory Science and Eating Behaviour Group Meetings	WUR

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1. Overview

1.1. Context of the research

Sweet taste plays an important role throughout human history. Anthropologically, sweet taste has been postulated as a learned signal for the presence of sugars and energy, and is easily detected in common plants, hence sought out in foraging (Beauchamp, 2016; Mattes, 2021; Ramirez, 1990). More recently, new sources of sweet taste have emerged, which may not contain calories, resulting in discordance between sweet taste and nutrient content, particularly calorie content (Lease et al., 2016; Martin & Issanchou, 2019; Teo, van Langeveld, Pol, Siebelink, de Graaf, Yan, et al., 2018; van Langeveld et al., 2017). Research has also repeatedly shown that sweet taste per se is not predictive of diet quality and weight status (Alexy et al., 2011; Deglaire et al., 2015; Drewnowski et al., 1991; Frijters & Rasmussen-Conrad, 1982). Instead, sweet-tasting foods are distributed and found across various dietary patterns (Cox, Hendrie, & Lease, 2018; Gazan et al., 2016; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018).

In recent years, however, sweet taste has been a popular target by public health initiatives to reduce obesity rates and sugar consumption (Pan American Health Organisation, 2016; Tedstone et al., 2015; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016). For example, the World Health Organisation Regional Office for the Eastern Mediterranean recommended the reformulation of sugar-rich foods and drinks, without the use of sweeteners, to help the general public adapt to less-sweet foods and drinks and prevent unhealthy weight gain, Type 2 diabetes and dental caries (World Health Organisation Regional Office for the Eastern Mediterranean, 2016). In the United Kingdom (UK), Public Health England also published a report stating that dietary sugar intake could be reduced without sugar replacements as that would allow one's taste buds to adapt to a less sweet taste (Tedstone et al., 2015). This informed the views and actions of the government on dietary sugars; for example, to advise the public through The Eatwell Guide to gradually let their palates adapt to lower sweet taste and eventually cut out sugar altogether (Public Health England, 2018a). These recommendations are based on an assumption that lower sweet taste exposure would lead to lower sweet taste preferences and subsequently lower sweet taste consumption in terms of dietary sugars. However, a review indicated that this assumption has not yet been proven true (Appleton et al., 2018).

The straightforward narrative of 'reduced exposure = reduced preference = reduced intake' is understandably attractive. Obesity rates in the UK have doubled since 1993, putting the figures at 27% for men and 29% for women in 2019 (*Statistics on Obesity, Physical Activity and Diet, England, 2020*, 2020). It is also predicted that one in three UK adults could be at increased risk of Type 2 diabetes by 2030 (Lacobucci, 2021). In parallel, research has found that high sugar consumption is associated with increased obesity prevalence through higher calorie intake (Siervo et al., 2013; Te Morenga et al., 2013) and Type 2 diabetes through sugar-sweetened beverages (Imamura et al., 2015). Globally, the intake of sweetened foods and beverages has also corresponded to the increase in obesity rates (Baker & Friel, 2014; Popkin & Nielsen, 2003). Preferences for certain sensory characteristics may contribute to higher intake of foods with these characteristics (Ahrens, 2015; Chmurzynska et al., 2020). As demonstrated by Chmurzynska and colleagues, a higher preference for fat taste was positively associated with a higher intake of high-fat foods (Chmurzynska et al., 2020). The relationship between exposure and preference was also established for salt taste, where a reduction in exposure to salt reduced salt taste preference through adaption (Bertino et al., 1982, 1986). As such, it is logical to assume the same for sweet taste, where preferences for sweet taste will lead to higher intakes of sweet taste including sugar, and that reducing exposure to sweet taste will then curb sweet taste preferences and thus reduce intakes of sugar. Obesity, diabetes and their associated health conditions not only result in economic burdens, but also reduce health-related quality of life (Allender & Rayner, 2007; Bommer et al., 2018; Cannon et al., 2018; Graz et al., 2018; Stephenson et al., 2021). There is an urgency in finding the solution(s) to these problems through reducing over-consumption of sugars.

Considering all of the above, the relationships between sweet taste intake, sweet taste exposure and sweet taste preference should be clarified, especially in the context of whole dietary intake and health outcomes. A reductionist approach has been taken in many studies related to sweet taste, either focusing on 1) specific sources of sweet taste e.g., non-nutritive sweeteners; 2) certain settings e.g., mealtime, beverages; or 3) dietary changes e.g., randomised controlled intervention trials. This prompts the need to investigate the entirety of sweet taste in a whole diet in relation to dietary patterns and health outcomes, to better understand the role of sweet taste at an individual, population, and global level.

This chapter will introduce the thesis by first defining and discussing relevant concepts, their importance and existing research gaps. Referring to Figure 1.1., this section has provided the context of the thesis research. Section 1.2. will define sweet taste, sweet taste exposure and sweet taste preference; and section 1.3. will touch on the relationship between sweet taste exposure and preference. Section 1.4. will explore the literature on associations between sweet taste exposure and health outcomes in individuals and section 1.5. will discuss factors that may influence consumer sweet taste exposure and/or preference at an individual and population level. Lastly, section 1.6. will review the quantification of sweet taste exposure in the diet and its application at a population and global level. At the end of this chapter, the research aim and objectives will be presented alongside the thesis structure.

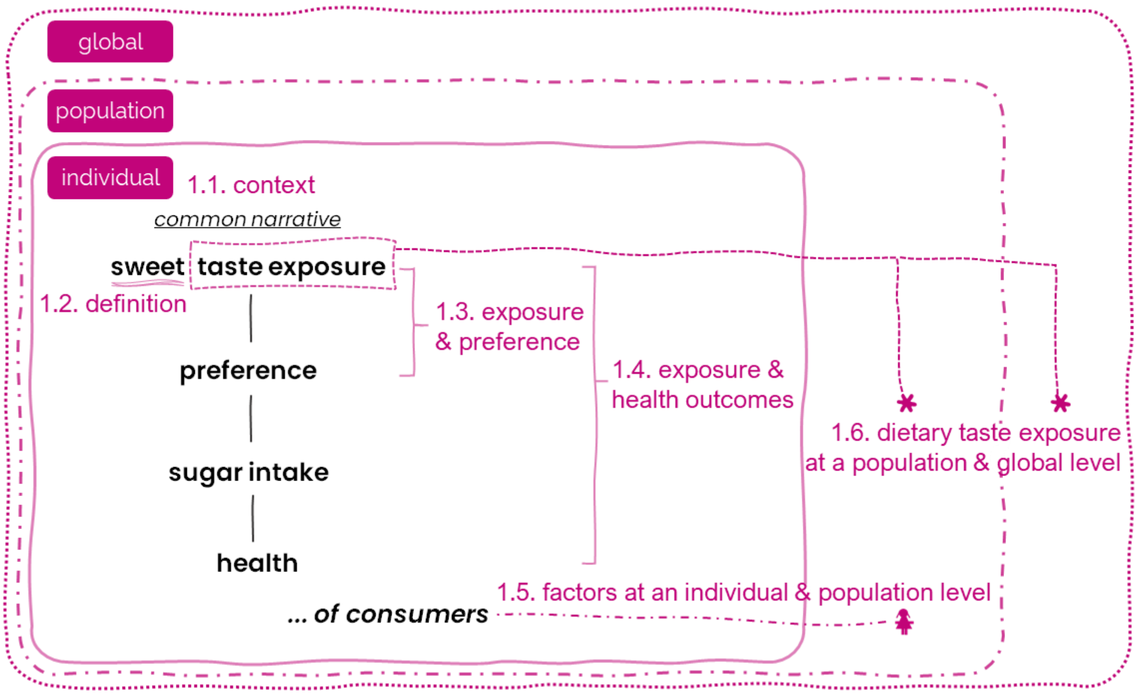

Figure 1.1. Structure of Chapter 1 – Overview.

1.2. Sweet taste

1.2.1. Sources

Sweet taste is the sensation experienced when sugar or another compound containing or resembling sugar in the mouth is sensed by taste 1 receptor member 2 (T1R2) and taste 1 receptor member 3 (T1R3) cells in taste buds (Jayasinghe et al., 2017; Lee & Owyang, 2017). These receptors can be stimulated by three categories of sweeteners:

1. Natural sugars

   These include glucose, fructose, sucrose and maltose.

2. Natural non-sugar sweeteners

   These include natural sugar alcohols (e.g., sorbitol, xylitol), stevia and monk fruit.

3. Artificial sweeteners

   These include isoglucose or glucose-fructose syrup, Acesulfame potassium (E950), Aspartame (E951), Cyclamate (E952), Neohesperidin dihydrochalcone (E959), Saccharin (E954), Sucralose (E955), Thaumatin (E957), Isomalt (E953) (Mortensen, 2006).

1.2.2. Scope of thesis

Sweet taste is defined as the sensation experienced from all or any of the sources specified above, in 1.2.1. Note: sweet taste can be provided by sugars and/or sweeteners. None of the work in this thesis focused on a particular source of sweet taste.

Sweet taste intake is defined as the dietary consumption of foods providing sweet taste, whereof may come from sweet-tasting foods, sugar and sweeteners.

Sweet taste exposure is defined as the experience of sweet taste in the mouth, as a result of sweet taste intake. Research on exposure to taste, flavour and food in the diet has been ongoing since the late 1960s, focused on its hypothesised effects on liking and boredom (Crandall, 1985; Moskowitz et al., 1975). For example, Crandall (1985) manipulated exposure to sweet doughnuts by providing participants with doughnuts over a period of 29 days with 13 exposure trials, and showed that the strength of liking for doughnuts increased with exposure. In another study, Moskowitz and colleagues (1975) classified the dietary history of participants into high or low exposure to sweet, sour, bitter and salt taste, and reported an effect of dietary history on taste preferences. These studies demonstrated that short-term intake with fixed frequency and duration (e.g., 13 exposure trials over 29 days) and long-term intake (e.g., habitual diet) of sweet-tasting foods result in exposure to sweet taste. Therefore, in this thesis, sweet taste exposure considers the frequency, intensity and/or duration of sweet taste intake.

Sweet taste preference is considered as both: 1) the choice of sweet taste over taste alternatives (relative impression) and 2) the liking for sweet taste (absolute judgement), including for a certain intensity or concentration of sweetness, which may be from various sources of sweet taste. The preference for sweet taste has long been regarded as innate (Alves et al., 2013; Birch, 1999; Desor et al., 1973; Nisbett & Gurwitz, 1970; Ramirez, 1990; Rosenstein & Oster, 1988), although pre- and post-natal sweet taste exposure may alter or reinforce sweet taste preferences in infants (Fidler Mis et al., 2017; Hetherington et al., 2011; Liem & Mennella, 2002; Mennella et al., 2001). For example, children with higher sweet taste exposure through sugar added routinely to their diets, preferred higher sweetness in cereals and apple juices, than children with no sugar added to their diets and had lower sweet taste exposure (Liem & Mennella, 2002).

Although 'preference' and 'liking' are distinct in the aspects of food acceptance they refer to (Mela, 2007), they are often used interchangeably in research on sweet taste (Armitage et al., 2021). For example, in a review on determinants of sweet taste preference, the authors also included studies that assessed liking of sweetened solutions on hedonic scales in addition to studies that measured preferred sweetened solution (Venditti et al., 2020). Thus, this thesis considers both absolute and relative judgement of sweet taste as sweet taste preference.

1.3. Sweet taste exposure and preference

This section will review what is known about the association between sweet taste exposure and sweet taste preference. Genetic influences and sweet-liker status will also be discussed, while the research gap will summarise what would be valuable to investigate next.

1.3.1. Associations between sweet taste exposure and preference

It has been hypothesised that dietary exposure to sweet taste affects the preference for and further intake of sweet taste in the diet. Given that there is a general liking for sweet-tasting foods through infancy and childhood (Mennella & Bobowski, 2015), and that these may foster long-term preferences in adulthood (Sylvetsky & Dietz, 2014), a possible underlying mechanism is that continual exposure to sweet taste sustains its preference. The opposite would then be valid – that continual lack of sweet taste exposure would reduce sweet taste preferences. This premise has been the foundation of several official guidelines to sugar reduction (Pan American Health Organisation, 2016; Public Health England, 2018a; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016). However, there is insufficient evidence for this. Studies varied vastly in their manipulation of exposure (e.g., intervention with sweetened beverages or low-sugar diet), methods to assess sweet taste exposure (e.g., modified sweet food frequency questionnaire or dietary record), stimuli used to evoke sweet taste (e.g., sucrose or sweeteners) and assessment of preference.

In a systematic review aimed to address the impact of dietary sweet taste exposure on sweet taste acceptance, preference, choice and intake in the diet, seven population cohort studies and 14 controlled trials were identified as relevant, and appraised (Appleton et al., 2018). The authors concluded that short-term exposure could effect changes in preferences, but evidence for the effect of longer-term exposure was limited and equivocal. Few studies that manipulated exposure to sweet-tasting foods managed to compare such exposure to a completely non-sweet exposure and exposure to other tastes was often the comparator (Griffioen-Roose et al., 2012; Hedrick et al., 2017; Hetherington et al., 2000; Liem et al., 2004; Sartor et al., 2011; Wise et al., 2016). In one study that compared short-term sweet to non-sweet exposure, participants were given a one-day diet that was predominantly sweet- or savoury-tasting. During an ad libitum lunch buffet the next day, participants who were shortly exposed to more sweet taste reported a lower liking, pleasantness and wanting for sweet foods (Griffioen-Roose et al., 2012). However, this may be attributed to sensory-specific satiety rather than a sustained hedonic shift. Such sensory-specific satiety occurs when there is diminished pleasantness from further sweet taste exposure, which can be activated by both sugar and sweeteners (Low et al., 2014; Rolls et al., 1988, 1990). An additional study (published since the review) provided participants with breakfast for three weeks, of either sucralose-sweetened cereal or plain cereal. After one and three weeks, there was no change in pleasantness and desire for sweet-tasting foods at breakfast and lunch (Appleton et al., 2022). Notably, exposure was only manipulated in one meal and participants of either exposure may have had similar sweet-tasting foods intake for the rest of the day. Additionally, results may be interpreted as an effect of with or without a sweetener, instead of sweet taste as a whole.

When individuals were experimentally exposed to sweet taste for a longer duration, resultant preferences for and intake of sweet taste were inconsistent (Hedrick et al., 2017; Piernas et al., 2013; Wise et al., 2016). Secondary analyses on two separate randomised controlled trials showed the same results; reduction of dietary sweet taste via sugar-sweetened beverages for six months resulted in higher intake of only one sweet food or beverage category (Hedrick et al., 2017; Piernas et al., 2013). Even though sweet taste preference was not explicitly measured, dietary intake of sweet foods, sweeteners and sugars were used as proxies. Adults with and without overweight all experienced the same lack of effect. In one trial, replacement of sugar-sweetened beverages with water led to a higher consumption of desserts but not of other sweet foods nor total or added sugars (Piernas et al., 2013). In the other trial, reduction in sugar-sweetened beverages per day led to increased intakes of beverages sweetened with low-energy sweeteners, but not sweet foods such as fruits (Hedrick et al., 2017). A more recent randomised controlled trial directly investigated the effect of sweet taste exposure on sweet taste preference, by supplementing different beverages over a period of 12 months; individuals were either exposed to unsweetened, sugar-sweetened, or artificially-sweetened beverages (Ebbeling et al., 2020). While favourite concentration of flavoured sucrose solution did not change for individuals who received sugar-sweetened beverages, it decreased for individuals who received unsweetened or artificially sweetened beverages. This suggests that exposure to sweet taste (sugar or artificial) in beverages does not have a clear effect on sweet taste preferences. Wise and colleagues (2016) measured sweet taste preferences in both liquid and semi-solid foods after a three-month diet intervention and saw no influence on most-preferred concentration nor on rated pleasantness. While it is possible that sweet taste exposure requires a longer duration to elicit changes in sweet taste preferences, the lack of consistent effects by short- and long-term exposure manipulations diminishes this possibility.

Longitudinal cohort studies could potentially shed light on the relationship between long-term exposure to and preference for sweet taste, by looking at habitual exposure through dietary intake assessments such as food dairies and food frequency questionnaires. While Liem and colleagues (2002) reported higher habitual sweet taste exposure with higher sweet taste preferences in children aged four to seven years, Liem and colleagues found the opposite effect in another cohort study on children aged four to five years (Liem et al., 2004). With a similar age range of two to six years old, research focused on early childhood dental caries compared children with different intake frequencies of sweets (regardless from sugar or sweeteners) and reported that children with lower intake frequencies had lower preferable concentrations of sucrose solution (Jurczak et al., 2020). Children with a higher habitual exposure to sweet taste in their diet could have preferences for higher sweet taste concentrations. However, in a cohort study undertaken on children across European regions, there was no difference in sweet taste preferences between higher and lower habitual consumption of sweet-tasting foods (Lanfer et al., 2012). The lack of conclusive evidence on this relationship is also observed in adults. In a group of female adults, Mahar and Duizer (2007) reported that female adults with higher frequencies of consuming sweetened beverages, either sugar- or artificially-sweetened, had higher liking for higher sucrose concentrations in orange juice. In another sample of female adults, those with higher intakes of energy, starch, fructose, glucose and total sugars had preferences for glucose solutions of higher concentrations; and a lower intake frequency of sweet-tasting foods was associated with lower preferences for sweetened beverages (Jayasinghe et al., 2017). These two studies suggest that individuals with lower dietary sweet taste exposure would have lower sweetness preferences with regards to beverages. In one study on male and female adults, participants with a higher total consumption of added or extrinsic sugar and a higher intake frequency of sweet-tasting foods preferred higher levels of sucrose across liquid, semi-solid and solid test foods (Holt et al., 2000). However, using habitual added sugar intake as a proxy for habitual sweet taste exposure, other researchers reported no effect of dietary exposure on liking for sweet taste in milk for both males and females (Stevenson et al., 2016). Notably, results from these studies only showed associations and no causality can be concluded.

In sum, both longitudinal cohort and experimental studies to date have not shown irrefutable evidence for the influence of sweet taste exposure on sweet taste preference.

1.3.2. Genetic influences and sweet-liker status

Individual variations exist in sweet taste exposure and preference. Regarding sweet taste exposure through sugar intake, there is evidence for genetic influences (Cai et al., 2004; Collaku et al., 2004) that may be mediated by sweetener-sensing mechanisms (Eny et al., 2008; Mace et al., 2007). Eny and colleagues (2008) identified a polymorphism of a facilitative glucose transporter (glucose transporter type 2, GLUT2) which was linked to higher sugar intake. Individuals with a Thr110Ile instead of (normal) Thr/Thr genotype had greater consumption of sucrose, fructose and glucose, from sweetened beverages, sweets, baked goods and chocolate. Interestingly, these individuals did not have higher intakes of fruits, fruit juices nor dairy products, which also contain sugars and are sweet tasting.

By the same token, individual differences in sweet taste preference exist (Pangborn, 1970) and may be influenced by genetic differences. A genome-wide linkage analysis revealed that liking for and intake frequency of sweet-tasting foods display 40-50% heritability (Keskitalo et al., 2007). These researchers found that variations in the chromosome containing TAS1R2 and TAS1R3 sweet taste receptor genes, chromosome 16p11.2, influence intake frequency of sweet-tasting foods. Subsequently, other studies found that variations in the TAS1R3 sweet receptor gene influenced sweet taste preference in adults. For example, mothers with the TT allele preferred water with a higher sucrose solution (Mennella et al., 2012, 2014). Notably, the effects of genotype on sweet taste preferences and intensity perception have not been observed in children. It could be that preference for sweet taste in children relates to the need for nutrients and hence, overrides genetic influences (Mennella & Bobowski, 2015).

Researchers have also began to classify individuals based on their sweet taste preferences – extreme sweet-likers, moderate sweet-likers and sweet-dislikers, by testing hedonic responses to a range of sucrose solutions or sucrose solutions of very high concentrations (Armitage et al., 2021; Holt et al., 2000; Iatridi et al., 2020; J. Y. Kim et al., 2014; Yeomans et al., 2007). Sweet-dislikers are thought to have lower tolerance for higher sweet concentrations, instead of disliking sweet taste altogether (Methven et al., 2016). This classification of sweet-liker status has been observed in large adult samples (Garneau et al., 2018; Iatridi et al., 2020). Researchers also found considerable differences between sweet-likers and sweet-dislikers in their proportions of added and total sugars to total energy intake (Holt et al., 2000) and intake of sugar-sweetened beverages (Garneau et al., 2018), where sweet-likers ate more sugars and sugar-sweetened beverages. When there are just two categories, sweet-likers or -dislikers, researchers showed that one month of sugar-sweetened soft drink consumption increased preference for sweeter sucrose solutions in sweet-dislikers but not sweet-likers (Sartor et al., 2011). This suggests that exposure to sweet taste could heighten preferences for individuals with low baseline preferences for sweet taste, although this is unlikely to be sustained since habitual carbohydrate and sugar intake does not seem to differ between these two categories of individuals (Methven et al., 2016). Regardless, sweet-liker status with three classifications may be an indicator of individual variations in sweet taste preference and perhaps also sweet taste intake and exposure.

1.3.3. Research gap on sweet taste exposure and preference

Section 1.3.1. discussed the literature on the association between sweet taste exposure and preference, which appear to challenge the narrative that sweet taste preferences may be altered through varied sweet taste exposure. Nevertheless, research has yet to show the effect of sweet taste exposure in the whole diet, from both sugar and sweeteners, on the adaptability of sweet taste preference. Section 1.3.2. reviewed the evidence regarding the genetic basis for individual variations in sweet taste exposure and preference and introduced sweet-liker status as a measure for individual variations in sweet taste preference. It is plausible that sweet taste exposure may have an effect on sweet taste preferences of sweet-dislikers due their lower motivation for reward-relevant stimuli (Iatridi et al., 2020; Sartor et al., 2011). It is of value to study the adaptability of sweet taste preference in a larger population, stratified according to sweet-liker status.

1.4. Sweet taste exposure and health outcomes

This section will discuss the position of sweet taste in relation to obesity and glucose regulation at an individual level. While the previous section touched on the ‘exposure–preference’ aspect of the ‘exposure–preference–sugar intake–health’ narrative, this section will review whether there is any direct association between sweet taste exposure and health outcomes. Sweet taste with obesity and glucose regulation will be reviewed separately and the research gap will summarise what would be valuable to explore next.

1.4.1. Sweet taste and obesity

Systematic reviews using meta-analyses have reported associations between increased obesity prevalence and high sugar consumption through higher calorie intake (Te Morenga et al., 2013) and increased type 2 diabetes prevalence with higher consumption of sugar-sweetened beverages (Imamura et al., 2015). Yet, looking at sweet taste in totality, there is limited evidence for its involvement in over-consumption and obesity.

A review on determinants of sweet taste preference reported that evidence points towards the absence of relationship between sweet taste preference and weight status (Venditti et al., 2020). Research on adults and children did not find differences in sweet taste preferences between individuals with lower or higher Body Mass Index (BMI) (Alexy et al., 2011; Grinker et al., 1987; Hardikar et al., 2017; Pepino et al., 2016; von Atzingen et al., 2012). In a study on infants of mothers with obesity, researchers used sucking responses to sucrose solutions as a measure for sweet liking but could not find any relationship with weight and fat of the infants (Grinker et al., 1987). When given apple juices of different sweetness levels, children who preferred higher levels of sweetness tended to be with obesity (Lanfer et al., 2012) or of any weight status (Alexy et al., 2011). In an adult sample comprising different races, sweet taste preferences did not differ between individuals with and without obesity (Pepino et al., 2016). Nonetheless, these studies focused on weight status, which has its limitations in diagnosing obesity (Banack et al., 2018; Okorodudu et al., 2010; Sommer et al., 2020; Wong et al., 2021).

Moreover, the assumption that sweet taste exposure should be reduced in efforts to reduce the prevalence of obesity suggests that sweet taste exposure is associated with obesity. Yet, this has not been shown. In one study, researchers investigated taste sensitivity and pleasantness with consumption behaviours in adults aged 19 to 79 years (Puputti et al., 2019). Participants were either in the healthy, overweight, or obese BMI category. Results showed that individuals with higher BMIs consumed fruits and berries less frequently and in smaller portions, but there was no association with consumption of sweet-and-fatty foods such as chocolate, ice-cream, and pastries. Using the weight of foods consumed from different taste and taste combinations in the diet as a proxy for dietary exposure to these tastes and combinations, sweet-and-sour and sweet-and-fatty exposure did not differ between individuals with and without overweight in Singapore (Teo et al., 2022). Meanwhile, studies on adolescents in the UK and adults in the Netherlands both found individuals with normal weight consuming more energy than individuals with overweight and obesity, from sweet-tasting foods (Bawajeeh et al., 2022; van Langeveld et al., 2018). Another group of researchers estimated dietary sweet taste intake by calculating grams of approximate sugar equivalent for sweetener-containing foods (Kamil et al., 2021). Their analysis on adults and children in the United States (US) revealed that dietary sweet taste intake was similar between the underweight, healthy weight, overweight and obese BMI groups (Kamil et al., 2021). These results suggest that exposure to sweet taste in the diet is not associated with weight status. Perhaps increased intake by individuals with overweight or obesity are driven by general preference for food, or preference for other tastes, instead of sweet taste, hence the excess energy intake (Te Morenga et al., 2013). It would be beneficial to investigate the associations between sweet taste exposure and other indicators of obesity and to clarify if sweet taste exposure itself is related to obesity, independent of sweet taste preference.

1.4.2. Sweet taste and glucose regulation

Individual differences in sweet taste preference may be associated with individual differences in glucose regulation. TAS1R2 and TAS1R3 sweet taste receptors have been discovered in gut endocrine cells, where glucose homeostasis, insulin secretion and appetite are regulated (Gerspach et al., 2011; Ochoa et al., 2015; Sclafani, 2007; Yee et al., 2011). In other words, the receptors that sense sweet taste in the mouth are also the receptors that sense sweet taste in the gut lumen. When sweet taste receptors sense sweet taste in the oral cavity, they send signals via the afferent nerve to the brain to perceive sweet taste consciously. They also send signals via the vagus nerve to the gastrointestinal tract to initiate functional responses (Low et al., 2014). When these receptors in gut sense sweet taste, they upregulate the expression of glucagon-like peptide 1 receptor and peptide tyrosine-tyrosine receptor, causing insulin secretion (Gerspach et al., 2011; Ochoa et al., 2015). It is clear that the sweet taste receptors in both the oral cavity and gut cooperate together to elicit physiological responses.

This suggests that healthy functioning sweet taste receptors in both locations will promote insulin and hence increase glucose uptake. Nonetheless, there is mixed evidence for the relationship between sweet taste exposure and glucose regulation. In healthy adults with normal weight, sucralose solutions led to impaired insulin responses when consumed with a carbohydrate (Dalenberg et al., 2020). However, the carbohydrate comparators, sucrose and maltodextrin, are different metabolically and physiologically. The results could have been confounded by the presence or absence of fructose. In response to this work, another group of researchers re-analysed the data to compare maltodextrin alone and with sucralose (Khan & Sievenpiper, 2021). They did not find any difference in insulin response, rejecting the statement that a combination of sucralose and a carbohydrate impairs insulin sensitivity. In another group of healthy adults, sucralose consumption over 12 weeks led to normal insulin responses and glycaemic control (Grotz et al., 2017). Sucrose and saccharin solutions also resulted in normal insulin responses in another study (Just et al., 2008). In a review by Daher and colleagues (2019), the literature on effects of non-nutritive sweeteners on insulin responses were heterogenous. It appears that different sources of sweet taste elicit different insulin responses. However, these studies differ in their stimulus for sweet taste receptors, concentrations for sweet taste receptor inhibitors and participant characteristics. Such studies are also not representative of a regular diet with different sources of sweet taste consumed alongside other macronutrients which may interact and influence physiological responses such as glucose regulation. The effect of sweet taste as a whole in the diet is unknown. Furthermore, its effect on glucose variability, an integral component of Type 2 diabetes (Breyton et al., 2021), is also unknown.

It would be helpful to first assess the relationship between dietary sweet taste exposure and glucose regulation in healthy adults, before investigating impaired glucose regulation. This may be assessed through parameters such as Haemoglobin A1c levels and parameters of short-term glucose variability (Breyton et al., 2021; Joshi et al., 2019; Lin et al., 2019).

1.4.3. Research gap on sweet taste exposure and health outcomes

This section has reviewed the literature on associations between sweet taste exposure and health outcomes, particularly obesity and glucose regulation. This is important given that sweet taste exposure has been a popular target by public health initiatives regarding obesity and Type 2 diabetes. However, it is unclear whether sweet taste exposure itself is associated with these health problems. Further research using a wide range of anthropometric measurements (fat mass, waist-to-hip ratio) and sweet stimuli in different contexts (meal-type, food texture) would be helpful to clarify if sweet taste exposure does change with and/or contribute to obesity. It will also inform on how individuals with and without obesity differ in their eating behaviours surrounding sweet taste. For example, whether they differ in their habits of adding sugar, artificial sweeteners, or other sources of sweet taste into their foods and drinks, or in their attitudes towards sweet-tasting foods. By understanding the relationship between sweet taste exposure and health outcomes, authorities may be able to come up with more suitable health initiatives and recommendations to target them.

1.5. Individual/consumer factors and sweet taste

This section of overview will discuss the position of sweet taste in relation to consumers and their intakes, at an individual and a population level. While previous sections went over the mechanisms of sweet taste exposure and preference, it is of value to investigate what consumers think about their sweet taste intake and exposure, as well as other factors that might influence their relationship with sweet taste and intake, both at an individual and population level. This section will first explain the importance of studying attitudes, followed by reviewing what is known about attitudes towards sweet-tasting foods, sugar, and sweeteners. Other potential influences, such as demographic factors and the sugar tax in the UK, will also be discussed. Lastly, the research gap will summarise what would be valuable to research next.

1.5.1. Importance of studying attitudes

Since the 1950s, attitude has been an important construct researched upon to explain behaviour (Ajzen & Fishbein, 2011). For example, Fazio and Towles-Schwen (1999) proposed that attitudes may predict behaviour when they are automatically activated, or guide intentions towards behaviour when deliberately activated. The theory of reasoned action, theory of planned behaviour, reasoned action approach and theory of reasoned goal pursuit all include attitude as a component which shapes intention, which then (partially) determines behaviour (Ajzen, 1991; Ajzen & Kruglanski, 2019; Fishbein & Ajzen, 1977, 2009). The theory of reasoned action suggests that the behaviour of an individual is predicted by their intention, which is a function of their attitudes and subjective norms (Fishbein & Ajzen, 1975). As an extension of this, the theory of planned behaviour posits that the behaviour of an individual is predicted by their intention and also perceived behavioural control (Ajzen, 1991). The reasoned action approach further extends this by differentiating each subcomponent, with attitudes comprising experiential and instrumental attitudes, perceived behavioural control comprising capacity and autonomy and perceived norms comprising injunctive and descriptive norms (Fishbein & Ajzen, 2009). More recently, to account for active goals which motivate behaviours, the theory of reasoned goal pursuit considers the approval goals and procurement goals of an individual to predict their behaviour (Ajzen & Kruglanski, 2019). Although these psychological theories differ in the extent to which attitude influences behavioural intention and behaviour, it is clear that attitude should be studied alongside research to understand eating behaviours.

One common thread through these psychological theories is that general attitudes may predict a combination of relevant behaviours, but only specific attitudes towards a specific behaviour may predict that behaviour. Moreover, attitudes may interact with beliefs, knowledge, perceived norms and personality traits, and even be modified by these other factors. Beliefs about possible outcomes of a behaviour may influence attitude towards a behaviour – either favourable when the beliefs are positive, or unfavourable when the beliefs are negative (Ajzen, 2012; Ajzen & Fishbein, 2011). For example, a belief that behaviour to reduce sugar intake is impossible may lead to an attitude that sugar reduction is futile. An attitude derived from a direct experience is also stronger and more predictive of a behaviour as compared to an attitude derived from second-hand information (Brügger & Höchli, 2019; Fazio et al., 1968; Glasman & Albarracín, 2006). For example, an individual's pleasant encounter with sugar will determine an attitude likely to override someone else's negative attitude towards sugar. Exploring attitudes is not sufficient to understand and explain behaviours. Perceived control and normative belief are crucial consideration factors (Ajzen & Schmidt, 2020).

Researchers have also considered the importance of other factors in understanding behaviour. Even if attitude, perceived control and normative belief are aligned with the behavioural intention, the behaviour may still require an active and dominant goal in place to occur (Kruglanski et al., 2018). Here is an example – the attitude would be to like drinking soda without sugar (artificially sweetened), normative belief would be that people hold drinking soda without sugar in high regard, and perceived control would be that the individual is good at avoiding soda with sugar. However, if there is no goal in place, such as reducing calorie intake, the individual might still not engage in drinking soda without sugar. Alternatively, if the individual aims to reduce calorie intake, but also wants to attend a party, it is now dependent on which active goal is more dominant. Notably, this specific behaviour needs to be chosen as the manner to attain the goal, which could be attained through other means. The extent to which this specific behaviour is evaluated by an individual as being likely to attain the goal will determine their desire and motivation to engage in the behaviour (Ajzen & Kruglanski, 2019). With considerations of these different types of desire, consumer researchers have proposed strategies to influence healthier eating behaviours. For example, to "carry a healthy sweet treat in one's pocket to eat instead of eating an unhealthy option" (Aguirre-Rodriguez et al., 2021, p. 2186), will be to provide an alternate manner to satisfy the appetitive desire to eat something sweet after a meal, consequently boosting the volitive desire to eat healthily and accordingly, attain the goal of healthy eating.

Putting everything into context, as an example, should an individual be preoccupied with other priorities in life, even though she thinks about dietary sugar or sweet taste reduction, evaluates herself as capable to do so, sees people around her doing so and feels motivated to do so, this individual may still not respond to public health initiatives that focus on the importance of dietary sugar or sweet taste reduction. Instead, this individual may respond well to initiatives that focus on the ease of doing so, even in light of other dominant goals in life, because this is related to her. Thus, it is important to study a multitude of attitudes, perceived control, relevance and motivation regarding eating behaviours surrounding sweet taste.

1.5.2. Attitudes towards sweet-tasting foods, sugars and sweeteners

Recent research on this topic has focused on overlapping themes between sugar-sweetened beverages, interventions, taxes and policies. These studies took place mostly in the US (Forde & Solomon-Moore, 2019; Morel et al., 2019; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019). Even though free sugars consumption in 2015 to 2016 were similar in the US and the UK, 12.7% and 11.1% of total energy intake respectively, the recommended free sugars intake differs between the two countries, 10% and 5% respectively (Bowman et al., 2019; Roberts et al., 2018). It is possible that the difference in dietary guidelines may generate different attitudes among consumers to meet the targeted intakes. While the majority of artificial sweeteners approved in both countries are similar, cyclamic acid and its sodium and calcium salts remain banned in America (Das & Chakraborty, 2016). These cross-country differences show the need to better understand consumer attitudes towards sweet taste, sugar and sweeteners, as well as sugar reduction strategies, in different countries. Harricharan and colleagues (2014) focused on registered dietitians across several European countries including France, Germany, Hungary, Portugal and the UK, in a qualitative study addressing low- or no-calorie sweeteners. There were distinct differences across the countries, for example, dietitians in the UK had less strong anti-sweetener views and expressed willingness to recommend them to clients. They were also more agreeable to take the stance of the authorities despite their own uncertainties about low- or no-calorie sweeteners. Since the general public is the target of public health initiatives, such as the sugar reduction programme, it is of interest and importance to find out their views and attitudes towards different sources of sweet taste.

1.5.3. Demographic factors

In addition to attitudes, demographic characteristics of individuals may influence their sweet taste intake, exposure or preference as well. In a sample of healthy adults, a higher education level was significantly associated with the habit of adding milk to coffee, while a lower education level was significantly associated with the habit of sweetening tea with sugar or honey (Puputti et al., 2019). Education is an indicator of socio-economic status, which influences dietary habits (Giskes et al., 2010). In the UK, the sugar reduction programme has had the least effect on total sugar purchased from soft drinks in the lowest socio-economic class (9% reduction, while the overall was a 24% decrease in total sugar purchased) (Public Health England, 2019). This suggests that health initiatives might be reaching certain population groups better than others. Moreover, a study in the US revealed that higher education level was associated with preferences for cereal with less sugar, in both adults and children (Mennella et al., 2011). Higher income level was also associated with lower preference for sucrose solutions. It is important to evaluate why preferences and habits for sweet taste differ across socio-economic groups and subsequently diversify strategies to each group.

The effect of age on sweet taste preference has been consistently proven, that it peaks during childhood and early adolescence, regardless of sweet taste sensitivity, then drops and maintains throughout adulthood (Desor & Beauchamp, 1987; Mennella et al., 2014; Zandstra et al., 1999). Mennella and Bobowski (2015) posited that higher sweet taste preferences in childhood may be related to the need for calories. In a study on children aged 11 to 15 years, children were grouped according to their preference for different sucrose solutions (Coldwell et al., 2009). The groups differed in levels of a biomarker for bone resorption and growth that is increased during a growth spurt (Yang & Grey, 2006). It is thus probable that at the cessation of physical growth, sweet taste preference decreases. Research has also observed that preference may increase again at old age, although the reason for this is not known yet (Mojet et al., 2005; Venditti et al., 2020). For example, adults aged 60 and above had a higher optimum sucrose concentration in iced tea compared to adults up to 33 years of age (Mojet et al., 2005).

On the other hand, the effect of biological sex provided no consistent findings (Mojet et al., 2005; Sartor et al., 2011; Weafer et al., 2017; Yeomans et al., 2007). When reviewing research on younger persons, boys preferred beverages with more sugar than girls (Mennella et al., 2011). In a group of young adults (mean age: 22.8±2.5 years), men appeared to have higher sweet liking than women of the same age (Sartor et al., 2011). Similarly, another study on young adults (median age: 22.0 years) reported that there were more extreme sweet-likers than sweet-dislikers in men compared to women (Iatridi et al., 2020). However, sweet-liker status distribution was similar between sex in another sample of young adults (median age: 20.2 years) (Iatridi et al., 2019). Men also had the same optimum concentration as women (mean age: 26.5±3.6 years) when adding aspartame to iced tea (Mojet et al., 2005). Yet, in elderly persons (mean age: 66±3.6 years), men had a higher optimum sweetness concentration than women when adding aspartame to iced tea (Mojet et al., 2005). The inconsistent findings may be partially explained by hormonal influences in females. In an early study on oral contraceptives, females who used contraceptives low in progestinic potency preferred much sweeter sucrose solutions than females who used contraceptives high in progestinic potency (Dippel & Elias, 1980). Progestin is a form of hormone that influences menstrual cycles, suggesting that hormonal changes may influence sweet taste preferences in females. As follows, several studies showed that sweet taste preferences decreased or increased during different phases of the menstrual cycle (Frye et al., 1994; Pliner & Fleming, 1983; Wright & Crow, 1973). Although these studies were not always in agreement on which phase and the direction of relationship, it is clear that hormones play a role in sweet taste preferences of females. Given that it is not possible to standardise the status of menstrual cycle in all female participants across all studies, sex differences in sweet taste preferences may appear to be inconsistent. It is thus inconclusive whether biological sex plays a key role in sweet taste preferences.

Ethnicity may also influence sweet taste intake and preference (Holt et al., 2000; Mennella et al., 2011; Turner-McGrievy et al., 2013). Significant differences in sweet taste preference were found between individuals who identified as Malaysians and individuals who identified as Australians, even though their habitual sweet-tasting food intake did not differ (Holt et al., 2000). The former rated the high concentrations of orange juice as much sweeter and rated them as less pleasant. In a sample of individuals with overweight or obesity, participants who identified as African-Americans were considerably more likely to be sweet-likers compared to other racial groups (Turner-McGrievy et al., 2013). This is in line with previous studies including individuals of African descent (Mennella et al., 2011; Pepino & Mennella, 2005; Reed & McDaniel, 2006). In another sample of healthy adults, White participants preferred breakfast cereals with less sugar content, as compared to Black participants (Mennella et al., 2011). It is evident that ethnicity is a demographic factor to be considered in understanding the position of sweet taste in relation to consumers, both at an individual and population level.

1.5.4. Soft Drinks Industry Levy

Since 2016, Public Health England initiated a sugar reduction and reformulation programme to reduce the amount of sugar in food products that contribute most to children’s intake (Tedstone et al., 2017). This led to the reformulation of The Eatwell Guide which advises the public to let their taste buds gradually adapt to lower sweet taste, in order to eventually cut out sugar altogether (Public Health England, 2018a). Guidelines on marketing and price promotions were also published to narrow health inequalities, alongside plans to increase accredited training in diet and health (Tedstone et al., 2015). Moreover, since 2018, the UK implemented a ‘Soft Drinks Industry Levy’ (SDIL). Commonly known as the sugar tax, the SDIL is a nationwide tax on soft drinks that contain at least five grams of sugar per 100 millilitres (HM Revenue and Customs, 2016).

Research on public perceptions of the SDIL showed mixed results, with one study showing strong support and belief of its effectiveness (Pell et al., 2019), and another study showing otherwise (Swift et al., 2018). Notably, these studies were conducted prior to the implementation of this policy. It has been five years since the introduction of SDIL, it is probable that opinions might have changed. Given that the government is pushing for sugar reduction, it is important to investigate consumers attitudes towards current strategies and identify any area or population group for segmentation and prioritisation.

1.5.5. Research gap on attitude towards and intake of sweet taste

Section 1.5.1. put forth the importance of studying attitudes and how they play an integral role in driving behavioural intentions and behaviours themselves. Following that, section 1.5.2. presented the need to consider consumer attitudes towards all sweet-tasting foods, sugar, and sweeteners. Sections 1.5.3. and 1.5.4. added other influences to be considered when attempting to clarify the relationships consumers have with these food items. Putting them together, consumer attitudes towards these food items may inform on their subsequent behaviours towards and intake of these food items. If dominant attitudes exist in certain population groups, and these attitudes are linked to higher sugar intakes, public health initiatives may then target these population groups and encourage attitudinal change to drive healthier intake.

To date, little research has been undertaken on the associations between attitudes towards and intake of sweet taste (and its various sources). Studies have been carried out to assess sugar intake and its relationship with attitudes towards sugar (Gupta et al., 2018). However, researchers have not included sweeteners nor assessed various sources together. To the postgraduate researcher's knowledge, there has also been no publication on the identification of latent populations with attitudes that may be linked to higher sugar intakes. Thus, attitudes towards sweet taste as a whole, the prevalence of these attitudes in a population and their associations with actual intake should be elucidated.

1.6. Sweet taste exposure in the diet

This section of overview will consider the quantification of taste in dietary intake, at a population and global level. As section 1.1. pointed out, research on sweet taste intake, exposure and preference has typically focused on specific sources of sweet taste and meal settings, instead of investigating the entirety of sweet taste in a whole diet. However, to truly clarify the mechanisms behind sweet taste exposure and preference in relation to each other and health outcomes, it is important to devise methods on quantifying sweet taste in the diet, amongst other tastes. This section will first review what is known about taste in dietary patterns i.e. dietary taste patterns, then discuss the research gap in this area.

1.6.1. Dietary taste patterns

Dietary patterns play an important role in determining nutrient and health status. “Healthy” dietary patterns have been linked to better metabolic health (Fallaize et al., 2018), lower risk for cardiovascular disease (Nestel & Mori, 2022), secondary prevention of heart failure (Dos Reis Padilha et al., 2018), lower diabetic risk (Zhao et al., 2020), reduced risk for low bone mineral density and fracture (Fabiani et al., 2019), and better cognitive health in older adults (Chen et al., 2019). Concurrently, taste plays a pivotal role in determining dietary patterns. Taste may be an early signal for nutrient content of a food (Teo, van Langeveld, Pol, Siebelink, de Graaf, Yan, et al., 2018; van Dongen et al., 2012; van Langeveld et al., 2017), improve food palatability, acceptance and liking (Bertino et al., 1986; Kourouniotis et al., 2016; Shimojo et al., 2014; Tang et al., 2020), activate reward in the brain (Berridge et al., 2009; Grabenhorst et al., 2010; E. T. Rolls, 2015), and influence satiation and satiety (Bolhuis et al., 2013; Griffioen-Roose et al., 2012; Low et al., 2014; McCrickerd & Forde, 2016; Yeomans & Chambers, 2011). Thus, dietary patterns should be assessed from a taste perspective as well.

To characterise dietary taste patterns in relation to eating behaviours and health outcomes, taste needs to be first quantified in dietary intake. Pertaining to sweet taste, quantification of exposure to its sources have been traditional food-borne exposure assessments focused on specific nutrients such as fructose (Ebrahimpour-koujan et al., 2018), singularly on sugar (Farsad-Naeimi et al., 2020) or sweetener (Debras et al., 2022; Martyn et al., 2018; Takehara et al., 2022), or on specific products such as beverages (Yin et al., 2021). Kamil and colleagues (2021) estimated exposure to sweet taste in totality by obtaining grams of approximate sugar equivalent for all sweetener-containing foods in the diets of adults and children in the US. However, foods that do not contain sweeteners or added sugars may still be sweet-tasting and other tastes in the diet are overlooked. In another study, consumers classified foods as either sweet, sour, bitter, savoury, salt or neutral tasting (Bawajeeh et al., 2022). Their diets could be characterised according to their dominant tastes, but there was no indication of intensity of those taste characteristics. Subjective classification also implied that prior experience of consumers with these foods may have influenced their decisions. There exist several sensory taste databases, each consisting of frequently and commonly consumed foods of a population and intensity values (sweet, salt, bitter, umami and salt taste, and fatty mouthfeel) of each food (Lease et al., 2016; Mars et al., 2020; Martin et al., 2014; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018). These values were rated by trained sensory panels. Subsequently, these sensory values are matched with the diet of the population and regarded similarly to macro- or micro-nutrients of foods to be analysed.

To date, dietary taste patterns of four populations have been elucidated. These are of Australia (Cox, Hendrie, Lease, et al., 2018), Malaysia (Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018), the Netherlands (van Langeveld et al., 2018) and Singapore (Teo et al., 2022). Sweet and salty taste and fatty mouthfeel were significant predictors of energy intake in Australia (Cox, Hendrie, Lease, et al., 2018). In Malaysia, bitter, neutral, sweet and sour, sweet and fatty, and savoury and fatty foods respectively contributed 2%, 14%, 15%, 19% and 50% to energy intake (Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018). In the Netherlands, bitter, fatty, sweet and sour, sweet and fatty, savoury and fatty, and neutral foods respectively contributed 3%, 7%, 14%, 23%, 25% and 28% to energy intake (van Langeveld et al., 2018). Lastly, in Singapore, bitter, sweet and sour, sweet and fatty, neutral, and savoury and fatty foods respectively contributed 3.4%, 6.6%, 7.1%, 29.6% and 53.0% to energy intake (Teo et al., 2022).

1.6.2. Research gap on dietary taste patterns across countries

Eating behaviours differ considerably between cultures and environments (Cunha et al., 2018; B. F. Kim et al., 2020; Tuorila & Hartmann, 2020). There is a need to better understand how dietary taste patterns vary across population groups and tailor public health initiatives accordingly. For instance, the World Health Organisation currently recommends the intake of free sugars to be less than 10% of total energy intake, while Public Health England recommends 5% (Tedstone et al., 2015; World Health Organisation, 2015). If dietary sweet taste exposure proves to be important in strategies related to sugar reduction, obesity or Type 2 diabetes, a clearer idea of dietary (sweet) taste patterns in different population groups and their relation to health outcomes may be necessary.

Moreover, dietary taste patterns of these countries were elucidated because each of them has its own sensory taste database (Lease et al., 2016; Mars et al., 2020; Martin et al., 2014; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018). It is unlikely that all populations (and countries) will have the resources to train their own sensory panels and rate their commonly and frequently consumed foods. The aforementioned databases are also subsets of their food composition databases, suggesting that tasting and rating all foods consumed by a population is laborious and if not, impossible. Therefore, the approach to quantifying taste in the diet and characterising dietary taste patterns needs to be refined and developed in a way that is realistic and allows for comparisons across populations and/or countries.

1.7. Aim and Objectives

1.7.1. Aim

To explore the role of sweet taste exposure in an individual's diet, covering health and attitudinal aspects; in a population as a whole; in relation to attitudes and other tastes; and in dietary taste patterns across countries.

1.7.2. Objectives

1.7.2.1. Objective One: To design a dietary intervention trial to assess the adaptability of sweet taste preferences through varied sweet taste exposure.

Little is known about whether and to what extent the innate preference for sweet taste can be modified by experiences later in life (Venditti et al., 2020). A long-term dietary intervention with a 'whole diet' approach to vary sweet taste exposure will enable us to better understand the potential adaptability of sweet taste preference, its mechanisms and its influences on sweet taste intensity perception, food choice and intake, dietary taste preferences, glucose variability and body composition. **Chapter 2** will lay out the details of this study design.

1.7.2.2. Objective Two: To investigate the associations of sweet taste exposure with sweet taste liking, sweetness preferences and health outcomes in individuals.

With the intervention trial of Chapter 2 designed and implemented, baseline measurements will be collected. This will allow for a direct investigation on any existing relationships between a whole diet approach of sweet taste exposure and sweet taste liking, sweetness preference, as well as health outcomes such as body composition and glucose variability. All findings will be presented and discussed in **Chapter 3**.

1.7.2.3. Objective Three: To explore attitudes towards sweet-tasting foods, sugar and sweeteners, towards consumption and towards related policies, in a sample of the general public of the UK.

A clear understanding of individuals' attitudes towards and subsequent acceptance, use and intake of sweet taste and its sources could lead to better forethought and implementation of public health policies regarding dietary sugars, sweet taste and sweetener intake. To the researcher's knowledge, a qualitative study on sweet-tasting foods as a whole, sugar and sweeteners has not been conducted on consumers living in the UK. Qualitative methodology will enable exploration of individuals' reasons behind their behaviours (Dean et al., 2015). A combination of focus groups, dyadic interviews and solo interviews will be conducted to generate a wide range of perspectives and understandings until data saturation is reached. **Chapter 4** will detail the methodology, results and discussion from this work.

1.7.2.4. Objective Four: To assess the associations between attitudes towards and intake frequencies of sweet-tasting foods, sugar and sweeteners, as well as identify the dominant attitudes, in a sample of the general public of the UK.

The findings from Chapter 4 will be used to design a questionnaire which assesses attitudes towards sweet-tasting foods, sugar and sweeteners. The questionnaire will also include measures of intake frequencies of these foods and demographic and lifestyle questions such as age, education level and BMI. A cross-sectional study will be performed to assess the associations between attitudes and intakes at a population level. This questionnaire will be distributed to the general public of the UK. The results will indicate the relationships between specific attitudes and dietary sweet taste and sugar intakes, and dominant attitudes in specific individuals or groups. This work will be explained in depth in **Chapter 5**.

1.7.2.5. Objective Five: To determine the most suitable approach to both characterise and compare dietary taste exposure and patterns across diets and/or populations.

The role of taste in dietary intake has been studied in several populations, by combining taste properties with food intake data (Cox, Hendrie, Lease, et al., 2018; Teo, van Langeveld, de Graaf, et al., 2018; van Langeveld et al., 2018). Yet, there exists different approaches to assess taste exposure and characterise dietary taste exposure across populations. This endeavour involves assigning values of taste properties to food intake data and the quantification of each taste exposure from a diet. Different methods for both steps will be identified and assessed on their suitability and feasibility to characterise dietary taste exposure and patterns, including sweet taste, and whether they can be applied across different diets. These will be detailed in **Chapter 6**.

1.7.2.6. Objective Six: To characterise and compare dietary taste exposure and patterns across countries.

Following the determination of suitable methods to characterise dietary taste exposures and their patterns from Chapter 6, these methods will be applied to different countries with different dietary sugars intake. Dietary taste exposures and patterns of Australia, France, the Netherlands, the UK and the US will be investigated and compared. Results will indicate if countries with varied dietary sugars intake also have similar variations in dietary sweet taste exposure. Moreover, this work will shed light on the applicability and transferability of results from the dietary intervention trial outlined in Chapter 2. The results will be presented and discussed in **Chapter 7**.

The context of this thesis has been introduced in **Chapter 1** (see Figure 1.2. on the right). The research aims and objectives have been identified, and the value of such research put forth. **Chapters 2 to 7** will address the six objectives. All their findings will be discussed in **Chapter 8**, focusing on their interpretation, significance, societal relevance, strengths and limitations, originality and directions for future research. Lastly, conclusions on the thesis will be drawn.

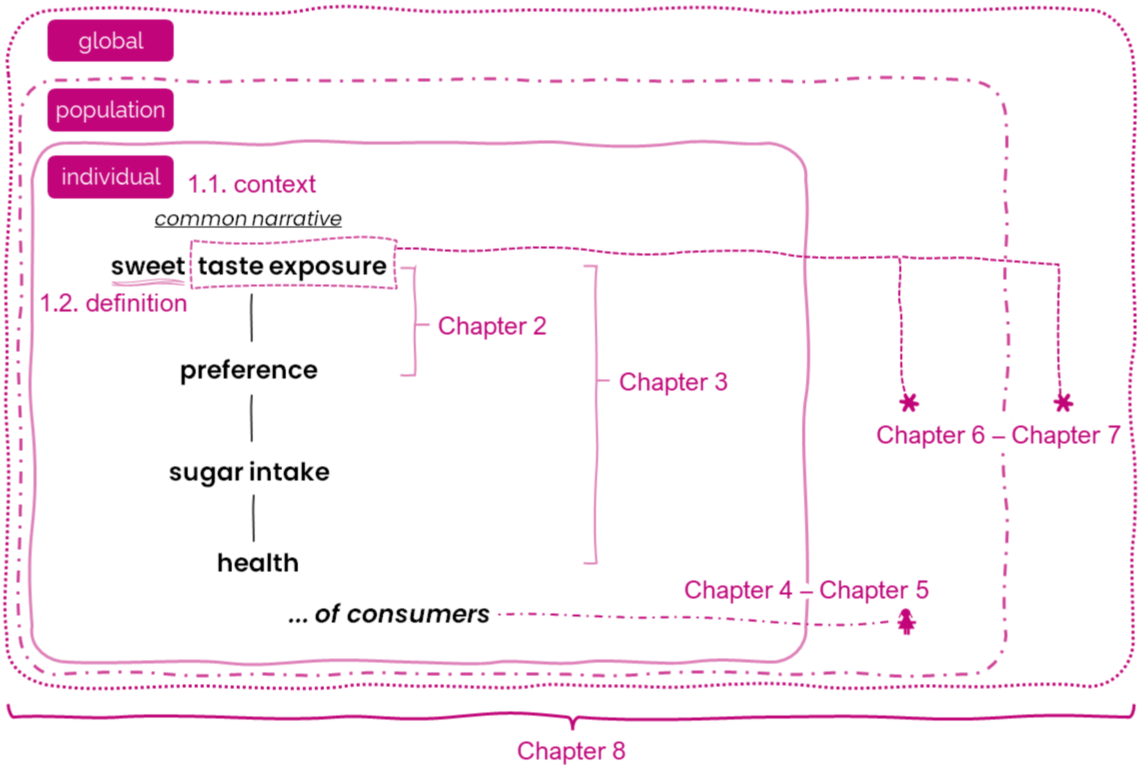

Figure 1.2. Structure of thesis chapters – Overview.

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2. Sweet Tooth I: Study design of a randomised controlled trial on the adaptability of sweet taste preference through varied sweet taste exposure

This chapter contains the design of randomised controlled trial that is part of a public-private partnership (PPP) project known as 'Sweet Tooth: nature or nurture?' (PPP number: AF-17107 [19NH01 Sweet tooth]). The committee consisting of companies and research organisations are involved in the design and organisation of this project. The postgraduate researcher has been in the core team meant to execute this project. Her contributions are as follows:

i. Literature review for final ethical approval and amendment;
ii. Setting up the investigator site file and other report documents;
iii. Minutes for committee and core team meetings;
iv. Development of breakfast, snacks, intervention diets and test foods including the final pilot test;
v. Development of cover story including study debrief materials;
vi. Logistical arrangements;
vii. Protocols;
viii. Recruitment and screening;
ix. Data collection for sensory and biological outcomes;
x. All study newsletters; and
xi. Any other support to the main PhD fellow of Wageningen University and Research.

2.1. Introduction

The fundamental premise of numerous public health initiatives on sugar reduction is dietary sweet taste exposure affects the preference for and intake of sweet taste in the diet (Pan American Health Organisation, 2016; Tedstone et al., 2015; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016). Yet, it appears that the lack of consistent results from short- and long-term exposure manipulations and longitudinal cohort studies undermines this notion (Chapter 1).

A reductionist approach has been taken in many of these studies either focusing only on 1) specific sources of sweet taste e.g., sugar-sweetened beverages (Hedrick et al., 2017) or sweets (Jurczak et al., 2020); 2) certain settings e.g., lunch buffet (Griffioen-Roose et al., 2012) or beverages (Ebbeling et al., 2020); or 3) dietary changes e.g., randomised controlled intervention trials using intake as a proxy for preference (Piernas et al., 2013; Stevenson et al., 2016). Moreover, attempts to modify sweet taste exposure were short-lived and may be explained by sensory-specific satiety rather than a sustained hedonic shift (Griffioen-Roose et al., 2012; Rolls et al., 1988). The longest dietary intervention was three months, by Wise and colleagues (2016), but the intervention was also lower sugar rather than lower sweet taste in the diet. Consequently, no one has tested the adaptability of sweet taste preference through a whole diet approach of manipulating sweet taste exposure.

Moreover, sweet taste preferences are typically assessed using sweet solutions e.g., sucrose solution (Ebbeling et al., 2020; Sartor et al., 2011) or sucrose added to a limited range of test foods, e.g., milk, fruit beverage or pudding (Stevenson et al., 2016; Wise et al., 2016). This is in spite of preference for specific sweet taste intensities being highly dependent on the food matrix (Abdallah et al., 1998; Divert et al., 2017). For example, a sucrose concentration of 30% weight by weight is preferred in cakes, but is considered too sweet in soft drinks. Instead, 10% weight by weight is optimal in soft drinks, and would be inadequate in cakes (Abdallah et al., 1998). Food matrix also plays an important role in downstream energy and metabolic responses (Forde & Bolhuis, 2022). Notably, these studies also use sucrose as the source of sweet taste, while there are other sources available. Furthermore, individuals' past experience may affect their liking for a food (Tan et al., 2015, 2017). Their experience with and preference for sweet taste in familiar foods may differ from foods they are unfamiliar with. Therefore, the adaptability of sweet taste preference should be evaluated across a range of foods that differ in familiarity and food matrix, across a range of concentrations derived from different sources of sweet taste.

It is still unclear how sweet taste preference, sweet taste intensity perception and other behaviours surrounding sweet taste may relate to glucose regulation, and how they may differ between individuals with and without obesity. As discussed in Chapter 1, sweet taste preferences were found to be higher in some foods (Puputti et al., 2019), lower (Pepino et al., 2016), or the same (Alexy et al., 2011; von Atzingen et al., 2012) between individuals with and without obesity. Similarly, sweet taste intensity perception was lower (Bartoshuk et al., 2006; Sartor et al., 2011) or the same (Low et al., 2016; Pepino et al., 2016) between individuals with and without obesity. However, none of these studies conducted their sensory evaluations across a range of test foods differing in familiarity and food matrix. Regarding behaviours surrounding sweet taste and glucose regulation, current literature on the effects of non-nutritive sweeteners on insulin responses are heterogenous (Daher et al., 2019), and certain sweet solutions seem to cause different insulin responses in individuals with and without obesity (Nichol et al., 2019). These associations have been tested in experimental settings. However, individuals also consume other macronutrients in their regular diet, which may interact and influence physiological responses such as glucose regulation. Given that reduction in sweet taste is in the narrative of sugar reduction in response to the prevalence of obesity, it is crucial to elucidate the relationship of (healthy) weight status and glucose regulation with sweet taste preference and intensity perception.

To sum up, the adaptability of sweet taste preference should be properly assessed using a variety of test foods; sweet taste exposure should be varied with a whole diet approach and for a longer time period; and these sensory measures should be studied alongside anthropometric and biological measures. With these in mind, a randomised controlled dietary intervention trial was designed and is currently running. This trial may also be referred to as the Sweet Tooth study. The primary aim of the Sweet Tooth study is to assess the effects of six-months low, regular and high dietary sweet taste exposure on sweet taste preference in foods and beverages. The secondary aims are to assess the effects of six-months low, regular and high dietary sweet taste exposure on i) sweet taste intensity perception in foods and beverages; ii) behavioural outcomes including food choice and intake, sweet-liker type, food cravings, taste preferences and dietary taste patterns; iii) anthropometric outcomes including body composition, waist-hip circumference and, body weight; and iv) biological outcomes such as HaemoglobinA1c, glucose variability, and biomarkers related to cardiovascular diseases and diabetes.

The main research hypothesis (H0) is specified as a 30% change in contribution of dietary sweet taste exposure to total energy intake will lead to at least 10% change in sweet taste preference on a 100-point scale over time. The first, second and third secondary hypotheses are that the impact of sweet taste exposure on sweet taste preference is modulated by differences in texture (H1), familiarity (H2) and taste intensity (H3). The fourth, fifth and sixth secondary hypotheses are that the impact of sweet taste exposure on sweet taste intensity perception is modulated by differences in texture (H4), familiarity (H5) and taste intensity (H6). The final four hypotheses are that dietary sweet taste exposure is associated with body composition (H7), HaemoglobinA1c (H8), glucose variability (H9) and biomarkers related to cardiovascular diseases and diabetes (H10).

2.2. Methods

2.2.1. Design

The Sweet Tooth study is a randomised controlled trial with six months of parallel intervention and four months of follow-up. The three intervention groups are regular sweet exposure (RSE; control), low sweet taste exposure (LSE), and high sweet taste exposure (HSE). All three groups of participants are enrolled concurrently and undergo the trial in parallel. All procedures have been developed and are implemented according to the ethical principles outlined in the Declaration of Helsinki (World Medical Association, 2001). Upon enrolment, participants are allocated randomly to an intervention group by an independent researcher. Participants have their baseline measurements taken approximately one month before their intervention diet begins. Subsequently, participants are required to visit the research facility in the first, third and final month of their intervention diet. Thereafter, the diet is no longer provided and participants have to visit in the seventh and tenth month, for their follow-up measurements.

2.2.2. Participants

2.2.2.1. Sample size

The sample size required for this trial is based on detecting change in most preferred sweet taste intensity from baseline to month six of intervention. It was possible to detect shifts from preference tests of approximately 10% difference in a sample of 30 participants in three different age groups (Zandstra et al., 1999), and in a sample of 60 participants in three different exposure groups (Liem & de Graaf, 2004). An effect size of 0.1 was deemed relevant and meaningful to be used in sample size calculation. Consequently, as a parallel trial with repeated measures, three groups, two time-points (baseline vs. month six), and a power of 80% at significance level 0.05, at least 147 participants are required to detect a difference of 10%. Additionally, it is shown that interventions with long durations are correlated with higher dropout rates (Lucey et al., 2016). Hence, to account for a potential dropout rate of 20%, the final sample size was decided to be 180 participants.

The Sweet Tooth study aims to enrol 180 adults aged 18 to 65 years. This study is conducted in the Netherlands and hence, study participants should be living in the Netherlands, proficient in Dutch, and able to visit the research facility in Wageningen University and Research (WUR) for all test sessions. Participants are blinded to the real purpose of the study and are instead told that the study aims to determine the effect of sensory properties of foods, like texture, taste and colour, on glucose metabolism and biomarkers related to risk for diabetes. The actual study aim will only be revealed to all participants at the end of the trial, when all participants have completed the follow-up period as well. Participants are informed that their participation is completely voluntary, and they can withdraw from the study any time without explanation. All participants are compensated for their participation, up till the time-point they stop. Reimbursement is 550 euros if participants complete the entire study, and an additional 150 euros if they also consent for glucose regulation measurements.

2.2.2.2. Eligibility criteria

Participants are determined eligible if they are within the age range of 18 to 65 years, have good general health (self-reported), and of normal weight or overweight (Body Mass Index (BMI) range of 18.5 to 30.0 kg/m^2). Participants should also have healthy blood glucose levels, determined as ≥ 6.1 mmol/L for fasting and ≥ 7.8 mmol/L for non-fasting condition. Participants should not have established diabetes mellitus or insulin resistance, endocrine, metabolic or other medical condition(s) that would influence glucose metabolism, have an eating disorder, taste or/and smell disorder, have gained or lost more than 3 kg in the last three months prior to study entry, suffer from lack of appetite, use medication that may influence taste perceptions and/or glucose metabolism, have food intolerances and/or allergies, are pregnant or lactating, have an excessive alcohol consumption (>14 glasses/week), use soft or hard drugs, are a student or personnel of the Division of Human Nutrition and Health of WUR, and are participating or planning to participate in another study, during the Sweet Tooth study. In case of pregnancy and/or systematic weight change of ≥ 4 kg over a three-month period, participants will be withdrawn from the study.

2.2.2.3. Recruitment

Participants are recruited through several channels. Firstly, email invitation with the information brochure, flyer and a link to the study website (https://isense-study.nl/), is sent to a pre-existing participant database of the division of Human Nutrition and Health of WUR. This invitation is routinely sent to the database every quarter to half a year. The flyer is also distributed on social media such as Facebook, printed media, and physically at streets or buildings with prior consent. Every interested individual is invited to an information meeting to receive further details and receive a consent form to sign. Once the individual and researcher have both signed the form, the individual has to complete a screening questionnaire that includes questions related to the eligibility criteria outlined in section 2.2.2.2. When deemed eligible, the participant is invited to the Human Nutrition Research Unit of the division for an on-site screening session. During this visit, a researcher will measure the participant's height and weight with a clinical stadiometer and scale (SECA, Germany), blood glucose levels with a finger prick (FreeStyle Freedom Lite, Abbott, UK), taste ability with the validated, standardized Taste Strip Test (Burghart Taste Strips, MediSense, Germany) (Mueller et al., 2003), and sweet-liker status with a 1M sucrose solution (Iatridi et al., 2019). The sweet-liker status assessment will be explained in further details in section 2.2.4.3. After the screening session, the results are evaluated by an independent medical investigator to confirm eligibility.

2.2.2.4. Randomisation

The BMI, sex, age, and sweet-liker status of each participant from their screening session are used to assign them to an intervention group. This is a process of stratified randomization which facilitates balanced baseline characteristics between all three groups, at a ratio of 1:1:1 (Altman & Bland, 1999). Randomization is performed by an independent researcher, using a computer-generated randomisation list. This list is stored in a password-protected folder, only accessible by authorised personnel. This trial is double-blinded, as both participants and researchers are blinded to the intervention allocation during both data collection and data analyses. Unblinding for participants will occur at trial termination, when the final participants complete their follow-up period. Unblinding for researchers will occur at the end, when statistical analyses are completed.

2.2.3. Dietary intervention

The Sweet Tooth study is controlled with partial dietary intervention, as participants receive 50% instead of 100% of the food items from their intervention diet. The rationale is to reduce participant burden of following a strict diet for half a year, to allow them to freely choose their fresh fruits and vegetables and potentially increase compliance by increasing convenience to them. The dietary intervention of this trial is based on a novel methodology that enables quantification of taste in the diet (van Langeveld et al., 2018). The LSE intervention group follows a diet that allows for 10-15% contribution of sweet taste to total energy intake. This is comparable to the dietary guidelines of the Netherlands, where 15% of energy intake comes from sweet-tasting foods (Health Council of the Netherlands, 2015; van Langeveld et al., 2018). The RSE intervention group follows a diet that allows for 25-30% contribution of sweet taste to total energy intake. This is based on the average Dutch diet, where 28% of energy intake comes from sweet-tasting foods (van Langeveld et al., 2018). The HSE intervention group follows a diet that allows for 40-45% contribution of sweet taste to total energy intake. This diet is also followed by the general public of the Netherlands. While the three intervention groups differ in their dietary sweet taste exposure, they are comparable in macronutrient composition; the energy provided by fat, protein, carbohydrates and fibres are similar (Table 2.1). Sweet taste in the diet comes from both natural sugars and sweeteners.

The average macronutrient composition, energy and weight of provided intervention foods for each group is shown in Table 2.2. As liquid food intake is associated with lower taste exposure as compared to solid food intake, emphasis was given to ensure the distribution of liquids, semi-solids and solids across all three intervention groups (Bolhuis et al., 2013; Viskaal-van Dongen et al., 2011). The three groups differ in their proportions of sugar-sweetened, low-calorie-sweetener-sweetened and non-sweet foods, as summarised in Table 2.3. The Dutch Smaak, Vet en Textuur database was used to allocate foods differing in taste profiles to the three intervention groups (Mars et al., 2020). To ensure that the groups differ in dietary sweet taste exposure from the provided intervention foods (50% of the diet), 7% of the foods provided to the LSE group are sweet-tasting, 35% of the foods provided to the RSE group are sweet-tasting, and 80% of the foods provided to the HSE group are sweet-tasting. Moreover, the provided intervention foods mainly include breakfast and snack items such as bread toppings, dairy products, nuts, chocolates and crackers, as dietary taste patterns in the Netherlands vary most during breakfast and snacking occasion (van Langeveld, 2018). Some examples of the daily menu and intervention foods delivered every fortnight, across all three intervention groups, may be referred to in Appendices 1 and 2.

Table 2.1. Energy and macronutrient composition of the intervention diets per day averaged over the 28-day rotating menu, calculated based on estimated energy needs of an average woman (2200 kcal).

Nutrients	**Low Sweet Exposure**	**Regular Sweet Exposure**	**High Sweet Exposure**
Energy (kcal)	2,191	2,207	2,206
Protein (g) (en%)	92.1 (17.0)	88.6 (16.3)	84.6 (15.5)
Fat total (g) (en%)	85.4 (34.4)	85.6 (34.2)	82.9 (33.1)
Saturated fat (g) (en%)	21.9 (9.0)	22.5 (9.2)	24.6 (10.0)
Carbohydrates (g) (en%)	244.4 (45.2)	251.1 (46.1)	260.5 (47.8)
Mono and disaccharides (g) (en%)	66.2 (12.1)	84.2 (15.3)	98.1 (17.8)
Polysaccharides (g) (en%)	175.7 (32.1)	163.6 (29.7)	160.4 (29.1)
Dietary fibre (g)	36.5	36.4	39.2
Sodium (mg)	2,375	2,031	1,984

Table 2.2. Macronutrient composition, energy and weight of the fortnightly-provided intervention foods for each intervention group.

Sweet Exposure		**Low**	**Regular**	**High**
Energy (MJ (kcal))	Liquids	13.1 (3,140)	14.1 (3,370)	14.5 (3,475)
	Semi-solids	40.6 (9,704)	40.7 (9,714)	40.8 (9,758)
	Solids	62.4 (14,894)	62.4 (14,909)	63.1 (15,062)
	Total	**116.1 (27,739)**	**117.2 (27,993)**	**118.5 (28,296)**
Protein (g)	Liquids	288.0	287.0	268.0
	Semi-solids	329.3	242.5	241.3
	Solids	475.8	232.6	253.0
	Total	**1,093.1**	**762.1**	**762.3**
Fat total (g)	Liquids	24.0	24.0	80.0
	Semi-solids	758.9	654.6	568.3
	Solids	789.0	719.1	661.9
	Total	**1,571.9**	**1,397.7**	**1310.2**
Carbohydrate (g)	Liquids	426.0	486.0	373.0
	Semi-solids	361.7	646.7	868.9
	Solids	1380.5	1766.9	1972.7
	Total	**2,168.2**	**2,899.6**	**3,214.5**
Mono and disaccharides (g)	Liquids	434.0	494.0	357.0
	Semi-solids	278.4	503.6	827.6
	Solids	827.6	948.1	1,474.0
	Total	**952.8**	**1,945.7**	**2,658.6**
Weight (g)	Liquids	14,000	14,500	14,500
	Semi-solids	4,465	4,015	3,820
	Solids	3,339	3,134	3,171
	Total	**21,304**	**21,149**	**21,491**

Table 2.3. Proportion of sweet tasting liquid, semi-solid and solid intervention foods provided per intervention group.

Number of	Products containing	Low Sweet Exposure	Regular Sweet Exposure	High Sweet Exposure
Liquids	Nutritive sweetener[1]	0	1	0
	Low & non-nutritive sweetener[1]	0	0	9
	Total	**0**	**1**	**9**
Semi-solids	Nutritive sweetener[1]	0	1	10
	Low & non-nutritive sweetener[1]	0	3	3
	Total	**0**	**4**	**13**
Solids	Nutritive sweetener[1]	1	8	10
	Low & non-nutritive sweetener[1]	2	1	1
	Total	**3**	**9**	**11**
Number of provided sweet-tasting foods (% of sweet-tasting products provided)		**3 (6.6%)**	**14 (35%)**	**33 (80%)**

[1]Number of sweet tasting intervention foods that are delivered to participants on a biweekly basis.

The intervention foods are provided ad libitum, where participants receive a surplus of foods without further instructions on how much they should consume. This is arranged to their homes every fortnight. Alongside the food items, participants receive a booklet every month, which includes checklists of intervention foods to record their daily consumption of intervention foods, thereby facilitating monitoring and dietary compliance. The booklet also consists of daily menus and recipe inspirations. Before participants begin with their intervention diet, they meet with a research dietitian for comprehensive dietary counselling and guidance. Such meetings are also arranged every month, where the dietitian checks their booklets, and encourages participants in their adherence to the diet.

2.2.4. Outcome measures

The outcomes of this trial can be categorised into several groups. The primary outcome is change in sweet taste preference from baseline to month six of dietary intervention. The secondary outcomes include sweet-liker status, sweet taste intensity perception, eating behaviours, anthropometry, biological and compliance measures. Behavioural outcomes include food choice and intake, taste preferences, dietary taste patterns and food cravings. Anthropometric measures are BMI, waist-to-hip ratio and body composition. Biological outcomes include glucose regulation and blood biomarkers related to cardiovascular diseases and diabetes. To measure compliance, there are 24-hour (24-h) dietary recalls and 24-h urine biomarkers. Lastly, to account for potential moderators on the intervention, physical activity, adverse events, demographic characteristics and awareness of study aim are measured.

2.2.4.1. Sweet (and salty) taste preference

Sweet taste preference is assessed in six sweet-tasting test foods. In addition, to evaluate if the effect(s) of dietary sweet taste exposure is specific to sweet taste, salty taste preference is also assessed in two salty-tasting test foods. As discussed in Section 2.1., sweet taste preference is highly dependent on the type of food matrix (Abdallah et al., 1998) and familiarity of the foods (Tan et al., 2015). Therefore, the test foods differ in food form (liquid, semi-solid and solid) and familiarity (familiar and unfamiliar). Each test food has five concentrations, from least sweet/salty (L-2) to most sweet/salty (L+2), adapted from a validated protocol to assess sweet and salt liking in different foods (Urbano et al., 2016). All foods were developed over a period of one year, with 127 participants across four pilot studies (Cad et al., *in preparation*). Table 2.4. provides an overview of the test foods with their concentration levels.

Table 2.4 Test foods used in both preference and intensity testing, with sweetness and saltiness concentration levels and percentages of added sweet source (sugar and sweeteners) and salt in % by weight, for each concentration.

	Test food	Food form	Serving size	Sweet concentration[1] (% by weight)				
				L-2	L-1	L-0	L+1	L+2
Familiar	**Strawberry-flavoured lemonade**[2]	Liquid	20 ml	0.00	1.26[a]	3.08[a]	8.56[a]	15.06[a]
	Chocolate-flavoured custard[2]	Semi-Solid	15 g	3.41[a]	6.59[a]	12.37[a]	17.57[b]	26.33[b]
	Plain Cake[2]	Solid	20 g	9.13[a]	16.74[a]	19.15[b]	21.88[b]	25.10[b]
Unfamiliar	**Watermelon-flavoured lemonade**	Liquid	20 ml	0.00	1.26[a]	3.08[a]	8.56[a]	15.06[a]
	Elderflower-flavoured custard	Semi-Solid	15 g	3.61[a]	6.98[a]	13.05[a]	18.90[b]	27.59[b]
	Tamarind-flavoured cake	Solid	20 g	9.13[a]	16.74[a]	19.15[a]	21.88[b]	25.10[b]
				Salt concentration [1] (% by weight)				
				L-2	L-1	L-0	L+1	L+2
Familiar	**Gazpacho**	Liquid	20 ml	0.05	0.15	0.30	0.72	1.46
	Butter cracker	Solid	3.5 g	0.00	0.71	1.37	3.50	7.05

[1]Five sweetness and saltiness concentrations, with the middle level (L-0) representing the optimal sweetness or saltiness sensation; initially based on the quantity present in the commercial products or recipes as described by Urbano et al. (2016), and adjusted after pilot-testing with Dutch consumers. [2]Recipes are also adapted from Urbano et al. (2016). [a]Added sugar. [b]Added sugar and sweetener (based on cyclamate and saccharin (Rio Zoetstof, Sweet Life AG, Switzerland)).

To measure both the preference (choice of one between two or more) and liking (the extent to which the choice is preferred) components of sweet taste preference (as defined in Chapter 1), rank-rating approach is used in this study (Kemp et al., 2017). At one go, participants are presented with all five samples of the same test food, each sample of one level of the concentration range (L-2 to L+2). Participants are instructed to taste and swallow a mouthful of each sample and rate it on liking using a single 100-unit Visual Analogue Scale (VAS; anchored from 'dislike extremely' to 'like extremely', and 'neither like nor dislike' in the middle). The five samples are rated on the same scale and hence, ranked against each other simultaneously. Ties are allowed, when two or more samples are equally liked. Participants are allowed to taste each sample as many times they want or need, as long as they rinse their mouth in between each taste.

The order of test foods are randomised across participants and across all test sessions. Each sample is labelled with a random 3-digit code, served in a standardised volume (refer to Table 2.4.), and at room temperature in translucent cups or trays. Water is provided as a palate cleanser of which participants have to rinse their mouths with, for 30 to 60 seconds between each sample. This is to minimise any possible carry-over effect. Preference evaluation is conducted in the sensory and eating behaviour booths of the Human Nutrition Research Unit of the division of Human Nutrition and Health of WUR, under normal lighting and odour-free conditions. Rank-ratings are recorded digitally using EyeQuestion Software (https://eyequestion.nl/).

Sweet-liker status is assessed using a 1M sucrose solution (Iatridi et al., 2019). Participants are instructed to rate their liking of this solution on a 100-unit VAS, anchored from 'dislike extremely' to 'like extremely'. This is performed just before the preference evaluation of each test day. Participants will be classified as sweet liker (SL), sweet disliker (SD) or neutral (N), using the following cut-off values: SL: rating ≥ 65; SD: rating ≤ 35; N: rating 36-64.

2.2.4.2. Sweet (and salty) taste intensity perception

Similar to preference, sweet taste intensity perception is assessed with six sweet-tasting and two salty-tasting test foods. These foods are the same used for preference, as summarised in Table 2.4. However, instead of the rank-rating approach, intensity perception is assessed with a 100-unit VAS (anchored from 'not sweet/salty at all' to 'extremely sweet/salty'). Each test sample is presented monadically (in contrast to all five concentrations of the same test food in preference). Participants are instructed to taste and swallow a mouthful of the sample and rate it on their perceived sweet or salt intensity. Identical to preference evaluation, intensity perception evaluation takes place in the sensory and eating behaviour booths, under normal lighting and odour-free conditions. The ratings are also recorded digitally using EyeQuestion Software (https://eyequestion.nl/).

2.2.4.3. Behavioural outcomes

Food choice and intake are measured using an ad libitum breakfast setting. A wide range of breakfast food products are presented to participants resembling a buffet. These foods vary in their taste (sweet-, savoury-, neutral- or bitter-tasting), to evaluate the effect of dietary sweet taste on choice and intake of sweet-tasting foods. Participants are given half an hour to eat as much as they like, and they do not know that their choice and intake are recorded. Records are done covertly, as the leftover foods are returned to the kitchen for weighing after participants have left the dining room. The proportion of consumed sweet to non-sweet foods are measured, and the resultant energy and macronutrient intake are calculated. Food choice is also measured through snack choice at the end of each test session. When participants have completed the intensity perception evaluation and ready to leave the unit, they are offered three snacks to choose one of them to takeaway. The snack choices vary in their taste (sweet-, savoury- or neutral-tasting). Participants do not know that their snack choice are recorded, as it is done covertly.

The PrefQuest questionnaire is used to assess individual preferences for sweet, salt and fat sensations (Deglaire et al., 2012). This questionnaire has been adapted to Dutch consumers and foods in three steps. Firstly, it was translated from French to Dutch by an official translation bureau (in’to Languages, Wageningen, The Netherlands). Secondly, French foods that are not commonly eaten by the Dutch were identified and replaced with commonly eaten Dutch foods that fall in the same taste and food category. This was carried out by two researchers and two dietitians, and based on the Dutch Smaak, Vet en Textuur database (Mars et al., 2020). For example, a traditional French smoked sausage (Morteau) was replaced by a traditional Dutch smoked sausage (Rookworst). Finally, images that did not represent Dutch eating habits were replaced with more suitable images.

A novel Taste Food Frequency Questionnaire (Taste FFQ) was developed to assess relative taste consumption from foods based on frequency, amount, and type of food consumed. This allows for evaluation of habitual dietary taste patterns. Using the Dutch FFQTOOL™, food items that contribute the most to total intake and explained variance in energy intake were selected (National Institute for Public Health and the Environment et al., 2018). Food items were also selected per taste cluster (Fat, Neutral, Sweet & Sour, Salt, Umami & Fat, Sweet & Fat and Bitter) (Mars et al., 2020; van Langeveld et al., 2018). To increase face validity and reliability, additional foods were added, such as table salt and cinnamon. The usability and applicability of this questionnaire was piloted in a sample of 52 participants and revised afterwards. The final Taste FFQ consists of 162 food items, including seven fat-, 35 neutral-; 25 sweet- and sour-; 56 salt-, umami- and fat-; 31 sweet- and fat-; and eight bitter-tasting foods.

Food cravings are assessed with the Control of Eating Questionnaire (CoEQ) (Dalton et al., 2015). This questionnaire has been translated from English to Dutch by an official translation bureau (in’to Languages, Wageningen, The Netherlands). It measures cravings across four components: craving control, positive mood, craving for sweet, and craving for savoury foods.

2.2.4.4. Anthropometry

For all anthropometric measurements, participants are instructed to change into light clothing without footwear. Height is measured with a stadiometer (SECA, Germany) to the nearest 0.1 cm. Weight is measured twice, using a calibrated digital weighing scale (SECA, Germany) to the nearest 0.1 kg. The average of the two measurements is used to calculate BMI. Waist and hip circumference are measured using a flexible tape (SECA 201, Germany), and recorded to the nearest 0.5 cm to calculate waist-to-hip ratio. Body composition including lean body mass, fat-free mass and body fat percentage is measured by a dual-energy X-ray absorptiometry (DEXA) scan (Lunar, United States).

2.2.4.5. Biological outcomes

At the beginning of each visit, participants have their fasting venous blood samples drawn by a trained phlebotomist. These samples are centrifuged within two hours of collection and stored at -80°C for later analysis. Subsequent analyses will obtain a range of biomarkers including fasting glucose, Haemoglobin A1c (HbA1c), insulin, total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL) and triglycerides. These are meant to assess the effects of the intervention on diabetes and cardiovascular health. HbA1c, glucose, total cholesterol, HDL, LDL and triglycerides are analysed in a clinical laboratory (Hospital Gelderse Vallei, Ede, the Netherlands), using the enzymatic methods (Atellica® CH analyzer) and/or High-Performance Liquid Chromatography (HPLC). Insulin is measured with enzyme-linked immunosorbent assay (ELISA). Moreover, white blood cells are stored at -80°C for future analyses on the indicative effects of gene variants (Bachmanov et al., 2011; Hwang et al., 2019; Keskitalo et al., 2007; Park et al., 2020). Glucose variability parameters are measured by the continuous glucose monitoring system (Freestyle® Libre) over 14 days.

2.2.4.6. Compliance

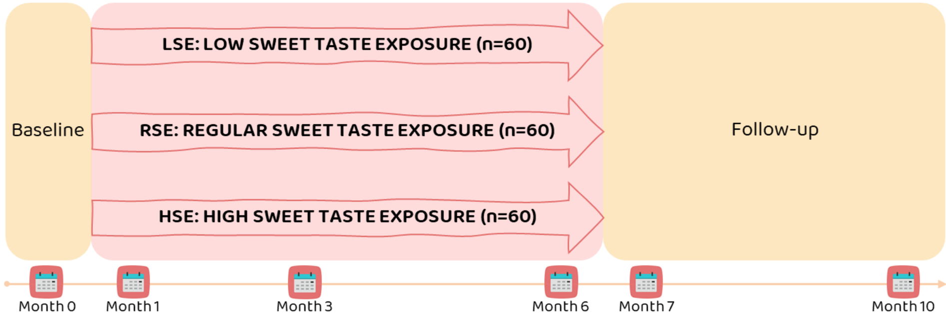
Study compliance is defined by adherence to the allocated intervention diet. Using urine biomarkers, long-term dietary sweet taste exposure can be confirmed at a group level, by measuring biomarker levels of urinary sucrose, fructose and five commonly consumed low-calorie sweeteners: acesulfame-K, saccharin, sucralose, cyclamate and steviol glycosides (Abreu et al., 2021; Gallagher & Logue, 2019; Logue et al., 2020; Tasevska, 2015; Tasevska et al., 2014). Urinary sodium and nitrogen levels are also used as biomarkers for daily intakes of sodium and protein, respectively. Adherence is estimated by the mean group presence of urine biomarkers in gram or milligrams. Before each test session, participants receive two 3-L urine containers containing preservative lithium dihydrogenphosphate, three 100mg para-aminobenzoid acid (PABA) tablets (KAL PABA, KALvitamines, Huizen, The Netherlands) and instructions on urine collection. PABA is used to check for completion of urine sampling, via its recovery dosage. 78% of ingested PABA is considered an acceptable recovery rate (Jakobsen et al., 2003). Participants have to collect their urine on the day before each test session. Collection begins after the first voiding upon waking up and ends after the first voiding upon waking up on the test day. Participants are instructed to record their voiding times, any use of medications and/or nutritional supplements and possible deviations from the protocol (e.g., missing urine). Urine of each participant is mixed, weighed, aliquoted and stored at −80°C until further analyses. In addition, adherence to the intervention diet is assessed with monthly 24-h dietary recall. This is estimated using average daily percentage of energy intake from sweet-tasting foods. Participants have to fill in the dietary recalls online, using the validated software programme Compl-Eat (www.compleat.nl) (Meijboom et al., 2017). This enables participants to complete these recalls off-site, at month two, four and five of the intervention.

2.2.4.7. Moderators

Habitual physical activity, demographic characteristics, adverse events and awareness of true study aim have potential moderating effects on sweet taste preferences and other outcomes. Therefore, they have to be measured and accounted for in the analyses. In the screening questionnaire, demographic characteristics of participants including their age, sex, education level, work situation, general disorders and medication use, living environment, alcohol and drug usage, smoking and diet status, and allergies are assessed. Habitual physical activity is assessed using a validated Short Questionnaire to Assess Health-enhancing Physical Activity (SQUASH) (Wendel-Vos et al., 2003). This questionnaire measures the intensity (low, moderate or high), duration (hour and minutes) and frequency (days per week) of different physical activities. These activities include occupation, leisure time, household, transportation means and other daily activities during a normal week of recent months. Any adverse event such as sudden illness is recorded in the case report file of each participant and informed by a medical investigator to the ethics committee. Awareness of the true study aim is assessed with a study debrief questionnaire given to each participant upon their completion of the final test session. Participants are asked to what extent they liked their allocated diet, how well they thought they adhered to the diet, how manageable it was to follow the diet, whether they will continue with the diet, if they will recommend the diet to people around them, what they thought other intervention diets were, and what they thought was the true aim of the study. It is an open-ended questionnaire that will be checked by the researchers to ensure true blinding of participants. At the end of the trial, a debrief letter will be sent to all participants explaining the true aim and trial set-up.

2.2.5. Procedure

Outcome measures are assessed at baseline, 1-, 3-, 6-, 7- and 10-months, at the Human Nutrition Research Unit of the division of Human Nutrition and Health of WUR. This is located on the WUR campus in the Netherlands. Figure 2.1. on the right provides an overview of the trial design. Each visit is approximately six hours long and follows a standardised operating procedure. Figure 2.2 illustrates the schedule of each visit. Participants are instructed to arrive at the facility at 7.30am in the morning, having fasted overnight. Participants first fill in a general health and well-being questionnaire to ensure that they are well to proceed. Qualified phlebotomists then perform the blood draw to obtain fasting venous blood sample. Following that, participants have their height, weight, and waist and hip circumference measured. Depending on the visit (baseline, 1-, 3-, 6-, 7- or 10-month) of the participant, body composition is also measured with a DEXA scan. Next, participants are led to the dining room for their ad libitum breakfast, where their food choice and intake are assessed covertly. After half an hour of breakfast, participants have an hour of break at one of the living rooms in the research unit. During this break, participants have to fill in the CoEQ, PrefQuest questionnaire and 24-h dietary recall. When these questionnaires are completed, participants may rest or use their devices. After an hour, participants are led to the sensory and eating behaviour booths of the research unit for the assessment of sweet taste preferences. During this hour, participants are not allowed to use their devices so as to fully focus on rating the test foods provided to them. Thereafter, participants have another hour of break at one of the living rooms. In this break, participants have to fill in the Taste FFQ and SQUASH. Once these questionnaires are completed, participants may rest or use their devices. After an hour, participants are again led to the sensory and eating behaviour booths for the assessment of sweet taste intensity perceptions. In this hour, participants are also not allowed to use their devices so as to fully focus on evaluating each test food presented to them. Participants who consented to having their glucose regulation measurements taken, were given a continuous glucose monitoring sensor and device (Freestyle® Libre) with which they could scan the sensor to obtain blood glucose levels in real-time. Participants were told to wear the sensor for 14 days before submitting the device back to the lab. Finally, at the end of the test day, participants are given three snacks to choose from and their snack choice are covertly recorded.



	Month 0	Month 1		Month 3			Month 6	Month 7	Month 10
Preference	✓	✓		✓			✓	✓	✓
Sweet-liker phenotype	✓	✓		✓			✓	✓	✓
Intensity Perception	✓	✓		✓			✓	✓	✓
Food choice & Intake	✓	✓		✓			✓	✓	✓
CoEQ	✓	✓		✓			✓	✓	✓
PrefQuest	✓	✓		✓			✓	✓	✓
Taste FFQ	✓	✓		✓			✓	✓	✓
BMI	✓	✓	✓	✓	✓	✓	✓	✓	✓
Waist-hip ratio	✓	✓		✓			✓	✓	✓
Body composition	✓						✓		✓
Glucose regulation	✓						✓		✓
Blood biomarkers	✓	✓		✓			✓	✓	✓
24-h dietary recall	✓	✓	✓	✓	✓	✓	✓	✓	✓
Urine biomarkers	✓	✓		✓			✓	✓	✓
SQUASH	✓	✓		✓			✓	✓	✓
Adverse events	✓	✓		✓			✓	✓	✓
Debrief questionnaire									✓

Figure 2.1. The Sweet Tooth study design. Each calendar icon represents one visit to the research facility to have outcome measurements assessed. These are at baseline (month 0), 1-, 3-, 6-, 7- and 10-months. BMI: Body Mass Index; CoEQ: Control of Eating questionnaire; Taste FFQ: Taste Food Frequency Questionnaire; SQUASH: Short Questionnaire to Assess Health-enhancing physical activity.

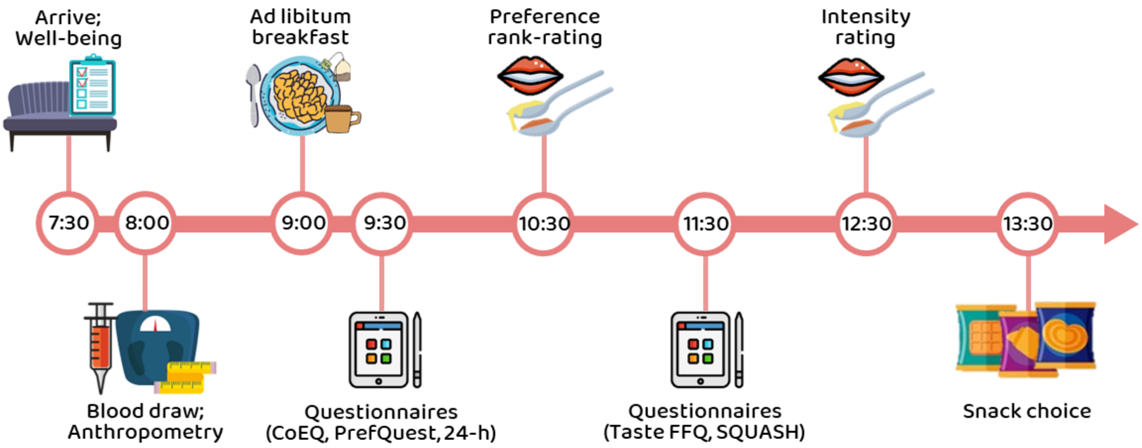


Figure 2.2. Visit schedule includes these outcome measures in chronological order – blood biomarkers related to CVD and diabetes, body weight, hip-waist circumference, body composition, food choice and intake (ad libitum test breakfast meal), food cravings (Control of Eating questionnaire; CoEQ), taste preferences (PrefQuest), 24-h dietary recall, sweet-liker status, sweet and salt taste preferences (sensory evaluation), dietary taste patterns (Taste FFQ), physical activity level (SQUASH), sweet and salt taste intensity perception (sensory evaluation) and food choice (snack choice).

2.2.6. Data analysis

Analysis will be conducted on an intention-to-treat basis. Unblinding will only take place at termination of the trial to establish the intervention outcome(s). The demographic, dietary and lifestyle characteristics of all three intervention groups will be presented with descriptive statistics. Continuous data will be presented with means, SD and 95% confidence intervals, and categorical variables will be presented with counts and percentages.

To address the main research hypothesis (H0: a 30% change in contribution of dietary sweet taste exposure to total energy intake will lead to at least 10% change in sweet taste preference on a 100-point scale over time), the effects of low, regular and high sweet taste exposure on sweet taste preference will be analysed using linear mixed effects models, with treatment (LSE, RSE and HSE) as the fixed between-subjects factor and time (baseline, 1-, 3-, 6- 7 and 10-months) as the fixed within-subjects factor. These linear models will adjust for covariates where appropriate and both unadjusted and adjusted models should be reported. If a main effect is identified, post-hoc test using Bonferroni correction will be performed to identify any meaningful difference between the means. Such differences will inform on the effects of varied sweet taste exposure. To address secondary hypotheses H1, H2 and H3 (the impact of sweet taste exposure on sweet taste preference is modulated by differences in H1: texture, H2: familiarity and H3: taste intensity); texture, familiarity and taste intensity of test foods will be entered into the linear mixed effects models with treatment (LSE, RSE and HSE) as the fixed between-subjects factor. Both unadjusted and adjusted models should be reported and if a main effect is identified, post-hoc test using Bonferroni correction will be performed to identify meaningful difference between the means.

To address H4, H5 and H6 (the impact of sweet taste exposure on sweet taste intensity perception is modulated by differences in H4: texture, H5: familiarity and H6: taste intensity), the effects of low, regular and high sweet taste exposure on sweet taste intensity perception over time will be analysed using linear mixed effects models, with treatment (LSE, RSE and HSE) as the fixed between-subjects factor and time (baseline, 1-, 3-, 6- 7 and 10-months) as the fixed within-subjects factor. Texture, familiarity and taste intensity of test foods will be entered separately in the models. Both unadjusted and adjusted models should be reported and if a main effect is identified, post-hoc test using Bonferroni correction will be performed to identify meaningful difference between the means. Lastly, to address H7, H8, H9 and H10 (dietary sweet taste exposure is associated with body composition (H7), HaemoglobinA1c (H8), glucose variability (H9) and biomarkers related to cardiovascular diseases and diabetes (H10)); body composition, HbA1c, glucose variability and biomarkers related to cardiovascular diseases and diabetes will be separately entered in linear mixed effects models, with treatment (LSE, RSE and HSE) as the fixed between-subjects factor, time (baseline, 1-, 3-, 6- 7 and 10-months) as the fixed within-subjects factor.

Statistical significance will be set at $p < 0.05$. All analyses will be conducted using R statistical software in R studio (version will be dependent on when data collection will be completed).

2.3. Discussion

This chapter details the design and protocol of the Sweet Tooth study, a randomised controlled trial aimed to investigate the adaptability of sweet taste preference. To the researchers' knowledge, this trial is the first of its kind to vary exposure to sweet taste using various sources of sweet taste, and accounting for sweet taste in the entire diet. This will inform the research field on the potential influence of long-term dietary exposure on sweet taste preferences, including the direction, duration and effect size. Additionally, it will improve understanding on the role of sweet taste in relation to obesity and other health outcomes.

Sweet taste preference and intensity perception are assessed in test foods that vary in texture (liquid, semi-solid and solid), familiarity (familiar and unfamiliar) and sweet taste intensity (five concentrations). This will shed light on whether these factors moderate the effect of exposure on preference and intensity perception. Moreover, sweet taste preference is assessed using the rank-rating approach (Kemp et al., 2017). This approach has been shown to utilise advantages from both side-by-side ranking and intensity rating, and inform on both preference (choice of one between two or more) and liking (the extent to which the choice is preferred) (Tang et al., 2020).

The methodology behind the dietary intervention of sweet taste exposure is also a novel way of looking at dietary exposure. Previously, dietary exposure has been tied with micro- or macro-nutrients and vitamins intake. Only since 2016 have researchers began to look at dietary intake from a taste perspective (Cox, Hendrie, & Lease, 2018; Lease et al., 2016; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018; van Langeveld et al., 2018). This allows for the quantification of sweet taste (amongst other tastes) in the diet and hence, calculation of how much energy intake comes from sweet taste in a regular diet, low-sweet exposure, and high-sweet exposure. By the same token, the Taste FFQ has also been developed to quantify habitual taste exposure in the diet, allowing for compliance check and a novel outcome measurement of dietary taste patterns. Dietary taste patterns will enable the analysis of associations between sweet taste and body composition, HbA1c levels, glucose variability, and biomarkers related to cardiovascular diseases and diabetes. Consequently, the role of sweet taste in health outcomes will be better understood.

Nonetheless, the Sweet Tooth study is not without challenges. The Taste FFQ, albeit novel, has not yet been validated. Other validated measurements such as urine markers for sucrose and sweeteners, and 24-h dietary recalls, will be used to evaluate the Taste FFQ as a reliable and valid measure of dietary taste exposure. Furthermore, the entire duration of an individual's participation is 10 months, with six visits in total. Interventions with long durations are correlated with higher dropout rates (Lucey et al., 2016). It may also be difficult to upkeep participants' compliance and motivation or satisfaction (Crichton et al., 2012). To manage these potential challenges, participants are provided with a wide variety of intervention food products from different brands and meet regularly with a dietitian who shares tips with them. For example, participants are guided on how to enjoy a night out but still keep within the diet. Participants also receive a booklet every month, containing daily menus, recipes and intervention foods checklists, to aid them in following their intervention diets. As this trial is controlled with partial dietary intervention, i.e., only half of the food items in their diet are provided, participants still have the freedom to choose various products, such as the type of bread to which they add their provided spreads on. Additionally, participants receive seasonal newsletters from the research team to increase their sense of belonging and involvement. Each newsletter contains updates on the trial, some healthy recipes, pictures of the research team and creative contributions from new research assistants. To account for potentially high dropout rates, enrolment will be 20% more than what was required from the sample size calculation.

Notably, the trial is also running in the midst of the COVID-19 pandemic. Its related restrictions such as the lockdowns in Summer 2020, Winter 2020 and Winter 2021 have influenced the trial progress. These restrictions might also have an influence on individuals' eating behaviours and dietary intake. However, such influences will be upon all three intervention groups rather than biased. The delivery of intervention foods to participants have also been ongoing successfully since the start of the trial. In fact, the reduced opportunities to travel abroad may aid in study compliance, since it is easier and more convenient for participants to partake in the study without any interruption to their intervention diets. Overall, despite delays caused by the pandemic, it has not affected the execution of the study protocol nor the ability of the trial to achieve its primary aim.

2.4. Trial status

The Sweet Tooth study was approved by the Medical Ethical Committee of Wageningen University and Research on 28th July 2020 (identifier: NL72134.081.19) and has been registered at ClinicalTrials.gov since 4th August 2020 (identifier: NCT04497974). Recruitment started in September 2020 and the first group of participants entered the trial in October 2020. Several delays occurred due to the COVID-19 pandemic. As a result, the initial estimate of baseline measurements being completed by June 2022 was no longer possible. The trial is ongoing and is estimated to be completed by end of 2024. The Sweet Tooth study is also monitored by BioFortis, a life sciences research company that checks for appropriate study procedures, proper documentations and records, ethical research conduct, appropriate interactions with participants, suitable recruitment techniques and quality data management. This ensures that the trial is running in accordance with the protocol until termination.

Since the submission of this thesis, the study protocol has been published in the BMC Public Health (Čad et al., 2023).

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3. Sweet Tooth II: Associations between dietary sweet taste exposure and sweet taste liking, sweetness preferences and health outcomes

3.1. Introduction

Sweet taste has been of focus in efforts to reduce the prevalence of obesity, despite the lack of evidence on any relationship between Body Mass Index (BMI) or BMI categories and sweet taste preferences, nor with consumption of sugar-sweetened foods (Chapter 1). At the same time, BMI has its limitations in diagnosing obesity (Banack et al., 2018; Okorodudu et al., 2010; Sommer et al., 2020; Wong et al., 2021). Due to this, an association between exposure to sweet taste and the prevalence of obesity may be masked and other indicators of obesity might shed light on the existence of this association. Adiposity, which is the degree of fat accumulation in the body, has been postulated as a more precise measure of obesity (Bays et al., 2013); yet, its association with sweet taste exposure has not been studied. An absence of association would be in accordance with weight status that reducing sweet taste exposure may not aid in reducing the prevalence of obesity. Therefore, it is important to assess if dietary sweet taste exposure is related to body fat.

The narrative of sweet taste exposure, sweetness preference and sugar intake has also been applied to policies on reducing the prevalence of Type 2 diabetes. However, it is unclear whether sweet taste exposure itself is associated with glucose variability, an integral component of Type 2 diabetes (Breyton et al., 2021). Sweet taste perception may be altered in individuals with Type 2 diabetes (Dye & Koziatek, 1981; Tepper et al., 1996; Wasalathanthri et al., 2014), but these studies did not study the effect of sweet taste on insulin responses. In samples of healthy adults, sucralose consumption led to normal insulin responses and glycaemic control (Grotz et al., 2017). Another group of healthy adults perceived sucrose as sweeter than saccharin and liked more, but insulin responses to both sweet taste stimuli were similar (Just et al., 2008). Notwithstanding, individuals consume other macronutrients in their regular diets, which may interact and influence physiological responses such as glucose regulation. For instance, minute fructose intake have been found to decrease postprandial glycaemic response to co-ingested glucose (Braunstein et al., 2020). Different combinations of sources of sweet taste may elicit different insulin responses and the effect of sweet taste exposure in the whole diet may be different too. It would be of value to assess the relationship between dietary sweet taste exposure and glucose variability.

While pre-existing associations between sweet taste exposure and preference have been assessed (Chapter 1), a randomised controlled trial that aims to investigate the adaptability of sweet taste preferences is underway (Chapter 2) and its baseline data could be used to corroborate literature on the relationship between sweet taste exposure, sweet taste liking and preferences. This chapter aimed, by estimating dietary sweet taste exposure in individuals, to evaluate if sweet taste exposure was associated with 1) sweet taste liking, sweetness preference and sweet-liker status; and 2) total fat in tissue, BMI, average blood glucose level over the past three months and glucose variability.

3.2. Methods

This cross-sectional study used baseline results from the Sweet Tooth study reported in Chapter 2. It is still ongoing and data was retrieved without compromising on blindness of the trial exposures. Eligibility criteria of participants may be referred to in Chapter 2 (section 2.2.2.2.) and details of all measures may be referred to in Chapter 2 (section 2.2.4.). This section focuses on specific measures relevant to the study aim and how they were examined with respect to the aim. The explanatory variable is dietary sweet taste exposure (3.2.1); while the response variables of interest consist of sensory outcomes (3.2.2): sweet taste liking, sweetness preference and sweet-liker status – aim 1; as well as health outcomes (3.2.3): total fat in tissue, average blood glucose level over the past three months and glucose variability – aim 2. BMI was included in this study as an authenticator of earlier studies. Several demographic and lifestyle characteristics were also included for descriptive results and as moderators in the analysis. Adapted from Chapter 2 Figure 2.2, this figure (Figure 3.1.) shows when each measure of interest was collected during the test day of the trial.

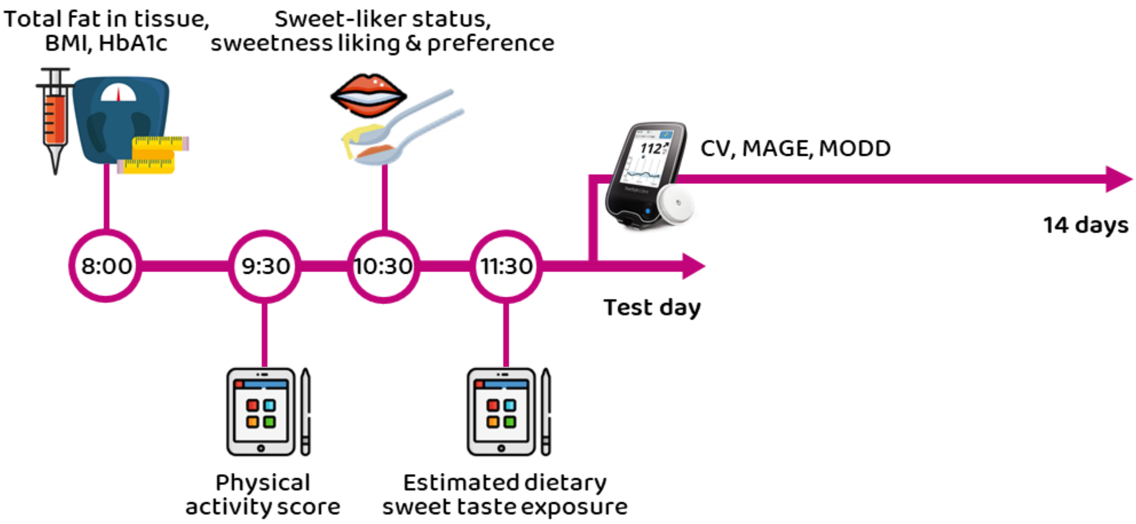

Figure 3.1. Outcome measures of interest in the current study in chronological order – anthropometry, blood biomarkers related to glucose level, physical activity, sweet-liker status, sweet taste liking and preferences, dietary sweet taste exposure and glucose variability. BMI: Body Mass Index. HbA1c: Haemoglobin A1c. CV: Coefficient of variation. MAGE: mean amplitude of glycaemic excursion. MODD: mean of daily differences.

3.2.1. Sweet taste exposure

The Taste Food Frequency Questionnaire (Taste FFQ) developed for the Sweet Tooth study allowed for an estimation of dietary sweet taste exposure, as detailed in Chapter 2 (section 2.2.4.3.). The Taste FFQ measured taste exposure from frequently consumed foods instead of the tastes of all foods consumed within a period e.g., 24 hours. Dietary taste exposure considers two aspects, namely the duration and intensity of taste (Lasschuijt et al., 2021). To estimate the taste duration aspect of taste exposure, all items from the questionnaire were assigned to one of four texture categories based on their structural properties and eating rates evaluated by Dutch sensory panellists (van den Boer, Kranendonk, et al., 2017); subsequently, foods received their corresponding eating rates (liquid: 306 ± 177 g/min, semi-solid: 63 ± 50 g/min, soft-solid: 30 ± 16 g/min and hard-solid: 19 ± 15 g/min). To obtain the taste intensity aspect of taste exposure, the value of sweet taste intensity of each food was obtained from a database that contains taste and mouthfeel intensity values of foods commonly consumed by the Dutch population (Mars et al., 2020). For each food, its sweet taste intensity value was multiplied by its consumed quantity estimated by the Taste FFQ and estimated eating duration to get its sweet taste exposure. This value was summed up across all items to get an estimated sweet taste exposure of a participant.

3.2.2. Sweet taste liking, sweetness preference, and sweet-liker status

Sweet taste liking and preference were assessed with the six test foods which were sweet-tasting, each created with five sweetness concentrations (Chapter 2.2.4.1). These test foods were strawberry-flavoured lemonade, watermelon-flavoured lemonade, chocolate-flavoured custard, elderflower-flavoured custard, plain cake and tamarind-flavoured cake. The liking ratings of these test foods by each participant were averaged to obtain an overall sweet taste liking for each individual (100-unit visual analogue scale anchored from 'dislike extremely' to 'like extremely', and 'neither like nor dislike' in the middle; the higher the score, the higher the sweet taste liking). From the ranking results of each participant, the preferred concentrations across these test foods were averaged to obtain the overall sweetness preference of the participant (% of weight of food; the higher the percentage, the higher the preferred concentration).

Sweet-liker status (SLS) was assessed using a 1 molarity of sucrose solution (Iatridi et al., 2019). As detailed in Chapter 2.2.4.1, participants were classified as either sweet liker (rating ≥ 65), neutral (rating 36-64) or sweet disliker (rating ≤ 35).

3.2.3. Health outcomes

Percentage of total fat in the tissue was taken from results of a dual-energy X-ray absorptiometry scan. BMI was calculated with measured height and weight. Haemoglobin A1c (HbA1c) from blood biomarkers of the trial was obtained as the average of the blood sugar level over the past 90 days, in percentage. Glucose variability parameters that are measured by the Continuous Glucose Monitoring (CGM) system appear to be indicative markers of glycaemic control (Breyton et al., 2021; Joshi et al., 2019; Lin et al., 2019); thus, sweet taste exposure in the whole diet could perhaps be studied in relation to glucose regulation in the same manner. Three parameters of short-term glucose variability which have previously shown strong correlations with HbA1c were selected – Coefficient of Variation (CV) measures within-day variability; Mean Amplitude of Glucose Excursions (MAGE) also measures within-day variability and has been widely used in research on Type 2 diabetes and metabolic disorders; and Mean of Daily Differences (MODD) measures inter-day variation. This study analysed glucose variability over 14 days. Glucose data could be downloaded from the CGM device using a web-based system (LibreView) and analysed with an R Shiny application intended for research studies (CGM Shiny).

3.2.4. Demographic and lifestyle characteristics

The age and sex of participants were obtained from the screening questionnaire of the trial, while their physical activity scores were calculated from the Short Questionnaire to Assess Health-enhancing Physical Activity by summing up the scores of low-, medium- and high-intensity activities (Wendel-Vos et al., 2003).

3.2.5. Data analysis

Shapiro–Wilk tests were conducted to test for normality of each variable and correlations were conducted to assess multi-collinearity. Basic linear model analysis was conducted to assess associations between sweet taste exposure and sweet taste liking and preference. Separate models were run for each outcome, all adjusting for sex and age since these factors may affect sweet taste exposure and/or preference (Chapter 1). One-way Analysis of Covariance analysis was conducted to assess if sweet taste exposure differed between the three sweet-liker status, adjusting for sex and age. Basic linear model analysis was conducted to assess associations between sweet taste exposure and health outcomes, and separate models were run for each outcome. The models for total fat from tissue and BMI were adjusted for sex, age and physical activity score, as these factors may separately influence total fat and BMI of the participants. The models for HbA1c and glucose variability parameters were adjusted for sex and age. Addition of interactions did not improve any model, and hence, they were excluded. Statistical significance was set at $p < .05$ and all analyses were performed using R statistical software (version 4.0.2) (R Core Team, 2020).

3.3. Results

3.3.1. Participants

Baseline data from 73 participants were included in the current study (Table 3.1). Data collection took place across all seasons. Most of these data (78.1%) were collected during a government mandated lockdown. Absolute taste exposure estimated from the Taste FFQ revealed that the average sweet taste exposure of participants was quite low (79.2 x10^3), since sweet taste exposure could range from 1.21x10^3 to 1000 x10^3 score g min.

Table 3.1. Participant characteristics – number, mean ± standard deviation (SD) and range (N=73).

		Mean ± SD	Range (Min – Max possible)	Shapiro-Wilk
Sex		13 Male, 60 Female		
Season[1]	Spring, n=	20; 27.4%		
	Summer, n=	8; 11.0%		
	Autumn, n=	23; 31.5%		
	Winter, n=	22; 30.1%		
Age, years		40.3±15.1	19-64 (18-65)	0.89*
Estimated sweet exposure, score g min		79.2±70.6 x10^3	15.1-351.2x10^3 (1.21-1000x10^3)	0.72*
Sweet taste liking, score		53.4±10.9	28.4-82.1 **(1-100)**	0.99
Sweetness preference, % w of food		13.5±3.2	8.14-22.4 **(4.21-22.4)**	0.95*
Sweet-Liker Status	Sweet Liker, n=	23; 31.5%		0.61*
	Neutral, n=	23; 31.5%		0.59*
	Sweet Disliker, n=	27; 37.0%		
Total fat from tissue, %		29.6±9.2	8.37-46.9 **(2~60)**	0.98
BMI, kg/m^2		23.1±2.8	18.0-28.7 **(18.5-30)** §	0.98
Total physical activity, score		8942±7019	2445-53150 **(270-75620)**	0.63*
HbA1c, mmol/mol		35.7±3.1	30.0-47.0 **(20~108)**	0.96*
Glucose variability	CV, %	17.5±4.2	10.3-33.3 (1~60)	0.93*
	MAGE, mmol/L	9.7±8.1	0.81-33.5 (0~40)	0.87*
	MODD, mmol/L	0.9±1.4	0.01-7.42 (0~20)	0.60*

[1] The season when baseline data was collected. § Following recruitment, inclusion criteria for BMI were 18.5-30 kg/m^2. However, baseline measures were taken several weeks after screening and upon current analysis, it was revealed that some participants were out of the acceptable range. BMI: Body Mass Index. HbA1c: Haemoglobin A1c. CV: Coefficient of variation. MAGE: mean amplitude of glycaemic excursion. MODD: mean of daily differences. Min: minimum value. Max: maximum value. *p < .05.

Most variables were non-normally distributed and Spearman's Rho was used to measure intercorrelations (Table 3.2). Only MAGE and MODD were highly correlated (*r* = 0.74), as would be expected (Breyton et al., 2021; Joshi et al., 2019; Lin et al., 2019). All variance inflation factors were below 4 and tolerance above 0.25, showing a sufficient lack of multi-collinearity between the independent variables (Tabachnick & Fidell, 2019).

Table 3.2. Intercorrelations (Spearman's Rho) between variables (N=73).

	Sex[1]	**Age**	**Exp**	**Liking**	**Pref**	**SLS**	**Fat**	**BMI**	**PA**	**HbA1c**	**CV**	**MAGE**	**MODD**
Sex[1]	1.00	.23*	-0.20	-.27*	0.04	0.11	.32**	0.03	0.04	0.11	-0.10	-0.09	0.13
Age		1.00	.34**	-.26*	-0.01	-0.11	.46**	.39**	-0.15	.53**	0.08	0.21	0.11
Exp			1.00	-.27*	0.08	-0.10	-0.05	0.20	0.06	0.14	-0.02	0.17	-0.08
Liking				1.00	-0.17	0.18	0.07	0.12	0.06	-0.15	-0.07	-0.04	-0.02
Pref					1.00	0.46**	-0.01	0.01	0.09	0.06	-0.11	-0.04	-0.22
SLS						1.00	-0.01	0.02	0.19	0.16	0.03	-0.03	-0.09
Fat							1.00	.64**	-0.06	0.18	-0.01	0.17	0.17
BMI								1.00	-0.11	0.25*	0.08	0.30**	0.23
PA									1.00	-0.06	-0.03	-0.08	-0.06
HbA1c										1.00	.271*	0.14	-0.05
CV											1.00	.48**	0.22
MAGE												1.00	.74**
MODD													1.00

[1] Computed with dummy variables, add (-) for Male. Exp: estimated sweet exposure (score g min). Pref: sweetness preference in foods (%). Liking: sweetness liking in test foods (1-100). SLS: Sweet-liker status (liker, neutral, disliker). Fat: total fat from tissue (%). BMI: Body Mass Index (kg/m^2). PA: total physical activity (score). HbA1c: Haemoglobin A1c (mmol/mol). CV: Coefficient of variation (%). MAGE: mean amplitude of glycaemic excursion (mmol/L). MODD: mean of daily differences (mmol/L). *p < .05, **p < .01.

3.3.2. Sweet taste exposure on sweet taste liking, sweetness preference and SLS

There were no significant direct associations between sweet taste exposure and sweet taste liking, t(69)=-1.07, p = .29, even though the model as a whole was significant, F(3,69) = 4.57, p = .01; and with preferred sweetness, F(3,69) = .12, p = .95. Sweet taste liking was significantly higher in biologically male, t(69)= 2.43, p = .02; and did not change with age, t(69)= -1.78, p = .08. Sweetness preference did not differ between gender, t(69)= 0.59, p = .56; nor with age, t(69)= 0.29, p = .78. Their regression plots are shown in Figure 3.2. on the right.

Sweet taste exposure did not differ between SLS, F(2,68) = 0.78, p = .46.

3.3.3. Sweet taste exposure on health outcomes

There were no significant direct associations between sweet taste exposure and total fat in tissue, t(68) = -1.07, p = .29, even though the model as a whole was significant, F(4,68) = 7.33, p < .01; with BMI, t(68) = 0.05, p = .96, even though the model as a whole was significant, F(4,68) = 3.24, p = .02; with HbA1c, t(69) = -1.30, p = .20, even though the model as a whole was significant, F(3,69) = 11.1, p < .01; on CV: F(3,69) = .62, p = .60; with MAGE: F(3,69) = .84, p = .48; and with MODD: F(3,69) = 1.36, p = .26) (Figure 3.2.). Older participants had higher total fat in tissue, t(68) = 4.02, p < .01; higher BMI, t(68) = 3.37, p < .01; and higher HbA1c levels, t(69)= 5.62, p < .01.

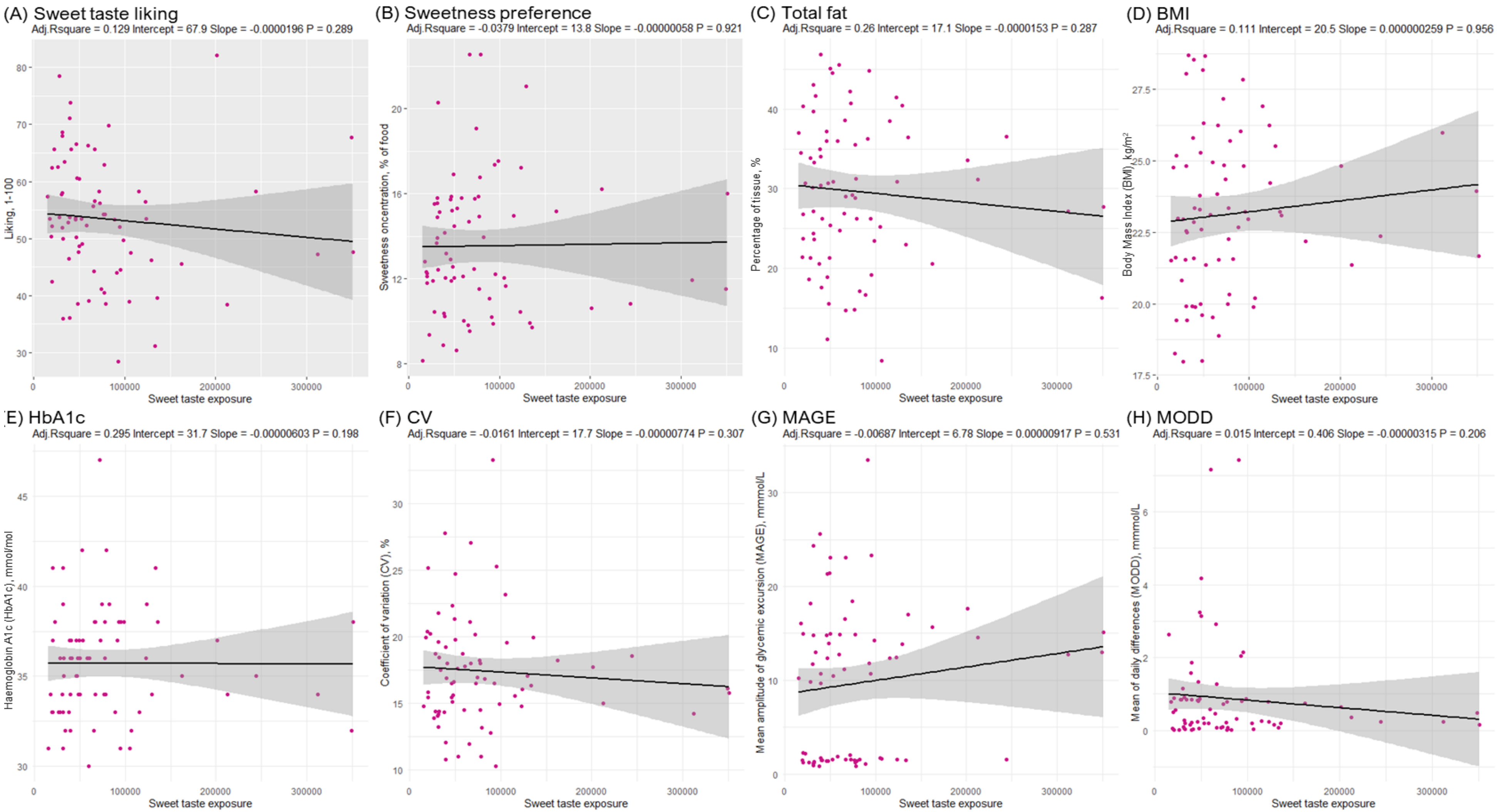

Figure 3.2. Regression plots of sweet taste exposure, score g min, against (A) Sweet taste liking, (B) Preference, (C) Total fat, (D) BMI, (E) HbA1c, (F) CV, (G) MAGE and (H) MODD; with the adjusted R^2, intercept and slope of each model, and p for the main effect of exposure (ANOVA Type 2). Shaded: sensory. Unshaded: health.

3.4. Discussion

The present work was a cross-sectional study aimed to evaluate for any associations between sweet taste exposure and sweet taste liking, sweetness preferences and health outcomes. Dietary sweet taste exposure, estimated using a novel Taste FFQ, was not associated with sweet taste liking, sweetness preference and sweet-liker status. It was also not associated with total fat in tissue, BMI, average blood glucose level and glucose variability. The lack of associations suggests that sweet taste preference and health are independent of sweet taste exposure in the diet.

The lack of relationship between baseline dietary sweet taste exposure and both sweetness liking and preference add to results from longitudinal cohort studies that estimated habitual sweet taste exposure through dietary intake assessments. No association was found between habitual added sugar intake as a proxy for habitual dietary exposure and liking for sweet taste in milk, in both male and female adults (Stevenson et al., 2016), although a negative association between intake frequency of sweet-tasting foods and liking of fruit juices was found in another group of female adults (Jayasinghe et al., 2017). Cohort studies on children also reported mixed evidence (Jurczak et al., 2020; Lanfer et al., 2012; Liem et al., 2004; Liem & Mennella, 2002). While these studies had different outcome measures from the current work, their results still implied that sweet taste liking and preference are independent of sweet taste exposure in the diet.

The current results on sweet-liker status corroborate with this, since sweet-liker, neutral and sweet-dislikers did not differ in their dietary sweet taste exposure. The proportion of the three sweet-liker statuses in this study differed from those in other studies in other countries. Studies in the United Kingdom (UK) and in the United States (US) had the majority of their participants classified as neutral (Garneau et al., 2018; Iatridi et al., 2019, 2020), while studies in South Korea had majority of their participants classified as sweet-likers (J. Y. Kim et al., 2014) or neutral (Kim et al., 2017). Instead, in this study, there were approximately equal number of sweet-likers, neutral-likers and sweet-dislikers. Biological males have been found to consistently show higher sweet liking and be classified as sweet-likers compared to females (see review: Armitage et al., 2021). The low number of males in this study (n=13) may account for the lower proportion of sweet-likers in this sample. This could also explain the low average sweetness liking and preferred sweetness concentration.

Adiposity, measured as total fat in tissue in this study, was not associated with sweet taste exposure in the diet. It was only significantly associated with age, where individuals of older ages had significantly higher percentage of total fat in tissue, in line with other studies (JafariNasabian et al., 2017; Nascimento et al., 2021; St-Onge & Gallagher, 2010). Since adiposity has been postulated as a more precise obesity measure than weight status, the present null result suggests that dietary sweet taste exposure does not differ between individuals with and without obesity. A possible explanation could be that sweet taste exposure may come from both caloric and non-caloric sweet sources. Research has consistently shown a positive correlation between sweet taste and mono- and di-saccharides contents, but not with dietary energy contents (Lease et al., 2016; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Yan, et al., 2018; van Langeveld et al., 2017). Sugar intake per se does not impact Type 2 diabetes, rather it is the high consumption of extra calories. Excessive energy intake from any caloric source will cause weight gain and promote Type 2 diabetes (Lean & Te Morenga, 2016; Te Morenga et al., 2013). Therefore, it is not exposure to sugar or sweet taste in the diet per se that results in excess energy intake and in obesity. This may also explain for the lack of association between BMI and dietary sweet taste exposure in this study. In a study sample from the US, intake of sweet-tasting beverages was significantly associated with BMI and body fat only in adults over 21 years, but not 21 years and below (Iatridi et al., 2020). This relationship was not observed in the UK sample of the same study. The present study sample has a mean age of 40.3±15.1 years, yet dietary sweet taste exposure was not significantly associated with BMI nor with total fat in tissue. Since adiposity and BMI are different indicators of obesity, one may have expected different results between them. Although BMI in this study sample ranged from 18.0 to 28.7 kg/m^2, mean of 23.1±2.76 kg/m^2, they were mostly within the healthy range. Perhaps a sample with more diverse BMI may be needed to observe a relationship with dietary sweet taste exposure, possibly with other factors like age involved. Nonetheless, the present findings corroborate previous work that showed no association between exposure to sweet taste in the diet and weight status (Chapter 1), and furthermore, showed no association with another indicator of obesity.

Average blood glucose level over the past three months, measured with HbA1c, was not associated with sweet taste exposure in the diet except with age. Individuals of older ages up to 64 years had significantly higher average blood glucose levels, lending support to previous studies (Siddiqui et al., 2022; van ’t Riet et al., 2010). The mean HbA1c in this sample also corresponded to a Dutch population-based study (van ’t Riet et al., 2010). Grotz and colleagues (2017) provided sucralose to a group of participants over a 12-week period and the HbA1c levels of these participants did not differ from those who consumed a placebo instead. Although the study was about sucralose as a sweetener instead of sweet taste as a whole, its results together with the present HbA1c results suggest that sweet taste exposure, be it from sweeteners or sweeteners and other sources, may not affect average blood glucose levels. Other studies also demonstrated no effects of sweet taste enhancers on glycaemic control (O’Connor et al., 2021). Indeed, the present study looked at sweet taste as a whole and dietary sweet taste exposure was not associated with any of the glucose variability markers. This suggests that sweet taste exposure in the diet is not related to glycaemic control, a key component of Type 2 diabetes. As mentioned above in relation to adiposity, excess caloric intake from any source would lead to weight gain and promote Type 2 diabetes. Sugar in the diet per se does not disrupt glycaemic control (Lean & Te Morenga, 2016), neither does sweet taste enhancers (O’Connor et al., 2021). Therefore, taking these sources of sweet taste in the diet together, it is plausible that dietary sweet taste exposure may not impair insulin responses nor disrupt glycaemic control. This opposes the assumption made by public policies aimed at reducing Type 2 diabetes incidence through the 'sweet taste exposure – preferences – health' connection.

While this study was an attempt to estimate dietary sweet taste exposure in individuals and how it may relate to their sweet taste liking and health, the interpretation of its results should consider the following limitations. Importantly, dietary sweet taste exposure was estimated from the Taste FFQ which has yet to be validated. It contains only the most frequently consumed foods that contribute to dominant tastes and combinations of the Dutch diet (van Langeveld et al., 2018), instead of all foods that may be consumed within a time period, e.g., 24-hour (24h). Consequently, estimating sweet taste exposure from these foods might be limited in the extent to which they represent the entire diets of individuals. The analysis on body fat used percentage of total fat in tissue, which is a measure influenced by lean mass. Percentage fat has been shown to classify more individuals as with obesity compared to BMI and Fat Mass Index (FMI) (Wong et al., 2021). In contrast, FMI provides a sole index of body fat and has race- and sex-specific reference ranges. Body fat taken with FMI may produce different results. The present study population consisted of mostly biological females, and had a lower BMI than the general Dutch population (van Rossum et al., 2020). Nonetheless, there was still a range of physical activity levels within this sample and measured across different seasons to evaluate baseline sweet taste exposure associations with sweet taste liking, sweetness preference and health outcomes. The mean age of this sample also corresponded to the mean age of the general Dutch adult population (van Rossum et al., 2020).

It is evident that the present measure of estimated dietary taste exposure could be improved in future research. The Taste FFQ needs to be evaluated for validity and precision as a tool to assess habitual dietary taste patterns; this would inform on the representativeness of diet that dietary taste exposure had estimated in this study. Concurrently, dietary sweet taste exposure could be calculated accurately from full dietary records e.g., 24-h recalls, and evaluated against health outcomes and sweet taste liking and preference. Another measure of body fat, such as FMI, could be used to substantiate the lack of association between obesity measures and sweet taste exposure. It would be of value to include participants with a wide range of BMI and FMI to ensure that no association is missed due to a truncated range of participant characteristics. Importantly, the distinction between taste preference and dietary taste exposure should be clarified. The liking of certain tastes and preferences for their intensities, could be evaluated in different food (sub-)groups and across different food matrices, alongside calculation of dietary taste exposure. Since different food textures and matrices bring about changes in taste exposure (Bolhuis & Forde, 2020; Forde & Bolhuis, 2022; Lasschuijt et al., 2021), perhaps sweet taste exposure is associated with sweet taste liking and preferences only in specific food matrices and/or groups. Moreover, food matrix influences satiety, which itself may influence taste perception and preference (Aguilera, 2019). Nonetheless, it is also plausible that sweet taste preferences and dietary sweet taste exposure are unrelated and both do not correlate with health outcomes. It might be valuable to evaluate the same health outcomes against sweet taste liking and sweetness preferences at a population level.

3.5. Conclusion

This chapter documented an assessment into dietary sweet taste exposure of individuals and how it may relate to their sweet taste liking and preferences. Results indicated the lack of pre-existing associations between them, suggesting a possibility that reducing sweet taste exposure would not lead to lower sweet taste liking and intensity preference. This study also assessed relationships between dietary sweet taste exposure and health outcomes. Results did not support the assumption that different amounts of sweet taste exposure would lead to different prevalence rates of obesity and Type 2 diabetes. Taken together, they did not support the assumption of a 'sweet taste exposure – preferences – health' connection.

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4. Sweet Talk I: Exploring attitudes towards sweet-tasting foods, sugar and sweeteners in the United Kingdom – a qualitative study

The following chapter has been published as:
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4.1. Introduction

The importance of studying attitudes towards different sources of sweet taste and sweet-tasting foods was discussed in Chapter 1. Intakes of sugar or sugar-sweetened foods may be associated with consumer perceptions of their health benefits (Fadupin et al., 2015; Ortega-Avila et al., 2019; Zytnick et al., 2015) or concerns (Forde & Solomon-Moore, 2019; Morel et al., 2019; Pielak et al., 2019), associated emotions (Palmedo & Gordon, 2019), experiences of pleasure (Fadupin et al., 2015; Morel et al., 2019; Pielak et al., 2019) and to some extent, knowledge of the health implications of excessive sugar consumption (Gupta et al., 2018). These attitudes and possible associations with sugar intake may also be confounded by coexisting attitudes to low-sugar alternatives, such as artificial sweeteners or less-sweet foods. Several health authorities, such as the British Diabetic Association, have provided information and recommendations on low- or no-calorie sweeteners while concurrently stating that more evidence is required on their long-term impacts on health and underlying mechanisms (British Diabetic Association, 2018). This approach may potentially lead to confusion and concerns to form any opinion on sweeteners. For example, some parents have expressed concerned regarding the ‘safety’ of sweeteners for their children (Sylvetsky et al., 2014) and dietetic practitioners have also been apprehensive about the health impacts of sweeteners (Harricharan et al., 2014). Adolescents have also shown reservations about sweeteners. In a sample of teenagers aged 15 to 21 years in Italy, attitudes towards sugar-free products leaned towards negativity; however, there was also a general uncertainty towards both sugar and sweeteners (Messina et al., 2004). Research on attitudes towards sweet-tasting foods in general, while limited, shows that suggestions such as forgoing sweet-tasting treats and pleasurable foods may be refused or accepted with reluctance (Forde & Solomon-Moore, 2019; Harricharan et al., 2014; Morel et al., 2019).

Despite their dissatisfaction with alternatives to low-sugar intake, consumers still show support for sugar reduction strategies (Curtice et al., 2016). For example, a group of adults supported the strategy of a “sugar-sweetened beverage free zone” in a community health centre (Palmedo & Gordon, 2019) and another group supported the implementation of an information-based campaign to reduce sugar intake amongst low-income consumers (Forde & Solomon-Moore, 2019). Furthermore, the 33rd report on British Social Attitudes showed that more than half of the respondents supported the idea of tax implementation and bans on advertising sugary drinks (Curtice et al., 2016). As introduced in Chapter 1, the ‘Soft Drinks Industry Levy’ (SDIL) has been implemented in the United Kingdom (UK) since 2018 (HM Revenue and Customs, 2016). Studies on public perceptions of the SDIL had been conducted prior to its implementation and showed mixed results (Pell et al., 2019; Swift et al., 2018). The effectiveness of sugar reduction strategies will depend on attitudes of individuals towards sugar, low-sugar alternatives and their relevant strategies. As such, increased understanding of current attitudes would aid in the development of better strategies and identify key areas of concern.

Given the importance of and push for lowering sugar intakes (Lacobucci, 2021; Tedstone et al., 2015, 2017; World Health Organisation, 2015), this study aimed to explore current attitudes towards sweet-tasting foods, sugar and sweeteners, including related policies, in a sample of the general public of the UK.

4.2. Methods

The ontological and epistemological position taken for this research is contextualism characterised by critical realism, which assumes an ultimate reality that can only be partially known and this knowledge obtained is context-sensitive (Braun and Clarke, 2013). Consequently, the current study used an exploratory qualitative methodology to gather attitudes and opinions in a sample of the general public living in the UK. The methods of data collection chosen were focus groups and interviews, and the method of data analysis was thematic analysis.

4.2.1. Acknowledgement

This research was initially conceptualised by the supervisor of the postgraduate researcher (CT), Katherine Appleton (KA). A Bachelor's student, Melissa Honey (MH), conducted three focus groups in 2018 under the supervision of KA. She transcribed all three audio recordings and coded them using thematic analysis. Subsequently, a research assistant, Sarah Delvin (SD), conducted a fourth focus group in 2019, transcribed its audio recording and also coded with thematic analysis. The postgraduate researcher, CT, refined the study design in 2019 and secondarily coded the data from previous focus groups again. CT conducted the remaining focus groups and interviews, transcribed the audio recordings and coded them through thematic analysis. KA and another postgraduate researcher, Lucky Boxall (LB), aided in her coding and the final theme formation.

4.2.2. Participants

Participants were pre-screened for eligibility and recruitment criteria included adults from age 18 to 65 years old, healthy (self-reported) and able to provide informed consent. Any history of eating disorder(s) was not recorded. Ethical approval for the study was granted by the Research Ethics Committee of Bournemouth University (ID: 29215) prior to commencement. All participants provided informed consent before participation and were compensated £10 for their time.

Several recruitment strategies were used to allow inclusion of participants from a range of backgrounds. Recruitment was first focused on university students in the UK, specifically female participants. Snowball sampling was used as a non-probability method, where a small group of participants were asked to invite others to participate if they met the eligibility criteria. The focus groups were arranged based on individual preferences for sugar, sweeteners or no preference. Next, parents of children at a local school were recruited, also using snowball sampling. The later stages of recruitment focused on general public living in the UK, by posting advertisements in public areas such as food establishments, libraries and online.

4.2.3. Focus groups and Interviews

The study used a combination of focus groups, dyadic interviews and solo interviews to generate a wide range of perspectives and understandings. Topics to be discussed were considered by researchers to be non-sensitive to participants and hence, suitable for discussion in a group setting. Focus groups set a welcoming environment for discussion and prompt realistic interactions between people. This encouraged the use of real-life vocabularies and conversation styles, and intended to maximise perceptions generated, including both collective and personal opinions. Solo and dyadic interviews were conducted for participants who were unable to attend a focus group session.

Focus groups and interviews were conducted from January 2018 to March 2020. Some focus groups were conducted prior to the implementation of the SDIL (HM Revenue and Customs, 2016), while others were conducted at different time points after this implementation. This arrangement aimed to collect attitudes in both the short- and long-term following implementation of the SDIL.

4.2.4. Moderator Guide

A moderator guide was created to structure all focus groups and interviews. Questions focused on participants' beliefs about sugar and sweeteners, their preferences and rationales, their considerations towards different sweetener terms or categories, attitudes towards reducing sugar intake versus reducing sweetness intake, as well as their opinions on current and potential strategies to reduce free sugar intakes. Questions were open-ended to encourage participants to share spontaneously. The moderator guide was piloted prior to use in six interviews and refined to ensure the clarity, relevance and value of each question. The revised moderator guide was then used for all focus groups and interviews.

At the beginning of each session, participants were asked to introduce themselves and share a memorable sweet-tasting food that they last consumed. This aimed to make everyone feel at ease to begin sharing. Visual materials were presented at various time-points during each session, with the purpose of generating more discussion. These included: pictures of the sugar content of several commercial beverages in sugar cubes, in relation to current recommendations by Public Health England (Tedstone et al., 2015, 2017); examples of different categories of sweeteners (Carocho et al., 2017; Das & Chakraborty, 2016); examples of packaging using graphic imaging similar to those that have been used for cigarettes under The Standardized Packaging of Tobacco Products Regulations 2015 (The Standardised Packaging of Tobacco Products Regulations 2015, 2015). The moderator guide and all visual materials are provided in Appendix 3.

4.2.5. Procedure

Focus groups and interviews were conducted based on established methods (Clarke & Braun, 2013; Malterud, 2001; Morgan et al., 2013). All focus groups were held at Bournemouth University Talbot Campus and all interviews were conducted at external locations as the participants were unable to travel to the campus. All aspects of the study participation were explained at the start of each session and participants were given ample time to ask questions. Participants were informed that participation was completely voluntary and that they had the right to withdraw from participating at any time or refrain from answering a particular question during the session without providing an explanation.

All sessions were conducted in a semi-structured manner to encourage both personal and collective opinions. All sessions were audio-recorded for transcription and analysis. All sessions began with an introduction and explanation on the study procedure, audio recording, confidentiality and anonymity. Each session lasted not more than an hour and there was one moderator in each session, In larger focus groups, a second researcher was present to take field notes. Three trained moderators (MH, SD and CT) facilitated the various sessions using the revised moderator guide, but the sequence and use of each question depended on the flow of each session. Towards the end of each session, moderators asked if participants had anymore thoughts on the topic that were not yet discussed. The session then continued until there was no further input from the participants. By the last focus group, no new attitudes or reasons were generated and data collection for the study was concluded.

4.2.6. Data Analysis

Thematic analysis was selected for this exploratory work so as to not be theoretically-bounded. Themes were identified using an inductive approach based on the explicit semantic content of the data (Clarke & Braun, 2013). Although a moderator guide was used during data collection, it did not serve as a coding scheme during analysis, nor was a coding scheme established. As this study was exploratory, theme formation was data-driven. Only discussions relevant to sweet-tasting foods, sugar and sweeteners were analysed. Discussion on attitudes or policies in other countries were also excluded, with the exception of explicit cross-country or cross-cultural comparisons.

Thematic analysis was performed based on six phases developed by Braun and Clark (2006). Respective moderators transcribed the audio recordings of all sessions that they conducted (MH, SD, CT). To aid in transcription, field notes were also referred to. All transcripts followed the orthographic style and notation system adapted from Braun and Clark (2006). Transcripts were not sent back to participants for correction; a review on member checking did not find supporting evidence that this improved research quality in studies with the main purpose of theory development (Thomas, 2017), and this would add to participant burden and reluctance to participate. All transcripts were imported into qualitative data analysis software NVivo (QSR International Pty Ltd. Version 12, 2020) to be coded.

To address unitization, this study adopted a strategy that focused on meaning units rather than naturally given units. The current set of transcripts had many "(in overlap)" between participants, suggesting that their speech, thoughts or ideas might have been disrupted. Therefore, the researcher selected entire interrupted speeches (meaning units). Initial codes were generated from each transcript by two researchers, independently, and then agreed upon. An inductive approach in this study meant that assessing inter-coder reliability and agreement could not be performed as per "when a preconceived coding scheme with a fixed number of codes is being used" (Campbell et al., 2013, p. 305). However, "negotiated agreement" between the two served to reconcile discrepancies in codes and unitization, and to improve inter-coder reliability, even though this was not measured explicitly. The postgraduate researcher (CT), acted as the principal investigator in this work, while four other researchers (MH, SD, LB and KA) acted as the secondary coder. The codes were then grouped together by CT to form sub-themes and themes, and then discussed and agreed upon by two secondary coders (KA and LB). All transcripts were reviewed again by CT to ensure no quotes were left out and to check the validity of themes.

4.2.7. Researchers and Reflexivity

The postgraduate researcher (CT) and all other researchers (MH, SD, LB and KA) were female with lean body weight, and the majority were involved in other projects on dietary sweetness at the time of this study. Three researchers had backgrounds in nutrition, eating behaviour and the drivers of food choice and intake, and one researcher had a history of eating disorders; all of which may have had an impact on the identification and definition of themes or sub-themes. One of the secondary coders (KA) was the supervisor of CT and interpersonal dynamics could have been involved. In this regard, they had a discussion in which KA reassured CT of a comfortable rapport that allows for honest and objective discussion between them, focused on generating proper results for this study. The abovementioned researcher biases were continuously examined throughout the research process.

4.3. Results

4.3.1. Participants

Seven focus groups, two dyadic interviews and one solo interview were conducted for this research. Twenty-nine participants (24 Female [F], 5 Male [M]) took part in seven focus groups, four participants (2F, 2M) took part in dyadic interviews and one participant (1F) took part in a solo interview. Participants were recruited from the student population of Bournemouth University (n=11), from local workplaces including the University (n=9), among the parents of a local school (n=5) and from the community (n=9). Seventeen participants were aged 18-30 years, four participants were aged 31-40 years, four participants were aged 41-50 years, four participants were aged 51-65 years, and age for five participants was not queried. Seventeen participants were students, eight participants were working professionals, three participants were retirees, one participant was not working and occupation for five participants was not queried. None of the participants reported being on a diet, having been diagnosed with diabetes or insulin resistance, or reported being intolerant or allergic to sugar, sweetener, wheat, gluten, rice, cereal or fruit. Three focus groups were undertaken from January to March 2018 before the implementation of the SDIL, one focus group was undertaken in July 2018 shortly after the implementation, and three focus groups and all interviews were undertaken from January to March 2020.

4.3.2. Attitudes towards Sweet Foods, Sugar and Sweeteners

A total of 24 different attitudes, beliefs or considerations towards sweet-tasting foods, sugar and sweeteners were identified. They are termed as "sub-themes" and grouped into six main themes (Figure 4.1).

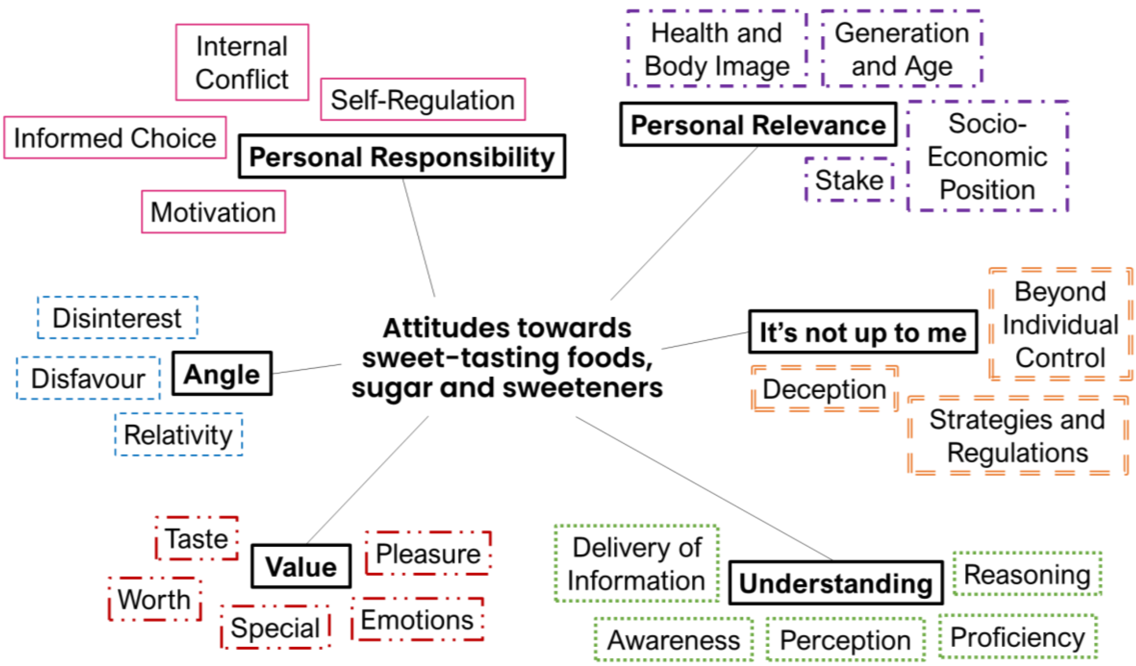

Figure 4.1. Attitudes towards sweet-tasting foods, sugar and sweeteners: themes and sub-themes. The six themes are in different colours and their theme headings are in **bold**.

All six themes are described neutrally, because the same term could be expressed as present or absent, or positively or negatively by different participants. The themes are presented in no particular order and interaction between themes was also possible. All themes included attitudes towards all three food items, namely: sweet-tasting foods, sugar and sweeteners; however, some sub-themes appeared more relevant to one or two of these food items.

'FG' refers to focus group, 'DI' refers to dyadic interview, 'I' refers to solo interview and 'P' refers to participant, e.g. [FG1, P1] labels a quote by the first participant in focus group one. The definition of all themes, sub-themes and extended quotes can be found in Appendix 4.

4.3.2.1. Value

- What sweet-tasting foods, sugar and sweeteners can provide.

Defined as 'what sweet-tasting foods, sugar and sweeteners can provide', this theme focused on the positive and negative aspects of consumption. During discussions on whether to choose sugar or sweeteners, many comments included 'taste' as an important factor that cannot be compromised. Some participants prefer the taste of sugar while others preferred the taste of sweeteners in products. However, general consensus was that excessive sweetness tastes unpleasant. Comments indicated that some participants preferred high-sugar products that tasted good over sweetener-based or reduced-sugar versions that tasted less pleasant. This demonstrates the value of a pleasant taste. There were also participants who expressed their acceptance of and support for sweeteners because it allows them to still have sweet taste in their diets even if they were to reduce sugar intake.

> *"And the taste of soda is better when is with sugar and if is (pause) if there's no sugar, then is isn't worth drinking it."* (FG2, P3)

> *"The taste, sweeteners are disgusting (laughs) in my opinion they taste very different and I, I don't like it."* (I1, P1)

> *"It still has to taste good I think that's the thing."* (DI1, P2)

'Pleasure' is defined as the satisfaction and enjoyment derived from the consumption of sweet-tasting foods, sugar or sweeteners. Such pleasurable experience may prompt some participants to disregard health implications or higher cost of high-sugar products, and instead, choose the foods that satisfy them. Comments indicated that cravings for sweet-tasting foods or sugar should be satisfied whenever the desire came. Some participants also mentioned that they do not regulate sugar intake when it came to certain food items, such as alcoholic drinks. Pleasure may also be derived from the appearance or presentation of foods. The packaging of sweeteners was reported as unappealing, affecting acceptance and intake.

"They just, just lookin' at them they come in a lil plastic box. Just don't like the look of it I just don't like the idea of it? Um (pause) yeah I don't use sugars, um in my coffee anyway I and I don't cook so, um (pause) yeah I don't really have a sugar in my in my house. But um, if I had to, I'd go for sugar not a sweetener I just don't like the look of them I don't know. Just look like little pills (laughs) something puts me off." (FG1, P4)

"Let's say we're not gonna have cake anymore because you can't make cake without either sugars or sweeteners alright so, if we get rid of both those things there's no more cake. (pause) To me, th-the life is too short, to do away with, good things in life." (DI1, P2)

"Although I do like a Jager bomb… Yeah so if I'm going out then it's a bit different, but all my inhibitions go out the window and I just let loose if I'm drinking." (FG6, P2)

Elevated pleasure with some foods was classified under the sub-theme 'Special', where these sweet-tasting foods were considered as rewards or treats, the opposite of an everyday affair. Comments suggested that some participants reserved their intake of these 'Special' foods for specific occasions, such as festive periods. They distinguished between special and normal sweet-tasting food items; for example, dessert was considered special and valued, while a biscuit was considered regular.

"But for me I would rather not buy diet or reduced sugar things I would make the sugary things more of a treat and have less often." (FG7, P3)

"So I never really (pause) m-my mom's always been sort of health, conscious so we (pause) it's probably bad on a Sunday night we used stop off at this local shop, and just get so much. So many sweets and (pause) and, bad things but. Yeah and just our day to, to have that and that was after we'd, been on, been round to my grandparent's for Sunday dinner so it was, sort of like our, cheat day y'know? But (pause) yeah I don't do that, too often." (FG1, P1)

In the sub-theme 'Emotion', participants expressed their sentiments and feelings derived from consumption of sweet-tasting foods and sugar, as well as the influence of mood on their choice and intake of these food items. Similar to pleasure, several statements suggested that participants valued the happiness derived from their consumption to the extent that if restricting intake would take away joy, they would rather have a higher intake and experience the positive emotions. There were also remarks on how sweet and sugary foods brought about childhood memories.

"It makes me happy and that's all I care about so (laughs)" (FG2, P6)

"Yeah like I don't really mind, I would rather be a bit curvy and happy and enjoy what I eat rather than obsessively worry all the time and restrict myself of things that I want." (FG6, P1)

The weighing of costs and benefits for sweet-tasting foods, sugar or sweeteners was summarised under 'Worth'. Comments suggested the recognition of multiple yet conflicting benefits of these food items. Sugar was recognised to provide quick energy and preservative properties, while sweeteners provided low caloric properties for weight management or diabetes. Participants reported value for money as an important consideration and the price point of a product could drive them to either reduce their sugar intake or choose an alternative. In fact, a few comments indicated that money was potentially considered as more important than health. Some participants also regarded the quality of a sweet or sugary food product, such as the branding, or the environmental cost, as important factors.

"I maybe care about the price! Rather than discriminate between sugar and sweetener." (FG3, P1)

"it's to understand what the health benefits if there are any or there are, and I assume there'll be a cost impact as well? And then it's not like we're running out of sugar? (laughs) So, it's not gonna help the planet. So I need to an angle to really think why why would I want to, change and if (pause) if I saw in, products that are on sale? (pause) I would look it up first and think okay, again why? And then I'll think about it." (FG3, P3)

"Let's say you need uh, a a boost for, the energy boost you can get but you can get it in other ways but (pause) uh sort of nutritionally as far as I understand there's not much benefit to (pause) unlike sh- salt, where people need, a little bit of salt in their diet." (FG1, P2)

4.3.2.2. <u>Angle</u>

- Negativity surrounding sweet-tasting foods, sugar and sweeteners.

In contrast to the positive nature of the previous theme 'Value', this theme 'Angle' took on more negative perceptions of sweet-tasting foods, sugar and sweeteners. The first sub-theme 'Disinterest' was defined as having indifference. Comments suggested that some participants did not specially include or exclude sweet-tasting foods, sugar and sweeteners in their diets. Some participants voiced out that concerns with sugar intake can be excessive and consuming sugar is 'not a big deal'. Disinterest in sweeteners was also related to the view that "artificial" or "synthetic" sweeteners need not be deemed as worse than "natural" sweeteners.

> *"To me, eating sweet things, is just, quite normal! Um I-I don't necessarily look upon it as a treat. It's like I fancy something sweet, I'm gonna have that."* (FG3, P2)

> *"I don't think that it's necessarily is uh (pause) I don't think it's necessarily the case that because something we can label it and call it uh because it is and we call it artificial or synthetic, it is necessa- that necessarily means, that it is (pause) less uh or, it's not as good or it is worse than something natural."* (FG1, P2)

The other angle, 'Disfavour', was more negative. Comments included concerns about the short- and long-term health implications of sugar and sweeteners, such as their carcinogenic properties. Sugar was perceived as non-nutritious and unnecessary in the diet, hence avoiding it was seen as a good decision. Sweeteners were perceived as chemicals made from laboratories, potentially carcinogenic and which should be avoided as well. Some participants believed that sweet-tasting foods, sugar and sweeteners are physically addictive, and that reducing their intake will lead to withdrawal symptoms. Comments included their consumption as being synonymous with vices such as drug-taking.

> *"I think I think people need professional help! You know for sugar? Cause of the fact that I've I- I- y-yeah. I think she's right. It is a drug (pause) and when I when I need, I need it. It's not like (pause) uh, oh I should have a cake, oh I shouldn't have. It's more like, I NEED A CAKE… So yeah I feel I feel (inaudible) education, but I think people are not really aware of the fact that it is quite addictive? And it it is quite, um harmful to your body? It is important but also professional help, might, yeah. Help people."* (FG2, P6)

> *"It's delivered, to refineries in, in tankers with the skull and crossbones, symbol on it… Because of the chemical contents within it."* (FG3, P2)

> *"They're consuming things, and probably getting hooked onto a taste (pause) without really realising it. Um and then it's difficult for them to shake that off as they get older."* (FG3, P2)

A final angle was termed as 'Relativity', which contained comparative considerations. Participants viewed sugar and sweeteners not in isolation, but in relation to each other, or other food components such as fat or salt. Comments suggested the concept of the 'lesser of two evils'. For example, sweeteners may be chemicals, but at least they provide sweetness in the diet without detrimental health implications of sugar. On the other hand, sugar may be caloric, but at least it does not cause cancer.

"The reason I don't pick diet is because I heard about aspartame and I've heard people get tumours. It might be a myth thing but both options are bad and it's better to do better the devil I know than I don't." (FG4, P1)

"It's just if you'd like the sweet taste. Like my dad for example, has sweeteners in his tea and coffee, as he couldn't have a coffee without anything in it. He chooses a sweetener over sugar as he feels it is healthier for him. (pause) Oh I guess if you have got for example younger children or even yourself who massively react to sugar and you notice a change in their personality then maybe sweeteners would be better in that situation." (FG7, P4)

4.3.2.3. Personal Relevance

- To be concerned personally and/or to change one's own behaviour.

While the previous themes 'Value' and 'Angle' are generic in nature, several concepts were considered to affect individuals differently. Some concepts were perhaps more relevant to "me", while other concepts were more relevant to others. Hence, the theme 'Personal Relevance' revolved around the presence or absence of reasons to be concerned personally with sweet foods, sugar and sweeteners, as well as to personally effect change. Individuals could view these food items negatively but did not see themselves as people who needed to reduce their intakes. Alternatively, some participants identified themselves as people who need the change and hence saw intake modifications as relevant to them. In this theme, personal relevance was described in relation to different characteristics and attitudes towards sugar reduction strategies were divided to focus on specific population groups. These were either the young, the old, children, parents, pregnant women, people of lower socio-economic position (SEP) or people with obesity or diabetes. There was general consensus that the effectiveness of strategies would largely depend on the target audience and that appropriate intakes differ across individuals; hence strategies should be personalised.

'Health and Body Image' was one of the characteristics, defined as how a person thought he or she looked in terms of body size and skin, and how healthy a person thought he or she was. Some participants thought their current body size and good health did not warrant a change in behaviour, while others voiced concerns with their skin, body image and future health.

"I am eating way too much sugar. but I'm also doing way more exercise than the average person (pause) I would say average. Um (pause) so is there actually a link? Am I actually safe to eat the amount of sugar I'm eating or is there actually a problem and I shouldn't be?

I don't know the answer to that but because, I'm not having any problem as you were saying as well. Then you know, th-there's nothing to spur you to change..." (FG3, P3)

"I think it depends on, on the individual! Because I do think they-they have theor (pause) advantages if, if you take someone that is (pause) morbidly obese (pause) would you be more concerned about the chemicals that you're puttin' in their body? Or if the sole aim for them would the most important thing factor was them to lose weight, (pause) then perhaps uh (pause) a sugar alternative might be the, the best solution in that (pause) in that case? If they were tryin' to lose weight, because they were at risk of, some kind of serious heart disease or something?" (FG1, P1)

Under 'Generation and Age', comments suggested the belief that taste preferences change with time and age, such that as one ages one might prefer and desire sweet-tasting foods less, rendering intake reduction irrelevant to those of older ages. Some participants expressed that the younger generation was at risk of health implications of sugar and had poorer knowledge, while others expressed that it was the older generation more at risk and lacked knowledge.

"I do, for the children? (Laughs) [But, not (laughs) but not for ourselves!] Not for ourselves yeah." (DI1, P1 and P2)

"I do think it's um, (pause) needed in workplaces cause I think you've got a generation (pause) perhaps slightly older than us? So it may be into you- into your forties and fifties. Who, haven't had any awareness of any of this, haven't been really affected by kinda social media drives because they are not really a social media generation. So I think there is a, a generation above us, that is kind of like, I don't know kinda hang on, we-we've missed them and actually you could capture them with some workplace intervention." (DI1, P2)

"For elder people I don't know like maybe, only for label, it's good for them because they know already, at their age. Because of low sugar is better for them. (pause) But for like um (pause) young age, have to like educate more. (pause) Yeah. Give information?" (FG2, P1)

In terms of 'Socio-Economic Position', comments suggested that people with different SEPs faced different challenges in sugar reduction. Individuals with lower income were believed to have higher intake of foods with high sugar contents.

"I don't mean to sound judgmental but the people I see who usually consume high energy and high sugar drinks are usually people who look quite rough and poor." (FG6, P3)

> *"It's got to be a holistic approach, because we are sat here as essentially comfortable financial group, but I think you have to educate the masses and peoples dietary budgets are very different. The problem is you can buy a burger king for two pounds against buying fresh fruit and vegetables which are much more expensive. Unfortunately, people are always going to default to the cheaper, easier option. Changes need to be made at the legislation level, hitting the source, who make it so readily available. We need to put more emphasis on the suppliers so that they take responsibility for it."* (FG7, P2)

The level of involvement and interest in the process and outcome of consuming sweet-tasting foods, sugar and sweeteners were summarised in sub-theme 'Stake'. Some individuals felt that they had higher tendencies than others to crave for sweet or sugary foods, saw sweet-tasting foods as staples or associated intake with socially desirable traits such as attractiveness; hence, they had a higher stake in taking action towards their consumption. On the other hand, others expressed that sugar reduction was less of a priority when they were faced with a myriad of challenges, such as heavy workload or family commitments.

> *"No I don't have any problem like cause I don't have cravings for it so I'm, I'm good."* (I1, P1)

> *"Although there are a notable amount of people now who are kinda you know driving the healthy lifestyle, there is still a lot of people who are, you know, probably more in line with where I am, and slightly beyond, which is like pffttt! Yeah, if you make it easy for me maybe but I've got other fish I need to fry right now and I'm not gonna get there."* (DI1, P2)

4.3.2.4. Personal Responsibility

- One has an active relationship with sweet-tasting foods, sugar and sweeteners.

Similar to the previous theme, 'Personal Responsibility' also shared the idea that individuals have an active relationship with sweet-tasting foods, sugar and sweeteners. Comments suggested that individuals valued the ability to understand each option and make their own decision. The sub-theme 'Informed Choice' reflected the greatest degree of responsibility, as an individual had complete choice over food choice and consumption. Participants reported that they did not like to merely be told what to do, but instead want to be educated on the rationales behind interventions, what is inside their foods and what are the health implications of different foods. Awareness and education could bring about behavioural changes, but individuals were viewed as responsible for their own consumption, so there are boundaries that regulations should not cross. With 'Informed Choice', it would be the fault of an individual for making poor decisions. Some participants viewed sugar tax as helpful in raising awareness of high sugar contents of some foods and driving consumers to reduce their intakes. Several comments also suggested that consumers should share the cost of sugar taxes as a way of taking up responsibility. However, sugar taxes were also perceived as unfair to consumers who moderate their intake of high-sugar products and keep their intakes within healthy ranges. To these individuals, levy should be placed on overconsumption instead of consumption per se. Tactics or regulations similar to those for cigarettes, such as plain packaging or graphic imaging, were also considered as helpful in clearer identification of high sugar products but would require gradual introduction to the public for acceptance and might still be easily ignored by consumers. Some participants expressed that labels and guidelines, such as the traffic light system, were not helpful or clear enough and still require effort on the part of consumers.

> *"I think you have to be s-sort of consciously aware of the quantities and the (pause) macronutrients that's (pause) in a product. Um (pause) when you're readin' reading those labels and and trying to make a sort of, an informed decision on on what you then buy I think that I think that's one of the real issues?"* (FG1, P1)

> *"No I don't think so, but because I'm I don't know what's in it and I've never kind of I always never curious cause I always knew what's in the cube so I always use the cube. I guess it's it's kind of what you know about it and familiarity."* (FG2, P5)

> *"Because at the end of the day, its' a free world and and we cou we're all at liberty to make our own choices. But (pause) the information just needs to be. A bit clearer."* (FG3, P2)

> *"Yeah but at the end of the day if the customer wants it then surely they should pay for it? They aren't forcing them to consume it."* (FG6, P1)

An active relationship with sweet foods, sugar and sweeteners might also include 'Self-Regulation', a sub-theme defined as managing one's own intake of these food items. There was the concept of balancing out one's sugar or sweet-tasting food intake with healthier foods or behaviours that are perceived as healthier, such as exercise. Comments suggested that some participants actively avoid or reduce sugar by rationing each consumption, reducing frequency of consumption, removing any foods from the immediate environment and by preparing their own sweet-tasting foods to include less sugar. Several participants considered sweet or sugary foods as a reward. Sugar replacement with sweeteners was accepted on the condition that sweeteners have lower calories, and sweeteners usage was believed to allow for higher intake of sweet-tasting foods. Taste preferences were also believed to be modifiable; changing preferences was a matter of habit and getting used to new taste intensities.

> *"The traffic light system, occasionally I'll, if I think I'll, all I'll measure it by is like adding up what's red in the sugar zone, I'll just go 'oh okay, that meal is mostly red for sugar so I'll make sure the other meals are not red in other areas' so I make sure it's like lower, a different colour for anything else I buy, and that they don't add up. I could be buying four fucking things in the red zone and be like 'oh yeah that's fine cause I've had like seven things in the orange or green'."* (FG4, P1)

> *"I programme myself to like it too I think I'm used to it, a lot of people say they can't taste it but I don't really care, you get used to bitter tastes, like I've got used to black tea, I used to hate it and now I love it."* (FG5, P1)

> *"I try and balance it, some days I think I have way over two thousand but the next day I'll be healthier and have a salad or something."* (FG6, P1)

Deliberation and compensation was also seen in the sub-theme 'Internal Conflict', where participants struggled to balance out different motives, feelings and behaviours, as though there is a pull and tug between two opposing internal voices towards sweet-tasting foods and sugar. There were mentions of "devil", "naughty", "demon", "indulgence" and "guilt" in association with sweet-tasting foods and sugar intake. These implied that participants struggle with motives of health versus enjoyment. While preferences for sweet-tasting foods and sugar were considered to be acquired and not innate, habits were also considered difficult to break. Some participants expressed an "all or nothing" mentality and were unable to halt intake at times. Sugar reduction was related to restraint and deprivation.

> *"Yeah or a bit of fruit but I don't always want a bit of fruit, I don't want that sort of sweet I want a bit of naughty sweet."* (FG5, P3)

> *"You feel you being demonised cause actually you deserve that treat cause you've worked for it."* (FG3, P3)

> *"I do crave fizzy drinks, but like, and I know they're bad, and I try not to do it that much but like, I don't really care even though I know they're bad, cause I want it."* (FG4, P4)

> *"Yeah I definitely have, I know I eat too much sugar, I'm always trying to go on a diet but I usually end up back at square one as I give in too easily."* (FG6, P1)

When dealing with different motives, the extent of drive or desire to change one's behaviour was reflected in sub-theme 'Motivation'. While some participants viewed themselves as responsible for their own intake, they still lacked the willpower, self-care or time to change their behaviours. Other participants felt driven to make changes. Comments suggested that on top of education and modifying food products, strategies should target behaviours, such as focusing on positive reinforcement to effect and maintain sugar reduction.

> *"I lack the willpower, at the moment to do it. I think this stage of life we're at at the moment, with two young children, where you're constantly tired. And I know, the answer to get natural energy and all the rest of it, is to eat healthily and do exercise. But when you're coming off the back of about two hours sleep, you don't really want those things."* (DI1, P2)

> *"Yeah. Um but there is a lot of temptation around us all the time everywhere um and I guess, it's um it's just making small adjustments and, and maybe different choices rather have a piece of fruit, um instead of a biscuit or, something like that."* (FG1, P4)

> *"Well for sure the educating the people but sometimes you know no matter how much knowledge you have it's more about changing the behaviour."* (I1, P1)

4.3.2.5. Understanding

- Acquiring, comprehending and applying insights on sweet-tasting foods, sugar and sweeteners.

The theme 'Understanding' included the various stages of acquiring, comprehending, inferring and applying insights on sweet-tasting foods, sugar and sweeteners. The sub-theme 'Delivery of Information' focused on how information is disseminated and received. Channels included celebrities or influencers, doctors, documentaries, films, friends, social media platforms, newspapers, the internet, television programs and hearsay. All channels were viewed as both reliable and unreliable. While some comments suggested that education and awareness was sufficient and health guidelines and promotions were aplenty, other comments indicated that information was not actually widely accessible to the general public and suggested a need for education in workplace, schools, hospitals or other organisations. Technology such as mobile applications and visual cues such as labelling and advertising were seen as impactful aids in sugar reduction strategies.

> *"I think schools do quite well, because my kids are a lot more aware of sugar than we ever were when we were kids. They even asked me to put an app on my phone where you can scan food bar codes and it tells you the number of sugar cubes in it."* (FG7, P5)

"Where's you said the World Health Organisation uh where, um I mean, you know (pause) presumably the the the broad sheets would have it but where else would you get uh a World Health Organisation message?" (FG3, P1)

"What was interesting to me was when Jamie Oliver went into schools and he said to the kids choose your lunch. He then said to them before you can eat this you need to burn off the calories around the running track that this food contains. I thought that was brilliant for visualising how much they have got to do to burn off their chosen food." (FG7, P2)

"The news media pack up on the headline and they don't really fully explain it and everybody just sees the headline and (pause) and and (pause) just changes habits, sometimes unnecessarily." (FG3, P2)

"How do we get our information and how much time do we spend and where do we get reliable sources about you know just, you have somebody on the internet who's an influencer or whatever and it has in the background a bottle of something uh and you know and there's people looking at that how do we choose our reliable sources to find out about these things so, it takes a lot of time and uh you'll have to look at these things and spend time, really trying to understand." (FG1, P2)

General knowledge and being conscious of issues related to sweet-tasting foods, sugar and sweeteners were summed under the sub-theme 'Awareness'. While some participants were aware of policies, guidelines and health implications related to sweet-tasting foods, sugar and sweeteners, "hidden sugars" in food products and their own intakes, others were not mindful of these and were unclear on the rationales behind recommendations. When questioned on their subconscious biases against certain food groups, sugar or sweeteners, some participants were also unsure of the origins of their opinions. When prompted specifically about the UK SDIL, some participants expressed confusion or surprise. They were unaware that the tax had already been implemented and suggested poor awareness of its details. Comments indicated that some participants accepted all label information as they were.

"In the sort of the whole process of promoting a balanced diet, then (pause) it's not necessarily, just about (pause) uh cutting down on sugar cane cutting down on coke because it's got too much sugar in it. It's about an awareness sort of. (pause) all the other products that don't look like sugary products." (FG3, P2)

"I know that it's generally considered bad for you but if, you wanted me to go into specifics before you answered that truthfully, I couldn't have given you, the specifics other than saying I know it's bad for me on a general level." (DI1, P2)

"Also I don't think people are aware of the damage that they are doing to their health because there's so much out there, or maybe people just turn a blind eye to it." (FG6, P1)

"If you had asked me two years ago I would have assumed if it was labelled no added sugar then it would have no sugar in it. It is only more recently that I suspect sweeteners have been added." (FG7, P4)

"I think instead of preventing it, they should encourage them and then help them see other options other than saying oh this is too expensive you can't buy it now... Cause I've seen it, after Brexit, in some shops (pause) For example there's a certain thing, sausage or whatever I buy, and there's five or ten p difference. People don't realise is just because I always buy that one, I will realise. But I won't know the reason behind it. I will just assume it's Brexit. But it might be, the sugar tax in that sausage. (pause) You don't know." (FG2, P5)

'Perception' referred to the way of interpreting or regarding information related to sweet-tasting foods, sugar and sweeteners. Responses indicated a large variation in perceptions, influenced by memories and prior experience with each food item. There were concepts of "healthy" versus "unhealthy" sugars; that the colour of a food was associated with how healthy and natural the food was, for example, brown sugar was more natural and healthier than "artificial" white sugar; and that "natural sugar" from fruits and honey were healthier than "chemical" artificial sweeteners. The terms "fresh", "natural" and "organic" were interpreted positively. Comments also suggested confusion in relation to food juices, food drinks and concentrates, but participants generally saw fruit as a healthy source of sweet taste. Low- or no-fat products were regarded as having high-sugar contents, while low- or no-sugar products were regarded as having high sweetener contents.

"But brown rice is better for you so surely brown sugar is." (FG5, P2)

"It doesn't count! Cause it's a drink!" (FG1, P1)

"It's a natural fruit. It's a natural sugar! It's natural sugar I think it's different sugar." (FG1, P4)

"Uh, so if you have like (pause) wholemeal food, it contains different types of sugar different types of carbs, (pause) as compared to fruits. Cause th-the fruit, um, they contain a lot of glucose and fructose which are like, simple sugars?... i-in fruit you-you've got th-th-the type of sugar that you actually use quite quickly?... So uh (pause) as compared to, let's say, whole-grain, um (pause) pasta or whatever, which also contains a lot of (pause) carb, that's that is a different type… from what I know, it's for your health, it's better to eat vegetables, rather than fruits? Or grains? If you if you need carbs. If you need this type of uh (pause) thing. It's better to eat grains or y'know cereals, without, added sugar. Uh, rather than fruit?" (FG1, P3)

"Oh yeah white is so bad for you, they have to bleach it and put sugar in it." (FG5, P2)

'Proficiency' was defined as a deeper knowledge and proficiency in matters related to sweet-tasting foods, sugar and sweeteners. There were concerns that the current sugar-reduction campaigns focused on sugar cubes and carbonated beverages, leading the public to think that only these items are unhealthy and should be avoided. There was general consensus regarding a lack of education and therefore lack of proper understanding of sweeteners and how to use them as replacement for sugar in preparing sweet-tasting foods with reduced sugar at home, such as in baking or cooking.

"It's a lot of lack of education in, like, knowing that actually if you, cook a tomato sauce or something like the sugars within the tomato, or you know there's a, the fruit and food and vegetables have, naturally occurring stuff in them. So you don't actually need to add, anything to it. So you will still get a feeling of like oh like in a cake you could add some banana or something, and you get some sweetness instead of (laughs) instead of adding sugar you know there's lots of things like that." (DI1, P1)

"People just don't realise it's not only about like, sugar cubes or something like that." (FG1, P3)

"I think a lot has been done to educate people on sugar, but there seems to be no education on sweeteners and what they are." (FG7, P4)

The sub-theme 'Reasoning' covered how an individual applies logic while processing information on sweet-tasting foods, sugar and sweeteners in order to form inferences. Participants reported being unable to interpret the large influx of marketing, nutrition and health information, and to cope with the saturation of the food environment. This caused them to be at a loss of whether to consume sugar or sweeteners as the source of sweet taste. Responses indicated some support for sweeteners for weight loss, diabetes, hyperactivity or other medical conditions. In addressing whether sweeteners should replace sugar, some participants agreed with using sweeteners as a short-term strategy to reduce dietary sugar in general, while others did not see the need and supported sugar reduction alone. There were concerns that people might stop exercising once they switch from sugar to sweeteners because they are consuming less calories. Comments suggested that sweeteners should contain additional health benefits such as vitamins, instead of only providing fewer calories, and that graphic imaging on plain packaging should also apply to many other products such as those high in salt or fat, since these foods were considered “bad” for health as well. There was general consensus that sugar reduction would require a holistic approach, involving government legislations, food products reformulations, education and motivation.

> *“Yeah like I don’t know what to believe any more because there are so many of this fad diets and all that I like don’t know who to trust.”* (FG5, P4)

> *“I think my concern would be if people, mis-interpreted the message that said sweeteners are okay, and sugars are less okay. People might think, well I won’t bother exercising now and they think then if if I just turn to sweeteners.”* (FG3, P1)

> *“I think maybe if you suffer from diabetes or something like that there are possibly some sweeteners that are better for blood sugar regulation, I don’t really know. Yeah, I think that would maybe be an advantage, but from my point of view, someone that doesn’t have a condition, I don’t see any advantage.”* (FG7, P3)

> *“But is this being considered? Because what now what I’m thinking is, um obviously uh there’re other stuff that are quite (pause) you know, not so beneficial even harmful, uh in the shops. So it’s not just bout sugar, but if we actually, go for this, these regulations in terms of what every single thing we eat (pause) then it would be the end of an era. Of marketing and brands and everything.”* (FG2, P6)

4.3.2.6. It’s Not Up to Me

- One takes a passive approach towards sweet-tasting foods, sugar and sweeteners, because intake is subjected to other factors.

In contrast to the active involvement of the individual in themes ‘Personal Responsibility’, ‘Personal Relevance’ and ‘Understanding’, this theme ‘It’s Not Up to Me’ reflected a passive approach to intake of sweet-tasting foods, sugar and sweeteners. Intake was considered to be ‘Beyond Individual Control’ due to factors that individuals felt unable to control. Instead, food choice and intake were determined by the social and cultural environment, such as family and friends, and food environment, such as food availability and accessibility. Some participants expressed that their childhood habits had persisted into adulthood. Peer pressure and social norms were highly influential, hence, the normalisation of obesity could increase sugar consumption, as high sugar intake was seen as acceptable or typical. On the other hand, others suggested that with peer pressure and social norms, the society is becoming healthier and that lowering sugar consumption is more acceptable. The sugar content of foods was seen as unnecessarily high, a fault of food manufacturers. Some participants expressed being subjected to subliminal advertising, labels and aggressive marketing strategies. A reason provided by participants for failing to notice the SDIL in place was that large price fluctuations in the economy may mask smaller tax-related increases in prices. From some participants, sugar reduction is beyond individual control because the addiction is difficult to overcome and would require professional help.

> *"Fair enough if you're big and you're top of reasonable BMI and that's the way, like I know someone who's got a thyroid problem and it doesn't matter how clean she eats she will put on weight and she'll go running every week but she's still a big woman and she can't help it, probably really depressing and crappy on their self-esteem."* (FG4, P1)

> *"Yeah as a kid I had way more sugar than my children have now. Every time I was picked up from school or play group my mum would give me a bag of sweets. Golden syrup on my porridge."* (FG7, P3)

> *"I think people need professional help! You know for sugar? Cause of the fact that I've I- I-y-yeah. I think she's right. It is a drug (pause) and when I when I need, I need it."* (FG3, P6)

> *"Yeah but at the same time you might want baked beans but you're not asking for all the extra added sugar which has gotten has increased drastically over the years like it didn't used to have that much sugar in it, and you can't really get ones without the enormous amount of sugar in it and that's not necessarily their fault, baked beans are supposed to be healthy for you, it's the manufacturers' fault for putting that much in there in the first place."* (FG5, P1)

Another passive approach was summed under the sub-theme 'Strategies and Regulations', referring to official legislations and large-scale measures. Consumers were considered not capable of knowing what is best for them and could not be relied on. Instead, it was the responsibility of the government to ensure both consumers and manufacturers take the right actions. Suggestions included setting reduced-sugar versions of foods as the default option and sugar tax was viewed as beneficial in driving manufacturers to lower sugar content of foods.

However, there were also concerns that implementation was dependent on individual manufacturers and that the food industry could choose to reject measures such as graphic imaging on plain packaging and sugar labelling. Current dietary recommendations, such as keeping below 30 grams of free sugars per day, were also seen as possibly unrealistic.

> *"You know, if it's really a health issue problem, it has to be you know, peep-people can't take responsibility most of the time, so you know that's, that's a lot to do with that! You know, teaching people how to take responsibilities… But, at the end of the day, you know, if that doesn't work, is like people are children you know, you have to tell them off and the only way is punishment! Isn't it?"* (I1, P1)

Lastly, the sub-theme 'Deception' included the ideas of traps, tricks and temptations used by food manufacturers and distrust of the food industry. The food industry was perceived to be corrupt, intentionally loading high amounts of sugar or sweeteners into foods and misleading consumers with unclear labels. Comments suggested that consumers were pitted against food manufacturers and that the tactics of the latter would triumph. Participants also expressed distrust of current food labels and of information provided by health professionals and scientific researchers.

> *"I think it's sneaky how much they put in stuff, it can be hard to stick to your plan or keep things in moderation when companies load things with sugar and fat."* (FG6, P3)

> *"Some big companies are being um getting paid by some of the big companies to the doctors and they are giving kind of (pause) prejudice or kind of biased advice? So you shouldn't always trust the professionals as well. I just like, do some research, ask people, what are their opinion, and stuff. So don't just go to professionals."* (FG2, P5)

4.4. Discussion

This study aimed to explore attitudes towards sweet-tasting foods, sugar and sweeteners, including how individuals viewed their relationships with these food items and related sugar reduction policies, in a sample of the general public in the UK,. Seven focus groups, two dyadic interviews and one solo interview were conducted from January 2018 to March 2020. The study identified the following six themes to describe attitudes to sweet-tasting foods, sugar and sweeteners: 'Value', 'Angle', 'Personal Relevance', 'Personal Responsibility', 'Understanding' and 'It's Not Up to Me'. Individuals expressed positive, negative or indifferent perceptions, and took either an active or passive approach to changing their intakes.

Most attitudes mentioned were related to all three food items: sweet-tasting foods, sugar and sweeteners. There were, however, in this sample, several sub-themes formed that were not relevant to sweeteners, namely 'Special', 'Emotions', 'Internal Conflict', 'Motivation' and 'Socio-Economic Position'. These mainly belonged to themes 'Value' and 'Personal Responsibility'. Participants might not have thought about the value of sweeteners or had the idea of taking personal responsibility towards them. This is despite some remarks on the use of sweeteners for weight management and diabetes. Notably, it might be specific to the study sample. This finding could be due to being unsure of the origins, benefits, effects and appropriate intakes of sweeteners. Studies have reported the lack of comprehension and certainty surrounding sweeteners and their health effects (Harricharan et al., 2014; Messina et al., 2004; Sylvetsky et al., 2014). This could have led to participants not actively thinking about sweeteners or to express less thoughts on what they were unsure of. In contrast, sugar was mentioned in every sub-theme, perhaps specific to the study sample. In a group of young female adults, no significant relationship was found between an individual holding negative attitudes towards sugar and accepting low- or no-calorie sweeteners (Ndofirepi et al., 2020). The formation of opinion towards sugar may be independent of the formation of opinion towards sweeteners.

At the same time, individuals expressed comparative considerations towards sweet-tasting foods, sugar and sweeteners, such as the concept of the 'lesser of two evils' between sugar and sweeteners. While attitudes captured by the theme 'Value' demonstrated a range of positive attitudes and benefits from consuming sweet-tasting foods, sugar and sweeteners, attitudes detailed in the theme 'Angle' demonstrated fewer positive attitudes and concerns towards them. Attitudes towards one food item could be dependent on competing alternatives. Perceived benefits including taste and pleasure are commonly reported as reasons for consuming sweet-tasting foods (Fadupin et al., 2015; Gupta et al., 2018; Morel et al., 2019; Pielak et al., 2019). This is not surprising as humans have an innate liking for sweet taste and many foods seen as treats are sweet-tasting (Beauchamp, 2016). Individuals also reported linking specific sweet-tasting foods to pleasurable experience, memories and emotions. Such associations between food and emotions (Macht, 2008; Sthapit et al., 2017) and food and memories (Knight et al., 2014; von Essen & Mårtensson, 2017) have been well-documented. Perception of both health benefits (Appleton & Conner, 2001; Fadupin et al., 2015; Hennessy et al., 2015; Messina et al., 2004; Ortega-Avila et al., 2019; Zytnick et al., 2015) and concerns (Forde & Solomon-Moore, 2019; Morel et al., 2019; Pielak et al., 2019; Sylvetsky et al., 2014) are frequently reported in association with sugar and sweeteners intakes.

The range in attitudes collected in this study under the 'Value' of sweet-tasting foods, sugar and sweeteners showed that relationships with intakes of these foods may depend on individuals and also on foods. In a study comparing consumption of a chocolate bar versus an apple, researchers found that both foods improved the moods of healthy women; however, chocolate consumption also caused guilt in some of them, possibly fostered through negative thoughts about food (Macht & Dettmer, 2006). Food rules learnt at a young age may have long-lasting effects on eating behaviours in adulthood. Jansen and colleagues (2020) reported that the value of foods taught at age four years already predicted higher emotional overeating and food responsiveness scores at age nine years. Memories of these parental rules about food are significantly related to adult eating behaviours (Puhl & Schwartz, 2003). This could explain why some participants in this study valued certain sweet-tasting foods over others, for example, that some sweet-tasting foods were only for reward on special occasions. Given the variation in attitudes that one might have towards sugar and its alternatives, it would be beneficial to investigate how these attitudes might influence intakes. This could inform researchers on which attitudes are dominant in higher intake groups and develop more effective targeted sugar reduction strategies.

Apart from the indifferent, positive or negative perceptions held towards sweet-tasting foods, sugar and sweeteners, the 'Personal Relevance' of modifying one's intake was also important to individuals. An individual could take interest in sugar and its properties, disapprove it as unhealthy, yet perceive it as currently irrelevant and therefore not feel personally concerned to reduce sugar intake. Relevance was determined on numerous demographic characteristics, such as gender, age and SEP, on personal situation, such as family commitments, and on personal interests, such as the importance of health and appearance. The importance of and variations in personal relevance on dietary sugar and sweetness behaviours is consistent with literature (Contini et al., 2015; Dean et al., 2012; Steinhauser & Hamm, 2018; van Kleef et al., 2005). Contrasting concerns and barriers towards healthier consumption across differing population groups is also evident (Forde & Solomon-Moore, 2019; Messina et al., 2004; Morel et al., 2019; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Pielak et al., 2019; Sylvetsky et al., 2014). Investigation into different population groups would be beneficial to identify the strategical needs of each group.

Individual differences were also observed in the theme 'Personal Responsibility' and individuals who believed that they were personally responsible for managing their own consumption of sweet-tasting foods, sugar and sweeteners, tended to regulate their own behaviours, such as their intake of other foods or engagement in physical activity. The belief that unhealthy eating could be compensated for by a healthy behaviour is not uncommon, with research showing the presence of it during unhealthy snack consumption (Amrein et al., 2017, 2021; Petersen et al., 2019). Perhaps having such beliefs would help individuals to view sugar reduction as achievable and manageable, since any mistake or ‘cheat day’ can be rectified. Participants appreciated being informed about foods and their health effects so that they can make their own choices and regulate their intakes themselves. This is consistent with other research on sugar and sweetener use (Morel et al., 2019; Ortega-Avila et al., 2019; Sylvetsky et al., 2014). Perceived personal choice and personal control have also been positively associated with more healthy food choices (Contini et al., 2015), dietary consumption (Bayer et al., 2020; Carbonneau et al., 2021; Maillet & Grouzet, 2021) and body weight (Halali et al., 2018; Robinson et al., 2022), as well as support for health promoting dietary guidelines (Traina et al., 2019). Self-regulation has also resulted in inner conflict or required additional motivation, depending on the individual. Nonetheless, the overriding concept of personal choice and responsibility remained paramount in this theme.

In order to make informed personal choices, the means to obtain, interpret and process information on sweet-tasting foods, sugar and sweeteners were also important, and acknowledged in the theme ‘Understanding’. Sub-themes recognised the use and acceptance of both conventional and novel types of information and channels, the importance of awareness and education in managing intakes, the diversity in perceptions and the presence of justifications to rationalise individual intakes. Even though information is often available, such as provided by Public Health England (Public Health England, 2018a) and the British Diabetic Association (British Diabetic Association, 2018), it may still be inaccessible by certain individuals or population groups, or misunderstood (Forde & Solomon-Moore, 2019; Harricharan et al., 2014; Hennessy et al., 2015; Messina et al., 2004; Morel et al., 2019; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Sylvetsky et al., 2014; Zytnick et al., 2015). The influence of media portrayal of scientific publications and policy discussions have also been demonstrated on consumer perceptions of sugars and sweeteners (Borra & Bouchoux, 2009). There is potentially a need for different types of information and education to be disseminated to different individuals to instigate dietary change.

On one hand, perceived relevance and autonomy control reflected in the previous themes may be positively associated with better overall diet quality, healthier eating behaviours and effective diet change. On the other hand, the perception of being constrained or sabotaged by external factors is also negatively associated with these outcomes (Carbonneau et al., 2021; Coumans et al., 2022; Maillet & Grouzet, 2021; Wąsowicz et al., 2021), and reflected in the theme ‘It’s Not Up To Me’. Some individuals felt subjected to factors beyond their control, such that behavioural change was not up to them. Instead, the responsibility was given to governments and the food industry. There were even ideas of 'deception', further reducing the role of the individual. The role of external influences, such as the social and cultural environment, on intakes of sweet-tasting foods, sugar and sweeteners has been well documented (Fadupin et al., 2015; Forde & Solomon-Moore, 2019; Hennessy et al., 2015; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Pielak et al., 2019; Zytnick et al., 2015). The distrust in health professionals, government agencies and the food industry was also consistent with literature (Forde & Solomon-Moore, 2019; Harricharan et al., 2014; Pielak et al., 2019). Despite this, strategies for change relied entirely on government legislation and regulation of the food industry. Consumers may differ in their beliefs of personal versus external responsibility on intakes of sweet-tasting foods, sugar and sweeteners, which warrants for tailored sugar reduction strategies.

The need for personal relevance, and the possible differing attitudes based on consumer groups, also suggest that strategies may be more effective when targeted at specific perceptions and motivations. In line with previous work, participants expressed a range of concerns over the acceptability, use and effect of sugar and sweeteners (Fadupin et al., 2015; Forde & Solomon-Moore, 2019; Hennessy et al., 2015; Morel et al., 2019; Pielak et al., 2019). Moreover, the idea of replacing sugar with sweeteners received mixed reactions. While this could serve as an interim plan to reduce sugar consumption and benefit consumers who appreciate sweet taste, concerns still lie with the safety and long-term health effects of sweeteners consumption. Distinction between dietary sugar and dietary sweetness was also unclear. Specific information targeted at corresponding concerns would help to inform and educate different consumers more beneficially. This is, however, only apt for individuals who feel personally responsible for their intakes of sweet-tasting foods, sugar and sweeteners. The importance of empowering individuals is apparent from the two contrasting themes 'Personal Responsibility' and 'It's Not Up to Me', Resources should be provided to enable and motivate individuals to take up responsibility for their own intakes and effect behavioural change.

The present study was limited by its quantitative nature, as the sample size was too limited to assess if certain attitudes were more important than others, or individual differences in the range of attitudes. Discussions were also contextual, reflecting the prevalent attitudes and sugar-related strategies in the UK at the time of the study. New legislation on advertising and labelling of high-sugar foods may influence consumer attitudes in the future (Borra & Bouchoux, 2009). Bias in the participants who volunteered and participated in the study may have also occurred, as they might have held more opinions and interest in this topic. However, several recruitment strategies were used alongside minimal inclusion criteria, allowing for a range of individuals with a range of attitudes. By the last focus group, researchers did not observe anymore new attitudes and thus, it was unlikely that any important concept had been missed. The study did not gather attitudes of individuals in specific groups, such as people with lower SEPs or people with obesity; hence, caution should be exercised to generalise any finding from this study. Lastly, analyses may also have been influenced by the backgrounds of the researchers. The possibility of this researcher bias was minimised by practicing reflexivity (see section 4.2.7.) and using a standardised moderator guide in all sessions. Nonetheless, similar research in the future could consider appointing an external qualitative researcher to check or validate the themes.

4.5. Conclusion

This qualitative study served to identify the attitudes, beliefs and considerations towards sweet-tasting foods, sugar and sweeteners, in a sample of consumers living in the UK. Six themes were identified: ‘Value’, ‘Angle’, ‘Personal Relevance’, ‘Personal Responsibility’, ‘Understanding’ and ‘It’s Not Up to Me’. Individuals reported indifferent, positive or negative perceptions of sweet-tasting foods, sugar and sweeteners, and took on either an active or passive approach to change their intake behaviours. Individuals also expressed deliberation between competing alternatives of consumption and motivation. The effectiveness of sugar reduction strategies may depend on the motivations, perceptions and priorities of individuals. To investigate the possibility of shifting consumer attitudes with the purpose of modifying sugar or sweetener choice and reducing sugar intakes, the next step would be to assess the relationship between attitudes and intakes, and to find out the dominant attitudes in specific population groups.

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5. Sweet Talk II: Associations between attitudes towards and intakes of sweet-tasting foods, sugar and sweeteners in a quantitative study

5.1. Introduction

Individuals' attitudes towards a food consumption behaviour have been established to be an integral determinant of their behavioural intentions, and even the behaviour itself. Attitudes play an important role in driving food choice, purchase or intake of organic (Arvola et al., 2008; Scalco et al., 2017), novel (Y. G. Kim et al., 2014; Menozzi et al., 2017), halal (Ali et al., 2018; Sherwani et al., 2018), healthy (Collins & Mullan, 2011; Conner et al., 2002; Grønhøj et al., 2013), fast (Dunn et al., 2011; Fila & Smith, 2006), snack (Lambert et al., 2020) and local foods (Kumar & Smith, 2017). For example, individuals' attitudes was the strongest factor for purchase intention of organic food, significantly predicted subsequent organic food consumption and mediated the effects of social norms on purchase intention (Scalco et al., 2017). Attitudes also partly mediated the effect of food values on actual purchase of organic food (Schäufele & Janssen, 2021).

Notwithstanding, attitude-behaviour associations can be moderated by the type of dietary behaviour and demographic characteristics (McDermott, Oliver, Simnadis, et al., 2015; McDermott, Oliver, Svenson, et al., 2015; Solomon, 2017). For example, McDermott and colleagues (2015) found that attitudes were more predictive of avoiding sugary foods such as sweets and desserts, than of following healthy eating guidelines. They also observed that these effects differed between age groups. This suggests that when targeting attitudes to drive sweet taste-related behaviours, distinction between the behaviours and characteristics of the target population(s) would be helpful. To develop potential strategies for reducing free sugar intakes, it would be helpful that dominant attitudes towards sweet-tasting foods, sugar and sweeteners, and their intakes, could be identified alongside individual intakes and characteristics.

Current evidence for associations between attitudes towards sugar, knowledge on the health implications of a high sugar intake and accompanying sugar intakes have been inconclusive (Gupta et al., 2018). These associations may also be confounded by attitudes and/or associations with alternatives to sugar intake. Individuals' choice and consumption of other sources of sweet taste, such as sweeteners, or of less sweet foods, and even their attitudes towards these alternatives, may affect the strength of associations between attitudes towards and intake of dietary sugars. Hence, a qualitative study was first undertaken to explore individuals' attitudes towards sweet-tasting foods, sugar and sweeteners, towards their consumption and towards related policies (Chapter 4). Indeed, participants considered sugar and sweeteners in relation to each other and differed in their positive and negative attitudes towards the food items. Individuals also conveyed different perceptions, motivations and concerns towards these food items. Such variations highlight the advantage of segmenting specific sugar reduction strategies in distinct consumer groups. For example, the dominant attitudes of individuals with the greatest need of change in sugar intake could be targeted for behaviour change.

Despite this, the prevalence of various attitudes in a population and their associations with frequency of intake are still unclear. Moreover, research to date has been limited to sugar, sweeteners, or both, neglecting sweet-tasting foods as a whole. Thus, the present study aimed to 1) examine the relationships between specific attitudes and intakes of dietary sweet taste, and 2) identify dominant attitudes towards sweet-tasting foods, sugar and sweeteners in specific population groups, in the United Kingdom (UK).

The rest of this chapter has been structured as follows – (5.2.) a section on materials and methods which were used to reach the research aims; (5.3.) a results section on the relationships between specific attitudes towards and intakes of sweet-tasting foods, sugar and sweeteners (aim 1); (5.4.) a discussion on the first set of results; (5.5.) another results section on the dominant attitudes in specific population groups (aim 2); (5.6.) a discussion on the second set of results; (5.7.) a summary on both sets of results and discussion; (5.8) a section on strengths, limitations and future research; and (5.9) the conclusion.

5.2. Methods

This study used a cross-sectional study design with a questionnaire composed of three sections: (1) estimated sweet-tasting foods, sugar and sweeteners intake frequencies; (2) attitudes related to these food items; and (3) demographic and lifestyle questions, in this order.

5.2.1. Participants

Aimed towards the general public living in the UK, 600 participants were recruited via interested persons databases, social media sites, Prolific (prolific.co) and Bournemouth University psychology student research participation platform (psychologyresearchbu.sona-systems.com). Exclusion criteria were less than 18 years of age and living less than one year in the UK. The study was granted ethical approval by the Ethics Committee of Bournemouth University (number: 32878), and all participants provided informed consent. Participants who were recruited from the recruitment platform Prolific were paid for their participation. Participants who were recruited from the university student research participation platform were given credits for their participation. All remaining participants were given an opportunity to win Amazon vouchers valued at £20 (1 in 10 chance) in a prize draw.

5.2.2. Intake frequency estimate

Usual consumption of sweet-tasting foods, sugar and sweeteners were estimated by asking for the frequency of consumption of the top National Diet and Nutrition Survey (NDNS) food groups that contributed to total sugar intakes relevant to the sugar reduction programme in the UK, 2012 to 2014 (Tedstone et al., 2015). These food groups are 'Biscuits', 'Breakfast Cereal', 'Cakes and Morning Goods', 'Chocolate and Sweet Confectionery', 'Ice Cream, Lollies and Sorbets', 'Puddings', 'Sweet Spreads and Sauces', 'Yogurts', 'Fruit Juice and Smoothies' and 'Soft Drinks' (Tedstone et al., 2015). To include the consumption of artificially-sweetened diet food and drinks, 'Chocolate and Sweet Confectionery', 'Ice Cream, Lollies and Sorbets', 'Yogurt' and 'Soft Drinks' were further split into 'not sugar-free or diet' and 'sugar-free or diet'. In addition, habitual sweet food-related behaviours were estimated with the frequency of adding sugar, honey and sweetener in coffee, tea and homecooked dishes. The response choices available for all intake questions were 'Rarely or never', 'Less than 1 a Week', 'Once a Week', '2-3 times a Week', '4-6 times a Week', '1-2 times a Day', '3-4 times a Day' and '5+ a Day'.

5.2.3. Attitudes

Attitudes towards sweet-tasting foods, sugar and sweeteners, and their intakes, were assessed through a 5-point Likert Scale for participants to specify their level of agreement or disagreement to 81 statements referring to various aspects of these foods. These statements were composed following the thematic analysis of a qualitative study conducted on the general attitudes of residents of the UK towards sweet foods, sugar and sweeteners (Chapter 4). The themes are 'Angle', 'Personal Relevance', 'Personal Responsibility', 'It's Not Up to Me', 'Understanding' and

'Value'. Four to 10 statements were provided per theme, where 23 statements were relevant to sweet-tasting foods, 29 to sugar, 26 to sweeteners and four to both sugar and sweeteners. Participants were required to answer all questions. Statements were written in the active voice and related directly to the respondent, for example, 'I feel guilty whenever I consume sweet foods'. Statements were both positively- and negatively-worded and presented randomly across all themes. Participants could select 'Strongly Disagree', 'Disagree', 'Neither agree nor disagree', 'Agree' or 'Strongly Agree' for each statement. There was also a ranking question, resulting in 82 questions to assess attitudes. Participants had to rank the importance of cost, health, pleasure, presentation and taste in relation to choice and consumption of sweet-tasting foods to assess their overall consideration towards sweet taste. The questionnaire was piloted among 13 volunteers. Changes were made to improve comprehension and flow, and the final list of questions per theme is in Appendix 5.

5.2.4. Demographic and Lifestyle Characteristics

Demographic characteristics measured were gender, age, ethnicity, highest education qualification level attained and socio-economic classification (SEC) based on employment. Gender choices were male, female, non-binary and prefer not to say; age was numerical in years; the question on ethnicity was developed by the UK government design system team (UK Government, 2020); the question on education level was adapted from the Office for National Statistics (Office for National Statistics, 2020); and the question on employment was adapted from the National Statistics SEC (Office for National Statistics, 2019). Lifestyle characteristics measured were Body Mass Index (BMI) based on self-reported height and body weight; presence of any health condition that may influence eating and food choice; adherence to any diet; and food intolerances or allergies to foods.

5.2.5. Questionnaire Administration

The questionnaire took approximately 15 minutes to complete and was administered online, including the process of consent. The first page of the questionnaire specified criteria for completing this questionnaire and anyone who did not meet the criteria, was not able to proceed. There was a participant information sheet for potential participants to read through and details of the research team to contact for any questions. Participants would then proceed to consent to having read the information sheet and that they were comfortable with participating in the study. Subsequently, participants would complete the questionnaire at their own pace and only submit when they felt ready. Participation in the prize draw was explained to participants when they had submitted their responses, and they could also choose to end without participating further. The full questionnaire may be referred to in Appendix 6.

5.2.6. Attention Check

An attention check is a commonly used tool to improve scale validity and identify careless responses (Kung et al., 2018). To collect responses that accurately represent attitudes and concurrently prevent excess deliberation, logical statements were chosen as the approach to the attention check. Logical statements are easy to implement and have moderate to high objectivity (Abbey & Meloy, 2017). Two logical statements were used as the questionnaire was already relatively long. The two statements are 1) All sugar is dug out from sugar mines at least 50 metres deep; 2) All sugar comes from the sea. These statements were presented with the other attitude statements in a randomised order. Any respondent that agreed or strongly agreed with either statement was removed from analysis.

5.2.7. Data Analysis

Firstly, any participant with incomplete data was removed from analysis. The characteristics of the remaining participants were assessed though descriptive statistics. Responses to all intake frequency questions were converted into 'times per day' by taking the median of each category. For example, '4-6 times a Week' was 5 (median of 4 to 6) divided by 7 (days in a week), which is 0.714. This allowed for an estimate of habitual sweet-tasting food consumption and related behaviours. All responses to attitude statements were coded from -2 to +2, with higher scores reflecting greater agreement. Negative statements were reverse-scored. The ranking question was analysed with the top ranked item coded as 5 and the lowest ranked item coded as 1 and included only as a descriptive result. The two attention check questions were removed. Participants who chose the option "neither agree nor disagree" for over 50% of the statements were removed from all subsequent analyses.

Responses of the remaining participants to the 81 statements on attitudes were entered into principal component analysis (PCA) in an exploratory manner to identify the underlying components that the questions were measuring. This reduced the number of variables into fewer principal components for subsequent analyses regarding attitudes. PCA was undertaken applying Varimax rotation and small coefficients with an Eigen-value below 0.30 were suppressed (Howard, 2016). Cross-loading items were defined as loading $\geq$ 0.30 on two or more factors and removed (Costello & Osborne, 2005). The number of principal components was determined from the Scree Plot and each component was summarised based on semantic reasoning. Attitude responses were converted into the principal components, by reverse-coding all relevant items, multiplying by the loading of items, and then taking an average per component. Coherence within each component was assessed using Cronbach's alphas.

Shapiro–Wilk tests were conducted for each independent variable (all participant characteristics and attitude components) to test for normality. Correlations were conducted on the variables to assess multi-collinearity. One-way Multivariate Analysis of Covariance (MANCOVA) was conducted to assess for any significant difference in estimated intake frequencies across all demographic and lifestyle characteristics, while accounting for covariates. BMI groups were created based on the definitions provided by the National Health Service (National Health Service, 2019). MANCOVA for the effect of gender on intake frequencies considered age and BMI as covariates. MANCOVA for the effect of age on intake frequencies considered gender and BMI as covariates. MANCOVA for the effect of BMI on intake frequencies considered gender and age as covariates. The remaining MANCOVA considered gender, age and BMI as covariates.

For aim 1, hierarchical multivariate linear regression analyses were conducted to assess associations between attitudes and intakes. Separate models were performed for each estimated frequency of intake and adjusted for participant characteristics. Demographic characteristics were entered in the first block, lifestyle characteristics in the second block and attitude components in the third block, all using the ‘Enter’ method to assess which factors are relevant.

For aim 2, Latent Profile Analysis (LPA) was undertaken to identify latent sub-populations within the sample in which dominant attitude components exists (Oberski, 2016). The three-step approach was undertaken: (1) build and estimate the optimal model, (2) classify participants into classes based on their posterior class membership probabilities, and (3) examine the associations between class membership and participant characteristics (Vermunt, 2010). In step (1), equal variances within and equal covariances across classes were assumed. Analytical Hierarchy Process was applied to incorporate Akaike’s Information Criterion (AIC), Approximate Weight of Evidence (AWE), Bayesian Information Criterion (BIC), Classification Likelihood Criterion (CLC), and Kullback Information Criterion (KIC); in order to determine the optimal number of classes (Akogul & Erisoglu, 2017; Tein et al., 2013).

For step (3), basic linear models were used to assess the differences in attitude component scores between the classes, each model adjusting for independent variables that were significantly correlated with that attitude component. Finally, multinomial logistic regression analysis was conducted to ascertain the effects of participant characteristics on their likelihoods of being classified into one class versus another. The class with the most healthy or desired attitudes was the reference category. Genders were re-categorised as ‘male’ and ‘not male’, ethnic groups were re-categorised as ‘white’ and ‘not white’, education levels were re-categorised as ‘at least a university degree’ and ‘no university degree’ and SEC was re-categorised as ‘at least professional occupations’ and ‘not professional occupations’. Results of the multinomial logistic regression analysis were reported according to the guidelines and recommendations set by Peng, Lee and Ingersoll (2010). Lastly, MANCOVA was conducted to assess for any significant difference in estimated intake frequencies between the three classes, adjusting for all demographic and lifestyle characteristics.

MANCOVA, LPA and multinomial logistic regression analysis were performed using R statistical software (version 4.0.2) (R Core Team, 2020; Rosenberg et al., 2019); remaining analyses were performed using SPSS (version 28). Statistical significance was set at 0.05. To control for type I error in multiple testing, significance thresholds for regression analyses and basic linear models were minimised to $\alpha' = .05$ / number of tests (Jafari & Ansari-Pour, 2019). Upon a significant main effect, a post-hoc Bonferroni test was conducted.

5.3. Results on attitudes, intakes and their relationships

5.3.1. Participants characteristics

A total of 600 questionnaires were submitted, out of which, one provided incomplete data and one failed the attention check. The remaining 598 participants varied in age (18-87 years), BMI (15.8-65.3 kg/m^2), ethnicity, highest education qualification attained and SEC (Table 5.1). Regarding lifestyle characteristics, 11% of participants had a health condition that could influence their eating and food choice, including diabetes, irritable bowel syndrome, hypo- or hyperthyroidism, depression, anxiety, polycystic ovary syndrome, an eating disorder, kidney failure and hypertension; 14% of participants had at least one food allergy or intolerance, including chocolate, nut, egg, seafood, lactose, gluten, certain fruits, spice and wine, and sensitivity to sugar; 15% of participants adhered to a weight management diet, such as calorie counting, intermittent fasting, avoiding sugar, reducing carbohydrates and lowering fat in the diet.

Compared to the UK population, this sample had more females, X^2 (2, N = 598) = 13.69, p < .01; younger adults, X^2 (5, N = 598) = 212.9, p < .01; fewer adults belonging to a Black ethnic group, X^2 (4, N = 598) = 33.11, p < .01; more adults with O levels, A levels, college diploma or equivalent while less adults with no formal education or a university degree, X^2 (5, N = 598) = 201.96, p < .01; more adults in socio-economic class 2 or 4 while less adults in class 1 or 5, X^2 (4, N = 598) = 183.20, p < .01; and more adults with underweight, healthy weight or morbid obesity while less adults with overweight or obesity, X^2(4, N = 598) = 76.70, p < .01.

Table 5.1. Participant characteristics – percentage (number of participants) in a category (N=598).

Gender		**Age, years, mean ± SD**	
Male, %	41.5 (248)	38.3±15.3 (range: 18-87)	
Non-binary, %	1.0 (6)		
Female, %	57.5 (344)	**Ethnic Group**	
		[1]White, %	90.8 (543)
Highest education level		[2]Asian, %	3.2 (19)
No Formal Qualifications, %	2.0 (12)	[3]Black, %	1.5 (9)
O Levels / GCSEs – equivalent, %	19.6 (117)	Mixed or Multiple, %	3.3 (20)
A Levels / Diploma – equivalent, %	44.0 (263)	[4]Other, %	1.2 (7)
University Degree, %	18.4 (110)		
Postgraduate Degree, %	10.2 (61)	**Socio-Economic Classification (SEC)**	
Vocational or Other, %	5.9 (35)	NS-SEC Class 1, %	26.3 (157)
		NS-SEC Class 2, %	25.9 (155)
BMI, kg/m^2, mean ± SD		NS-SEC Class 3, %	7.5 (45)
26.5±6.8 (range: 15.8-65.3)		NS-SEC Class 4, %	18.1 (108)
		NS-SEC Class 5, %	22.2 (133)

[1] White: British, Irish, Gypsy/Traveller, Roma and Other. [2] Asian: Bangladeshi, Chinese, Indian, Pakistani and Other. [3] Black: African, Caribbean and Other. [4] Other: Arab, other and prefer not to say. SD: Standard deviation. GCSE: General Certificate of Secondary Education. NS: National Statistics.

5.3.2. Attitudes

A total of 581 questionnaires were used for the PCA, as 17 participants chose the option "neither agree nor disagree" for more than 50% of the statements (range: 50.6-77.8%). This analysis revealed six principal components (PC) which explained 39.1% of the variance, following six iterations. PC1 explained 7.9% of the variance, PC2 explained 7.7% of the additional variance, PC3 explained 6.6% of the additional variance, PC4 explained 6.4% of the additional variance, PC5 explained 6.0% of the additional variance and PC6 explained 4.5% of the additional variance (Table 5.2 on the right, continued on the next page). There were 16 cross-loading items, including statements on sweet-tasting foods, sugar and sweeteners; while 10 items did not load onto any factor with a coefficient of >0.30. These 26 items were removed from subsequent analyses. The loadings of items in each component and the removed items may be referred to in Appendix 7.

PC1 consisted of 10 statements with a Cronbach's alpha of 0.813. The statements expressed that the food items (sweet-tasting foods, sugar and sweeteners) had an influence or impact on the individual, hence this component was named 'Personal Impact'. PC2 consisted of 13 statements with a Cronbach's alpha of 0.763. The statements included "I…", hence this component was named 'Personal Management'. PC3 consisted of 5 statements with a Cronbach's alpha of 0.689. The statements expressed a sense of apathy or nonchalance, hence this component was named 'Apathy'. PC4 consisted of 7 statements with a Cronbach's alpha of 0.676. The statements expressed unfavourable or undesirable attitudes towards the food items, hence this component was named 'Negativity'. PC5 consisted of 8 statements with a Cronbach's alpha of 0.777. The statements were about knowledge and awareness, hence this component was named 'Perceived Understanding'. PC6 consisted of 5 statements with a Cronbach's alpha of 0.663. The statements expressed ideas of external influences regarding intakes of food items that one does not feel to have the capacity to act in accordance to oneself, hence it was named 'Perceived Nonautonomy'.

Taste was ranked most frequently as the most important factor to consider regarding the choice and consumption of sweet-tasting foods (Figure 5.1; see Appendix 8 for intake frequencies). This was followed by pleasure, cost, health and lastly, presentation as the least important factor.

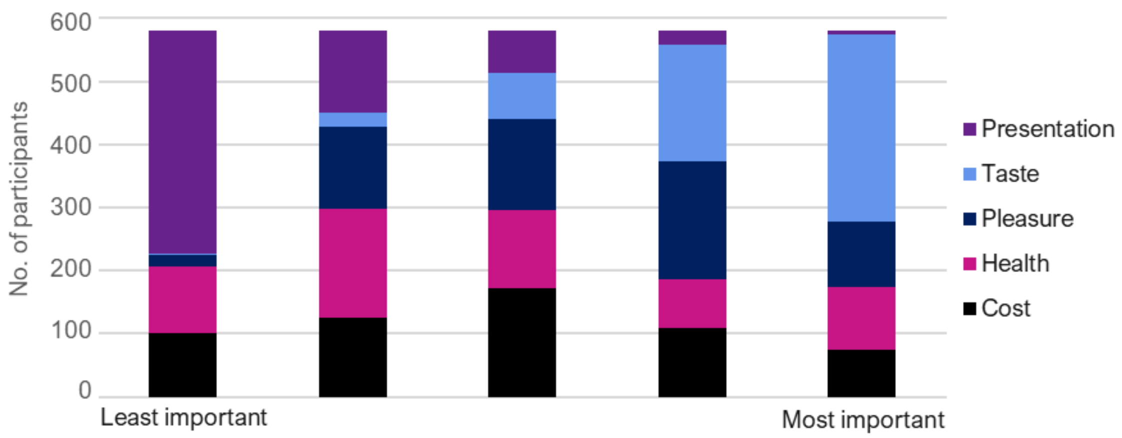

Figure 5.1. The relative importance of consideration factors for sweet taste (N=581).

Table 5.2. Statements in each component and their theme and sub-theme in Chapter 4.

PC1: Personal impact	**Sub-theme**	**Theme**
I tend to crave sweet foods.	stake	
I tend to crave sugars.	stake	personal relevance
I tend to crave sweeteners.	stake	
I want to reduce my intake of sweet foods.	stake	
The presence or absence of sweet foods in my diet influences my mood.	emotion	
The presence or absence of sugars in my diet influences my mood.	emotion	value
The presence or absence of sweeteners in my diet influences my mood.	emotion	
I feel indifferent towards sweet foods.	disinterest	
Sweet taste is physically addictive.	disfavour	angle
Sugar is physically addictive.	disfavour	

PC2: Personal management	**Sub-theme**	**Theme**
When I consume sugars, I balance out my diet through exercising and/or eating other healthy foods.	self-regulation	
When I consume sweeteners, I balance out my diet through exercising and/or eating other healthy foods.	self-regulation	
When I consume sweet foods, I balance out my diet through exercising and/or eating other healthy foods.	self-regulation	personal responsibility
My choice and/or consumption of sugars depends on how much knowledge I have on them.	informed choice	
My choice and/or consumption of sweeteners depends on how much knowledge I have on them.	informed choice	
I only consume sweet foods during special occasions.	special	
I only consume sugars during special occasions.	special	value
I only consume sweeteners during special occasions.	special	
I categorise my intake of sweet foods into "special" and "normal".	special	
My health or body image will determine whether I modify my sugar intake or not.	health body image	
My health or body image will determine whether I modify my sweet foods intake or not.	health body image	personal relevance
My health or body image will determine whether I modify my sweeteners intake or not.	health body image	
The people that I am with (family, friends, colleagues) influence my intake of sweeteners.	external influences	it's not up to me

PC3: Nonchalance	**Sub-theme**	**Theme**
People are too concerned about cutting down on sweet foods.	disinterest	
People are too concerned about cutting down on sugars.	disinterest	
People are too concerned about cutting down on sweeteners.	disinterest	angle
Sugar is not as bad as fat for your health.	relativity	
Adding sugar in food products is unnecessary.	disfavour	

Table 5.2. Statements in each component and their theme and sub-theme. (continued)

PC4: Negativity	**Sub-theme**	**Theme**
Sweeteners are worse for your health than salt.	relativity	angle
Sweeteners are physically addictive.	disfavour	
Sweeteners are not as bad as fat for your health.	relativity	
Adding sweeteners in food products is unnecessary.	disfavour	
I feel guilty whenever I consume sweeteners.	internal conflict	personal responsibility
Labels are misleading and deceptive.	deception	it's not up to me
The food environment hinders me from reducing my intake of sweeteners.	external influences	
PC5: Perceived understanding	**Sub-theme**	**Theme**
I know where to find credible information on sugars.	delivery of info	understanding
I know where to find credible information on sweet foods.	delivery of info	
I know where to find credible information on sweeteners.	delivery of info	
If someone asks me, “what are sweeteners?”, I am able to explain to him/her.	education	
If someone asks me, “what is sugar?”, I am able to explain to him/her.	education	
I do not know whether to consume sugar or sweeteners.	reasoning	
I know how to replace sugar with sweeteners in cooking and/or baking.	education	
I know what strategies or policies have been put in place to reduce sugar consumption in the UK.	awareness	
PC6: Perceived Nonautonomy	**Sub-theme**	**Theme**
Desire or need for sweet foods changes with age.	generation age	personal relevance
Desire or need for sugar changes with age.	generation age	
Desire or need for sweeteners changes with age.	generation age	
It is impossible to completely eliminate sugar out of my diet.	pleasure	value
It is impossible to completely eliminate sweet foods out of my diet.	pleasure	

5.3.3. Collinearity and correlations

All variance inflation factors were below 4 and tolerance above 0.1 (Table 5.3 on the right), showing a sufficient lack of multi-collinearity between the independent variables (Tabachnick & Fidell, 2019). All independent variables were non-normally distributed ($p < .003$), except for PC3 ($p = 0.095$), and Spearman’s Rho was used to measure intercorrelations. Inter-correlation coefficients were all below 0.70 (Table 5.4 on the right).

Table 5.3. Collinearity statistics between and Shapiro–Wilk statistics of each variable (N=581).

Independent Variables	Collinearity Statistics		Shapiro-Wilk	
	Tolerance	Variance inflation factor	Statistic	Sig.
Gender[1]	0.823	1.214	0.634	< .001
Age	0.799	1.251	0.938	< .001
Ethnic Group[2]	0.930	1.076	0.321	< .001
Highest Education Level	0.772	1.295	0.754	< .001
NS-SEC	0.771	1.298	0.841	< .001
BMI	0.849	1.178	0.884	< .001
Presence of Health	0.899	1.112	0.364	< .001
Presence of Allergy	0.891	1.123	0.408	< .001
Adherence to Diet	0.873	1.146	0.428	< .001
PC1: Personal Impact	0.828	1.208	0.984	< .001
PC2: Personal Management	0.791	1.265	0.992	.003
PC3: Apathy	0.846	1.182	0.992	.003
PC4: Negativity	0.847	1.181	0.996	.095
PC5: Perceived Understanding	0.854	1.171	0.990	.001
PC6: Perceived Nonautonomy	0.903	1.107	0.991	.001

[1] Gender was classified into male (1), non-binary (2) and female (3). [2] Ethnic group was classified into White (1) and non-White (2). NS-SEC: National Statistics Socio-Economic Classification. PC: Principal Component.

Table 5.4. Intercorrelations (Spearman's Rho) between variables (N=581).

	Gender	Age	Ethnic[1]	Educ[2]	NS-SEC	BMI	Health	Allergy	Diet	PC1	PC2	PC3	PC4	PC5	PC6
Gender	-	-.269**	-.009	.268**	-.251**	-.174**	.059	.113**	.102*	-.206**	-.076	-.066	-.072	.127**	-.067
Age		-	-.130**	-.182**	.107*	.320**	.083*	-.063	.006	.131**	.061	-.116**	.016	-.232**	.102*
Ethnic[1]			-	.079	.016	-.123**	-.016	.067	-.082*	.032	.010	.033	-.092*	-.096*	-.002
Educ[2]				-	-.423**	-.191**	-.019	.170**	.035	-.124**	-.161**	-.158**	-.152**	-.041	.040
NS-SEC					-	.069	.025	-.109**	-.154**	.044	.156**	.090*	.105*	-.015	-.043
BMI						-	.119**	-.049	.060	-.146**	.182**	.018	.048	-.039	.026
Health							-	.175**	.185**	-.118**	-.020	.022	-.031	-.018	.022
Allergy								-	.152**	-.035	-.024	-.064	-.163**	-.069	.067
Diet									-	-.074	-.192**	-.138**	-.038	-.051	.040
PC1										-	.050	.123**	.212**	-.041	.155**
PC2											-	.147**	.219**	.201**	.101*
PC3												-	.214**	.089*	-.137**
PC4													-	.039	.042
PC5														-	-.028
PC6															-

[1] Ethnic Group was classified into White including British, Irish, Gypsy/Traveller, Roma and Other (1), Asian including Bangladeshi, Chinese, Indian, Pakistani and Other (2), Black including African, Caribbean and Other (3), and Others including Arab, other and prefer not to say (4). [2] Educ: Highest education level attained. NS-SEC: National Statistics Socio-Economic Classification. PC: Principal Component. $^{*}p < .05$, $^{**}p < .01$.

5.3.4. Estimated intake frequencies

The mean intake frequencies across demographic characteristics are summarised in Table 5.5 and across lifestyle characteristics in Table 5.6 on the next page. The number of participants who responded to each option can be found in Appendix 8. MANCOVA showed that there was no statistically significant difference between genders on all five estimated intake frequencies after controlling for age and BMI, $F(10, 1146) = 1.36$, $p = .19$, Pillai's Trace = .024, partial $\eta^2 = .012$. There was also no significant difference between age groups on all estimated intake frequencies after controlling for gender and BMI, $F(25, 2865) = .900$, $p = .61$, Pillai's Trace = .039, partial $\eta^2 = .008$. Similarly, there was no significant difference between the ethnic groups after controlling for gender, age and BMI, $F(20, 2288) = 1.48$, $p = .08$, Pillai's Trace = .051, partial $\eta^2 = .013$.

Between highest education levels, there was a statistically significant difference on the combined estimated intake frequencies after controlling for gender, age and BMI, $F(25, 2860) = 2.46$, $p < .01$, Pillai's Trace = .105, partial $\eta^2 = .021$. Participants with different highest education levels attained varied significantly in their frequencies of adding sugar into coffee, tea and homecooked dishes, $F(5,572) = 6.11$, $p < .01$. Individuals with no formal qualifications added sugar the most frequently, which was significantly higher than individuals with A-levels and above, smallest $t(588) = 2.21$, $p \leq .02$. Individuals with a postgraduate degree added sugar the least frequently, which was significantly less than individuals with A-levels and lower, smallest $t(588) = 3.18$, $p \leq .02$.

There was no significant difference between SECs on estimated intake frequencies after controlling for gender, age and BMI, $F(20, 2288) = 1.49$, $p = .08$, Pillai's Trace = .051, partial $\eta^2 = .013$. In contrast, BMI groups displayed a statistically significant difference on all estimated intake frequencies after controlling for gender and age, $F(20, 2292) = 1.81$, $p = .02$, Pillai's Trace = .062, partial $\eta^2 = .016$. BMI groups differed in their frequency of adding sweeteners into coffee, tea and homecooked dishes, $F(4,574) = 3.84$, $p < .01$. Participants in the normal BMI group added sweeteners fewest times per day, significantly lower than participants classified as with morbid obesity, $t(293) = -3.94$, $p < .01$. All other BMI groups did not differ significantly, $p \geq .18$.

There was no significant effect of presence of health condition on estimated intake frequencies after controlling for gender, age and BMI, $F(5, 572) = .845$, $p = .52$, Pillai's Trace = .007, partial $\eta^2 = .007$. Adherence to a diet had a significant effect on estimated intake frequencies after controlling for gender, age and BMI, $F(5, 572) = 2.85$, $p = .02$, Pillai's Trace = .024, partial $\eta^2 = .024$. Individuals who adhered to a diet added sugar less frequently into coffee, tea and homecooked dishes than individuals who did not adhere to a diet, $t(579) = 2.73$, $p < .01$. These individuals also consumed sugar food groups less frequently than individuals who did not adhere to a diet, $t(579) = 2.18$, $p = .03$. There was no significant effect of presence of allergy on estimated intake frequencies after controlling for gender, age and BMI, $F(5, 572) = .865$, $p = .51$, Pillai's Trace = .008, partial $\eta^2 = .008$.

Table 5.5. Intake frequencies[1] across demographic characteristics, mean ± SD (N=581).

Demographic characteristics		**Adding sugar[2]**	**Adding honey**	**Adding sweetener**	**Sugar food groups**	**Sugar-free groups**	**Total sweet groups**
(A) Gender	Male (n=241)	1.33 ± 2.13	0.23 ± 0.81	0.58 ± 1.43	1.86 ± 2.00	0.22 ± 0.42	2.09 ± 2.07
	Non-binary (n=6)	0.38 ± 0.62	0.01 ± 0.03	1.02 ± 2.51	1.79 ± 2.08	0.12 ± 0.23	1.90 ± 2.09
	Female (n=334)	0.85 ± 1.72	0.25 ± 0.97	0.57 ± 1.64	1.78 ± 1.71	0.35 ± 0.83	2.13 ± 2.03
(B) Age Group	18 to 24 (n=241)	0.76 ± 1.24	0.30 ± 1.13	0.46 ± 1.56	1.65 ± 1.89	0.31 ± 0.78	1.96 ± 2.24
	25 to 34 (n=73)	0.84 ± 1.66	0.42 ± 1.26	0.47 ± 1.14	1.70 ± 1.59	0.21 ± 0.26	1.91 ± 1.63
	35 to 44 (n=134)	1.31 ± 2.23	0.19 ± 0.72	0.73 ± 1.79	1.84 ± 1.99	0.34 ± 0.71	2.18 ± 2.07
	45 to 54 (n=107)	1.11 ± 2.02	0.24 ± 0.77	0.69 ± 1.67	1.87 ± 1.75	0.26 ± 0.70	2.13 ± 1.89
	55 to 64 (n=69)	1.40 ± 2.54	0.06 ± 0.21	0.72 ± 1.54	2.11 ± 1.81	0.34 ± 0.82	2.45 ± 2.21
	65 above (n=26)	0.96 ± 1.79	0.12 ± 0.22	0.03 ± 0.11	2.14 ± 1.70	0.25 ± 0.38	2.38 ± 1.78
(C) Ethnic Group	White (n=241)	1.06 ± 1.94	0.21 ± 0.80	0.58 ± 1.59	1.80 ± 1.77	0.29 ± 0.67	2.10 ± 1.94
	Mixed (n=20)	0.82 ± 1.61	0.51 ± 1.53	0.78 ± 1.64	1.31 ± 1.19	0.33 ± 0.79	1.64 ± 1.53
	Asian (n=17)	0.95 ± 1.81	0.47 ± 1.12	0.34 ± 0.94	1.59 ± 1.58	0.08 ± 0.16	1.67 ± 1.64
	Black (n=9)	0.80 ± 1.37	0.34 ± 0.55	0.30 ± 0.32	3.10 ± 3.90	0.75 ± 1.62	3.86 ± 5.37
	Other (n=6)	1.39 ± 1.09	1.44 ± 3.46	0.51 ± 0.61	3.36 ± 3.77	0.38 ± 0.57	3.74 ± 3.73
(D) Education level	No formal (n=11)	3.08 ± 3.29[c]	0.21 ± 0.60	0.84 ± 1.93	2.21 ± 2.19	0.21 ± 0.24	2.42 ± 2.12
	O levels[3] (n=112)	1.54 ± 2.42[bc]	0.16 ± 0.62	0.88 ± 1.68	2.09 ± 2.27	0.27 ± 0.64	2.36 ± 2.45
	A levels[4] (n=260)	1.14 ± 1.81[b]	0.19 ± 0.73	0.49 ± 1.46	1.60 ± 1.54	0.26 ± 0.57	1.86 ± 1.70
	Vocational[5] (n=34)	0.74 ± 2.19[ab]	0.07 ± 0.28	0.50 ± 1.21	2.57 ± 2.39	0.21 ± 0.34	2.78 ± 2.36
	University (n=106)	0.57 ± 1.29[ab]	0.35 ± 1.24	0.59 ± 1.91	1.77 ± 1.33	0.37 ± 0.84	2.14 ± 1.58
	Postgrad (n=58)	0.30 ± 0.82[a]	0.54 ± 1.41	0.37 ± 1.03	1.86 ± 2.31	0.42 ± 1.07	2.28 ± 2.89
(E) NS-SEC	NS-SEC 1 (n=155)	0.63 ± 1.42	0.25 ± 0.79	0.52 ± 1.32	1.78 ± 1.61	0.34 ± 0.81	2.12 ± 2.01
	NS-SEC 2 (n=152)	0.86 ± 1.45	0.24 ± 1.06	0.33 ± 0.86	1.85 ± 2.30	0.26 ± 0.43	2.11 ± 2.38
	NS-SEC 3 (n=45)	1.07 ± 1.89	0.41 ± 1.31	0.75 ± 1.62	1.77 ± 1.40	0.24 ± 0.39	2.01 ± 1.59
	NS-SEC 4 (n=98)	1.34 ± 2.36	0.33 ± 1.06	0.65 ± 1.73	1.74 ± 1.38	0.28 ± 0.51	2.01 ± 1.42
	NS-SEC 5 (n=131)	1.52 ± 2.35	0.12 ± 0.40	0.82 ± 2.16	1.89 ± 1.93	0.32 ± 0.94	2.21 ± 2.22

[1] Number of times per day. [2] Within each column, frequencies labelled with different letters are different at *p* < .05, tested with Bonferroni correction, where ‘a’ always represents the smallest value. [3] O levels includes General Certificate of Secondary Education. [4] A levels includes Diploma. [5] Vocational includes prefer not to say. NS-SEC: National Statistics Socio-Economic Classification.

Table 5.6. Estimated intake frequencies[1] across lifestyle characteristics, mean ± SD (N=581).

Lifestyle characteristics		**Adding sugar**	**Adding honey**	**Adding sweetener**	**Sugar food groups**	**Sugar-free groups**	**Total sweet groups**
(A) BMI group[2,3]	Underweight (n=25)	1.04 ± 1.91	0.43 ± 1.71	0.42± 1.24[ab]	2.53 ± 3.14	0.33 ± 0.86	2.85 ± 3.59
	Normal (n=260)	1.02 ± 1.75	0.29 ± 1.05	0.37 ± 1.10[a]	1.70 ± 1.68	0.25 ± 0.55	1.95 ± 1.76
	Overweight (n=167)	1.16 ± 2.16	0.24 ± 0.74	0.74± 1.57[ab]	1.74 ± 1.75	0.28 ± 0.54	2.01 ± 2.01
	Obese (n=94)	1.11 ± 2.11	0.12 ± 0.40	0.62± 1.97[ab]	1.99 ± 1.66	0.46 ± 1.15	2.46 ± 2.11
	Morbidly Obese (n=35)	0.94 ± 1.70	0.13 ± 0.53	1.36 ± 2.73[b]	2.09 ± 2.41	0.23 ± 0.27	2.32 ± 2.39
(B) Health[4]	Yes (n=65)	0.76 ± 1.49	0.26 ± 0.86	0.85 ± 2.11	1.65 ± 1.23	0.28 ± 0.42	2.14 ± 1.12
	No (n=516)	1.08 ± 1.95	0.24 ± 0.91	0.54 ± 1.47	1.84 ± 1.90	0.30 ± 0.72	1.93 ± 1.30
(C) Diet[5,6]	Yes (n=88)	0.54 ± 1.20[a]	0.16 ± 0.57	0.71 ± 1.62	1.43 ± 1.34[a]	0.42 ± 0.98	2.16 ± 2.06
	No (n=493)	1.14 ± 2.00[b]	0.26 ± 0.95	0.55 ± 1.55	1.89 ± 1.90[b]	0.27 ± 0.62	1.85 ± 1.96
(D) Allergy	Yes (n=80)	0.96 ± 1.79	0.17 ± 0.36	0.54 ± 1.75	1.48 ± 1.42	0.23 ± 0.47	2.18 ± 2.12
	No (n=501)	1.06 ± 1.93	0.25 ± 0.96	0.58 ± 1.53	1.87 ± 1.89	0.31 ± 0.72	1.72 ± 1.42

[1] Number of times per day. [2] Participants with a BMI below 18.5 kg/m^2 were classified as with 'Underweight', BMI within the range of 18.5 to 24.9 kg/m^2 as with 'Normal weight', BMI within the range of 25 to 29.9 kg/m^2 as with 'Overweight' group, BMI within the range of 30 to 39.9 kg/m^2 in the 'Obese' group, and BMI of 40 kg/m^2 or above in the 'Morbidly Obese' group. [3] Within each column, frequencies labelled with different letters are different at p < .05, tested with Bonferroni correction, where 'a' always represents the smallest value. [4]Any health condition that could influence their eating and food intake choice. [5] Any weight management diet. [6] Within each column, frequencies labelled with different letters are different at p < .05.

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5.3.5. Attitudes, characteristics and intake frequencies

Regarding the frequency of adding sugar per day, demographic characteristics (step 1) were significantly but minimally associated (R^2 = .055, F(5,575) = 7.81, *p* < .01); adding lifestyle characteristics (step 2) did not add significantly to the model (R^2 = .061, $F(4,571)_{change}$ = 1.88, *p* = .11). Individuals who attained higher education levels added sugar less frequently than those who attained lower levels (β = -.164, *t*(575) = -3.67, *p* < .01). Principal components of attitude (step 3) significantly albeit slightly improved the model (R^2 = .094, $F(6,565)_{change}$ = 4.45, *p* < .01). Individuals who agreed with more statements that they personally managed their intakes added sugar more frequently than individuals who agreed less (β = .135, t(565) = 3.05, p < .01). The regression results of the final model (step 3) are reported in Table 5.7A on the right.

Similarly, demographic characteristics (step 1) were significantly but minimally associated with the frequency of adding honey per day (Table 5.7(B)) (R^2 = .023, F(5,575) = 3.76, *p* < .01), and the addition of lifestyle characteristics (step 2) did not add significantly to the model (R^2 = .022, $F(4,571)_{change}$ = .872, *p* = .48). Individuals who attained higher education qualification levels added honey more frequently than those who attained lower qualification levels (β = .139, *t*(575) = 2.85, *p* < .01). Principal components of attitude (step 3; Table 5.7B) also significantly although slightly improved the model, contributed by qualification level (R^2 = .039, $F(6,565)_{change}$ = 2.63, *p* = .02).

Demographic characteristics (step 1) were not associated with the frequency of adding sweeteners per day (R^2 = .001, F(5,575) = 1.16, *p* = .33), but adding lifestyle characteristics (step 2) added significantly to the model (R^2 = .012, $F(4,571)_{change}$ = 2.56, *p* = .04). Individuals with higher BMI added sweeteners more frequently than those who with lower BMI (β = .119, *t*(575) = 2.74, *p* < .01). Principal components of attitude (step 3; Table 5.7C) did not improve the model (R^2 = .023, $F(6,565)_{change}$ = 2.11, *p* = .05).

Table 5.7. Regression results only for the final model (step 3) on addition frequencies (N=581).

	A) Adding sugar per day	*B*	S.E.	95% CI	β	*t*	*p*
Demographics	(Constant)	1.522	0.611	[.322, 2.72]		2.492	0.013
	Gender[1]	-0.072	0.085	[-.238, .094]	-0.037	-0.851	0.395
	Age	0.009	0.006	[-.002, .020]	0.073	1.647	0.100
	Ethnic Group[2]	-0.105	0.274	[-.642, .433]	-0.016	-0.382	0.703
	Highest qualification	-0.139	0.043	[-.223, -.055]	-0.146	-3.253	0.001
	NS-SEC	0.082	0.056	[-.028, .191]	0.066	1.461	0.145
Lifestyle	BMI	-0.011	0.012	[-.035, .013]	-0.037	-0.871	0.384
	Health	-0.378	0.252	[-.873, .117]	-0.062	-1.499	0.134
	Allergy	0.308	0.232	[-.148, .763]	0.056	1.327	0.185
	Diet	-0.280	0.225	[-.722, .162]	-0.053	-1.243	0.214
Attitudes	PC1: Personal Impact	-0.215	0.202	[-.611, .181]	-0.046	-1.067	0.286
	PC2: Personal Management	0.790	0.259	[.281, 1.30]	0.135	3.048	0.002
	PC3: Apathy	0.329	0.203	[-.070, .727]	0.070	1.621	0.106
	PC4: Negativity	0.592	0.240	[.120, 1.06]	0.106	2.462	0.014
	PC5: Perceived Understanding	-0.327	0.170	[-.662, .007]	-0.082	-1.922	0.055
	PC6: Perceived Nonautonomy	0.096	0.187	[-.272, .464]	0.021	0.512	0.609
	B) Adding honey per day	***B***	**S.E.**	**95% CI**	**β**	***t***	***p***
Demographics	(Constant)	0.048	0.298	[-.537, .633]		0.160	0.873
	Gender[1]	0.004	0.041	[-.077, .085]	0.004	0.095	0.924
	Age	-0.005	0.003	[-.010, 0.00]	-0.084	-1.854	0.064
	Ethnic Group[2]	0.249	0.134	[-.013, .511]	0.079	1.863	0.063
	Highest qualification	0.062	0.021	[.022, .103]	0.139	2.995	0.003
	NS-SEC	0.008	0.027	[-.045, .062]	0.014	0.302	0.763
Lifestyle	BMI	-0.003	0.006	[-.015, .009]	-0.023	-0.519	0.604
	Health	0.100	0.123	[-.142, .341]	0.035	0.812	0.417
	Allergy	-0.183	0.113	[-.405, .039]	-0.070	-1.618	0.106
	Diet	-0.049	0.110	[-.265, .166]	-0.020	-0.448	0.654
Attitudes	PC1: Personal Impact	0.113	0.098	[-.081, .306]	0.051	1.144	0.253
	PC2: Personal Management	-0.014	0.126	[-.263, .234]	-0.005	-0.113	0.910
	PC3: Apathy	0.249	0.099	[.055, .444]	0.112	2.520	0.012
	PC4: Negativity	-0.007	0.117	[-.237, .224]	-0.003	-0.058	0.953
	PC5: Perceived Understanding	-0.212	0.083	[-.376, -.049]	-0.113	-2.556	0.011
	PC6: Perceived Nonautonomy	-0.013	0.091	[-.193, .166]	-0.006	-0.147	0.883
	C) Adding sweetener per day	***B***	**S.E.**	**95% CI**	**β**	***t***	***p***
Demographics	(Constant)	-0.663	0.518	[-1.68, .355]		-1.279	0.201
	Gender[1]	0.023	0.072	[-.118, .164]	0.015	0.323	0.747
	Age	0.002	0.005	[-.007, .011]	0.022	0.469	0.639
	Ethnic Group[2]	0.110	0.232	[-.346, .566]	0.020	0.473	0.637
	Highest qualification	0.004	0.036	[-.068, .075]	0.005	0.099	0.921
	NS-SEC	0.082	0.047	[-.011, .175]	0.081	1.727	0.085
Lifestyle	BMI	0.026	0.010	[.006, .047]	0.113	2.545	0.011
	Health	0.128	0.214	[-.292, .548]	0.026	0.600	0.549
	Allergy	0.069	0.197	[-.317, .456]	0.015	0.353	0.724
	Diet	0.175	0.191	[-.200, .550]	0.040	0.919	0.359
Attitudes	PC1: Personal Impact	-0.234	0.171	[-.570, .102]	-0.062	-1.366	0.172
	PC2: Personal Management	-0.193	0.220	[-.624, .239]	-0.040	-0.876	0.381
	PC3: Apathy	0.235	0.172	[-.104, .573]	0.061	1.363	0.173
	PC4: Negativity	0.522	0.204	[.121, .923]	0.114	2.560	0.011
	PC5: Perceived Understanding	0.151	0.144	[-.132, .435]	0.047	1.048	0.295
	PC6: Perceived Nonautonomy	-0.123	0.159	[-.435, .189]	-0.034	-0.776	0.438

[1] Gender was classified into male (1), non-binary (2) and female (3). [2] Ethnic group was classified into White and non-White. *B*: Unstandardised B. S.E.: Standard Error. CI: Confidence Interval. Β: Standardised Beta. NS-SEC: National Statistics Socio-Economic Classification. PC: Principal Component. p-value passed α' threshold = 0.004.

Neither demographic (step 1) nor lifestyle characteristics (step 2) were associated with the frequency of consuming sugar food groups per day (R^2 = -.002, F(5,575) = .786, *p* = .56 and R^2 = .003, $F(6,565)_{change}$ = 1.74, *p* = .14, respectively). The model improved significantly with the principal components of attitude (step 3) (R^2 = .074, F $(6,565)_{change}$ = 8.27, *p* < .01). Individuals who agreed with more statements that sweet-tasting foods, sugar and sweeteners, and their intakes, impacted them, consumed sugar food groups less frequently than those who agreed less (β = -.238, *t*(565) = -5.42, *p* < .01). Concurrently, individuals who agreed with more statements that they personally managed their intakes, consumed sugar food groups more frequently (β = .186, *t*(565) = 4.13, *p* < .01). The regression results of the final model (step 3) are reported in Table 5.8A on the right.

Likewise, the frequency of consuming sugar-free food groups per day was neither associated with demographic (step 1) and lifestyle characteristics (step 2) (R^2 = .007, F(5,575) =1.80, *p* = .11 and R^2 = .012, $F(6,565)_{change}$ = 1.78, *p* = .13, respectively). The model also did not improve with the principal components of attitude (step 3; Table 5.8B) (R^2 = .023, F $(6,565)_{change}$ = 2.03, *p* = .06).

Neither demographic (step 1) nor lifestyle characteristics (step 2) were associated with the frequency of consuming total sweet-tasting food groups per day (R^2 = .006, F(5,575) = 1.73, *p* = .13 and R^2 = .010, $F(6,565)_{change}$ = 1.47, *p* = .21, respectively). The model improved significantly with the principal components of attitude (step 3; Table 5.8C) (R^2 = .075, F $(6,565)_{change}$ = 7.69, *p* < .01). Individuals who agreed with more statements that sweet-tasting foods, sugar and sweeteners, and their intakes, impacted them, consumed total sweet-tasting food groups less frequently than those who agreed less (β = -.252, *t*(565) = -5.74, *p* < .01). Concurrently, individuals who agreed with more statements that they personally managed their intakes, consumed total sweet-tasting food groups more frequently (β = .148, *t*(565) = 3.28, *p* < .01). Individuals who were of older ages also consumed total sweet-tasting food groups more frequently (β = .135, *t*(565) = 3.03, *p* < .01).

Table 5.8. Regression results for only the final model (step 3) on intake frequencies (N=581).

	A) Sugar groups per day	***B***	**S.E.**	**95% CI**	**β**	***t***	***p***
Demographics	(Constant)	1.383	0.593	[.217, 2.55]		2.330	0.020
	Gender[1]	-0.051	0.082	[-.212, .111]	-0.027	-0.619	0.536
	Age	0.015	0.005	[.004, .025]	0.121	2.714	0.007
	Ethnic Group[2]	0.219	0.266	[-.303, .742]	0.034	0.824	0.410
	Highest qualification	0.015	0.042	[-.066, .097]	0.017	0.371	0.711
	NS-SEC	-0.046	0.054	[-.153, .060]	-0.039	-0.854	0.393
Lifestyle	BMI	-0.015	0.012	[-.038, .008]	-0.054	-1.255	0.210
	Health	-0.236	0.245	[-.717, .246]	-0.040	-0.961	0.337
	Allergy	-0.297	0.225	[-.739, .145]	-0.056	-1.319	0.188
	Diet	-0.218	0.219	[-.647, .212]	-0.043	-0.995	0.320
Attitudes	PC1: Personal Impact	-1.062	0.196	[-1.45, -.677]	-0.238	-5.420	<0.001
	PC2: Personal Management	1.040	0.252	[.545, 1.53]	0.186	4.129	<0.001
	PC3: Apathy	0.237	0.197	[-.150, .624]	0.052	1.202	0.230
	PC4: Negativity	0.204	0.234	[-.255, .663]	0.038	0.872	0.384
	PC5: Perceived Understanding	-0.026	0.165	[-.351, .299]	-0.007	-0.159	0.874
	PC6: Perceived Nonautonomy	-0.068	0.182	[-.425, .290]	-0.016	-0.373	0.709
	B) Sugar-free groups per day	***B***	**S.E.**	**95% CI**	**β**	***t***	***p***
Demographics	(Constant)	-0.324	0.229	[-.774, .125]		-1.417	0.157
	Gender[1]	0.052	0.032	[-.010, .114]	0.075	1.647	0.100
	Age	0.003	0.002	[-.002, .007]	0.056	1.211	0.226
	Ethnic Group[2]	0.104	0.103	[-.097, .306]	0.043	1.017	0.309
	Highest qualification	0.027	0.016	[-.004, .059]	0.079	1.689	0.092
	NS-SEC	0.025	0.021	[-.016, .066]	0.057	1.212	0.226
Lifestyle	BMI	0.004	0.005	[-.005, .013]	0.043	0.968	0.333
	Health	-0.083	0.094	[-.268, .103]	-0.038	-0.876	0.382
	Allergy	-0.110	0.087	[-.281, .061]	-0.055	-1.267	0.206
	Diet	0.135	0.084	[-.031, .300]	0.070	1.595	0.111
Attitudes	PC1: Personal Impact	-0.197	0.076	[-.345, -.048]	-0.117	-2.603	0.009
	PC2: Personal Management	-0.103	0.097	[-.294, .088]	-0.049	-1.059	0.290
	PC3: Apathy	-0.057	0.076	[-.207, .092]	-0.034	-0.755	0.451
	PC4: Negativity	0.030	0.090	[-.147, .207]	0.015	0.336	0.737
	PC5: Perceived Understanding	0.102	0.064	[-.023, .228]	0.071	1.605	0.109
	PC6: Perceived Nonautonomy	0.081	0.070	[-.057,.219]	0.050	1.151	0.250
	C) Total sweet groups per day	***B***	**S.E.**	**95% CI**	**β**	***t***	***p***
Demographics	(Constant)	0.993	0.618	-0.221		1.607	0.109
	Gender[1]	0.006	0.092	-0.175	0.003	0.060	0.952
	Age	0.018	0.006	0.006	0.135	3.025	0.003
	Ethnic Group[2]	0.293	0.130	0.038	0.093	2.256	0.024
	Highest qualification	0.051	0.073	-0.092	0.033	0.700	0.484
	NS-SEC	-0.028	0.060	-0.147	-0.021	-0.465	0.642
Lifestyle	BMI	-0.009	0.013	-0.035	-0.030	-0.700	0.484
	Health	-0.305	0.273	-0.841	-0.047	-1.117	0.265
	Allergy	-0.413	0.251	-0.907	-0.070	-1.644	0.101
	Diet	-0.074	0.244	-0.552	-0.013	-0.302	0.763
Attitudes	PC1: Personal Impact	-1.254	0.218	-1.683	-0.252	-5.742	<0.001
	PC2: Personal Management	0.922	0.281	0.371	0.148	3.284	0.001
	PC3: Apathy	0.162	0.221	-0.271	0.032	0.736	0.462
	PC4: Negativity	0.249	0.260	-0.261	0.042	0.959	0.338
	PC5: Perceived Understanding	0.096	0.184	-0.265	0.023	0.524	0.601
	PC6: Perceived Nonautonomy	0.027	0.203	-0.371	0.006	0.135	0.893

[1] Gender was classified into male (1), non-binary (2) and female (3). [2] Ethnic group was classified into White and non-White. *B*: Unstandardised B. S.E.: Standard Error. CI: Confidence Interval. Β: Standardised Beta. NS-SEC: National Statistics Socio-Economic Classification. PC: Principal Component. p-value passed α' threshold = 0.004.

5.4. Discussion on attitudes, intakes and their relationships

The associations of attitudes towards sweet-tasting foods, sugar and sweeteners, with their frequency of intake have been unknown. Through a questionnaire developed from the qualitative study in Chapter 4, the present study examined these attitudes and intake frequencies of 581 adults living in the UK. Six principal components explained 39.1% of the variance in attitude responses: ‘Personal impact’ (PC1), ‘Personal management’ (PC2), ‘Apathy’ (PC3), ‘Negativity’ (PC4), ‘Perceived understanding’ (PC5) and ‘Perceived nonautonomy’ (PC6). Some attitudes were significantly associated with intake frequencies. Individuals who felt they could manage their intakes of sweet-tasting foods, sugar and sweeteners added sugar more frequently in their coffee, tea or homecooked dishes, and consumed sugar food groups and total sweet-tasting food groups more frequently; while individuals who felt they were less affected by these foods or their intakes consumed sugar food groups and total sweet-tasting food groups more frequently.

5.4.1. Attitude components and themes from the qualitative study

The six attitude components mapped roughly to the six themes in Chapter 4. ‘Personal Impact’ (PC1) addressed ‘Value’, which was what sweet-tasting foods, sugar and sweeteners could provide, such as influencing one’s mood. Individuals who assigned greater values to these food items might then feel more personal impact from them. ‘Personal Management’ (PC2) addressed ‘Personal Responsibility’, which was about having an active relationship with sweet-tasting foods, sugar and sweeteners. Individuals who engaged in an active relationship with these food items would then be in the direction of personally managing their intakes. While ‘Apathy’ (PC3) mostly addressed the ‘disinterest’ sub-theme of ‘Angle’, it revealed an overall detachment of feelings or a void of strong attitudes that other individuals might have, be it towards the food items themselves, the concerns over them, or their intakes. In contrast, ‘Negativity’ (PC4) addressed the ‘disfavour’ sub-theme of ‘Angle’ through its strong disapproval or negativity towards the food items and their intakes; and also subtly reflected ‘It’s Not Up to Me’, as it expressed strong negative attitudes towards external influences such as the food environment and strategies put in place.

‘Perceived Understanding’ (PC5) matched with ‘Understanding’, except in the area of proficiency, as the questionnaire did not specifically test for knowledge. The scores instead reflected how well individuals perceived their abilities to acquire, comprehend and apply insights on sweet-tasting foods, sugar and sweeteners. The last component, ‘Perceived Nonautonomy’ (PC6) addressed ‘It’s Not Up to Me’ in whether one takes on a passive role in the consumption of sweet-tasting foods, sugar and sweeteners; and also ‘Personal Relevance’, with the factor/cause for personal relevance as something perhaps beyond individual control. In other words, when a factor/cause, such as age or pleasure, becomes relevant to an individual to become personally concerned with changing their sweet-tasting food, sugar or sweetener intake, individuals scoring higher on PC6 would perceive it as beyond their control to change, while a low score reflects an individual perceiving themselves as having some autonomy over their intakes of these food items. Taken together, current results are in line with the results and inference from Chapter 4 that individual variations in perceptions, motivations and concerns exist towards sweet-tasting foods, sugar and sweeteners, both in a small sample of consumers (Chapter 4), as well as in a wider sample of the general public living in the UK.

5.4.2. Associations between attitudes and intakes

The current study provided a clearer understanding on how attitudes may relate to intake of sweet-tasting foods, sugar and sweeteners. Based on the results of the regression analyses, individuals more in agreement with personally managing their intakes added sugar, consumed sugar food groups and consumed total sweet food groups more frequently. While perceived personal management have been positively associated with more healthy food choices (Contini et al., 2015) and dietary consumption (Bayer et al., 2020; Carbonneau et al., 2021; Maillet & Grouzet, 2021), it does not necessarily mean making informed and well-intended decisions. Thinking that one is in charge of their behaviour may simply be about having a personal relationship with these food items. It has been demonstrated that consumers appreciate making their own decisions and regulating their own intakes themselves (Morel et al., 2019; Ortega-Avila et al., 2019; Sylvetsky et al., 2014). A possible management style could be engaging in compensatory behaviours (Amrein et al., 2017, 2021; Petersen et al., 2019). Suggestions on how to self-regulate have been put forth by consumers, such as moderating intake of other foods or engaging in physical activity (Chapter 4). Hence, individuals who are in agreement with this might then consume sugar, sugar food groups and sweet-tasting foods in general more frequently because they engage in these compensatory behaviours afterwards. In the present sample, 15% adhered to a weight management diet; it is possible that these individuals may have faced experiences that influenced their attitude formations and habitual intakes, such as engaging in compensatory behaviours. Nonetheless, controlling for diet adherence alongside BMI, presence of health conditions and allergies in the regression analyses did not lead to significant associations between attitude components and estimated intake frequencies. The concept of having a personal relationship with sweet-tasting foods, sugar and sweeteners was again demonstrated when individuals who felt more personal impact from these food items consumed sugar food groups and total sweet food groups less frequently. In contrast, individuals who feel less personal impact would then be able to consume more frequently.

Out of the six attitude components, only ‘Personal Impact’ (PC1) and ‘Personal Management’ (PC2) were relevant to the intake measures in this study. Based on nationwide data from the United States (US), there were consumers who had similar attitudes to ‘Apathy’ (PC3) (Chen & House, 2022). They did not bother with healthier foods and intake, tended to make food choices independently and were generally characterised as detached from food involvement. These consumers were least likely to consume fruits and vegetables, or choose low-calorie alternatives (Chen & House, 2022). Instead, in this study, being apathetic towards sweet-tasting foods, sugar and sweeteners did not lead to higher frequencies of adding sugar or consuming sugar food groups. Negativity in the present study also did not affect any intake frequency. In contrast, Ndofirepi and colleagues (2020) observed a positive relationship between the approval and trust, and the acceptance of artificial sweeteners. In the same study, they did not find any association between negativity towards sugar and acceptance of its alternative, sweeteners. In another cross-sectional study, positivity towards sugar-sweetened beverages was positively correlated with intake of sugar-sweetened beverages (Hennessy et al., 2015). It may be that negative attitudes towards sweet-tasting foods, sugar or sweeteners in the present study were counteracted by one another. However, this is unlikely, since the statements per attitude component were examined (Table 5.2) and most statements in ‘Negativity’ (PC4) were regarding sweeteners, yet they did not correlate with lower addition frequency of sweeteners.

The lack of association between ‘Perceived Understanding’ (PC5) and intake frequencies did not match those of earlier studies. Prada and colleagues (2020) found a significantly negative association between perceived capability and knowledge of individuals and their frequency of sugar intake in a sample of Portuguese adults. Bae and Choi (2021) reported similarly negative associations in a sample of Korean adolescents. One might also expect that individuals more in agreement with personally managing their intakes, would have higher perceived ability and understanding in order to manage their intakes. Personal management and perceived understanding were indeed correlated in this study ($r(579)=0.201$, $p < .01$), but the latter was not associated with intake frequencies. Perhaps perceived understanding is closely tied to actual understanding, which has been reviewed as inconsistently and weakly associated with sugar consumption (Gupta et al., 2018). The lack of effect of ‘Perceived Nonautonomy’ (PC6) on intake frequency was also surprising. Individuals who perceive themselves as having the power to change their intakes and actually managing their intakes, have been reported to choose more healthy foods (Contini et al., 2015). This attitude has also been reported by numerous studies, such as the qualitative study in Chapter 4, suggesting its high prevalence (Fadupin et al., 2015; Forde & Solomon-Moore, 2019; Hennessy et al., 2015; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Pielak et al., 2019; Zytnick et al., 2015). In this study, perceived nonautonomy, along with apathy, negativity and perceived understanding, were attitudes that individuals may have towards sweet-tasting foods, sugar and sweeteners, and their intakes, but that did not drive actual intakes and do not need to be targeted for sugar reduction strategies.

5.4.3. Associations between characteristics and intakes

The effects of demographic characteristics on estimated frequencies did not compare well with the literature. In this study, there was no effect of gender, inconsistent with results from population-based studies, which showed that men had higher sugar intakes compared to women (Fontes et al., 2020; Marriott et al., 2019; see review: Walton et al., 2021). A possible explanation could be the use of gender instead of sex when comparing the differences between men and women rather than male and female. In the current study, participants were asked to select the gender which they identify with, rather than their biological sex. Despite using the terms ‘men’ and ‘women’, the above population-based studies and review compared sugar intake differences between male and female adults. This interchangeable and incorrect usage of “gender” and “sex” is reportedly common in health research (Day et al., 2016; Gogovor et al., 2021; Johnson et al., 2009). It is plausible that there are sex differences but not gender differences in intakes of sweet-tasting foods, sugar and sweeteners, as shown in the current study.

The effect of age was observed for the frequency of consuming total sweet-tasting foods per day, where the frequency increased with age. Population-based studies have shown that sugar intake decreases with age (Fontes et al., 2020; Marriott et al., 2019; Walton et al., 2021) and sweetener intake increases with age (Kamil et al., 2021; Sylvetsky et al., 2017; Sylvetsky & Rother, 2016). In the current study, frequency of adding sweeteners per day did increase across the age groups until 55 to 64 years, then decreased drastically in 65 years and above. Even though the group aged 65 years and above was small (n=26), another study conducted in Lebanon also reported a peak in sweeteners consumption in their sample at 26 to 40 years, declining thereafter (Daher et al., 2022). Consumption of sugar food groups gradually increased across the age groups, albeit insignificant. This was also observed from the regression analyses which showed that an increase in age was associated with a higher frequency of consuming sugar food groups per day, albeit insignificant (p = .007). The significant association between age and frequency of total sweet food groups per day could be due to the increased frequency of consuming sugar food groups.

Ethnic groups also did not differ, even though other studies have reported various intake differences across ethnic groups, such as a higher prevalence of sweeteners consumption (Kamil et al., 2021; Sylvetsky et al., 2017; Sylvetsky & Rother, 2016) and a higher estimated dietary sweetness level (Kamil et al., 2021) in individuals belonging to white than in individuals belonging to non-white ethnic groups. Based on our results, the white ethnic group consumed both sugar food groups and sugar-free food groups less frequently than the black ethnic group. There were only 9 participants in the latter group which also had larger standard deviation, so these findings might not generalise to the overall population. Sugar intake has been highest in the black ethnic group in the US (Ricciuto et al., 2022), yet highest in the white ethnic group in the UK (Harith et al., 2018) and in the Netherlands (Huisman et al., 2018).

Highest education level attained and SEC though moderately correlated, did not result in multicollinearity in this study and previous research (Darin-Mattsson et al., 2017). While both are independent constructs (Brayne & Calloway, 1990; Darin-Mattsson et al., 2017; Manstead, 2018), their effects on the frequency of adding sugar were similar. Individuals with higher education levels attained and higher SEC added sugar less frequently, though the latter association was not significant. The effect of education level attained mirrors results from representative surveys of France, the Netherlands and the US that showed lower educational attainments correlating with higher added sugar intakes (Azaïs-Braesco et al., 2017). Another study on Finnish adults also found that education levels were related to the habit of adding sugar or honey to tea (Puputti et al., 2019). The present findings that highest education level attained was associated with adding sugar less frequently but adding honey more frequently suggests that individuals with higher education use honey as a sugar replacement, instead of using sweeteners. There were several comments from the qualitative study (Chapter 4) about preference of honey over sugar, also in coffee and tea, sometimes because it is “natural”. This is in spite of honey being included under the definition of ‘free sugars’ (Tedstone et al., 2015).

From the qualitative study in Chapter 4, comments also suggested that individuals in lower SECs were the ones with higher consumption of sugar-sweetened foods and beverages. Analyses on the progress between 2015 and 2018 by Public Health England (2019) showed that sugar sales per household was lower in the lowest SEC compared to the two classifications above it; yet, drinks purchased by this group contained a higher sugar content on average compared to the drinks purchased by the higher SECs. The lowest SEC also had the least reduction in sales over two years. However, this was not observed in the present study. Perhaps this is due to the current study sample not fully reflecting the UK population, X^2 (4, N = 598) = 183.20, p < .01. It is also plausible that the effect of SEC might be seen on actual intakes instead of frequency of intake.

Consistent with the literature, there were differences in sweeteners intakes between BMI groups (Martyn et al., 2018; Sylvetsky et al., 2017; Sylvetsky & Rother, 2016; Tapanee et al., 2021). Individuals with normal weight added sweeteners the least frequently, while individuals with morbid obesity added them the most frequently. Although the current study measured estimated intake frequency and not actual intake, it could be speculated that sweetener intake increases with BMI. Individuals with underweight were also adding sweeteners more times per day, possibly due to its usage association with dieting (Appleton & Conner, 2001; Daher et al., 2022). Yet, adherence to a weight management diet in this sample did not show a significantly higher frequency of adding sweeteners nor consuming sugar-free food groups per day; instead, these individuals added sugar less frequently and consumed sugar food groups less frequently per day. Perhaps studies on clinical populations of dieters, such as individuals with eating disorders, would be able to clarify which BMI group(s) diet by replacing sugar with sweeteners and which BMI group(s) diet by reducing sugar intake without any replacement.

5.5. Results on dominant attitudes in population groups

5.5.1. Latent attitude groups

The results of the information criteria in determining the number of classes (step 1 of LPA) are summarised in Table 5.9. Applying the analytic hierarchy process based on the fit indices AIC, AWE, BIC, CLC, and KIC (Akogul & Erisoglu, 2017), the best solution was a 3-class Model. Comparison between the 3-Class Model and a model without predictors showed that the 3-Class Model fits significantly better than an empty or null model (likelihood ratio χ^2: 85.3, p < .001).

Table 5.9. Information criterion of n-class models.

Classes	LogLik	AIC	AWE	BIC	CLC	KIC	Entropy	BLRT	*p*[1]
1	-1068	3270	3639	3388	3218	3300	1	-	-
2	-1068	3285	3751	2433	3217	3322	0.179	-0.386	0.97
3	-1573	3229	3790	3408	3148	3273	0.684	69.9	0.01
4	-1559	3214	3872	3424	3119	3265	0.700	28.7	0.01
5	-1545	3199	3953	3440	3091	3257	0.642	28.6	0.02

[1] p-value of the bootstrap likelihood ratio test. LogLik: Log-Likelihood. AIC: Akaike's Information Criterion. AWE: Approximate Weight of Evidence. BIC: Bayesian Information Criterion. CLC: Classification Likelihood Criterion. KIC: Kullback Information Criterion (KIC). BLRT: Bootstrap Likelihood Ratio Test.

The classes in the 3-Class Model differed significantly in their scores across all attitude components (Table 5.10). Their parameters are shown in Figure 5.2 on the right and further description on their response patterns are presented in Appendix 9. Classes 2 and 3 were similar in how much they felt personally impacted by, apathetic about, and negativity to sweet-tasting foods, sugar and sweeteners, and their intakes. Notably, they were scoring near 0 on their apathy and negativity. All classes differed significantly from each other in how well they perceived their understanding of sweet-tasting foods, sugar and sweeteners to be, and in how much they perceived themselves to have autonomy over these intakes.

Table 5.10. Class differences in attitude component scores (N=581).

Score for each attitude component	**Class 1 (n=52)**	**Class 2 (n=162)**	**Class 3 (n=367)**	**F-statistic**
Personal Impact	-0.487±0.4 [a]	<u>-0.196±0.4</u> [b]	-0.209±0.4 [b]	8.24 *
Personal Management	0.100±0.3 [ab]	<u>0.152±0.3</u> [b]	0.074±0.3 [a]	5.86 *
Apathy	-0.615±0.4 [a]	<u>-0.172±0.4</u> [b]	-0.204±0.4 [b]	7.70 *
Negativity	-0.512±0.3 [a]	<u>0.074±0.3</u> [b]	0.034±0.3 [b]	15.6 *
Perceived Understanding	-0.552±0.4 [a]	<u>0.424±0.3</u> [c]	-0.327±0.3 [b]	146 *
Perceived Nonautonomy	<u>0.094±0.5</u> [c]	-0.445±0.4 [a]	-0.293±0.4 [b]	24.0 *

Within a row, the <u>highest score is underlined</u> and scores labelled with different letters are different at p < 0.05, tested using Bonferroni corrected post-hoc comparisons, where 'a' always represents the smallest value. * p < 0.001.

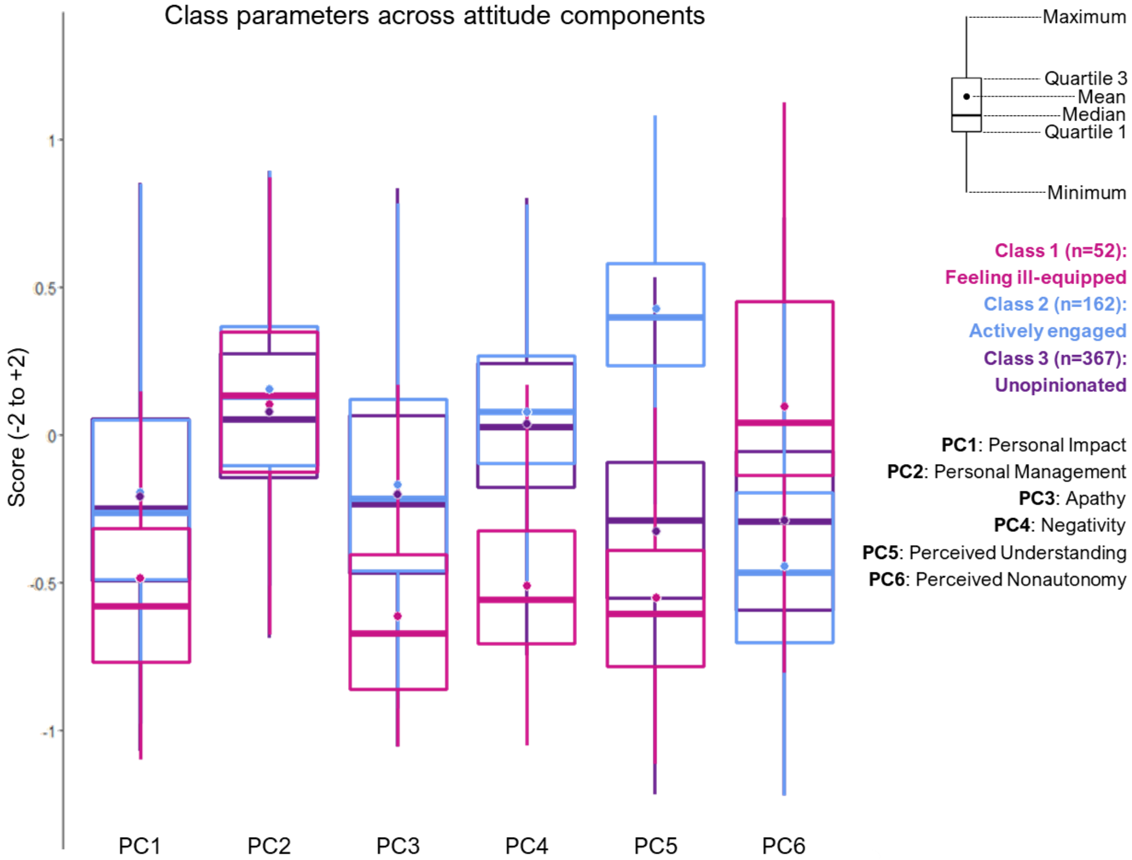

Figure 5.2. Box-plots of each class across the six attitude components, based on the 3-class model.

Since Class 1 (n=52) felt less personally impacted by sweet-tasting foods, sugar and sweeteners; was average in its interest towards personally managing intakes of these food items; was less apathetic about the food items and their intakes; felt less negative towards these food items; perceived their understanding of these food items to be low; and perceived themselves as not having the autonomy over their intakes of these food items; individuals in this class can be described as feeling ill-equipped. Class 2 (n=162) on the other hand, felt more personally impacted by sweet-tasting foods, sugar and sweeteners; were more in the direction of personally managing their intakes of these food items; felt average apathy and negativity towards the food items; perceived themselves as having good understanding of these food items; and also perceived themselves as having autonomy over their intakes of these food items; thus, individuals in this class can be characterised as being actively engaged. Finally, Class 3 (n=367) felt personally impacted by sweet-tasting foods, sugar and sweeteners to some extent; was less into personally managing their intakes of these food items; felt average apathy and negativity towards these food items; also perceived their understanding to be slightly poorer; and perceived themselves as having some autonomy over their intakes of these food items; hence, individuals in this class can be described as being unopinionated.

5.5.2. Intake frequencies of latent attitude groups

The three classes differed in some of their estimated intake frequencies (Table 5.11). Participants in Class 1, who felt ill-equipped, added sweeteners significantly less than participants who were in Class 2, actively engaged, $t(212) = -2.14$, $p < .01$; and consumed sweet-tasting food groups significantly more frequently than participants in Class 3, the unopinionated participants, $t(417) = 2.65$, $p = .008$.

Table 5.11. Estimated intake frequencies across classes (N=581).

No. of times per day	**Class 1: Feeling ill-equipped (n=52)**	**Class 2: Actively engaged (n=162)**	**Class 3: Unopinionated (n=367)**	F (2,569)	p^1
Adding sugar	0.681±1.5	0.936±1.6	1.14±2.1	0.88	0.41
Adding honey	0.295±0.7	0.193±0.7	0.256±1.0	0.65	0.52
Adding sweetener	0.163±0.5 ^{a}	0.721±1.9 ^{b}	0.572±1.5 ^{ab}	3.48	0.03
Sugar food groups	2.27±2.1	1.88±2.1	1.72±1.7	2.58	0.08
Sugar-free food groups	0.438±1.2	0.347±0.9	0.252±0.5	1.63	0.20
Total sweet food groups	2.71±2.7 ^{b}	2.23±2.41 ^{ab}	1.98±1.73 ^{a}	3.45	0.03

[1] Represents the p-value associated with the main effect of class membership on each of the intake frequency, having adjusted for all characteristics. Within a row, individual frequencies labelled with different letters are different at $p < .05$, tested using Bonferroni corrected post-hoc test, where ‘a’ represents the smallest value.

5.5.3. Demographic and lifestyle characteristics of latent attitude groups

The demographic and lifestyle characteristics of participants classified into each of the three classes are summarised in Appendix 9. Multinomial logistic regression aimed to ascertain the effects of these characteristics on the likelihoods of participants feeling ill-equipped (Class 1) or being unopinionated (Class 3) as compared to being actively engaged (Class 2; reference category). The model performed significantly better than the null model, likelihood ratio $\chi^2 = 67.7$, $p < .01$. It was statistically significant, χ^2 (4, N = 581) = 57.0, $p < .01$, explained 13.4% of the variance in attitudes, and correctly classified 66.6% of the cases.

With reference to Table 5.12, a year increase in age decreases the odds of being actively engaged compared to feeling ill-equipped and being unopinionated, by 1.04 and 1.02 times, respectively. Not obtaining a university degree was associated with a 67% increase in the relative risk of being actively engaged than feeling ill-equipped. In other words, participants of younger ages or who did not obtain at least a university degree, were more likely to be actively engaged.

Table 5.12. Multinomial logistic regression model results (N=581).

Feeling ill-equipped ***instead of actively engaged*** [1]	**β**	**S.E.**	**Wald's χ^2**	***p***	***e* $^{\beta}$ (O.R.)**	***e* $^{\beta}$ 95%CI [**	***e* $^{\beta}$ 95%CI]**
(Intercept)	-3.195	0.88	-3.63	<0.001	0.04	0.01	0.23
Not Male *vs.*[2] *Male*	-0.334	0.37	-0.89	0.373	0.72	0.34	1.49
Age	0.038	0.01	3.26	0.001	1.04	1.02	1.06
Not White *vs. White*	1.454	0.62	2.36	0.018	4.28	1.28	14.30
No university vs. *University*	-1.116	0.39	-2.89	0.004	0.33	0.15	0.70
Not professional *vs. Professional*	0.015	0.37	0.04	0.967	1.02	0.49	2.09
BMI	0.042	0.02	1.78	0.076	1.04	1.00	1.09
Health condition *vs. Healthy*	0.136	0.52	0.26	0.794	1.15	0.41	3.19
Diet *vs. No Diet*	0.822	0.42	1.97	0.048	2.27	1.01	5.14
Allergy *vs. No Allergy*	1.032	0.46	2.26	0.024	2.81	1.15	6.88
Being unopinionated ***instead of actively engaged*** [1]	**β**	**S.E.**	**Wald's χ^2**	***p***	***e* $^{\beta}$ (O.R.)**	***e* $^{\beta}$ 95%CI [**	***e* $^{\beta}$ 95%CI]**
(Intercept)	0.538	0.51	1.05	0.295	1.71	0.63	4.68
Not Male *vs. Male*	-0.592	0.22	-2.67	0.007	0.55	0.36	0.85
Age	0.023	0.01	3.16	0.001	1.02	1.01	1.04
Not White *vs. White*	1.056	0.44	2.42	0.016	2.88	1.22	6.77
No university *vs. University*	-0.638	0.24	-2.65	0.008	0.53	0.33	0.85
Not professional *vs. Professional*	0.264	0.21	1.23	0.218	1.30	0.86	1.98
BMI	-0.001	0.02	-0.05	0.962	1.00	0.97	1.03
Health condition *vs. Healthy*	0.266	0.35	0.77	0.442	1.31	0.66	2.57
Diet *vs. No Diet*	0.083	0.29	0.28	0.779	1.09	0.61	1.93
Allergy *vs. No Allergy*	0.504	0.33	1.53	0.126	1.66	0.87	3.16

[1] Class 2 – Actively engaged (n=162) was the reference category due to it being the 'preferred' attitude.
[2] Each group after "vs." was the reference category for that comparison. S.E.: standard error. O.R.: Odds Ratio. Exponentiated regression coefficients of a logistic model may be interpreted as the odds ratio which describes the relationship between odds when a variable increases by 1 unit. Wald's χ^2: Z-score. *p*: of 2-tailed Z test. p-value passed α' threshold = 0.006.

5.6. Discussion on dominant attitudes in population groups

The prevalence and prominence of attitudes towards sweet-tasting foods as a whole, sugar and sweeteners, were investigated in the aforementioned sample of 581 adults living in the UK. Three dominant classes of attitudes were identified: feeling ill-equipped (Class 1, n=52), being actively engaged (Class 2, n=162) or being unopinionated (Class 3, n=367). These classes differed significantly in their attitude scores, as well as their frequencies of adding sweeteners and consuming sweet-tasting food groups. Age and highest education level influenced the likelihood of individuals feeling ill-equipped or being unopinionated, instead of being actively engaged.

5.6.1. Being actively engaged

Individuals in Class 2 scored higher for both personal impact (PC1) and personal management (PC2) compared to those in the other classes. While principal components do not inter-correlate, these results suggest that individuals who feel high personal impact from sweet-tasting foods, sugar and sweeteners also manage their own intakes of these food items; hence, they are actively engaged. In a study on frequency and intake of snacking palatable foods, Swiss adults who felt high personal impact but had high self-control snacked less frequently and consumed less overall (Horwath et al., 2020). This demonstrated that the impact of food may be moderated by self-control in individuals actively engaged in their consumption. Yet, decisions made may not always be well-intended or informed. Their agreement with having a personal relationship with these food items, be it from feeling impact or managing them, might influence them to be actively engaged in their intakes of these foods but might not directly relate to healthier dietary behaviours. LPA on contemporary food shoppers in the US also identified a 'passionately involved' class, who did not always engage in healthy eating habits (Chen & House, 2022). Furthermore, the association between attitude towards and consumption of sugar-sweetened foods and beverages also depends on whether one is choosing or avoiding consumption (McDermott, Oliver, Svenson, et al., 2015). Hence, though actively engaged, this sub-population did not demonstrate lower dietary sugar intakes than others. It is worth noting, however, that perceived personal choice and management have been positively associated with healthier dietary consumption (Bayer et al., 2020; Carbonneau et al., 2021; Maillet & Grouzet, 2021) and body weight (Halali et al., 2018; Robinson et al., 2022). Perhaps this association requires a good knowledge and understanding of healthy dietary sugar or general intake. The current sub-population of actively engaged individuals scored their understanding to be high, but this is self-perceived and not an actual assessment of their knowledge. While the association between greater knowledge and lower sugar consumption has been reported to be inconsistent and weak, it may also differ for individuals who are actively engaged (Gupta et al., 2018). In any case, active engagement in eating behaviour has been linked to significantly lower BMI (Leong et al., 2012). It would be beneficial to encourage more consumers to be actively engaged.

Being of a younger age or not obtaining at least a university degree increases the likelihood of an individual being actively engaged compared to being unopinionated or feeling ill-equipped. In the study of Chen and House (2022), the latent class of ‘passionately involved’ consumers were also significantly younger, but had mostly attained college or postgraduate education and held more professional occupations (were of higher SEC). Similarly, another study observed a positive association between education level attained and interest in foods and their intakes (Alonso et al., 2012). In a sample of Swiss adults, paying attention to sugar in one’s diet was associated with an increase in age (Hagmann et al., 2018). Notably, paying attention may not result in taking action. From the qualitative study in Chapter 4, comments suggested that the level of interest and involvement in the process and outcome of consuming sugar, sweeteners and sweet-tasting foods depended on personal relevance and level of priority. For example, sugar reduction would be less of a priority when faced with a multitude of challenges, such as family commitments or heavy workload. Perhaps individuals of younger ages or without university degrees had less distractions or factors that might take priority over healthier sugar or sweet taste consumption; therefore, they are more likely to be actively engaged. It might be of value to target these consumer or population groups to improve their knowledge on a healthier dietary sweet-tasting food, sugar and sweetener consumption, so that their high perceived understanding would be matched with their actual understanding. The combination of personal active engagement and a good grasp of knowledge may then lead to reduced dietary sugar intake.

5.6.2. Feeling ill-equipped

In the qualitative study (Chapter 4), there was general consensus on the lack of education and consequently, lack of proper understanding of sweeteners and how to use them as replacements for sugar in preparing sweet-tasting foods with reduced sugar at home, such as in baking or cooking. This could perhaps explain why individuals who felt ill-equipped added sweeteners significantly less than participants who were actively engaged, since they also perceived their understanding to be much lower than individuals who were actively engaged or unopinionated. Individuals who felt ill-equipped consumed sweet-tasting food groups significantly more frequently than individuals who were unopinionated, largely from sugar food groups. The feeling of being out of control is consistent with literature, where the role of an individual is reduced and/or minimised. Instead, autonomy is given to governments, the food industry and health professionals (Fadupin et al., 2015; Forde & Solomon-Moore, 2019; Hennessy et al., 2015; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Pielak et al., 2019; Zytnick et al., 2015). An apparent measure may be to educate these individuals, similar to individuals actively engaged, on how to reduce their intakes of sugar and sugar food groups and use sweeteners instead. However, simply deepening knowledge may be insufficient for this class of individuals. They strongly perceived themselves as having little autonomy over their intakes of sweet-tasting foods, sugars and sweeteners. As mentioned earlier, management over the intakes of these foods may be successfully when individuals are actively engaged. Perceived personal management has been reported to be positively associated with more healthy food choices (Contini et al., 2015). However, if individuals do not think that they have the power to change their intakes, they may not take any action at all even if they have the know-how. It would be advantageous to empower individuals, before education can take place and effect.

Individuals of older age have increased likelihood to feel ill-equipped, which compares well with the literature (Aljassim & Ostini, 2020; Andrus & Roth, 2002). In this study, an increase in age was indeed associated negatively with perceived understanding ($r(579) = -.232$, $p < .01$) and positively with perceived nonautonomy ($r(579) = 0.102$, $p < .05$). Interestingly, obtaining at least a university degree increased the likelihoods of individuals feeling ill-equipped compared to being actively engaged. Higher education level has been positively associated with greater dietary knowledge (Aljassim & Ostini, 2020; Andrus & Roth, 2002; Turrell & Kavanagh, 2006), and even perceived autonomy (Park et al., 2018). Besides, older adults and those with better knowledge on obesity and sugar-sweetened beverages have been reported to show greater support for the Soft Drink Industry Levy in the UK (Pell et al., 2019). Yet, this class of consumers still perceived themselves as poor in understanding and low in autonomy. Regardless, research has shown the importance of perceived autonomy in healthier eating behaviours and dietary intake (Kell, 2008; Leong et al., 2012). In fact, it could be a significant factor alongside knowledge in enhancing desired dietary behaviours (Moreau et al., 2015). In one study on patients with Type 2 diabetes, there was a distinction between individuals who wanted to actively engage in healthier behaviours and individuals who did not feel in charge of their health and their behaviours (Turchioe et al., 2020). These researchers proposed perceived autonomy as a key determinant of which category an individual belonged to (actively engaged or feeling nonautonomous) and their subsequent health behaviours. Hence, towards individuals who feel ill-equipped, tending to be of older ages and who obtained at least a university degree, sugar reduction strategies could prioritise guiding them to view their relationship with sweet-tasting foods, sugar or sweeteners as a personal and manageable one. A shift from feeling ill-equipped towards being actively engaged and having true understanding, may also improve the support for sugar reduction strategies (Traina et al., 2019).

5.6.3. Being unopinionated

Class membership was the highest for individuals who were unopinionated, with more than half of the study sample belonging to this class. These individuals were scoring in between Classes 1 and 2, nearing 0 on the scale, suggesting that the majority of consumers in this study felt undecided regarding sweet-tasting foods, sugar and sweeteners. Notably, this is different from being nonchalant, as individuals in this group scored near 0 on their apathy. Rather than being actively engaged, or feeling ill-equipped, these individuals either did not make any decision yet, or decided to not make any decision and maintain status quo. Perhaps some of them are still navigating through the mass of information available from both conventional and novel types of channels (Chapter 4), further emphasizing the need for better education and strategies for different individuals. The presence of this group of consumers is not unique to the present study, as other researchers have also identified “uninvolved consumers” (Chen & House, 2022), “unengaged consumers” (van Huy et al., 2019), and “uncommitted consumers” (Żakowska-

Biemans, 2011) in their sample populations; although termed differently, these consumers were described as being disconnected or detached from any involvement with foods and their intakes.

Attitude-behaviour associations regarding sugar intake have not been strongly observed in the current study and add to the limited evidence that has been described as 'weak or inconsistent' (Gupta et al., 2018, p. 192). One may then conject that being unopinionated would not be an issue and attitudes could be disregarded. At the same time, it is of concern that a large number of consumers living in the UK do not appear to be actively engaged with the information currently available, such as health guidelines and recommendations provided by the government (British Diabetic Association, 2018; Public Health England, 2018a). Confusion and misunderstanding of sweet-tasting foods, sugar and sweeteners have been expressed in the qualitative study (Chapter 4), and the larger sample of unopinionated consumers in this study seems to support it. Research has found that confusion may lead to avoidance of dietary guidelines in general (van Royen et al., 2022), possibly explaining why Class 3 scored their perceived understanding to be low, but did not feel ill-equipped. Being of an older age increased the likelihood of an individual to be unopinionated. In another sample of consumers, a latent class of "uninvolved consumers" was also associated with being of an older age; but also with identifying as female, belonging to a white ethnic group, having lower household income and weekly food expenditure, and not obtaining a university degree (Chen & House, 2022). Regardless, the group of consumers who were passive in their dietary behaviours had the highest prevalence of obesity and took up 21% of the 4374 persons included in their study (Chen & House, 2022). Since being unopinionated may be related to obesity, it would be valuable to encourage these consumers towards active engagement.

Based on the current findings, one could suggest that sugar-reduction strategies could focus on various sub-consumer groups based on their demographic and lifestyle characteristics and target their different attitudes to effect change.

5.7. Intake – attitudes – characteristics

This chapter first aimed to examine the relationships between specific attitudes and intakes of dietary sugar, sweeteners and sweet taste. The range in and variations of attitudes collected from the qualitative study (Chapter 4) was also present in this larger sample of consumers in the UK. However, only two attitudes were associated with intake – personal impact and personal management. The former attitude correlated to lower intake frequency of sugar and sweet-tasting food groups, while the latter attitude correlated with higher intake frequency of sugar and sweet-tasting food groups as well as higher addition frequency of sugar. The second half of this chapter aimed to identify the most prevalent attitudes towards sweet-tasting foods, sugar and sweeteners, and explore if these attitudes were held by specific (sub-) population groups. Three latent classes of individuals were revealed from the present sample; being actively engaged, feeling ill-equipped or being unopinionated. Being of a younger age increases the likelihood of an individual to be actively engaged compared to the other two classes. Not obtaining at least a university degree also increases the likelihood of an individual to be actively engaged compared to feeling ill-equipped. Individuals who felt ill-equipped added sweeteners less frequently than those actively engaged and consumed sweet-tasting food groups more frequently than those unopinionated.

Taken together, some factors were consistently significant in the connections between intakes, attitudes and characteristics (see Figure 5.3. on the next page for associated variables of both aims). Age and highest education level attained were the only individual characteristics that were significantly associated with either intake frequencies or latent classes, or even both. An increase in age correlated with an increase in likelihood to feel ill-equipped, and both increases were separately correlated with an increase in intake frequency of sweet-tasting food groups. An increase in age also correlated with an increase in likelihood to be unopinionated, but being unopinionated was correlated with a decrease in intake frequency of sweet-tasting food groups. Highest education level attained was negatively associated with adding sugar and positively associated with adding honey, while also positively associated with the likelihood to feel ill-equipped (Class 1) and negatively associated with the likelihood to be actively engaged (Class 2); but both latent classes were not associated with the frequency of adding sugar or adding honey. Regardless, the recurrence of age and highest education level attained as significant factors suggest that other factors play a less significant or relevant role in their relationship with intake frequencies and/or in the relationship between intake frequencies and attitudes. In other words, older age and higher education levels attained could be the focus of strategies to reduce sugar intake, to improve attitudes. Future work with more varied samples in demographic characteristics and attitudes could investigate and clarify the role of these individual characteristics on attitudes and intake, whether they are independent drivers or are moderators.

Out of the six attitudes that explained a considerable amount of variance in attitude responses, only the degree to which an individual i) feels personally impacted by sweet-tasting foods, sugar and sweeteners, as well as ii) is in the direction of personally managing the intakes of these foods, are significantly associated with intake frequencies, particularly sugar and sweet-tasting food groups. This conveys that the other four attitudes may not be as relevant when investigating drivers of intake frequencies. At the same time, LPA revealed three classes with different attitudes combinations and strengths within this study sample. This revealed patterns across the attitudes that were hidden when studied on their own. For example, perceived understanding and perceived nonautonomy, although insignificant towards intake frequencies on their own, were the two components that significantly differed between each of the latent classes. Therefore, it may not be helpful to look at attitudes separately especially when investigating their relationships with intakes. Individuals can hold different attitudes concurrently, as demonstrated in the qualitative study (Chapter 4) and earlier studies (Fadupin et al., 2015; Forde & Solomon-Moore, 2019; Hennessy et al., 2015; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Pielak et al., 2019; Zytnick et al., 2015). It may also explain why the relationship between attitudes and intakes has been reviewed as inconclusive (Gupta et al., 2018). Profiling study samples based on their attitudes, such as performed in this study through LPA, may be more informing than evaluating individual attitudes on their own. Combined with assessing the effects of individual characteristics, such approach may provide the 'who', 'what' and 'how' for sugar reduction strategies.

Based on the present findings, it may be beneficial to 1 – tailor education-related strategies ('how') towards individuals of younger ages or without university degrees ('who'), so that their active engagement may be matched with good grasp of knowledge ('what') to reduce their dietary sugar intakes; 2 – suggest manageable or simple ways ('how') on reducing dietary sugar intakes to individuals of older ages or with university degrees ('who'), to mitigate their challenge of having other priorities or commitments ('what'); 3 – empower ('how') individuals of older age and who obtained at least a university degree ('who') to view themselves as having the autonomy over sweet-tasting foods, sugar and sweeteners ('what'); 4 – guide older individuals ('who') on how to process sweet- or sugar-related information from various channels ('how'), to involve themselves in these foods and their intakes ('what').

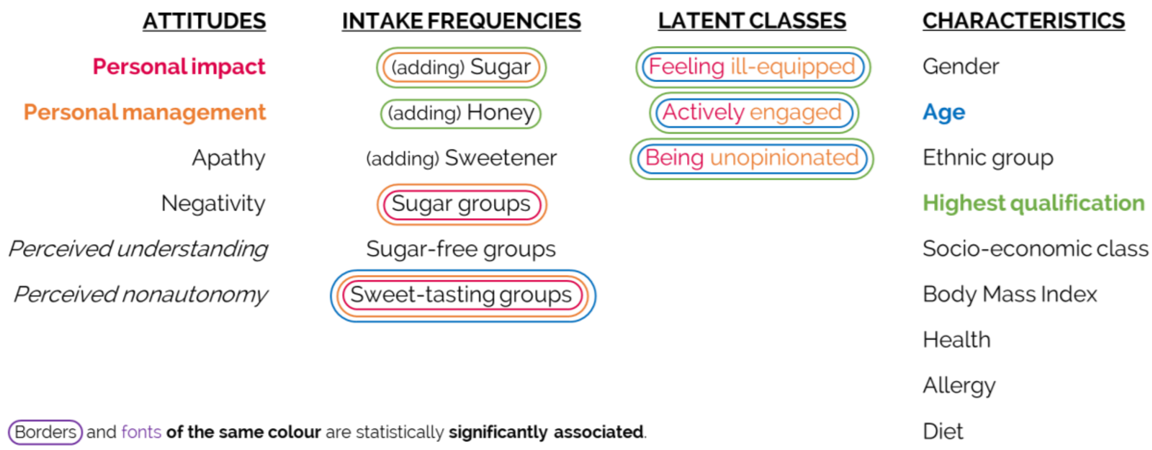

Figure 5.3. Variables of individual demographic and lifestyle characteristics, attitude components, latent classes of attitudes and estimated intake frequencies – with associations emphasised.

5.8. Strengths, limitations and future research

This study provided the prevalence of certain attitudes in a sample of the UK population and identified characteristics that would increase the likelihood of having a certain attitude. Through LPA, hidden clusters of populations within the current sample were identified based on their responses to the six attitude components. The six attitude components were also formed through participants' responses to all attitude statements on sweet-tasting foods, sugar and sweeteners. As a result, the three dominant classes of individuals – feeling ill-equipped, actively engaged and unopinionated, were data-driven and described the distributions of both attitudes and individuals (Oberski, 2016). The associations between attitudes towards and frequencies of adding or consuming sweet-tasting foods, sugar and sweeteners were also clarified in a sample of the UK population. Consistent with the literature, some attitudes were associated intakes while others were not, and this differed with consumer groups as well. Moreover, this study showed that attitudes related to intake frequencies of sweeteners and sweet-tasting foods in general, while research has typically focused on specific foods or food groups such as sugar and sugar-sweetened beverages. The corroboration of variation in attitudes with previous work further testifies the demand for segmentation and prioritising of specific sugar reduction strategies in distinct consumer groups (Chapter 4). Through LPA, demographic characteristics that would increase the likelihood of having a certain attitude were also identified. Therefore, this study provided a start to identifying how consumer or population groups could be segmented and which of them ought to be prioritised.

Nonetheless, the role of attitudes is limited and if not, small; thus, it is recommended that future work also evaluates individuals' actual understanding and not just perceived understanding, the role of the food environment (Gupta et al., 2018), as well as the efficacy of sugar-reduction strategies when stratified and prioritised. Since adjusted R^2 values of the regression models on estimated intake frequencies were small (range: 0.023 – 0.094), it is evidently desirable for more factors to be considered when looking at the drivers of sweet-tasting foods consumption. Furthermore, the non-representative sample in this study has to be noted when interpreting the results. While recruitment targeted the general public of the UK, the final sample did not statistically represent the UK population fully. Participants were majority in the white ethnic group, below the age of 55, of normal weight and attained their highest education level at O levels or GCSEs equivalent. Moreover, the growing proportion of the UK population who identify their sexual orientation differently has not been well represented in this study (Sharfman & Cobb, 2022). About 15% of the present sample also adhered to a weight management diet, which could have influenced their attitude formations and intake habits. Thus, the present evidence and information on the attitudes that individuals may have on sweet-tasting foods, sugar and sweeteners, their associations with intakes, as well as consumer groups with different strategical requirements might not be generalised to the whole population of the UK.

Notably, the current analysis estimated individuals frequency of intake, instead of their actual intake per day. The total amount of sweet taste intake from the diet may be poorly represented just from summing up sugar food groups and sugar-free food groups. The lower frequency of adding or consuming sugar and sugar food groups could also be possibly driven by the government's efforts to reduce dietary free sugars, since sugar sales from soft drinks have decreased in the UK, following the announcement to the implementation of the Soft Drink Industry Levy (Bandy et al., 2020). Future work on associations with intakes would benefit from more detailed intake assessments as well. Dietary measures such as 24-hour recalls instead of a food frequency questionnaire would aid in more accurate estimation and calculation of dietary sweet taste intake or its resultant exposure, to evaluate against attitudes. While these measures are self-reported and thus prone to self-reporting errors and bias, more implicit observations or experimental manipulations could also be carried out to precisely assess attitudes and intakes.

5.9. Conclusion

This chapter explored the presence and range of attitudes towards sweet-tasting foods, sugar and sweeteners, in a sample of the general public in the UK. Individuals may feel personally impacted by these food items, may be in the direction of personally managing their intakes of these food items, be nonchalant towards these food items and their intakes, hold negativity towards these food items and their intakes, perceive their understanding of these food items to be high, or perceive their autonomy over their intakes to be low. Individuals who felt they could manage their intakes consumed sugar and sugar food groups more frequently; while those who felt they were less affected also consumed sugar and sugar food groups more frequently. At the same time, individuals could hold several of these attitudes concurrently. Three latent sub-populations with distinct combinations and strengths of attitudes were identified within the sample, suggesting the benefit of studying attitudes in combination. Individuals were either feeling ill-equipped, actively engaged or unopinionated, with the likelihoods dependent on their ages and highest qualification level attained. It may be beneficial to segment consumer groups accordingly and either educate, advise, empower or guide them towards active engagement with sweet-tasting foods, sugar and sweeteners, and have healthier dietary sugar or sweet taste intake.

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6. Sweet Spot I: Approaches to characterise and compare (sweet) taste exposure in dietary taste patterns

6.1. Introduction

Dietary patterns are defined as "the quantities, varieties, or combinations of different foods and beverages in a diet and the frequencies with which they are habitually consumed" (Sánchez-Villegas & Martínez-Lapiscina, 2018). A healthy dietary pattern is one that is linked to good nutrition and health status, and a dietary pattern in general, is strongly determined by taste (Chapter 1). For this reason, it would be valuable to investigate the role of taste in the associations between dietary patterns and health outcomes; however, preliminary to this investigation, dietary taste patterns should first be characterised with a consistent and meaningful approach. To this end, researchers have attempted to study dietary patterns from a taste perspective (Chapter 1). However, studies differed both in their approach to quantify taste in the diet, and in their approach to characterise dietary taste patterns (Cox, Hendrie, Lease, et al., 2018; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Yan, et al., 2018; van Langeveld et al., 2018). Characterisation of dietary taste patterns ought to account for the quantities, varieties and combinations of different tastes in a habitual diet, as well as the frequencies with which they are being consumed.

The first step in characterising dietary taste patterns is to ensure all foods that are consumed are characterized in terms of taste. The creation of a taste database – a database comprised of foods with their values rated by a trained sensory panel, is time-consuming, expensive and labour-intensive. This limits the number of foods that may be tested and included into a taste database. Researchers have mostly used taste databases that were created with trained sensory panels rating each food in a laboratory setting (Cox, Hendrie, & Lease, 2018; Cox, Hendrie, Lease, et al., 2018; Teo et al., 2022; van Langeveld et al., 2018), or trained panellists rating the foods back in their homes (Martin et al., 2014). These methods similarly resulted in each food receiving rated intensity values for sweet, sour, bitter, umami and salt taste and fatty mouthfeel. The availability of such taste databases is limited to Australia (Lease et al., 2016), the Netherlands (Mars et al., 2020), Malaysia (Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018) and France (Martin et al., 2014). Alternatively, a database could be created by asking consumers to assign each food to one dominant taste, either sweet, sour, bitter, savoury, salt or neutral tasting (Bawajeeh et al., 2022). This method employs day-to-day consumers to classify each food to a specific taste, reducing resources spent on training sensory panels and rating foods in a laboratory setting. Nevertheless, this method is more subjective and would result in each food having only one taste characteristic, without any indication of intensity of that taste characteristic.

These methodological differences in quantifying dietary taste may lead to different interpretations of dietary taste patterns and perhaps cause confusion or misunderstanding on what dietary taste patterns mean. These differences also prevents further comparison across populations, which is important given that eating behaviours differ across environments (Cunha et al., 2018; Kim et al., 2020; Tuorila & Hartmann, 2020). In order to ensure all foods in the food intake data are characterized in terms of taste, The first step would involve assigning taste values from a taste database to the food intake data, including foods not in the database ('untested foods'). This step is crucial in assessing dietary taste patterns as it forms the basis of subsequent analyses, similar to how conventional food composition databases provide nutrient contents of foods to convert intake data into nutrient intakes. The chosen method would ideally result in an accurate taste profile of each untested food in the intake records. Moreover, the assignment method should be feasible in different contexts. At the moment, it is unclear how best it is to assign these taste values to food intake data and whether one method is preferrable to the other.

The assignment of taste values from a taste database to the rest of the untested foods could be performed systematically based on similarities in food description first, then based on nutrient content, within each food (sub-)group. All taste values of the tested food would then be assigned to the 'best matched' food (Lease et al., 2016). For example, sweet, salt, bitter, umami and salt taste, and fatty mouthfeel values of tested 'soup, vegetable, homemade' would be all assigned to un-tested 'soup, minestrone, homemade'. Alternatively, the untested foods within a food (sub-)group could all receive the same values based on a chosen measure of central tendency, such as, the mean taste values of all tested foods within that (sub-)group (Teo et al., 2022; Teo, van Langeveld, de Graaf, et al., 2018; van Langeveld et al., 2018). For example, sweet, salt, bitter, umami and salt taste, and fatty mouthfeel values of tested foods in sub-group 'Soups' (including 'soup, vegetable, homemade') would be averaged and assigned to the remaining untested foods in the sub-group 'Soups' (including 'soup, minestrone, homemade').

The second step in characterising dietary taste patterns would be to determine the contribution of each taste from all recorded foods, to dietary intake. All foods, now with assigned taste values, could be grouped according to their similarities in taste values. Dietary taste patterns in the Netherlands, Malaysia and Singapore have been characterised using the cluster method to assess the contribution of each taste to the diet (Teo et al., 2022; Teo, van Langeveld, de Graaf, et al., 2018; van Langeveld et al., 2018). The quantity of food consumed from each cluster has been calculated based on the consumption records and averaged to assess its contribution to energy intake on a population level. This has been informative in showing what are the taste combinations that were prominent in the diets of these countries, such as 'Sweet and Fatty' in the Netherlands, and similar taste combinations that were present across the diets, such as 'Sweet and Sour' across the three countries. Nonetheless, comparisons can only be made within the same cluster analysis(e.g., male and female can only be compared if their intakes are clustered together and their clusters are made up of the same foods(van Langeveld et al., 2018).

In the creation of taste databases, trained sensory panellists rated taste and mouthfeel intensity values per eaten portion of each food (Lease et al., 2016; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018). However, foods in the diet are consumed in larger quantities and in several portions. To account for the amount of food consumed, the concept of sensory/taste[1] amount was introduced during the characterisation of dietary taste patterns in Australia (Cox, Hendrie, Lease, et al., 2018). Intensity values per eaten portion of each food would be multiplied by the consumed quantity in grams, with the resultant value as the total taste amount exposed in the mouth throughout consumption of that food. Although an eaten portion is likely to be more than one gram, making this an estimation of actual taste amount, it is still a feasible and understandable approach to quantify each taste experienced from the diet.

In their next step, Cox and colleagues (2018) controlled for energy intake by dividing the taste amounts of each food by its energy density in kilojoules, giving rise to taste density. The idea of taste density is similar to nutrient density, where macro- and micro-nutrients are sometimes presented as (micro-)grams per standard calories or kilojoules. Non-caloric items were given one kilojoule per hundred grams as their energy density (Cox, Hendrie, Lease, et al., 2018). This addressed the issue of undefined taste densities for some foods and consequently, undefined taste densities from some diets, allowing further analyses to be made. However, studies have suggested a global increase in consumers of low- or no-calorie-sweetened products (Martyn et al., 2018). Since the calorie component in this equation becomes null, it is challenging to interpret and understand taste density in a diet, especially with growing tasty but, non-caloric components in the diet.

Another aspect to consider when quantifying each taste experienced from the diet, is the duration of the taste experience. The magnitude of taste experienced in the oral cavity during food consumption is determined by both the intensity of the stimulus and the duration of exposure to the stimulus (Lasschuijt et al., 2021). The intensity of sweet, sour, bitter, umami, salt taste and fat mouthfeel experienced in a diet may be quantified with taste amounts. However, the duration aspect of taste exposure is largely determined by oral processing and eating rate, which is affected by the former (de Graaf, 2012). It seems that eating rate should be added into the equation of quantifying taste in the diet, perhaps in place of calories. The taste amount obtained of each taste could be further utilised in a way that includes the duration of exposure. The

[1] For the purpose of this study, it is important to distinguish between sensory and taste. Sensory would, by definition, include other senses, such as olfaction. However, since the present work is focusing on taste, the terms ‘sensory amount’ and ‘sensory density’ from the work of Cox and colleagues (2018), are replaced with ‘taste amount’ and ‘taste density’ respectively.

aforementioned approaches to quantifying the contribution of each taste to the diet could be explored and compared to assess their suitability, feasibility and ease of comprehension.

This chapter aims to provide the approach that most successfully characterises taste in dietary patterns, so that dietary taste patterns of different populations may be assessed and compared in the future and further investigated in relation to health outcomes. Various approaches for both steps will be explored and evaluated against each other (Figure 6.1); in terms of their suitability in describing dietary taste patterns and taste exposure, feasibility to execute across diets and/or populations and ease of interpretation. As the current work was a piece of step-by-step sequential research, there were multiple methods and results. Hence, the rest of this chapter has been structured as follows; firstly, the datasets used in both of the steps will be detailed (6.2); next, comparison of approaches to the first step will be explained, conducted and discussed (6.3); then, comparison of approaches to the second step will be explained, conducted and discussed (6.4); and finally, findings from both comparisons will be discussed, particularly with regard to their suitability and feasibility in intended research directions (6.5).

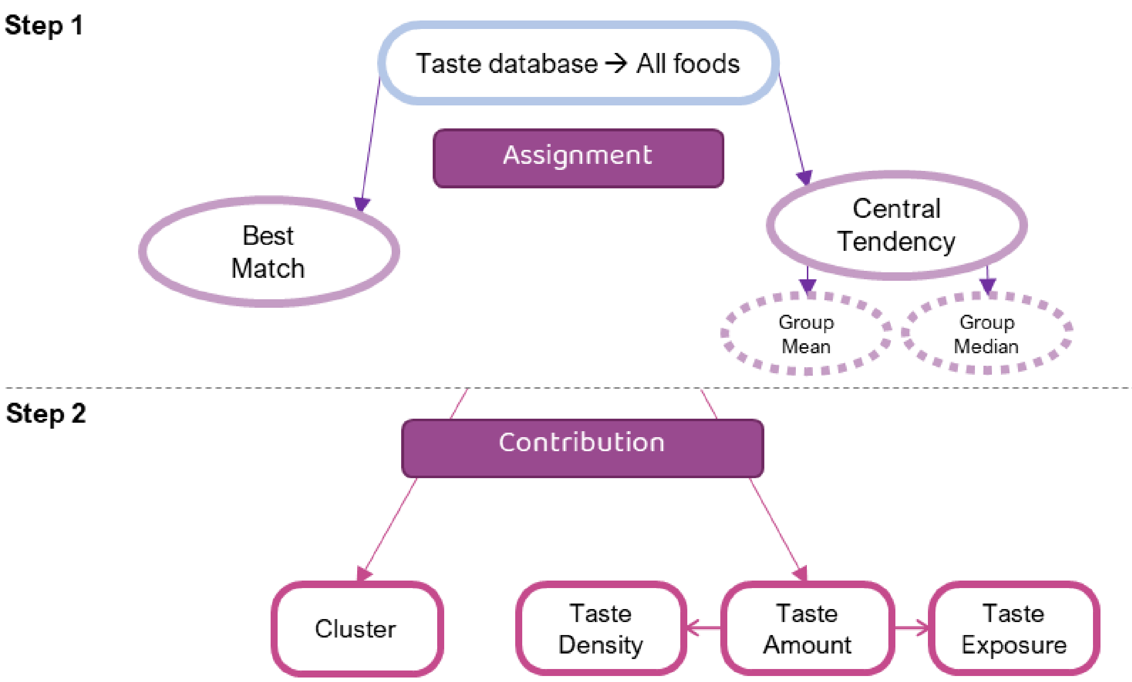

Figure 6.1. Two-step approach to characterising taste exposure in dietary taste patterns, including different existing and new methods. Step 1: assignment of taste values from a taste database to the food intake data. Step 2: contribution of each taste to the diet.

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6.2. Datasets

The present work involved collaboration with the Australian Government agency, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Food and Nutrition research lab and Wageningen University and Research (WUR) Sensory Science and Eating Behaviour lab. Datasets, syntaxes and results were shared and discussed for common understanding and interpretation. The taste database and consumption data from Australia and the eating rate with texture database from the Netherlands were used to achieve the aims of this chapter.

6.2.1. Taste database

The Sensory-Diet Database was created by CSIRO Food and Nutrition lab (Lease et al., 2016), consisting of 720 foods representative of the Australian diet based on nutritional and/or sensory differences, food grouping and frequency of consumption. Their sweet, sour, bitter, umami, salt taste, hardness, cohesiveness, moistness and fatty mouthfeel, and flavour intensity values (unit: score) were rated by a trained sensory panel (n=8) (Lease et al., 2016), using modified Spectrum™ scales of 0 to 100mm (Civille & Carr, 2015; Meilgaard et al., 2007). For the purpose of the current study, only sweet, sour, bitter, umami, salt taste, and fatty mouthfeel values were taken from the database. The reference solution for each taste and the product that represented a high level of that taste are as follows – sweet: sucrose 2–16%, cola; sour: citric acid 0.05–0.2%, lemon juice; bitter: caffeine 0.05–0.2%, soaked tea bags; salt: sodium chloride 0.2–0.8%, potato chips; and umami: monosodium glutamate 0.3–0.6%, parmesan cheese. Grapes and olive oil were used to represent low and high levels of fatty mouthfeel respectively. Moreover, only foods consumed by the adult population, age 18 to 65 years, were included. Each food belonged to a major (2-digit code), sub-major (3-digit code) and minor (5-digit code) food group, and has a unique food code (8-digit), all according to the Australian Food, Supplement and Nutrient Database (AUSNUT).

6.2.2. Eating rate with texture database

The Eating Rate Database was created by WUR Sensory Science and Eating Behaviour lab (van den Boer, Werts, et al., 2017), consisting of 240 foods representative of the Dutch diet based on variations in macronutrients, texture and taste, and representation of different food groups and different eating occasions (e.g., snack, lunch, dinner). Each food was consumed by at least four participants out of 89 adults in total. The serving size of each food allowed for multiple bites or sips, but not limiting further consumption in a way that would influence satiety and eating rate.

Apple, wholewheat bread and semi-skimmed yogurt were reference foods used to correct for individual variations in eating rates. A calibration factor was calculated for each participant according to how fast the participant consumed these reference foods relative to the other participants (van den Boer, Werts, et al., 2017). The observed eating rate of each food by each participant was calculated by dividing the amount eaten in grams (g) by the eating duration in minutes (min), then divided by their calibration factor. Finally, the calibrated eating rates were averaged to give the eating rate of each tested food (g/min). Each food was assigned to a texture category, either liquid, semi-solid, soft-solid or hard-solid (Stieger & Van de Velde, 2013). Hence, an average eating rate for each category could be calculated, as follows – liquid: 306 ± 177 g/min, semi-solid: 63 ± 50 g/min, soft-solid: 30 ± 16 g/min and hard-solid: 19 ± 15 g/min.

6.2.3. Consumption data

The National Nutrition and Physical Activity Survey (NNPAS) 2011 to 2012 included persons from aged 2 years and above, living in Australia. It was representative of the population in terms of age, gender, regions, degree of urbanisation and education level. The collection of food consumption data followed the guidelines of Food Standards Australia New Zealand (Australian Bureau of Statistics, 2013). Two non-consecutive 24-hour dietary recalls were conducted, the first through a computer-assisted personal interview, and the second, through a computer-assisted telephone interview. Both dietary recalls were performed by trained dieticians using an adapted version of the Automated Multi-Pass Method developed by the Agricultural Research Service of the United States Department of Agriculture, and energy intakes were calculated using AUSNUT. During the first dietary recall, height and weight of participants were measured. A total of 12153 persons completed at least the first dietary recall and had their height and weight measured. For the purpose of the current study, only the adult population of age 18 to 65 years was included. This resulted in 7528 adults, of which 4015 were biologically female; with mean age 42.2 ± 13.0 years and mean BMI 27.4 ± 5.6 kg/m^2.

6.3. First step: Assignment of taste values

This section details the comparison made on various methods used to assign taste values from the taste database to the rest of the untested foods in the consumption data. The first method was 'best match', where each tested food was assigned to an untested food based on their similarities in food description first, then based on their nutrient contents. The second and third methods were based on measures of central tendency, where the 'group mean' or the 'group median' of tested foods within a (sub-)group were assigned to the untested foods within that group. All methods were then compared. The methods and analysis performed are presented first (6.3.1), followed by the results (6.3.2) and then, an interim discussion (6.3.3).

6.3.1. Methods and analysis

As the taste intensity values of alcohol, sweetened coffee and sweetened tea were not included in the Sensory-Diet Database but could be found in the Taste, Fat and Texture Database (Mars et al., 2020) of the Netherlands, the values of these items were added from this latter database and assigned to corresponding foods in the consumption data based on their unique 8-digit food code. The remaining 4749 foods in the consumption data had no tested values of sweet, sour, bitter, umami, salt taste and fatty mouthfeel, and had to be assigned values from the taste database. Prior to that, food entries in the consumption data meant to be single food items, yet separately recorded within the same eating occasion, were combined. In the current consumption data, only coffee and tea entries needed to be combined with sweetening and/or milk agents.

Any coffee entry (e.g., 11201002: Coffee, black, from instant coffee powder, without milk) that was entered with a sweetener entry (e.g., 31201008: Intense sweetener, containing stevia, powdered formulation) were combined into one coffee with sweetener entry (e.g., 11201007: Coffee, from instant or ground beans, no milk, with stevia). Any coffee entry (e.g., 11201001: Coffee, espresso style, without milk) that was entered with a milk entry (e.g., 19101006: Milk, cow, fluid, regular fat (~3.5%), not further defined) were combined into one coffee with milk entry (e.g., 11202009: Coffee, espresso style, without milk + MILK). Subsequently, these entries that were also recorded with a sugar entry (e.g., 27101006: Sugar, white, granulated or lump) were combined into one coffee with milk and sugar entry (e.g., 11202041: Coffee, black, from instant coffee powder, without milk + MILK + SUGAR). Any coffee entry (e.g., 11201003: Coffee, long black style, from ground coffee beans, without milk) that was entered with a sugar entry (27101003: Sugar, raw) and without a milk entry, were combined into one coffee with sugar entry (11201006: Coffee, not further defined + SUGAR). These combinations were performed sequentially to avoid double entry. Similarly, any tea entry (e.g., 11101001: Tea, regular, black, brewed from leaf or teabags, plain, without milk) that was recorded with a sugar entry (e.g., 27101006: Sugar, white, granulated or lump) were combined into one tea with sugar entry (e.g., 11101009: Tea, regular, black, brewed from leaf or teabags, flavoured, without milk + SUGAR). Subsequently, the untested foods were assigned values based on methods introduced in section 6.1.

The ‘best match’ method was to best match each untested food to a tested food from the taste database, based on similarities in their food description first, then nutrient contents, within each food (sub-)group (Cox, Hendrie, Lease, et al., 2018; Lease et al., 2016). Experts from the CSIRO Food and Nutrition lab performed the matching. If there was only one tested food in a sub-group, it was equivalent to assigning values based on any measure of central tendency. The second and third methods were to assign all untested foods within a food (sub-)group the same values, based on a chosen measure of central tendency, either with the group mean or the group median of tested foods within that (sub-)group.

Paired sample t-tests were performed to compare between the assignment methods, namely, best match, group mean and group median. As correlation quantifies the degree of relatedness between two variables rather than their level of agreement, it was considered unsuitable to determine which assignment method was preferrable. Moreover, it would be expected that any two methods which aim to measure the same outcome would be significantly correlated according to statistical tests. Therefore, the Bland and Altman plot system was included to evaluate the agreement between assignment methods (Giavarina, 2015). This approach does not provide a test result on which method to use, and instead, provides the bias and range of agreement within which 95% of differences are included. There is no ‘gold standard’ and an *a priori* limits of agreement expected could not be set in the present analysis. The best match method was decided as the reference measure against group mean and group median, since it considered specificity by experts as compared to a more generic value by group mean and group median. Therefore, preference for a measure of central tendency was determined by which had the least mean differences from best match values. The Bland-Altman plots were also observed for their patterns on differences between the methods, with best match method as the reference measure against group mean and group median again.

A result was considered significant when $p < .05$. All analyses were performed using R statistical software (version 4.0.2) and its relevant packages (Allaire et al., 2017; Datta & Love, 2018; Kassambara, 2020, 2021; Kassambara & Mundt, 2020; R Core Team, 2020; Wickham et al., 2019).

6.3.2. Results

A total of 4749 untested foods in the food intake data were best matched to one of the 747 tested foods from the taste database to obtain their taste values or were assigned the mean or median values of the tested foods within their food (sub-)groups. The average tastes and mouthfeel values across all foods differed between the assignment methods. The differences in values between 'best match' and the two measures of central tendency are presented in Table 6.1. Only salt taste values of best match and group mean, and sour taste values of best match and group median were not significantly different. Largest differences were seen in fatty mouthfeel values (2.17 ± 8.26). There were smaller differences between group mean and best match (range: 0.15-1.19), than between group median and best match (range: 0.11- 2.11).

Table 6.1. Differences in the taste intensity values averaged across all untested foods between assignment methods.

		Mean ± SD [1]	**95% CI** [1]	***t*(5468)** [2]	***p***
Best match vs. group mean	Sweet taste	0.42 ± 8.75	[0.19, 0.65]	3.58	< .001
	Sour taste	-1.19 ± 6.59	[-1.36, -1.02]	-13.5	< .001
	Bitter taste	-0.58 ± 5.47	[-0.72, -0.43]	-7.92	< .001
	Umami taste	0.31 ± 6.71	[0.13, 0.48]	3.43	< .001
	Salt taste	-0.15 ± 8.63	[-0.38, 0.07]	-1.32	.188
	Fatty mouthfeel	0.97 ± 8.02	[0.76, 1.18]	9.09	< .001
Best match vs. group median	Sweet taste	0.97 ± 8.52	[0.74, 1.19]	8.35	< .001
	Sour taste	-0.11 ± 6.10	[-0.27, 0.05]	-1.34	.180
	Bitter taste	0.54 ± 4.31	[0.42, 0.65]	9.16	< .001
	Umami taste	1.17 ± 7.42	[0.97, 1.34]	11.6	< .001
	Salt taste	1.12 ± 9.04	[0.88, 1.36]	9.16	< .001
	Fatty mouthfeel	2.17 ± 8.26	[1.95, 2.39]	19.4	< .001

[1] Values of paired differences. SD: standard deviation. CI: confidence intervals. [2] Total number of foods.

Looking at the Bland-Altman plots on the right (Figure 6.2), assigned values using both measures of central tendency displayed similar patterns to those assigned using the best match method. The difference in intensity values between best match and group mean assignment methods ranged from 21.5 to 34.3, and the difference in intensity values between best match and group median assignment methods ranged from 16.7 to 35.0. The larger the 'actual' intensity value of a food (if rated by a trained panel), the larger the difference in values assigned by best match and group mean or median. Compared to the best match method, both measures of central tendency systematically assigned larger values of sweet, sour, bitter, umami, salt taste and fatty mouthfeel to foods.

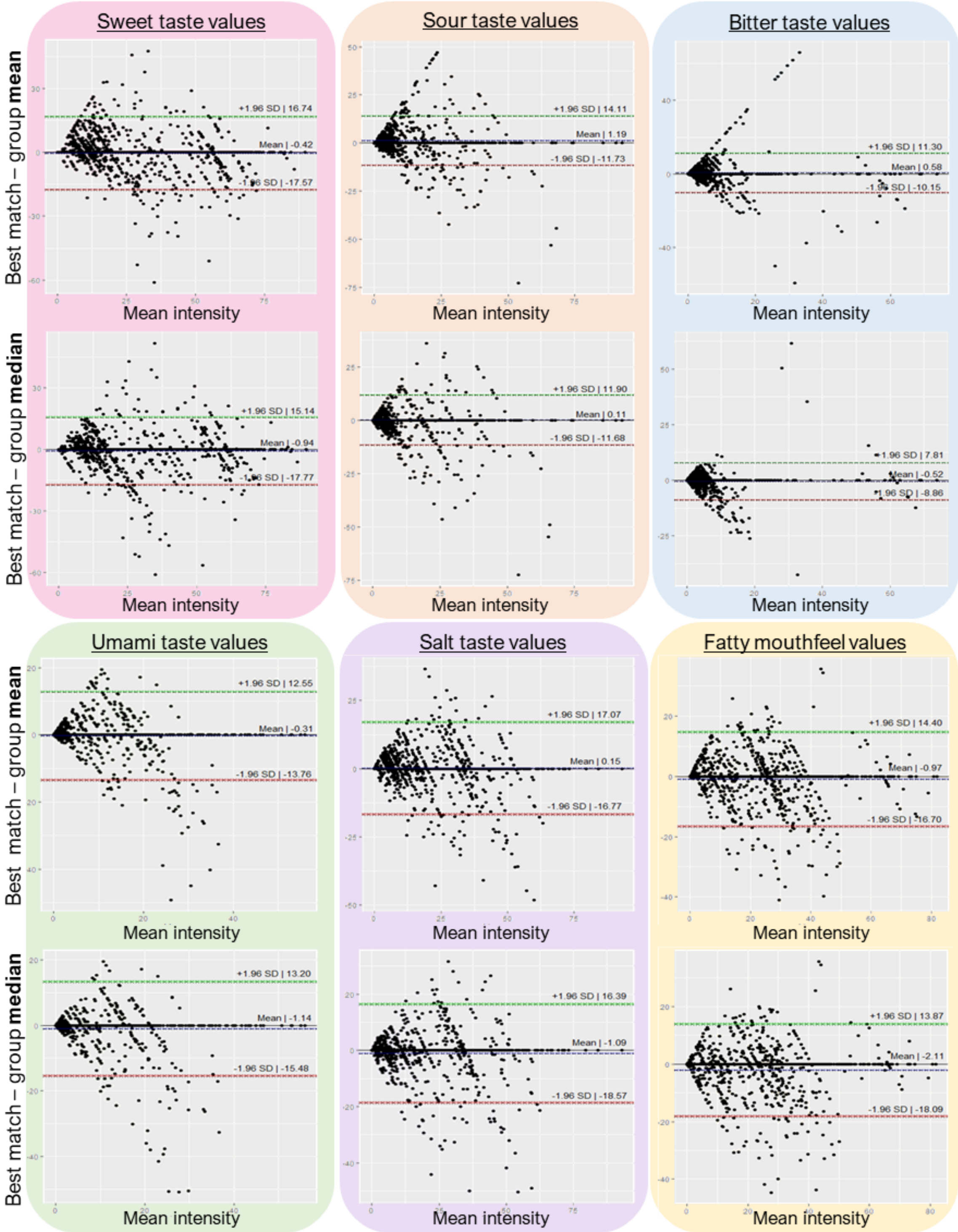

Figure 6.2. Bland-Altman plots of the differences between best match and group mean, and differences between best match and group median; for all tastes and mouthfeel values.

6.3.3. Interim discussion

Best match method was chosen as the reference to compare both group mean and group median, as it allowed for item-specificity and variation, while both methods of central tendency assigned centralised values to all foods within the same sub-group. Nonetheless, if none or only one food was tested in a sub-group, best match was the same as taking a measure of central tendency and thus, there was no extra benefit from using the best match method. It also took a considerable amount of time to best match approximately 4800 foods. Moreover, best match, group mean and group median all faced the same issue in which foods within the same food sub-group may not taste the same. Food (sub-)groups in food composition databases are formed based on their key nutrients rather than their tastes. For example, pickled, smoked or salted cabbage would taste different from boiled cabbage despite all of them belonging to the food group of vegetables. As best match method required experts from both nutrition and sensory fields to match each untested food to a tested food in the database, it was a time-consuming and expensive method. To compare dietary taste exposure patterns of different populations, it may not be possible to find the required expertise to fulfil this method. Therefore, considering potential logistical issues in practice, best match method was not selected.

Both group mean and median systematically assigned larger tastes and mouthfeel intensity values to foods. This may be problematic as the intensity values could be overestimated and result in an inaccurate characterisation of dietary taste patterns. Nonetheless, comparisons between the two measures of central tendency and best match showed that the mean differences are negligible, considering a 1-100 scale. A measure of central tendency may be more feasible to reach the aim of assessing and comparing dietary taste exposure patterns across populations. Between the two measures of central tendency, group mean showed smaller differences from best match than group median did. Since the preference for either measure of central tendency was decided a priori to be determined by which had the least mean differences from best match value, group mean was selected as the assignment method for subsequent analyses in the second step. The strengths and limitations of each method for this step is summarised in Table 6.2.

Table 6.2. Strengths (+) and limitations (-) of each method for step 1.

	Best match	**Central tendency**	
Step 1: Assignment of taste values from taste database to untested foods	+ Item-specificity and variation + Expert evaluation - Time-consuming and expensive - Similar to central tendency if ≤ 1 food tested in a sub-group i.e., no extra benefit/advantage - Foods within a sub-group may not taste the same	+ Centralised values + More objective + Less time-consuming - Foods within a sub-group may not taste the same - Systematically assigned larger values	
		Group mean	**Group median**
		+ Smaller differences from best match	

6.4. Second step: Characterisation of dietary taste patterns

This section details the comparison made on various methods used to characterise dietary taste exposure patterns from the consumption data. It is structured as follows – firstly, the methods, analysis and results of the cluster method will be presented (6.4.1); then the methods, analysis and results of the taste amount and density method (6.4.2); followed by the methods, analysis and results of the taste exposure method (6.4.3); and then, an interim discussion (6.4.4).

6.4.1. Cluster

The first method was to group all foods according to their similarities in taste values using hierarchical cluster analysis. The quantity of food consumed from each cluster could then be averaged to assess contribution of each taste cluster to total energy intake on a population level.

6.4.1.1. Methods and analysis

Hierarchical cluster analysis aims to form clusters consecutively. Agglomerative clustering was chosen so that each food is initially considered as a single-element cluster with a unique taste profile. Intensity values were standardised to have a mean of 0 and standard deviation of 1 priorly, so as to make all taste and mouthfeel values comparable. A distance measure, which calculates how similar two foods, as well as a clustering method, which defines how cluster membership is assigned, had to be decided (Murat & Sakallıoğlu, 2010). Therefore, various distance measures and clustering methods were paired and compared against each other. Cophenetic Correlation Coefficient (c) and Wilks' lambda (λ) were used as criteria to evaluate each pair of methods and determine the most suitable agglomerative clustering approach (Akogul & Erisoglu, 2017; Murat & Sakallıoğlu, 2010; Saraçli et al., 2013). A higher value of c and a lower the value of λ indicate a more statistically sound hierarchical clustering structure. Nonetheless, the resultant clusters also have to make sense from a taste and nutrition perspective. Therefore, theoretical reasoning was considered alongside statistical results when deciding the final clustering approach, the number of clusters and the names of the clusters. Each cluster would ideally have a unique dominant taste or taste combination with a minimum number of descriptors that are useful. The clusters formed by Euclidean, Manhattan and Maximum distance measures using Ward's clustering method were named according to which taste or mouthfeel had the highest value(s). Food groups belonging to each cluster should also be logical based on food description and nutrient content. For example, 'cake-type desserts' should not be found in a 'savoury' and/or 'salt' cluster.

The energy intake per taste cluster was calculated separately for each dietary recall day, and then averaged to obtain the energy intake per cluster for each participant. Subsequently, the average of the population was calculated to obtain percentage contribution of each taste cluster to total energy intake, and compared between sexes as an example. All analyses were performed using R software (version 4.0.2) and its relevant packages (Allaire et al., 2017; Kassambara, 2020, 2021; Kassambara & Mundt, 2020; Maechler et al., 2019; R Core Team, 2020; Wickham et al., 2019).

6.4.1.2. Results

The cophenetic correlation coefficients and Wilk's lambdas of possible combinations between distance measures and clustering methods are presented in Table 6.3. These values inform how well the pairwise distances of resultant clusters match with those between the original unmodeled datapoints (Saraçli et al., 2013), and were calculated based on six clusters specification, since there are five tastes and one mouthfeel variable.

Table 6.3. Statistics of various distance measures and clustering methods.

Distance measure		Clustering method			
		1. Ward's	2. Average	3. Weighted	4. Centroid
	i) Euclidean	c = 0.519	c = 0.839	c = 0.693	c = 0.774
		λ = 0.00258	-	-	-
	ii) Manhattan	c = 0.563	c = 0.750	c = 0.616	c = 0.732
		λ = 0.00372	-	λ = 0.0386	-
	iii) Maximum	c = 0.536	c = 0.871	c = 0.625	c = 0.831
		λ = 0.00381	-	-	-
	iv) Canberra	c = 0.677	c = 0.750	c = 0.714	c = 0.572
		λ = 0.0196	λ = 0.196	-	-

c: Cophenetic Correlation Coefficient. λ: Wilk's Lambda.

The standardised data produced similar results for Euclidean, Minkowski and Pearson distance measures and since Minkowski is a generalisation of the Euclidean and Manhattan distance measures (Witten et al., 2016), only results from the Euclidean measure are shown. There were 13 clustering structures without a λ value because they produced at least one cluster with a single observation i.e., food item, and they were from the Average, Weighted and Centroid clustering method. When cluster specification was reduced by half, it still remained the case for Centroid clustering regardless of distance measure. For Average clustering method and Weighted clustering method, their Wilk's Lambda values were still considerably higher than values from Ward's clustering method, indicating that the differences between their produced clusters were not as significant and meaningful (Murat & Sakallıoğlu, 2010). Therefore, Ward's clustering method was chosen as the clustering method for subsequent analyses.

It was decided a priori that each cluster should have its unique dominant taste or taste combination with a minimum number of descriptors that are useful; the value(s) that was highest within a cluster was underlined in Table 6.4 on the right. The scatter plots from each distance measure using Ward's clustering method can be found in Appendix 10. Euclidean, Manhattan and Maximum distance measures produced similar dominant tastes in each cluster (Table 6.4A-C). In contrast, Canberra distance measure resulted in two similar clusters (Table 6.4D) and remaining clusters did not have as high values as compared to the other distance measures; hence, it was excluded.

Table 6.4. Taste and mouthfeel values of six clusters formed by Ward's clustering method with (A) Euclidean, (B) Manhattan, (C) Maximum and (D) Canberra distance measures.

A) Euclidean (mean ± SD)						
No. of foods	**n=78**	**n=834**	**n=1007**	**n=357**	**n=1456**	**n=814**
Sweet taste	10.6±5.5	13.6±7.6	52.6±10.1	32.4±12.5	15.8±5.9	8.7±6.5
Sour taste	5.0±3.7	5.9±4.8	7.1±5.9	36.4±10.0	7.7±5.6	2.8±1.7
Bitter taste	55.4±4.4[1]	7.8±6.7	3.3±2.6	6.4±6.5	2.5±2.2	2.4±3.2
Umami taste	0.7±0.3	3.1±1.9	0.7±0.4	2.2±2.7	17.0±6.0	8.0±5.6
Salt taste	1.6±0.8	10.4±7.0	9.0±4.4	9.3±10.3	34.6±9.0	13.6±6.4
Fatty mouthfeel	6.6±4.4	7.4±4.8	17.0±10.3	12.0±15.4	26.3±9.8	29.1±13.6
B) Manhattan (mean ± SD)						
No. of foods	**n=78**	**n=813**	**n=1070**	**n=319**	**n=1152**	**n=1108**
Sweet taste	10.6±5.5	13.5±7.5	51.2±11.4	33.1±12.4	17.6±5.3	8.1±4.1
Sour taste	5.02±3.7	5.9±4.7	7.1±5.8	35.2±8.7	10.4±9.0	2.6±1.6
Bitter taste	55.4±4.4	8.1±6.8	3.2±2.6	6.7±6.9	2.6±2.2	2.3±2.8
Umami taste	0.7±0.3	3.1±2.0	0.7±0.6	1.6±1.8	18.4±5.8	9.3±5.1
Salt taste	1.6±0.8	10.4±7.0	8.9±4.4	6.4±5.5	35.3±8.6	19.8±11.2
Fatty mouthfeel	6.6±4.4	7.4±4.9	17.9±10.6	10.4±14.9	28.4±9.4	25.5±13.4
C) Maximum (mean ± SD)						
No. of foods	**n=78**	**n=1438**	**n=1009**	**n=466**	**n=1474**	**n=81**
Sweet taste	10.6±5.5	10.6±7.4	52.1±11.1	30.4±12.6	15.7±5.8	8.7±2.5
Sour taste	5.0±3.7	3.8±3.1	6.4±5.4	31.0±12.7	7.9±6.3	4.7±2.4
Bitter taste	55.4±4.4	4.5±0.4	3.4±2.3	8.6±8.8	2.6±2.6	2.3±4.9
Umami taste	0.7±0.3	6.0±5.0	0.8±0.6	1.9±2.4	16.9±3.1	2.4±1.6
Salt taste	1.6±0.8	11.7±5.4	9.1±4.2	7.3±8.5	34.6±9.0	26.2±10.1
Fatty mouthfeel	6.6±4.4	16.6±9.8	17.0±10.1	9.8±14.1	26.3±10.1	66.1±4.6
D) Canberra (mean ± SD)						
No. of foods	**n=1128**	**n=965**	**n=410**	**n=258**	**n=1366**	**n=419**
Sweet taste	10.8±6.2	48.6±12.5	46.0±12.8	18.0±5.8	15.9±5.9	5.5±1.0
Sour taste	5.9±9.7	6.6±0.8	24.5±10.6	17.0±9.4	7.6±7.3	2.5±0.4
Bitter taste	10.0±14.4	3.1±3.3	5.2±3.8	7.0±2.5	2.2±1.5	2.1±0.5
Umami taste	2.7±2.3	8.8±8.3	1.2±1.2	9.4±8.0	17.0±5.7	12.9±2.8
Salt taste	11.3±9.7	9.6±3.9	5.0±3.7	24.4±10.9	34.4±8.8	12.8±2.5
Fatty mouthfeel	15.0±17.3	21.1±9.1	3.0±3.5	14.3±6.8	27.1±9.8	25.8±1.4

[1] Underlined values that are highest within that cluster. SD: standard deviation.

Across Euclidean, Manhattan and Maximum distance measures, Cluster 1 (n=78) consistently had the highest value in bitter taste and was named 'Bitter'. Cluster 2 (n=813-1438) consistently had low values in all tastes and mouthfeel and was named 'Neutral'. Cluster 3 (n=1007-1070) consistently had the highest value in sweet taste and was named 'Sweet'. Cluster 4 (n=319-466) consistently had the highest values in both sweet and sour tastes, hence it was named 'Sweet and Sour'. Cluster 5 (n=1152-1474) consistently had the highest values in salt taste and fatty mouthfeel, hence it was named 'Salt and Fat'. Lastly, Cluster 6 (n=81-1108) consistently had the highest value in fatty mouthfeel and was named 'Fat'.

The detailed list of minor food groups and their resultant clusters by Ward's clustering method with Euclidean, Manhattan and Maximum distance measures can be referred to in Appendix 11. Several notable minor food groups and their clusters are presented in Table 6.5. For example, Manhattan distance clustered some meats as 'fat' only without 'salt and fat' and mature legume and pulse products or dishes as 'fat' instead of 'neutral'. Maximum distance clustered cream and dairy milk as 'neutral' instead of 'fat'. Discussion among the research team concluded based on a priori criteria that the Euclidean distance measure produced the most logical clusters. Therefore, this approach was used in subsequent analyses.

Table 6.5. Cluster differences between Euclidean, Manhattan and Maximum distance measures.

Food groups	**Euclidean**	**Manhattan**	**Maximum**
Tea	Bitter, Neutral	Bitter, Neutral	Bitter, Sweet & Sour
Pastries	Sweet, Salt & Fat, Fat	Sweet, Salt & Fat, Fat	Neutral, Sweet
Batter-based products	Sweet, Fat	Sweet, Fat	Neutral, Sweet
Savoury biscuits	Neutral, Salt & Fat	Neutral, Salt & Fat, Fat	Neutral, Salt & Fat
Corn snacks	Salt & Fat	Fat	Salt & Fat
Other snacks	Salt & Fat	Fat	Salt & Fat
Regular breads & bread rolls	Neutral, Salt & Fat	Neutral, Fat	Neutral, Salt & Fat
Flour, other cereal grain, starch	Neutral	Neutral, Fat	Neutral
Cream	Sweet & Sour, Fat	Sweet & Sour, Fat	Neutral, Sweet & Sour
Dairy milk (cow, sheep & goat)	Sweet, Fat	Sweet, Fat	Neutral, Sweet
Mixed dishes where cereal is the major ingredient	Salt & Fat	Salt & Fat, Fat	Neutral
Eggs	Fat	Fat	Neutral
Dishes where egg is the major ingredient	Fat	Fat	Neutral
Mammalian game meats	Salt & Fat	Fat	Salt & Fat
Beef, sheep & pork, unprocessed	Salt & Fat, Fat	Fat	Neutral
Poultry & feathered game	Salt & Fat, Fat	Fat	Neutral
Organ meats & offal, products & dishes	Salt & Fat	Fat	Salt & Fat
Processed meat	Salt & Fat	Salt & Fat, Fat	Salt & Fat
Fin fish	Salt & Fat	Fat	Salt & Fat
Crustacea & molluscs	Salt & Fat	Fat	Salt & Fat
Other sea & freshwater foods	Salt & Fat	Fat	Salt & Fat
Packed (commercially sterile) fish & seafood	Salt & Fat	Fat	Salt & Fat
Fish & seafood products	Salt & Fat, Fat	Fat	Salt & Fat
Mature legume & pulse, products & dishes	Neutral	Neutral, Fat	Neutral
Other fruiting vegetables	Neutral, Sweet, Salt & Fat, Fat	Neutral, Sweet, Fat	Neutral, Sweet, Sweet & Sour, Salt & Fat

_ _ _ indicates a cluster that differed from clusters formed by the other two distance measures.

To check if additional clusters would improve cluster formation, values were calculated again to compare between having six and seven clusters (Table 6.6). Five of the clusters remained the same. To form the seventh cluster, the sixth cluster was split into two clusters that were both highest in their fatty mouthfeel values (i.e., ‘Fat’ and ‘Fat 2?’). This did not lead to more meaningful and understandable clusters; hence, six clusters specification was chosen. Among the six clusters, ‘Salt and Fat’ cluster contributed the most to total energy intake, followed by ‘Sweet’, ‘Fat’, ‘Neutral’, ‘Sweet and Sour’ and lastly, ‘Bitter’ cluster contributed the least.

Table 6.6. Taste and mouthfeel values alongside percentage contribution to total energy intake from each taste cluster using Ward’s with Euclidean method, in (A) six, and (B) seven clusters.

A) 6 clusters						
	Bitter (n=78)	**Neutral** (n=834)	**Sweet** (n=1007)	**Sweet Sour** (n=357)	**Salt Fat** (n=1456)	**Fat** (n=814)
Energy (kcal)	145.2	357.3	449.7	227.4	676.7	374.5
Energy (%)	7.0	17.3	21.8	11.0	32.8	18.1
Sweet	10.6±5.5	13.6±7.6	<u>52.6±10.1</u>	<u>32.4±12.5</u>	15.8±5.9	8.7±6.5
Sour	5.0±3.7	5.9±4.8	7.1±5.9	<u>36.4±10.0</u>	7.7±5.6	2.8±1.7
Bitter	<u>55.4±4.4</u>	7.8±6.7	3.3±2.6	6.4±6.5	2.5±2.2	2.4±3.2
Umami	0.7±0.3	3.1±1.9	0.7±0.4	2.2±2.7	17.0±6.0	8.0±5.6
Salt	1.6±0.8	10.4±7.0	9.0±4.4	9.3±10.3	<u>34.6±9.0</u>	13.6±6.4
Fatty	6.6±4.4	7.4±4.8	17.0±10.3	12.0±15.4	<u>26.3±9.8</u>	<u>29.1±13.6</u>

B) 7 clusters							
	Bitter (n=78)	**Neutral** (n=834)	**Sweet** (n=1007)	**Sweet Sour** (n=357)	**Salt Fat** (n=1456)	**Fat?** (n=723)	**Fat 2?** (n=91)
Energy (kcal)	145.2	357.3	449.7	227.4	676.7	360.2	92.3
Energy (%)	7.0	17.1	21.6	10.9	32.5	17.3	4.4
Sweet	10.6±5.5	13.6±7.6	<u>52.6±10.1</u>	<u>32.4±12.5</u>	15.8±5.9	8.7±6.8	8.8±3.6
Sour	5.0±3.7	5.9±4.8	7.1±5.9	<u>36.4±10.0</u>	7.7±5.6	2.5±.4	4.5±2.6
Bitter	<u>55.4±4.4</u>	7.8±6.7	3.3±2.6	6.4±6.5	2.5±2.2	2.3±2.3	3.0±7.0
Umami	0.7±0.3	3.1±1.9	0.7±0.4	2.2±2.7	17.0±6.0	8.7±5.6	2.7±2.4
Salt	1.6±0.8	10.4±7.0	9.0±4.4	9.3±10.3	<u>34.6±9.0</u>	12.1±3.5	25.6±10.3
Fatty	6.6±4.4	7.4±4.8	17.0±10.3	12.0±15.4	<u>26.3±9.8</u>	<u>24.6</u>±4.5	<u>65.0</u>±6.7

The percentage contribution of each taste cluster to energy intake was compared between male and female adults. As shown in Figure 6.3, males had higher percentage contributions than females from ‘Bitter’, ‘Salt and Fat’ and ‘Fat’ clusters, while females had higher percentage contributions than males from ‘Neutral’, ‘Sweet’ and ‘Sweet and Sour’ clusters. Notably, this comparison was possible as food intake from both sexes were included in the cluster formation, resulting in similar taste clusters. Otherwise, intake from males might have resulted in a cluster which the female did not have, or vice versa, and energy contribution by that cluster would not have had a match or counterpart to compare with. Therefore, comparisons between diets and/or populations using the cluster method requires cluster formation on all of them together, so that they have the same taste clusters to compare against one another in dietary intake contributions.

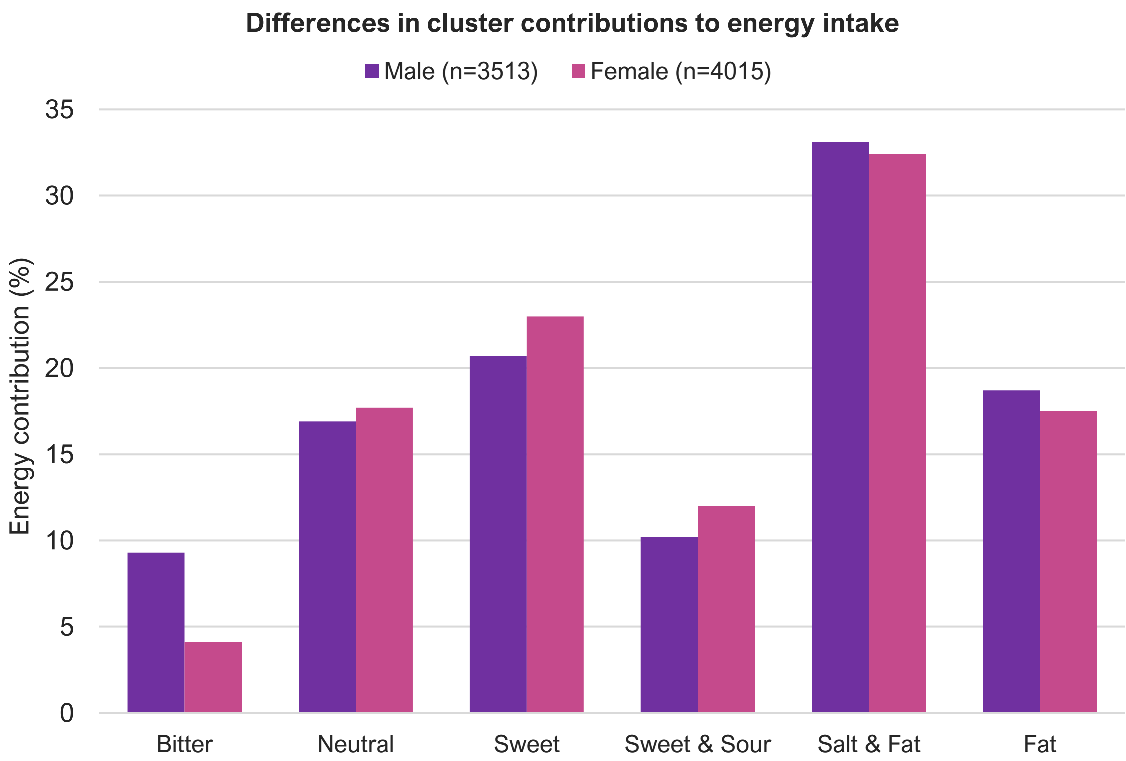

Figure 6.3. Sex differences in cluster contributions to energy intake, in percentage.

6.4.2. Taste amount and taste density

The second method was to multiply the taste values of foods by their consumed quantity in grams to obtain the taste amount of each taste. This would then be divided by consumed calories to obtain the taste density of each taste and an average could also be taken at a population level to assess the contribution of each taste density in relation to other tastes.

6.4.2.1. Methods and analysis

Taste amount (TA: score g) for each taste was calculated per food by multiplying its intensity value (TI: score) of that food with the consumed quantity in grams (g).

$$TA_{food} = TI_{food} \times consumed\ quantity$$

Subsequently, these values from all foods consumed in a day were summed up for each dietary recall day, then averaged across the days to obtain the taste amount for each participant. Finally, the averages of the population were calculated.

$$TA_{day\ 1} = TA_{food\ A} + TA_{food\ B} + TA_{food\ C} + \ \dots$$

$$TA_{participant} = \frac{TA_{day\ 1} + TA_{day\ 2}}{2}$$

$$TA_{population} = \frac{TA_{participant\ 1} + TA_{participant\ 2} + TA_{participant\ 3} + \cdots}{N}$$

Taste density (TD: score g/kcal) was calculated per food by dividing the taste amount (TA: score g) by the consumed energy in calories (kcal).

$$TD_{food} = \frac{TI_{food}\ \times\ consumed\ quantity}{consumed\ energy} = \frac{TA_{food}}{consumed\ energy}$$

Similar to taste amount, these values from all foods consumed in a day were summed up for each dietary recall day, then averaged across the days to obtain the taste density for each participant.

Two examples of breakfast were used to compare the effect of caloric difference on taste density, as well as discern the preference for taste amount or taste density. Between them, food items remained the same except for the drink, where ‘Tea weak infusion + sugar’ in Breakfast 1 was replaced with ‘Red smoothie, fruit/juice blend, purchased’ in Breakfast 2, which has higher sweet and sour taste intensity values and higher calories.

The taste amount for each taste and mouthfeel from the whole diet was compared between male and female adults. Foods and beverages were also separately examined to assess their own effects on taste amounts. All analyses were performed using R statistical software (version 4.0.2) and its relevant packages (Allaire et al., 2017; Datta & Love, 2018; Kassambara, 2020, 2021; Kassambara & Mundt, 2020; Maechler et al., 2019; R Core Team, 2020; Wickham et al., 2019).

6.4.2.2. Results

The two breakfast examples are presented in Tables 6.7 and 6.8, with the consumed quantity, energy in calories, and taste and mouthfeel values of each food item. Table 6.7A shows the taste and mouthfeel intensity values of each food from the Sensory-Diet database for breakfast 1. Referring to Table 6.7B, salt taste amount was the highest, followed by fat, sweet, bitter, umami and lastly, sour taste amount was the least from breakfast. Referring to Table 6.7C, sweet taste density was the highest, followed by bitter, fat, sour, salt and lastly, umami taste density.

Table 6.7. Breakfast 1 with consumed quantities, calories, taste, and mouthfeel values.

A)	**Grams**	**Calories**	**Taste intensity (score)**					
			Sweet	**Sour**	**Bitter**	**Umami**	**Salt**	**Fat**
Bread, 50% white 50% wholemeal	87.7	202	5.5	7	2.3	5.3	25.9	11
Egg fried in Polyunsaturated fat	62	115	6.8	2.1	1.7	0.9	9.0	19.9
Margarine, Flora original	10	40.8	11.9	9.2	2.9	10.1	33.2	75
Sausages, pork, grilled	129	334	10.9	3.2	2.4	28.7	49.1	47.7
Tea weak infusion + sugar	310	42.7	20	4	16	0	1	2
B)	**Grams**	**Calories**	**Taste amount (score g)**					
			Sweet	**Sour**	**Bitter**	**Umami**	**Salt**	**Fat**
Bread, 50% white 50% wholemeal	87.7	202	482	614	204	467	2272	964
Egg fried in Polyunsaturated fat	62	115	420	132	103	56.8	556	1231
Margarine, Flora original	10	40.8	119	91.7	29.2	100	332	750
Sausages, pork, grilled	129	334	1410	416	313	3708	6329	6156
Tea weak infusion + sugar	310	42.7	6200	1240	4960	0	310	620
Total taste amount:			**8628**	**2494**	**5610**	**4333**	**9799**	**9721**
C)	**Grams**	**Calories**	**Taste density (score g/ kcal)**					
			Sweet	**Sour**	**Bitter**	**Umami**	**Salt**	**Fat**
Bread, 50% white 50% wholemeal	87.7	202	2.39	3.04	1.01	2.31	11.2	4.77
Egg fried in Polyunsaturated fat	62	115	3.65	1.15	0.90	0.49	4.84	10.7
Margarine, Flora original	10	40.8	2.92	2.25	0.72	2.47	8.13	18.4
Sausages, pork, grilled	129	334	4.21	1.25	0.94	11.1	18.9	18.4
Tea weak infusion + sugar	310	42.7	145	29.0	116	0	7.26	14.5
Total taste density:			**158**	**36.7**	**120**	**16.4**	**50.4**	**66.8**

With reference to breakfast 2 in Table 6.8, the red smoothie has higher sweet and sour taste intensity values than the tea with sugar (Table 6.8A). It was then unsurprising that the total consumed sweet and sour taste amounts from breakfast 2 were greater than that of breakfast 1 (see Table 6.8B). However, since the red smoothie also has higher calories than tea with sugar, the resultant total sweet and sour taste densities from breakfast 2 were lower than that of breakfast 1, despite equal consumed quantities (see Table 6.8C).

Table 6.8. Breakfast 2 with consumed quantities, calories, taste, and mouthfeel values.

A)	**Grams**	**Calories**	**Taste intensity (score)**					
			Sweet	**Sour**	**Bitter**	**Umami**	**Salt**	**Fat**
Bread, 50% white 50% wholemeal	87.7	202	5.5	7	2.3	5.3	25.9	11
Egg fried in Polyunsaturated fat	62	115	6.8	2.1	1.7	0.9	9.0	19.9
Margarine, Flora original	10	40.8	11.9	9.2	2.9	10.1	33.2	75
Sausages, pork, grilled	129	334	10.9	3.2	2.4	28.7	49.1	47.7
Red smoothie, fruit/juice blend	310	142.6	54.5	6.8	4.1	0.7	4.2	1.5
B)	**Grams**	**Calories**	**Taste amount (score g)**					
			Sweet	**Sour**	**Bitter**	**Umami**	**Salt**	**Fat**
Bread, 50% white 50% wholemeal	87.7	202	482	614	204	467	2272	964
Egg fried in Polyunsaturated fat	62	115	420	132	103	56.8	556	1231
Margarine, Flora original	10	40.8	119	91.7	29.2	100	332	750
Sausages, pork, grilled	129	334	1410	416	313	3708	6329	6156
Red smoothie, fruit/juice blend	310	142.6	16906	2119	1274	228	1290	473
Total taste amount:			**13302**	**13708**	**1610**	**5456**	**12478**	**9804**
C)	**Grams**	**Calories**	**Taste density (score g/ kcal)**					
			Sweet	**Sour**	**Bitter**	**Umami**	**Salt**	**Fat**
Bread, 50% white 50% wholemeal	87.7	202	2.39	3.04	1.01	2.31	11.2	4.77
Egg fried in Polyunsaturated fat	62	115	3.65	1.15	0.90	0.49	4.84	10.7
Margarine, Flora original	10	40.8	2.92	2.25	0.72	2.47	8.13	18.4
Sausages, pork, grilled	129	334	4.21	1.25	0.94	11.1	18.9	18.4
Red smoothie, fruit/juice blend	310	142.6	76.3	87.3	6.73	7.88	21.0	4.93
Total taste density:			**89.4**	**95.0**	**10.3**	**24.3**	**64.1**	**57.2**

The two examples demonstrated that taste amount reflects the intensity of each taste experienced from an entire meal, regardless of the energy density of each food. On the other hand, taste density reflects the average intensity of each taste experienced per calorie of a meal. However, taste density requires that every food in a meal has at least one calorie. For instance, if the tea in breakfast 1 was consumed without sugar, it would not have been possible to calculate its taste density (6200 divided by 0 is undefined) and subsequently, total taste density. Therefore, taste density is limited in its utility to characterise taste in dietary patterns and was excluded from subsequent analyses.

The taste amount for each taste and mouthfeel from the whole diet was compared between male and female adults (Figure 6.4A). Total umami, salt and fat taste amounts were largely contributed by foods compared to beverages only (Figure 6.4B), while total sweet, sour and bitter taste amounts were largely contributed by beverages compared to foods only (Figure 6.5C).

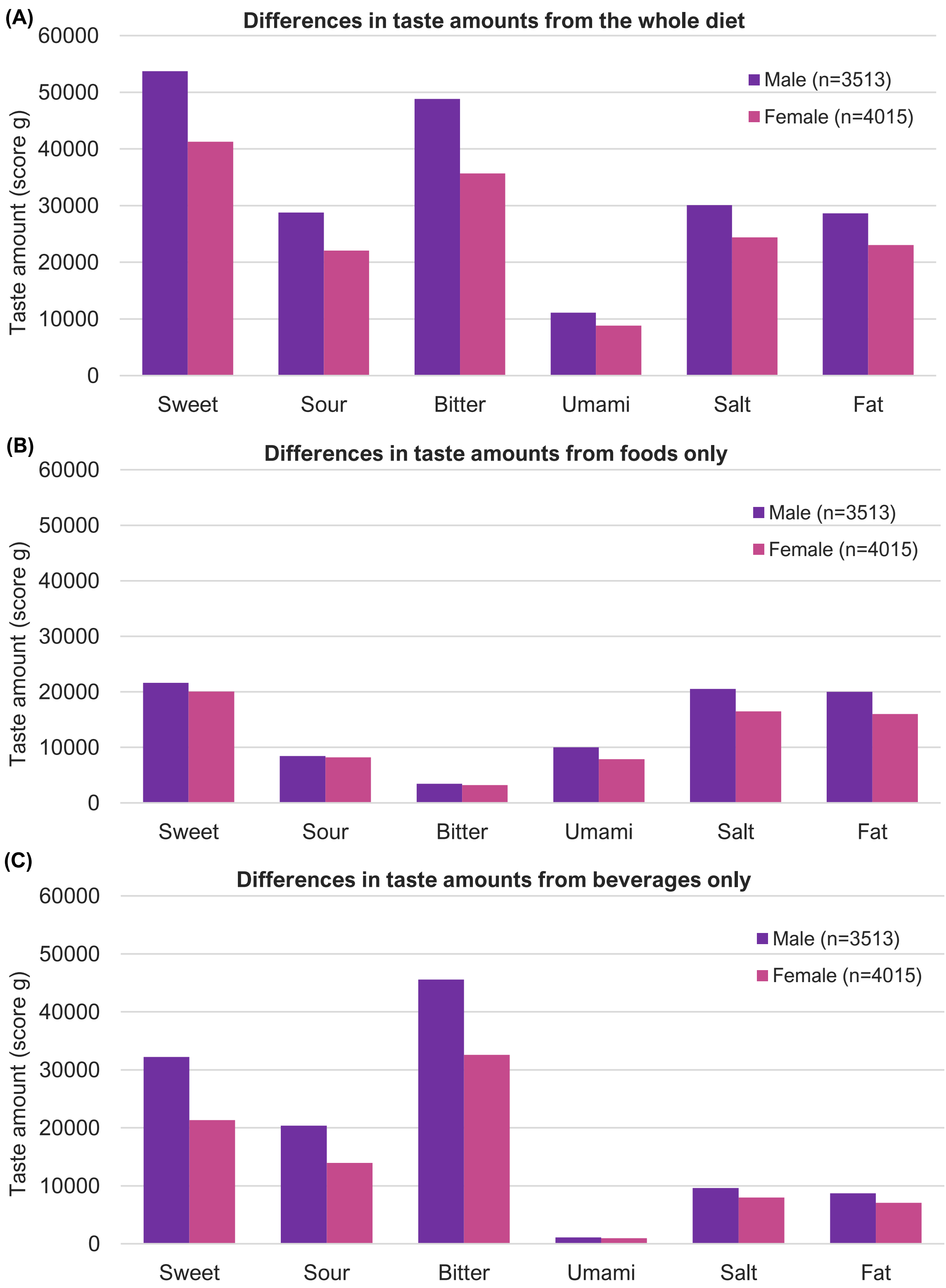

Figure 6.4. Sex differences in taste amounts from (A) whole diet, (B) food, and (C) beverage only.

6.4.3. Taste exposure

The third method was to use the taste amount obtained in the previous method and multiply it by consumption duration, to calculate taste exposure. Similar to taste amount and taste density, an average could also be taken at a population level to assess the contribution of each taste exposure in relation to other tastes.

6.4.3.1. Methods and analysis

All foods were assigned to a texture category, either liquid, semi-solid, soft-solid or hard-solid, based on previous definitions (Stieger & Van de Velde, 2013) as well as tested eating rates from the Eating Rate Database (van den Boer, Werts, et al., 2017). A secondary researcher independently assigned 10% of the foods as validation and any disagreements were discussed and resolved. Any adjustments were made to the whole dataset. Consequently, a standard for evaluating eating rate categories was developed and can be found in Appendix 12. Each food then received the average eating rate of its assigned category, e.g., 24101056: Potato, peeled, boiled, microwaved or steamed, drained – soft-solid – estimated eating rate of 30 g/min.

Taste exposure was calculated per food by multiplying the taste amount (score g) with the average duration taken to eat the food (min). The taste amounts from each food were taken from section 6.4.2, while the eating duration was taken from the averaged eating rate of its assigned category. An example focused on sweet taste exposure is shown in Table 6.9.

Taste exposure was then summed up for each dietary recall day, averaged to obtain the taste exposure for each participant, and averaged again on a population. The magnitude of each taste exposure was also calculated as a percentage of total taste exposure and averaged on a population. Both magnitude and percentage were compared between male and female adults. All analyses were performed using R statistical software and its relevant packages (Allaire et al., 2017; Kassambara, 2020, 2021; Kassambara & Mundt, 2020; R Core Team, 2020; Wickham et al., 2019).

Table 6.9. Examples of sweet taste exposure across foods in different eating rate categories.

	Milk chocolate bar	**Chocolate mousse**	**Chocolate custard**	**Chocolate milk**
Category	Solid	Soft-solid	Semi-solid	Liquid
Consumed quantity (grams)	100	100	100	100
Consumed energy (kcal)	548	182	100	89
Eating duration (min)	4.9	2.3	0.8	0.2
Sweet taste intensity (score)	55	46	34	37
Sweet taste amount (score g)	5500	4600	3400	3700
Sweet taste exposure (score g min)	26950	10580	2720	740

6.4.3.2. Results

Most foods from the consumption data were assigned to the soft-solid category, with 2062 foods (45.4%). This was followed by the hard-solid category with 1670 foods (36.7%), the liquid category with 479 foods (10.5%) and lastly, the semi-solid category with 334 foods (7.3%).

The resultant taste exposure for each taste and mouthfeel from the diets of male and female adults are presented in Figure 6.5A, and their percentages of total taste exposure are presented in Figure 6.5B. Male adults had greater taste exposures from the diet than female adults across all tastes and mouthfeel in absolute magnitude. However, the percentage of total taste exposure from sweet, umami, salt and fat taste exposure were higher for female adults than for male adults. Male adults had a higher percentage of their total taste exposure from bitter taste exposure, and both sexes had similar sour taste exposure to total taste exposure.

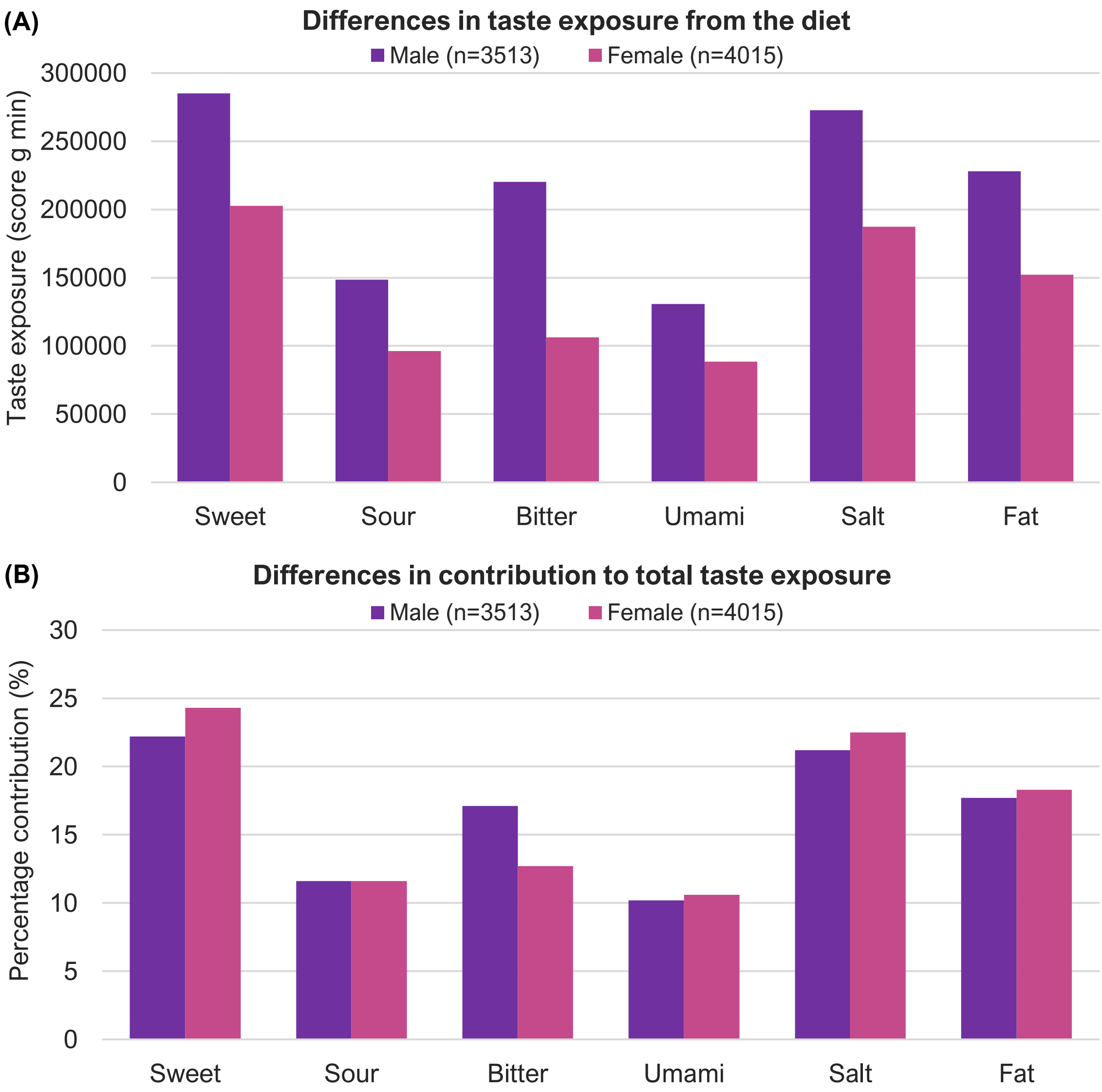

Figure 6.5. Sex differences in (A) their taste exposures from the diet and (B) their percentage contributions to total taste exposure.

6.4.4. Interim discussion

Hierarchical cluster analysis allowed for tastes to combine in a cluster, which could aptly describe dietary patterns of a population by informing on the taste combinations prominent in that diet, and how much each taste cluster contributes to total energy intake. At the same time, since cluster formation is dependent on the sample population, comparison across diets is not possible. Taste amounts informed on the intensity of each taste exposed in the diet regardless of energy density of the foods. However, differences between foods and beverages of different consumption rates could not be captured. Taste density informed on the average intensity of each taste experienced per calorie of a meal. However, it requires that every food in a meal has at least one calorie. Adding on to taste amounts, taste exposures could take into account both the intensity and the duration of each taste intensity experienced during consumption. This allowed for calculations of the absolute magnitude and percentage contribution of each taste exposure, which then characterises the dietary taste patterns of a population and creates the possibility of assessing health outcomes or nutrient intakes alongside taste exposure.

Therefore, both cluster and taste exposure were decided as suitable methods for the second step of characterising dietary taste patterns, providing both descriptions and comparisons. The strengths and limitations of each method for this step is summarised in Table 6.10.

Table 6.10. Strengths (+) and limitations (-) of each method for step 2.

	Cluster	Taste amount	Taste density	Taste exposure
<u>Step 2:</u> Contribution of each taste to the diet	+ Dominant taste combinations - Sample-specific - Comparison requires cluster formation on all diets together i.e., not feasible	+ Intensity of taste exposed during eating + Regardless of energy density + Comparison is feasible - Duration of taste exposed not captured	+ Role of each taste in a standard amount of diet + Comparison is feasible - Undefined for foods with 0kcal	+ Intensity and duration of taste exposed during eating + Absolute values and patterns of dietary taste + Comparison is feasible - Estimation of eating durations

6.5. Discussion

This chapter aimed to present suitable and feasible approaches to characterise taste in dietary patterns, with the consideration of comparing dietary taste patterns of different populations in future work. The endeavour to characterise taste exposure in dietary taste patterns was split into two steps. The first step was the assignment of taste values from the taste database to untested foods. Best match was used as the reference against two measures of central tendency, group mean and group median. Best match provided item-specificity and variation, but was time-consuming, expensive and similar to taking a measure of central tendency if only one food was tested in a (sub-)group. Group mean resulted in smaller differences from best match than group median did and thus, was the most feasible way to assign values from a taste database to food intake data of different diets and/or populations. The second step was the assessment of contribution of each taste to the diet. Cluster formation was sample-specific, which could describe the dominant taste combinations but could not be compared across diets and/or populations. Taste amount revealed the intensity of taste exposed during consumption, regardless of energy density, but the duration of consumption was not captured. Taste density provided the intensity of taste exposed in a standard amount of diet (per calorie) but could not be computed when there were foods with zero energy density. Finally, taste exposure combined both intensity and duration aspects of exposure during consumption. Although eating durations were only estimated, taste exposure could provide the absolute magnitude and the patterns of dietary taste. These dietary taste exposures and patterns can then be characterised and compared across diets.

The difficulties and resources involved in the creation of taste databases have been described in the introduction. It may be challenging to have taste databases of all foods consumed and across different diets. Therefore, a suitable assignment method would result in a taste profile of each untested food in the consumption records as close to the ‘actual’ profile as possible (had it been rated by a trained panel) and would be feasible to perform in different diets and/or populations.
Despite the best match method being item-specific and decided by experts in nutrition or sensory fields, it is not practical in terms of continually best-matching each food in different populations where experts are unavailable. It also systematically assigned smaller values, which may potentially add to underestimation in nutrition research (section 6.3.3). On the other hand, taking a measure of central tendency of each food (sub-)group would be more feasible and group mean appears to perform better than group median (section 6.3.3). For future cross-population comparisons on a diet without its own taste database (i.e. a diet that needs to receive taste values from another taste database; a recipient diet), an available taste database (Lease et al., 2016; Mars et al., 2020; Martin et al., 2014; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018) may be chosen as the most suitable based on eating habits or culture. Foods from the taste database could be paired with the same or similar food in the recipient diet. Following that, group

means could be calculated per (sub-)group and assigned to the rest of the foods within each sub-group. Subsequently, the recipient diet could be characterised for its taste patterns.

In assessing the contribution of each taste to the diet, the cluster method has been useful in deducing which tastes and taste combinations are prevalent in a diet, informing their prevalence in terms of caloric contribution (Teo et al., 2022; Teo, van Langeveld, de Graaf, et al., 2018; van Langeveld et al., 2018). Teo and colleagues (2018) reported that male adults in both Malaysia and the Netherlands consumed more energy from ‘Savoury and Fatty’ cluster than female adults did. However, exact comparisons could not be made because each cluster formation on the foods was country-specific. The diet of Malaysia resulted in five clusters, while that of the Netherlands resulted in six clusters. Moreover, the presence of a similar cluster might still be different in its intensity values. In other words, the average intensities representing the ‘Savoury and Fatty’ cluster in Malaysia might be different from those representing the ‘Savoury and Fatty’ cluster in the Netherlands. Including more diets and/or populations for comparisons would cause even more confusion and problems, such as the sixth cluster of the Netherlands not having a counterpart to compare with. A potential solution would be to perform cluster analysis on all consumed foods across the diets and/or populations. This would then create standardised taste clusters and subsequent comparisons could be made. Nonetheless, it would be impractical to redo cluster analyses each time a new diet and/or country is included. Therefore, the value of this method is limited to descriptions, and not comparisons, of diets and/or populations.

In their attempt to resolve null calorie components in the taste density equation, Cox and colleagues (2018) assigned non-caloric foods with one kilojoule per hundred grams as their energy density. However, doing this changes the apparent contribution of taste to the diet as a whole. It is an arbitrarily chosen value and assigning another energy density value may drastically change the resultant density of each taste. Moreover, including energy density in the equation of assessing contribution of taste to the diet may reduce its suitability in describing dietary taste patterns and taste exposure. As demonstrated in the two breakfast examples (Table 6.7 and 6.8), the red smoothie was more sweet and sour than the tea with sugar, but its taste density did not reflect this due to its higher energy density than tea with sugar. It is evident that taste density is unsuitable for the current intended research direction.

Taste amount was helpful in assessing the contribution by each taste to the diet, but only regarding the intensity of taste exposed during consumption. It accounted for consumed quantity but was lacking in the duration of which the quantity was consumed. Regarding this aspect of taste exposure, duration is largely determined by food texture (de Graaf, 2012; Lasschuijt et al., 2021). As such, an average eating rate per texture category was calculated based on the Eating Rate Database (van den Boer, Werts, et al., 2017) in this study, and assigned to foods in the consumption data. In the literature, there are several smaller databases of foods and their eating rates (Forde et al., 2013, 2017; Viskaal-van Dongen et al., 2011). Hardness ratings in taste databases may also be proxy representations of food texture and eating rate (Forde et al., 2013; Lease et al., 2016). This increases the feasibility and ease in which taste exposure may be quantified in diets and/or populations.

There are several important limitations of this study that deserve consideration. Firstly, individual variations exist in taste perceptions and taste preferences (Cicerale et al., 2012; Jayasinghe et al., 2017; Kato & Roth, 2012; Lim et al., 2008; Pangborn, 1970; Reed & McDaniel, 2006). The intensity values rated by the trained sensory panellists may not have reflected actual taste intensities experienced by some individuals, and the standard preparation methods of tested foods may not have matched the methods by consumers. Moreover, individual variations also exist in rate of eating (Fogel et al., 2017, 2018; Lasschuijt et al., 2021; van den Boer, Kranendonk, et al., 2017), and foods are eaten with wide variations in rates (Forde et al., 2017; van den Boer, Werts, et al., 2017; Viskaal-van Dongen et al., 2011). The simplified method of estimating eating duration using average eating rates of four texture categories may be practical but limited in its accuracy. An individual who drank a chocolate milk slowly would have had a longer experience of each taste intensity as compared to an individual who drank it quickly, but this would not be captured in the current method. The quantification of taste exposure also did not account for the duration of aftertaste of any foods (Suwonsichon, 2019). Nonetheless, the perception of aftertaste was found to only prolong activation in certain brain regions and not others (James et al., 2009), and it is challenging to measure a range of eating rates and their aftertaste duration for all foods in the diet. The current method still provides an average magnitude of taste exposure experienced by the population.

Another shortcoming of this study is the use of 24-h dietary recalls as the consumption data. This method is prone to mis-reporting of foods and portion sizes, including omitting, under-reporting or over-reporting (Jones et al., 2021; Whybrow et al., 2020), which may reduce the accuracy of quantifying dietary taste of the population. Future work should consider study population(s) with both 24-h dietary recalls and weighed food records, to perform a sensitivity analysis. At the same time, the 24-h dietary recall method is frequently used for nation-wide consumption surveys, as it is still relatively accurate given its practicality in data collection. Notwithstanding the limitations of this study, the work presented in this chapter still provide potential next steps to assess and compare taste exposures in dietary taste patterns across diets and/or countries.

6.6. Conclusion

This chapter provided approaches that may successfully characterise taste exposure in dietary taste patterns, in order to compare these patterns across diets of different populations. Various methods were tried and evaluated against each other in terms of their suitability in describing dietary taste patterns and taste exposure, feasibility to execute across diets and/or populations and ease to be interpreted. Group mean was selected as the method to achieve the first step of assigning taste values from the taste database to untested foods, as it was most feasible and efficient to be performed across diets and/or populations and had the least differences from best matched values. Cluster and taste exposure were selected as complementary methods to achieve the second step, which is to characterise dietary taste patterns. Cluster may inform on the dominant taste combinations of a diet and how they contribute to energy intake within one diet and or/population, while taste exposure may inform on the exposure of each taste during consumption and enable various comparisons across diets and/or populations. Altogether, these approaches present the possibility to assess dietary taste patterns within countries (cluster) and compare taste exposures in dietary taste patterns across countries (taste exposure). This possibility should be explored and utilised in order to clarify the role of taste in the associations between dietary patterns and health outcomes.

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7. Sweet Spot II: Characterisation and comparison of dietary taste exposure and patterns in Australia, France, the Netherlands, the United Kingdom and the United States

7.1. Introduction

Chapter 1 of this thesis explained the importance of studying dietary patterns from a taste perspective and reviewed the literature on dietary taste patterns and their methodological differences or limitations across research. The characterisation of dietary taste exposure and patterns has two steps – first is the assignment of sweet, sour, bitter, umami, salt taste and fatty mouthfeel intensity values from tested to untested foods; second is the quantification of each taste exposure from a diet. Different methods for both steps were explored and assessed on their suitability and feasibility, also to compare across diets and/or populations (Chapter 6). The analyses showed that group mean was the most feasible method for the first step to be performed across populations, and that cluster and taste exposure are complementary methods for the second step. Cluster makes it possible to discover dominant taste combinations and their contribution to energy intake, while taste exposure quantifies the exact exposure of each taste during consumption and their relative contributions to energy intake and enables comparisons across populations.

This chapter aimed to employ these methods to characterise and compare dietary taste exposure of different countries. While dietary taste patterns have been explored in four nationally-representative diets (Cox, Hendrie, Lease, et al., 2018; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018; van Langeveld et al., 2018), comparisons have been difficult due to their differences in methodology and interpretation (Chapters 1 and 6). Additionally, these studies focused on the quality (sweet, sour, bitter, umami, salt and fat) and intensity (not at all to extremely) aspects of taste. The magnitude of taste exposure is also determined by the duration of taste experienced in the oral cavity during food consumption, which is driven by oral processing and eating rate (de Graaf, 2012). Given their potential impacts on satiation and food intake (Lasschuijt et al., 2021), the intensity and duration of different taste qualities should be studied together in the diet. Taste exposure, considering both aspects, has been found to affect satiation and food intake in individuals in the same way, but with different effect sizes between population groups (Hogenkamp et al., 2011; Ketel et al., 2019; Mars et al., 2009; Stribiţcaia et al., 2020). It is of value to better understand how dietary taste exposure varies across population groups.

In this chapter and thesis, dietary taste exposure is defined as the absolute magnitude of a taste exposed during consumption in the diet, while dietary taste pattern is defined as a dietary taste exposure relative to other taste exposures or the total dietary taste exposure, as a percentage.

For example, sweet taste exposure of a diet may be $60x10^3$ score g min; while the sweet taste pattern is 24% of total taste exposure in the diet.

Sweet taste preferences have been found to peak at early adolescence and decrease throughout adulthood (Chapter 1). Moreover, taste perception decreases with age and the prevalence of diminished or distorted taste perception increases significantly above the age of 65 years (Barragán et al., 2018; Schiffman, 2009). Therefore, the current work focused on the diets of adults aged 18 to 65 years. Since sweet taste exposure has been assumed to be associated with sweet taste preference and dietary sugars intake (Pan American Health Organisation, 2016; Public Health England, 2018a; Tedstone et al., 2015; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016), dietary taste exposures could perhaps differ across countries varying in their total sugars intakes. It would be of interest and value to investigate dietary taste exposure and patterns of countries with lower sugar purchase per capita per day and compare them with those of countries with higher sugar purchase per capita.

The current study aimed to characterise and compare the dietary taste exposures and patterns of Australia, France, the Netherlands, the United Kingdom and the United States.

7.2. Methods

Accounting for the availability of consumption and taste data, the US with highest sugar purchased per capita per day (126.5 grams), the Netherlands (102.5 grams), Australia (95.6 grams), the UK (93.2 grams) and France (68.5 grams) were shortlisted as the countries to compare in this work (Ferdman, 2015). The taste databases of Australia (Lease et al., 2016), France (Martin et al., 2014) and the Netherlands (Mars et al., 2020), as well as the eating rate with texture database from the Netherlands (van den Boer, Werts, et al., 2017) were used to achieve the aims of this chapter.

7.2.1. Taste databases and assignment

7.2.1.1. Australia

The taste and mouthfeel intensity values of frequently consumed foods in Australia were taken from the Sensory-Diet Database (Lease et al., 2016), as described in detail in Chapter 6.2.1. This database was applied to the consumption data of Australia. It was also applied to the UK and the US due to similarities in food intake and culture. Firstly, foods from the database were paired with equivalent or similar foods based on food descriptions in the food composition databases of the two countries – the UK Nutrient Databank and US Food and Nutrient Database for Dietary Studies (FNDDS). The paired foods received their corresponding taste and mouthfeel intensity values. These values were averaged per Nutrient Databank subsidiary food group or per What We Eat in America (WWEIA) category group and assigned to the remaining foods within each group.

7.2.1.2. France

The French food taste database was created by The Centre for Taste and Feeding Behaviour (Martin et al., 2014), consisting of 590 foods consumed by experienced sensory panellists living in France. The sweet, sour, bitter, umami, salt taste, and fatty mouthfeel of these foods were rated by the same group of trained panellists (n=12) (Martin et al., 2014) using modified Spectrum™ scales of 0 to 100mm (Civille & Carr, 2015; Meilgaard et al., 2007). The reference solutions and products for each taste and mouthfeel can be found in Appendix 13. After training in the laboratory, panellists prepared each test food and evaluated their taste and mouthfeel at home. Panellists were required to include a variety of foods and evaluate at least 75 foods every month. Tasting notebooks were provided to the panellists to record their ratings, method of preparation, seasoning, ingredients, and any additional information at the point of consumption. Panellists were also retrained every month at the laboratory. A set of control foods were given to the panellists for evaluation every month, to be prepared according to their product packaging. These evaluations were compared with the laboratory results to check for quality control of at-home evaluations. This database was applied to French consumption data by pairing foods from the taste databases to equivalent or similar foods in the French food composition database, assigning them the corresponding taste and mouthfeel intensity values and averaging them in each (sub-)group of the database to assign to the remaining foods within each (sub-)group.

7.2.1.3. The Netherlands

The Taste, Fat and Texture (TFT) Database is a publicly available sensory database created by Wageningen University and Research (Mars et al., 2020), consisting of 627 frequently consumed foods in the Netherlands that also contributed most to energy intake variation, and their sweet, sour, bitter, umami, salt taste and fatty mouthfeel values. These values were rated by a trained sensory panel (n=15) (Teo, van Langeveld, Pol, Siebelink, de Graaf, Martin, et al., 2018), using modified Spectrum™ scales of 0 to 100mm (Civille & Carr, 2015; Martin et al., 2014). The reference solutions and products for each taste and mouthfeel can be found in Appendix 13. All foods were prepared according to their product packaging or to the normal household practice (van Langeveld et al., 2018). Serving temperatures ranged from -18°C for frozen desserts, to 22°C for foods eaten at room temperature, and up to 65°C for warm drinks and foods. For the purpose of the current study, only foods consumed by the adult population, age 18 to 65 years, were included. For example, baby foods were excluded as they were not present in the consumption records of adults. Moreover, values of food products that were served at different temperatures were averaged. There remained a total of 500 foods. This database was applied to consumption data of the Netherlands by pairing foods from the taste databases to equivalent foods in the food composition database, assigning them the corresponding taste and mouthfeel intensity values and averaging them in each (sub-)group to assign to the remaining foods within each (sub-)group.

7.2.2. Eating rate with texture database

To account for the taste duration component of taste exposure, eating duration of foods were estimated with the Eating Rate Database (van den Boer, Werts, et al., 2017) which has been described in detail in Chapter 6.2.2. All foods recorded across all countries were assigned to a texture category with a corresponding average eating rate: liquid (306 ± 177 g/min), semi-solid (63 ± 50 g/min), soft-solid (30 ± 16 g/min) or hard-solid (19 ± 15 g/min). This was performed using the standard that was developed in the previous chapter (Appendix 12). A secondary researcher independently assigned 10% of the foods as validation and all differences were resolved.

7.2.3. Consumption data

7.2.3.1. Australia (AU)

The nationally representative consumption survey of Australia, National Nutrition and Physical Activity Survey (NNPAS) 2011 to 2012, has been described in detail in Chapter 6.2.3.

7.2.3.2. France (FR)

The third French Individual and National Food Consumption Survey (INCA3) 2014 to 2015 included children and adults aged 1 month to 79 years, living in mainland France excluding Corsica. A three-stage cluster sampling design was applied to select participants – geographical units, households and individuals, stratified by geographical region and size of urban area to ensure national representativeness. The collection of food consumption data followed the guidelines of the European Food Safety Authority (European Food Safety Authority, 2009). Three non-consecutive 24-hour dietary recalls were conducted per person over three weeks, and over all four seasons at a population level. The dietary recalls were performed by trained professional interviewers and dieticians over the telephone, using the computer-directed interview programme, GloboDiet (IARC©). A total of 4460 persons completed at least two dietary interviews, including 2275 adults of ages 18 to 79 years old (Dubuisson et al., 2017). Energy intakes were calculated using the GloboDiet software and each food has a unique food code (FoodEx2 code) alongside a Globodiet group. The height and weight of each participant were measured during one home visit. The ages of participants were not recorded but classified into nine age groups. As a result, the current study could only include the adult population of age 18 to 64 years, totalling 1610 adults.

7.2.3.3. The Netherlands (NL)

The Dutch National Food Consumption Survey 2012 to 2016 included children and adults aged 1 to 79 years, living in the Netherlands. It was stratified by age and gender, representative of different regions, degree of urbanisation and education level, and only one person per household were permitted to participate. The collection of food consumption data followed the guidelines of the European Food Safety Authority (European Food Safety Authority, 2009). A total of 4313 persons completed the data collection, including 1540 adults of ages 18 to 69 years (van Rossum et al., 2020). Two non-consecutive 24-hour dietary recalls were conducted and at a population level, spread over all days of the week and the four seasons. The dietary recalls were performed by trained dieticians using a computer-directed interview programme, GloboDiet (IARC©). Energy intakes were calculated using the Dutch Food Composition Database (NEVO) and each food has a unique food code (nevocode) alongside a GloboDiet group. During the dietary recalls, height and weight of participants were self-reported to the dieticians. The average weight and height of both days were calculated. For the purpose of the current study, only the adult population of age 18 to 65 years was included. This resulted in 1508 adults.

7.2.3.4. The United Kingdom (UK)

The combined seventh and eighth waves of the nationally representative consumption survey of the UK, the National Diet and Nutrition Survey (NDNS) 2014 to 2016, included children and adults aged 1.5 and above, living in the UK. It was stratified by age and representative of all four countries. Each participant filled in a food and drink diary developed by National Centre for Social Research and Medical Research Council Human Nutrition Research (UK Data Archive, 2014); for four consecutive days, and at a population level, began on a randomly allocated date, spread over all days of the week and the four seasons. The dietary diary included detailed instructions, examples, practice pages, advice on food descriptions, pictures for food and drink portion/ volume/ spoon size, four days of diary and general questions about the diet. A total of 2723 persons completed at least three dietary interviews, including 1417 adults of aged 19 and above (Public Health England, 2016). Energy intakes were calculated using the UK Nutrient Databank and each food has a unique food code (NDNS FoodNumber) alongside a main and a subsidiary food group code. The height and weight of each participant were measured during one home visit. For the purpose of this study, only the adult population of age 18 to 65 years was included, totalling 1172 adults.

7.2.3.5. The United States (US)

The ninth nationally representative consumption survey of the US, National Health and Nutrition Examination Survey (NHANES) 2015 to 2016, included children and adults of all ages, living in the US. A four-stage cluster sampling design was applied to select participants – counties, census blocks, households and individuals, ensuring national representativeness of all counties, income, race and ethnic groups (Chen et al., 2020). Two non-consecutive 24-hour dietary recalls were conducted per person and at a population level, over all four seasons. The dietary recalls were performed in-person for the first day, and over the telephone on the second day, both using a computerised software developed by the US Department of Agriculture. A total of 7027 persons completed both dietary interviews (National Center for Health Statistics, 2018). Energy intakes were calculated using the FNDDS and each food has a unique food code (FNDDS Foodcode) alongside a What We Eat in America (WWEIA) category group. The height and weight of each participant were measured during the in-person visit. For the purpose of the current study, only the adult population of age 18 to 65 years was included. This resulted in 4140 adults.

The characteristics of participants in all five national consumption surveys are summarised in Table 7.1. Notably, all national consumption surveys included pregnant women, smokers, individuals with excess alcoholic intake and individuals with health conditions, all of whom may have altered taste perceptions (Duffy, 2020; Duffy et al., 2019; Kullakçi & Sonkaya, 2021; Ng et al., 2019; Silva et al., 2016; Sizer et al., 2022). This, alongside unknown factors in population-wide surveys, may have an effect on the average dietary taste exposures of the population. Nonetheless, these considerations were discussed in section 7.4.

Table 7.1. Participant characteristics from the national consumption surveys.

	AU	**FR**	**NL**	**UK**	**US**
No. of adults	7528	1610	1508	1172	4140
Sex	3513 M, 4015 F	670 M, 940 F	744 M, 764 F	498 M, 674 F	1990 M, 2150 F
BMI, kg/m^2	27.4 ± 5.6	25.4 ± 4.7	26.0 ± 9.0	27.3 ± 5.5	29.1 ± 8.0
Age, years	42.2 ± 13.0	[1]18-44: n=780 45-64: n=830	39.3 ± 14.5	41.6 ± 13.6	41.1 ± 14.0

[1]The ages of participants in the third French Individual and National Food Consumption Survey were only recorded in age groups instead of exact age in years. AU: Australia. FR: France. NL: the Netherlands. UK: the United Kingdom. US: the United States. BMI: Body Mass Index. M: Male. F: Female.

7.2.4. Data processing and analysis

The current analysis followed the same steps detailed in Chapter 6.3.1. to combine separately recorded food entries in the consumption data that were meant to be single food items, also to assign values from the respective taste databases to food intake records of each country. Since alcohol, sweetened coffee and sweetened tea were not tested in the Australian taste database, the values of these items were taken from the Dutch TFT Database and applied to the consumption data of Australia, the UK and the US. Similarly, as coffee sweetened with sweeteners were not tested in the French taste database, the values of these items were also taken from the Dutch TFT Database and applied to the French consumption data.

To characterise dietary taste patterns with the cluster and taste exposure methods, the current analysis took the same steps detailed in Chapter 6.4.1 and 6.4.3. respectively. Since cluster formation is dependent on the sample population, cluster comparison across the countries was not possible (Chapter 6.4.4). To investigate dietary intake in both grams and calories across the countries, two basic linear model analyses were performed, adjusting for Body Mass Index (BMI) and sex which have been found to influence dietary intake (Meiselman Editor, 2020). To compare the absolute values of each and total dietary taste exposure across countries, separate basic linear model analyses were performed for sweet, sour, bitter, umami, salt, fat and total exposure. Each model was adjusted for BMI, sex, consumed grams and calories to control for these factors that may influence intake (Meiselman Editor, 2020). Age was not included as it was not recorded in INCA3. To observe and compare dietary taste exposure patterns, the percentage contribution of each taste exposure to total taste exposure was calculated at the country level. Similarly, separate basic linear models were performed for sweet, sour, bitter, umami, salt and fat percentage contribution to total exposure per country, and each were adjusted for BMI, sex, consumed grams and energy intake. Within every model, statistically defined outliers were removed and Bonferroni-corrected post-hoc analysis was performed to assess differences between each pair of countries.

All analyses were performed using R statistical software (version 4.0.2) and its relevant packages (Allaire et al., 2017; Datta & Love, 2018; Kassambara, 2020, 2021; Kassambara & Mundt, 2020; Maechler et al., 2019; R Core Team, 2020; Wickham et al., 2019).

7.3. Results

All five countries had the largest proportion of their consumed foods assigned to the soft-solid category (36.1-52.7%) and the least number of their consumed foods assigned to the semi-solid category, except for France, whose diet had the least number of consumed foods assigned to the liquid category (Table 7.2).

Table 7.2. Percentage (and number) of foods in each texture category across the countries.

	AU	FR	NL	UK	US
Liquid	10.5 *(479)*	9.9 *(1706)*	16.9 *(314)*	11.0 *(304)*	9.1 *(440)*
Semi-solid	7.3 *(334)*	14.7 *(2531)*	12.9 *(241)*	10.2 *(282)*	6.6 *(321)*
Soft-solid	45.4 *(2062)*	48.1 *(8299)*	36.1 *(673)*	41.7 *(1154)*	52.7 *(2554)*
Hard-solid	36.7 *(1670)*	27.4 *(4725)*	34.1 *(635)*	37.1 *(1025)*	31.6 *(1535)*

AU: Australia. FR: France. NL: the Netherlands. UK: the United Kingdom. US: the United States.

7.3.1. Dietary intake

Australia, France, the Netherlands and the US were similar in average consumed grams, higher than the UK which had the least average consumed grams $F(7,14288) = 651.5$, $p < .001$ (Figure 7.1). The Netherlands had the highest average consumed calories. Australia and the US were again similar in average energy intake, and the UK had the least average energy intake, $F(7,14386) = 887.1$, $p < .001$.

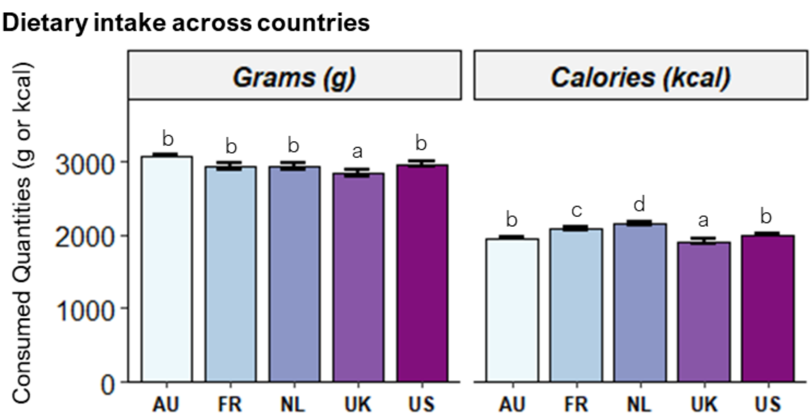

Figure 7.1. Dietary intake from the national diets of Australia (AU), France (FR), the Netherlands (NL), the United Kingdom (UK) and the United States (US) – in grams (g) and calories (kcal). Within grams and within calories, using Bonferroni-correction, bars with different letters are different at $p \leq .05$ and $p \leq .01$ respectively, where 'a' always represents the smallest value.

7.3.2. Dominant taste clusters

The taste clusters of each country and their energy amounts are presented in Figure 7.2 on the right, with similar clusters arranged in rows. 'Bitter' cluster typically consisted of coffee, tea, beers, chocolate and vegetables; while 'Sweet and Sour' consisted of mostly fruit juices and drinks, some wine, salad dressing and pickled items. ‘Salt and Fat’ typically comprised meat, fish, cheese, rice and pasta dishes; while ‘Neutral’ mainly had cereal, bread and some vegetables. ‘Fat’ mainly had butter, oil, some meat and fried dishes; while ‘Sweet’ mainly had fruits, candy, soft drinks, cakes and desserts. ‘Umami, Salt and Fat’ typically consisted of processed meat, some cheese and bread products; while ‘Sweet and Fat’ typically comprised pastries and dairy dessert; and ‘Sour, Salt and Fat’ consisted of some soft cheeses, processed legumes and preserved vegetables.

While clusters and their energy intake contribution should not be compared across the countries directly, the diets of all five countries consisted of a ‘Bitter’ cluster which contributed the least to total energy intake. All countries also had a ‘Sweet and Sour’ cluster and a ‘Salt and Fat’ cluster. ‘Salt and Fat’ cluster contributed the most to total energy intake of Australia, France and the US. The diet from the UK resulted in six clusters similar to that from Australia. The diets of France, the Netherlands and the US resulted in seven clusters, but the ‘Sour, Salt and Fat’ cluster in the French diet was unique and not found in other countries. Further description and the list of food (sub-)groups in each cluster per country is provided in Appendix 14.

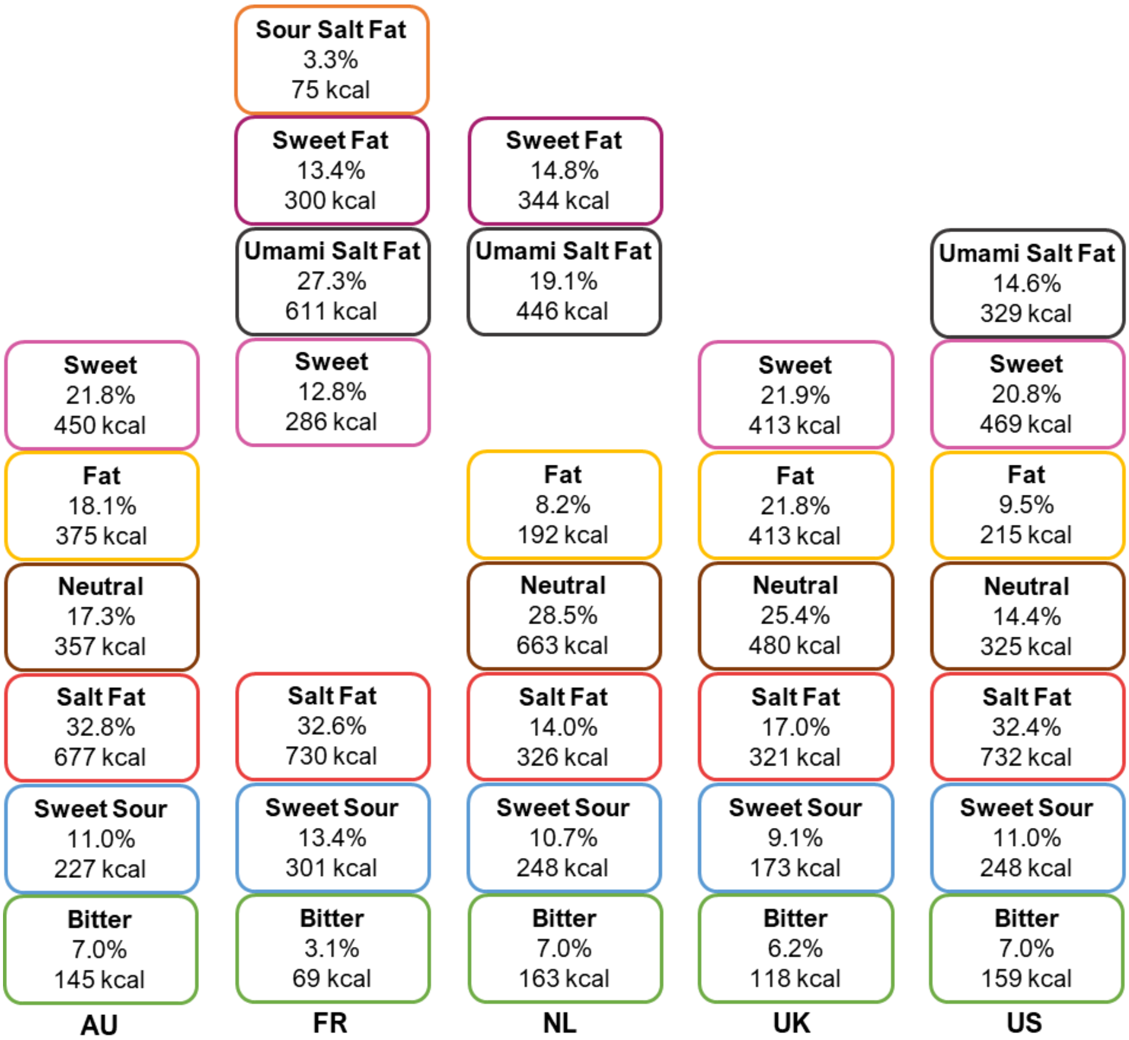

Figure 7.2. Taste clusters, their energy amounts and percentage contributions to diets of Australia (AU), France (FR), the Netherlands (NL), the United Kingdom (UK) and the United States (US).

7.3.3. Dietary taste exposure (patterns)

The dietary taste exposure of each country from each taste and mouthfeel are presented in Figure 7.3A on the right, while the percentage contributions of these exposures to total taste exposure of each country are presented in Figure 7.3B. Within each country, their absolute dietary taste exposures were combined into stacked plots in Figure 7.4A on the next page and their percentage contributions stacked in Figure 7.4B.

Countries differed from each other in their sweet taste exposure, $F(8,13690) = 1507$, $p < .001$. It was lowest in the Netherlands and greatest in Australia. Even though Australia and the US differed significantly in their absolute sweet taste exposure, both had similar percentage contribution to total exposure. The UK had the second lowest absolute sweet taste exposure, but the highest percentage contribution. Sweet taste contributed the most to total exposure in the UK, the US and Australia. Countries differed in their sour taste exposure, $F(8,13733) = 1056$, $p < .001$. Australia and the US were similar in both absolute sour exposure and its contribution to total exposure. French absolute sour taste exposure and its percentage contribution were the highest, while both for the UK were the lowest.

Bitter taste exposure differed between each country, $F(8,13272) = 1482$, $p < .001$. It was the highest in Australia and lowest in the Netherlands. However, both as well as the US had similar percentage contributions to their respective total taste exposures. The UK had the second lowest absolute bitter taste exposure, but the highest percentage contribution to its total exposure. Countries differed in their umami taste exposure, $F(8,13569) = 582.8$, $p < .001$. The US had higher absolute umami exposure and its percentage contribution to total exposure than France, the Netherlands and the UK. For all countries and across the taste exposures, umami taste exposure contributed the least to their respective total taste exposures.

Salt taste exposure differed between countries, $F(8,13696) = 1032$, $p < .001$. Similar to umami, The US had higher absolute salt exposure and its percentage contribution to total exposure than the Netherlands and the UK. French salt taste exposure contributed the most to its total taste exposure. Countries differed in their fatty mouthfeel exposure, $F(8,13743) = 1117$, $p < .001$. Although the Netherlands had the lowest fatty mouthfeel exposure, its fatty mouthfeel contribution to total exposure was the highest. French fatty mouthfeel exposure was the highest, however, its fatty mouthfeel contribution to total exposure was similar to that of the UK.

Countries differed in their total taste exposure, $F(8,14717) = 1372$, $p < .001$. The US and Australia were similar in their total taste exposure and both were higher than the other countries. Total taste exposure from the Dutch diet was the lowest, followed by the UK and France. The exact values of all taste exposures, their percentage contributions and the total dietary taste exposure of the five countries may be referred to in Appendix 15.

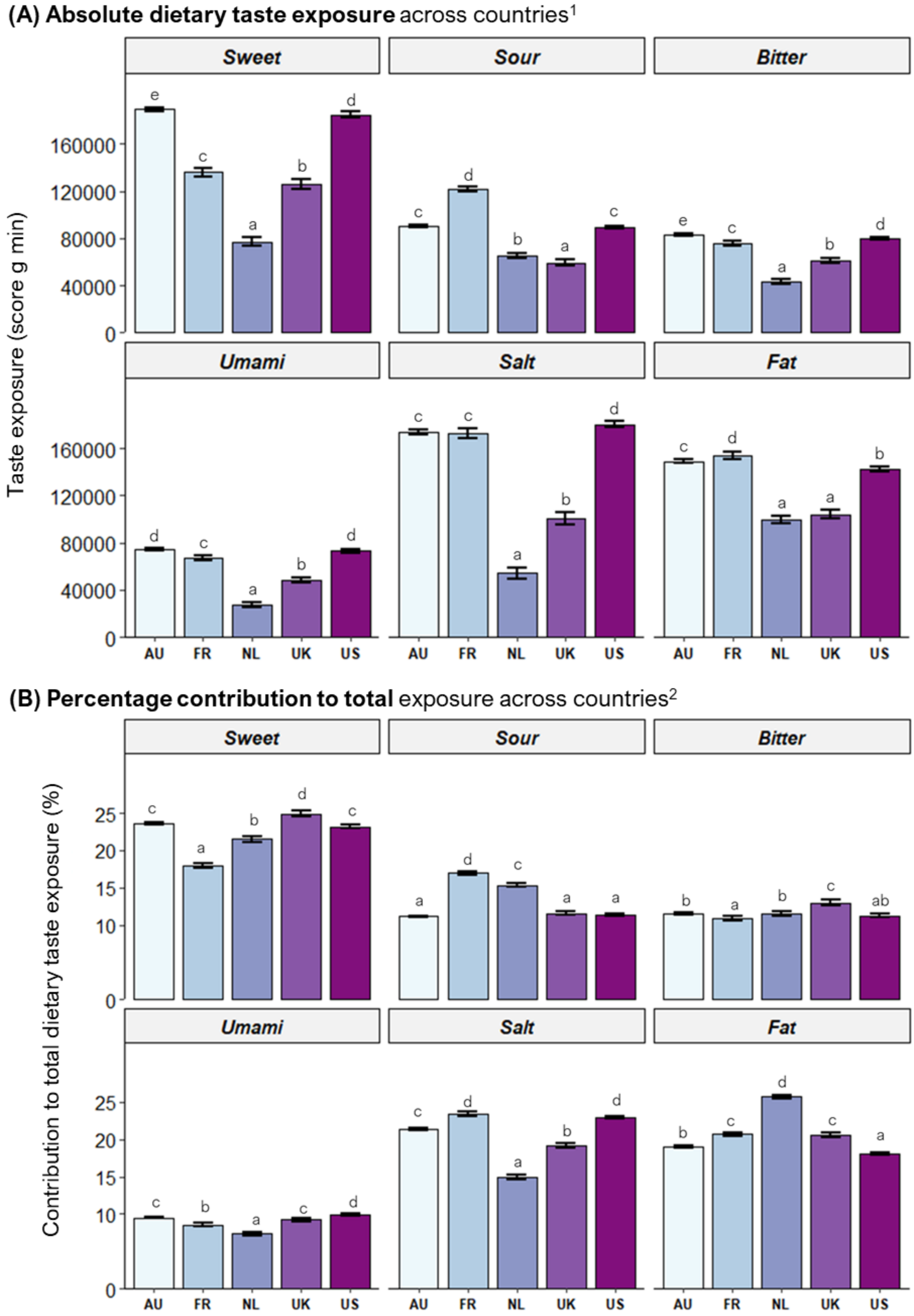

Figure 7.3. Dietary taste exposure in **(A)** absolute values and **(B)** percentage contribution to total exposure for Australia (AU), France (FR), the Netherlands (NL), the United Kingdom (UK) and the United States (US) – by sweet, sour, bitter, umami and salt taste and fatty mouthfeel separately. Within each taste or mouthfeel, using Bonferroni-correction, bars with different letters are significantly different at $^{1}p \leq 0.038$ or $^{2}p \leq .0096$, where ‘a’ always represents the smallest value.

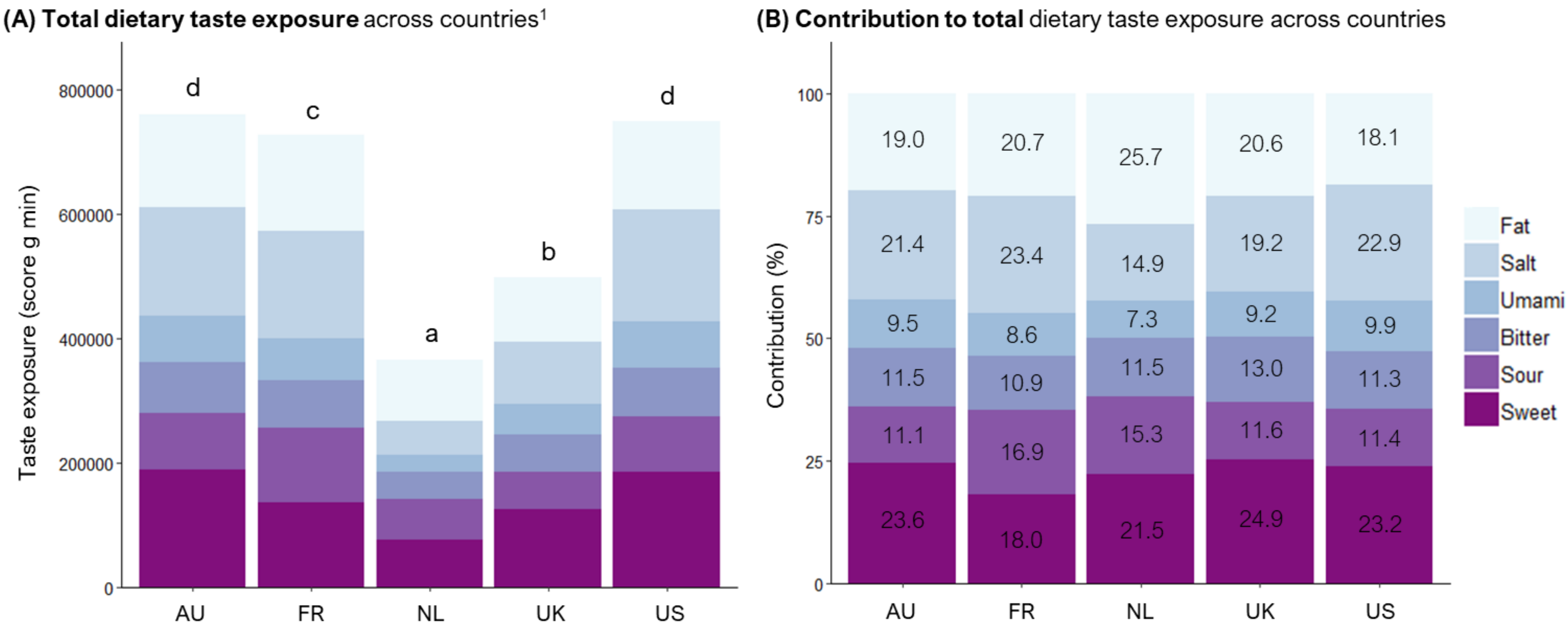

Figure 7.4. Stacked plots from each taste and mouthfeel in **(A)** absolute values and **(B)** percentage contribution to total dietary taste exposure for Australia (AU), France (FR), the Netherlands (NL), the United Kingdom (UK) and the United States (US).

[1]Bars labelled with different letters are different at $p < .001$, using Bonferroni-correction, where 'a' always represents the smallest value.

7.4. Discussion

This chapter characterised and compared the dietary taste exposure and patterns of Australia, France, the Netherlands, the UK and the US, to quantify intensity and duration of different taste qualities together in the diet and compare them across nationally-representative diets. Variations between the five countries were observed in the magnitudes of their dietary taste exposures, and the contributions of these exposures to total taste exposure of the respective countries. Notwithstanding, there were also similar patterns of contributions to total dietary taste exposures. In addition, diets across the countries consisted of different numbers of dominant tastes and taste combinations, although some of them appeared consistently. This novel angle studying dietary patterns revealed differences in taste exposure in different diets.

'Salt and fat' cluster in the Australian diet contributed the most to energy intake (32.8%, 677kcal). This result is in line with previous research on the contribution of different tastes and mouthfeel to dietary energy intake in Australia (Cox, Hendrie, Lease, et al., 2018), where fatty mouthfeel was the strongest predictor of total energy intake (β=0.492, $p < .01$), followed by salt (β=0.16, $p < .01$) and sweet taste (β=0.138, $p < .01$). 'Sweet' cluster in Australia contributed the second most to energy intake (21.8%, 450kcal). At the same time, dietary sweet taste exposure contributed the most (23.6%) to total taste exposure, while dietary salt taste exposure came second with 21.4%. The slight difference between dietary taste contribution to energy intake and to total exposure suggests that dietary taste exposure may not be related to dietary energy intake. Sweet taste exposure may come from both caloric (sugar) and non-caloric (sweeteners) sources, resulting in dissociation between foods' dominant taste(s) and energy or nutrient densities. Indeed, a weaker association between sweet taste and monosaccharide and disaccharide contents was observed in ultra-processed foods, which may be sweet-tasting foods reformulated with sweeteners instead of sugar (Teo et al., 2022). The Australian diet resulted in six clusters, while three of the other countries had seven clusters, and it also did not have a cluster with umami taste. One may conject that this diet lacks strong characteristics that other countries with seven clusters may have. Yet, its umami taste exposure and total dietary taste exposure were similar to that of the US, which had seven clusters, including one with umami taste. Moreover, even though the diet of Australia did not have a 'sweet and fat' cluster, its absolute dietary sweet and fat exposures were high. Taken together, it is evident that cluster (range and dominance of tastes) and taste exposure (intensity and duration of tastes) are different and complementary in the information they provide regarding taste in a diet.

Disregarding energy density and taste exposure duration, researchers reported the amount of sweet taste in the Australian diet as being the highest ($46.1\pm3.0\text{x}10^3$ score g), followed by fatty mouthfeel ($27.9\pm1.4\text{x}10^3$ score g) and salt taste ($24.4\pm1.2\text{x}10^3$ score g) (Cox, Hendrie, Lease, et al., 2018). These were similar to the current findings, except than dietary salt taste exposure was higher than dietary fat taste exposure. This difference could be due to the inclusion of taste duration in the current study. Eating rate is reported to be negatively associated with both salt and fat intensities (van den Boer, Werts, et al., 2017) and the proportion of foods with longer eating rates may differ between foods with high salt intensities and foods with high fat intensities. Out of the top 10% of foods in the Australian taste database with the highest salt taste intensities, none belonged to the liquid texture category, 19 were assigned as semi-solid, 307 as soft-solid and 129 as hard-solid. In contrast, out of the top 10% of foods with the highest fatty mouthfeel intensities, 31 belonged to the liquid texture category, 38 were assigned as semi-solid, 293 were soft-solid and 93 were hard-solid. There were indeed more salty foods in the soft- or hard-solid categories and more fatty foods in the liquid or semi-solid categories. This likely resulted in longer and shorter taste durations of the foods respectively, and consequently, in the taste exposure differences.

Dietary taste patterns of the Dutch diet have previously been investigated based on the previous Dutch National Food Consumption Survey 2007 to 2010, using the cluster method (van Langeveld et al., 2018). The study discovered six clusters of dominant tastes and taste combinations, while the current study discovered seven clusters. 'Salt and fat' cluster appeared as the seventh cluster, contributing to 14.0% of dietary energy intake. This likely came from reduced energy intake from 'sweet and fat' cluster (23.0% to 14.8%), 'sweet and sour' (14.0% to 10.7%) and 'umami, salt and fat' cluster (24.0% to 19.1%), although energy intake from 'neutral' (27.0% to 28.5%) and 'bitter' cluster (4.0% to 7.0%) also increased slightly. These findings suggest that the Dutch diet shifted from a more sweet-dominant diet to a more salty and fatty-dominant diet. The prevalence of fatty mouthfeel in the Dutch diet was also reflected in the dietary taste exposure results. Amongst all taste exposures, dietary fat taste exposure was the highest ($99 \pm 2 \times 10^3$ score g min; 25.7±0.1%). This shift in diet could be due to greater adherence to the 2015 Dutch health guidelines to minimise consumption of beverages containing sugar, such as fruit juice and soda (Kromhout et al., 2016). Nonetheless, a more salty and fatty-dominant diet may not be ideal. Research on Western and Asian populations have shown that a diet higher in 'savoury-fatty' or 'salt' taste is of lower diet quality and may be associated with increased dietary energy intake (Cox, Hendrie, & Lease, 2018; Teo et al., 2022). Fatty mouthfeel has also been reported to be the strongest predictor of dietary energy intake, followed by salty taste (Cox, Hendrie, Lease, et al., 2018). Total dietary taste exposure was the lowest for the Netherlands, although the cluster method resulted in seven dominant tastes and taste combinations. This highlights a difference between the cluster and taste exposure methods. While the Dutch diet may consist of a range of tastes (cluster results), each taste may not be high in amount consumed or intensity (taste exposure results). This is also reflected in 'neutral'-tasting foods contributing the most to energy intake (28.5%), while contributions from the other taste clusters ranged from 7.0% to 19.1%.

Dominant tastes in the dietary intake of adolescents in the UK (ages 10 to 19 years) have been elucidated by assigning each consumed food to a dominant taste – either sweet, sour, bitter, savoury, salt or neutral tasting (Bawajeeh et al., 2022). While this differed from the cluster method in this study, and was focused on a younger population, it revealed that sweet- and neutral-tasing foods contributed the most (34% each) to dietary energy intake, followed by savoury-tasting (21%), salty-tasting (10%), bitter tasting (1%) and sour-tasting foods (<1%). In the present study, 'neutral' cluster contributed the most to dietary energy intake as well (25.4%). 'Sweet' cluster alone contributed 21.9%, and together with 'sweet and sour' cluster, sweet-tasting foods contributed significantly to dietary energy intake with 31.0%. This aligned with the results from dietary taste exposure. Dietary sweet taste exposure was the highest contributor to total taste exposure. Despite different methods between this and Bawajeeh et al. (2022)'s study, some of the results were similar. Even though dietary taste exposure may not necessarily be related to dietary energy intake, especially in ultra-processed foods such as sweetener-reformulated products (Teo et al., 2022), it reflected sweet taste as the most dominant taste exposure in diets of both adults (the present study) and adolescents in the UK (Bawajeeh et al., 2022). Notably, Bawajeeh and colleagues (2022) asked adult consumers to allocate one main taste per food; therefore, the dominant taste of each food was selected based on prior experiences and understanding, and taste preferences and/or perceptions may differ from that of adolescents.

The current study included fatty-mouthfeel of foods in the diet and 'fat' cluster alone contributed to 21.8% of dietary energy intake in the UK. This affirms findings from the National Diet and Nutrition Survey 2014-2016 which stated that the average total fat intake met their recommendation of maximum 35% of energy intake (Roberts et al., 2018). However, if summing up 'fat' and 'salt and fat' clusters, the resulting fat-tasting foods contributed an excess of 3.8% to energy intake. Interestingly, bitter- and sour-tasting foods contributed only 1% to energy intake in adolescents (Bawajeeh et al., 2022), while 'bitter' cluster foods contributed 6.2% and 'sweet and sour' cluster foods contributed 9.1% to energy intake in adults. Additionally, savoury-tasting foods contributed 21% to energy intake in adolescents, while it was not a dominant taste in adults since there was no cluster including strong 'umami' intensities. Taken together, the results suggest a shift in dietary taste patterns from adolescents to adults, with more bitter- and sour-tasting foods and less umami-tasting foods in the diet. This may stem from higher intake of fruit and vegetables in adults (4.2 portions per day) than in children (2.7 portions per day) (Public Health England, 2018b) or the adaptation to bitter-tasting drinks such as coffee and beer as an adult (Mennella & Bobowski, 2015), lending support to the robust relationship between tastes and nutrient contents in foods (McKinney et al., 2019; Teo et al., 2022; van Langeveld et al., 2017). Nonetheless, less umami-tasting foods would suggest lower protein intake by adults, which is not the case. Adults in the present study consumed on average 73.9 grams of protein a day, making up 16.8% of their total energy (Public Health England, 2018b); while adolescents in the study of Bawajeeh and colleagues (2022) consumed on average 62.6 grams of protein a day, making up 15.5% of their total energy. The foods that were allocated as savoury-tasting foods by consumers in the latter study were meats and poultry, meat-based dishes and curries, burgers and meat-based pastries, vegetables- and cheese-based foods, oily fish and sushi (Bawajeeh et al., 2022), which are in ‘fat’ and ‘salt and fat’ clusters in the present study. Hence, the lack of cluster including strong ’umami’ intensities for the UK diet in the present study may simply be due to methodological differences. Similar to the Dutch diet, ‘neutral’-tasting foods contributed the most to energy intake (28.5%), possibly indicating that most foods in the diet were not intense in their tastes. It was also reflected by the total dietary taste exposure being second lowest amongst the five countries.

The number of clusters do not appear to reflect taste exposure, since both Australia and the UK resulted in six clusters, but Australia had 1.5 times higher total dietary taste exposure than the UK, and the US had 2.7 times higher total dietary taste exposure than the Netherlands, even though both consisted of seven clusters. van Langeveld and colleagues (2018) attempted to sum up percentage contributions to dietary energy intake per taste when it appeared in a cluster, e.g., sweet taste contribution = contributions from ‘sweet and sour’ and ‘sweet and fat’ clusters. Creating an example from the present study, sweet taste contribution for Australia would be a sum of ‘sweet’ (21.8%) and ‘sweet and sour’ (11.0%), that is 32.8% of energy intake contributed by sweet taste (see Appendix 16 for the energy contribution per taste across the five countries calculated in this manner). However, this variation in energy contribution per taste across the countries did not mirror the variation in dietary exposure per taste across the countries, both in absolute values (score g min) and in their percentage contributions to their total dietary taste exposure. Tastes that were not high enough in their intensities to appear in any cluster would also be excluded, e.g. umami absent in the clusters of Australian and the UK diets. This implies that summing up tastes across clusters in which they appear in may not accurately indicate the contribution or significance of the individual tastes, and/or that the energy provided by each dominant taste or taste combination is simply not equivalent to the magnitude of that taste or taste combination experienced in the oral cavity. The latter explanation could also explain the differences observed between some of the current results and previous research on dietary taste patterns of Australia, the Netherlands and the UK. Since cluster method incorporates the taste intensity aspect of taste exposure, it is somewhat surprising that taste exposure, facilitated by both intensity and duration aspects, no longer reflects results from the cluster method. This conveys the importance of accounting for taste duration.

Tastes and their intensities have consistently been shown to be in line with nutrient contents in foods across the world (Lease et al., 2016; Martin & Issanchou, 2019; Teo et al., 2022; Teo, van Langeveld, Pol, Siebelink, de Graaf, Yan, et al., 2018; van Dongen et al., 2012; van Langeveld et al., 2017). More importantly, dietary taste patterns, without accounting for taste duration, have also been reported to relate to corresponding (macro-)nutrients intakes. For instance, sweet-tasting foods from ‘sweet and sour’ and ‘sweet and fat’ clusters were directly associated with reported monosaccharide and disaccharide intakes (van Langeveld et al., 2018). Similarly, dietary sweet taste positively correlated with sugar contents (Cox, Hendrie, Lease, et al., 2018). Notwithstanding, dietary taste patterns accounting for both taste intensity and taste duration have not been studied in relation to corresponding (macro-)nutrient intakes. From the present study, the contribution of sweet to total dietary taste exposure was the highest in the UK with 24.9%, followed by Australia with 23.6%, the US with 23.2%, the Netherlands with 21.5% and lastly France with 18.0%; with a range of 18.0% to 24.9%. On the other hand, intake of total sugars was the highest in the Netherlands with 21.1%, followed by the UK with 20.6%, the US with 20.3%, Australia with 19.1% and France with 18.3%; with a relatively narrower range of 18.3 to 21.1% (Walton et al., 2021). The order of countries from the highest to the lowest dietary sweet taste exposures was different from the order from the highest to the lowest dietary sugar intakes. It appears that dietary sweet taste exposure may not be associated with dietary sugar intakes. Therefore, the widely-accepted narrative to lower sweet taste exposure in the diet to reduce preference and lower sugar intakes may apply to different diets and/or countries differently (Kromhout et al., 2016; Tedstone et al., 2015; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016). Notably, the current study used a cross-sectional design. Future steps could be taken to clarify the presence and direction of associations between dietary taste exposure patterns, nutrient intake, diet quality and health outcomes related to dietary energy intake.

Consequently, the findings from this chapter should be interpreted with the following limitations in mind. It is possible that dietary taste patterns differ by sex and weight status, even though evidence for it is limited (Cox et al., 2016; Cox, Hendrie, Lease, et al., 2018; van Langeveld et al., 2018). Nonetheless, sex-ratio (50.6-65.3% were biologically female) and average BMI (25.4-29.1 kg/m^2) were relatively similar across the five countries and both variables were adjusted for in each linear model. There are also limited taste databases available, resulting in foods consumed by the UK and the US obtaining taste values rated by an Australian sensory panel. Food products may taste different in different countries due to different ratio and/or contents of ingredients. This might have resulted in inaccurate quantifications of dietary taste exposures in the UK and in the US. Using another taste database such as the Dutch TFT database or the French database may possibly lead to different results. Moreover, the French taste database comprised many composite foods (Martin et al., 2014), while that of the Australian and Dutch comprised more singular foods (Lease et al., 2016; van Langeveld et al., 2018). This may explain for the lack of neutral-tasting foods as well as the unique 'Sour, Salt and Fat' cluster in the French cluster results. Nonetheless, the absolute values and percentage contributions of dietary taste exposures from the French diet were not extremely high or low and shared similarities with other countries. The utility of total taste exposure in absolute value may be limited, largely determined by cultural aspects and the types of foods in the diet. In contrast, the individual taste exposures, such as in Figure 7.3, or the percentage contributions of these to total exposure, as in Figure 7.4B., are more useful and informative on the patterns and distribution of tastes in the diet.

The limitations of (1) using taste databases rated by trained sensory panellists, (2) using simplified estimation of eating duration with texture categories, (3) the use of 24-h dietary recalls, and (4) individual variations in taste perception and eating rate, have been acknowledged and discussed while developing approaches to characterise dietary taste exposure and patterns (Chapter 6).

In spite of the shortcomings discussed above, this work was still an attempt at quantifying the total magnitudes of six tastes and mouthfeel exposed during consumption, and for a whole diet. It provides a novel approach by incorporating oral processing behaviours, established as drivers of food intake, at a dietary intake level and across population groups. A natural progression of this work is to utilise the newly developed approaches to characterise and compare dietary taste exposure and patterns of different (sub-)populations. While descriptions of taste exposure in different diets is intriguing and population-specific research is recommended, caution has to be taken to avoid mere repetition of the same analyses. The suitability of a taste database to assign values to a population diet has to be carefully ascertained, the distinction between contribution to dietary energy intake and contribution to total dietary taste exposure has to be clear, and the impact of food processing on nutrient-sensing in individuals has to be further ascertained (Teo et al., 2022). Subsequently, these dietary taste exposures and patterns could be studied in clinical populations and assessed for any associations with risks of chronic diseases, such as Type 2 diabetes. Another course of action would be to explore the combination of cluster and taste exposure. For example, each dietary taste exposure per individual could be clustered and the energy intake per dietary taste exposure cluster could be calculated for each dietary recall day and as an average of the population. However, this would still be problematic for non-caloric food items. Thus, future work could refine the methods of cluster and taste exposure further, such that the complementary information provided by them could be captured and condensed in a more efficient approach.

7.5. Conclusion

This study was able to quantify the total magnitude of a taste exposed during consumption at a dietary level, assess this dietary taste exposure relative to other taste exposures or total dietary taste exposure, and compare them across countries. Australia, France, the Netherlands, the UK and the US varied in the magnitudes of their dietary taste exposures, the percentage contributions of these exposures to the total taste exposure per country, as well as their dominant tastes and taste combinations. Comparisons with previous research pointed to several shifts in diets across years and ages. Similarities were also observed, with the diets of all five countries comprising ‘bitter’, ‘sweet and sour’ and ‘salt and fat’ taste clusters, and with dietary sweet taste exposure contributing the most to total exposure in the diets of Australia, the UK and the US. Cluster and taste exposure provided complementary information on the tastes of these diets and could be further studied in relation to dietary nutrients intakes. Variations across the countries also point to the importance of population-specific research and recommendations. Taken together, this work brings about a number of opportunities for future research.

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8. General Discussion

This thesis began by introducing the common narrative that sweet taste exposure is associated to sweet taste preference, which drives sugar intake and subsequently, influences health outcomes ('exposure–preference–sugar intake–health'). Chapter 1 explored the literature on the relationship between sweet taste exposure and health outcomes, on the adaptability of sweet taste preference, on consumer attitudes and the quantification of sweet taste exposure in the diet. The significances and limitations of these issues and research gaps were discussed. It was evident that the role of sweet taste exposure in an individual's diet, at a population level, and in dietary taste patterns across countries needed to be further clarified.

The six objectives of this thesis were met by Chapters 2 to 7 correspondingly, to better understand the position of sweet taste at the individual, population and global level. The findings have been discussed in detail in each of the chapters and a summary is provided in Table 8.1. on the next page. This final chapter will conclude the thesis by reviewing the main research findings, explore the underlying mechanisms of these findings, discuss the limitations, strengths and aspects of originality of this thesis, propose directions for future research, consider the society relevance and finally, state concluding remarks.

Table 8.1. Summary of findings from each chapter.

	Research Objective	Findings
Chapter 2	To design a dietary intervention trial to assess the adaptability of sweet taste preferences through varied sweet taste exposure.	A randomised controlled trial was designed and finalised by the committee of a public-private partnership project. The postgraduate researcher was involved in the setting up and execution of the trial, which has been approved, registered, and ongoing since October 2020.
Chapter 3	To investigate the associations of sweet taste exposure with sweet taste liking, sweetness preferences and health outcomes in individuals.	Dietary sweet taste exposure, estimated from a taste food frequency questionnaire (Taste FFQ), was not associated with sweet taste liking, preference and sweet-liker status. It was also not associated with total fat, body mass index (BMI), average blood glucose level and glucose variability. These suggest that sweet taste preference and health outcomes are independent of sweet taste exposure in the diet.
Chapter 4	To explore attitudes towards sweet-tasting foods, sugar and sweeteners, their consumption, and related policies, in a small sample of the general public of the United Kingdom (UK).	A total of 24 attitudes towards sweet-tasting foods, sugar and sweeteners were identified and grouped into six main themes – 'Value', 'Angle', 'Personal Relevance', 'Personal Responsibility', 'Understanding' and 'It's Not Up to Me'. Individuals varied in their perceptions and approaches taken towards their intake behaviours. The effectiveness of sugar reduction strategies may depend on the motivations, perceptions and priorities of individuals.
Chapter 5	To assess associations between attitudes towards and intake frequencies of sweet-tasting foods, sugar and sweeteners, as well as identify the dominant attitudes, in a large sample of the general public of the UK.	Individual variations in attitudes were again observed in a larger sample. Six attitude components explained 39.1% of the variance in responses and mapped onto the six themes in Chapter 4. The latent sub-populations of attitudes were to feel ill-equipped, be actively engaged or be unopinionated. Age and highest education qualification of individuals influenced their likelihood of holding these attitudes. Actively engaged individuals added sweeteners more frequently than individuals feeling ill-equipped, who consumed total sweet food groups more frequently than unopinionated individuals.
Chapter 6	To determine the most suitable approach to both characterise and compare dietary taste exposure and patterns across diets and/or populations.	Group mean was selected as the most feasible and efficient method to assign taste values from a taste database to food intake data across diets and/or populations. Complementary methods were used to characterise dietary taste patterns. Cluster informed on the dominant taste combinations and their contributions to energy intake of a diet, while taste exposure informed on the exposure to each taste during consumption and enabled comparisons. Altogether, these approaches provided the possibility to assess and compare dietary taste exposures and patterns across diets.
Chapter 7	To characterise and compare dietary taste exposure and patterns across Australia, France, the Netherlands, the UK and the United States (US).	These countries varied in the magnitude of dietary taste exposure the percentage contribution of these exposures to total taste exposure of that country, and the dominant tastes (combinations). There were also similar patterns of contributions to total taste exposure and dominant tastes (combinations) which appeared across all these countries. Comparison with the literature pointed to some shifts in diets across years and ages. Altogether, they convey the importance of population-specific research and guidelines.

8.1. Main research findings

Across the chapters, three topics stood out:

1. Independence of dietary sweet taste exposure
2. Individual and population variation
3. (Sub-)population-specific strategies

8.1.1. Independence of dietary sweet taste exposure

From Chapter 3, dietary sweet taste exposure estimated from the newly-developed taste food frequency questionnaire (Taste FFQ) displayed no association with sweet taste liking, sweetness preference, sweet-liker status, total fat in tissue, body mass index (BMI), average blood glucose level and glucose variability. The questionnaire in Chapter 5 assessed the intake frequencies of sweet-tasting foods, sugar and sweeteners during a typical week over the past month, but without consumed quantities to quantify taste exposure. Regardless, sweet taste exposure is a result of sweet taste intake and the intake frequency of these food items was an indicator of dietary sweet taste exposure. The results showed that the separate and combined intake frequencies of sweet-tasting foods, sugar and sweeteners were not robustly associated with attitudes, which included how much value individuals placed on sweet taste, an implicit reflection of liking. Both chapters demonstrated that sweet taste exposure in the diet does not reflect liking of and preference for sweet taste, neither does it relate to health outcomes.

8.1.2. Individual and population variation

Firstly, variations were observed in attitudes towards sweet-tasting foods, sugar and sweeteners, towards their intakes and towards related policies. The qualitative study in Chapter 4 revealed 24 attitudes, beliefs and considerations that individuals could have, which could be categorised into six main themes. The relatively small sample of individuals varied in their extent of positivity, negativity and indifference towards these food items and their intakes. These individuals took on either an active or a passive approach to change their consumption behaviours and some of them expressed deliberation between competing alternatives of consumption and motivation. Individuals also varied in their responses to current guidelines and strategies, either supporting, opposing or being surprised that some strategies have already been implemented. Similarly, in Chapter 5, a larger sample of individuals expressed varying positivity, negativity or apathy towards sweet-tasting foods, sugar and sweeteners and their intakes. Regarding consumption behaviours, these individuals also varied in the roles they took on or viewed themselves as having, either an active or a passive role. About 40% of variance in their responses could be explained by six attitude components which mapped to the six main themes from the smaller sample. These two chapters revealed a considerable range and variations in attitudes that the general public may have towards sweet-tasting foods, sugar and sweeteners, their intakes and related policies.

Variations were also observed in the quantification of taste exposure in diets. From Chapter 7, the nationally-representative diets of five countries differed considerably in the magnitudes of their taste exposures from different tastes and mouthfeel, as well as in the percentage contribution of these exposures to total dietary taste exposure. The countries varied in their total dietary taste exposure, despite some similarities in their dietary taste patterns, such as dietary sweet taste exposure contributing the most to total exposure in Australia, the UK and the US. These countries also displayed variations in their dominant tastes, taste combinations and the contribution of these tastes (combinations) to dietary energy intake.

8.1.3. (Sub-)population-specific strategies

There was general consensus from the qualitative study in Chapter 4 on the need for education on sweet-tasting foods, sugar and sweeteners to be improved. Comments conveyed that although information is often available, it might still be inaccessible or misunderstood by certain individuals or population groups. Strategies involving education could be more effective when designed with different groups in mind. Some individuals displayed a lack of attachment or opinion towards sweet-tasting foods, sugar and sweeteners and their intakes, either by expressing their ‘disinterest’ in the qualitative study, or by agreeing more with statements in the ‘apathy’ attitude component of the questionnaire in Chapter 5. Other individuals showed strong negativity towards the food items, towards their intakes and towards external influences, either by expressing their ‘disfavour’ and/or ‘it’s not up to me’ in the qualitative study, or by agreeing more with statements in the ‘negativity’ component of the questionnaire. It is plausible that individuals who feel apathetic need a change in motivation or perception to view their intakes of these foods as something of importance, while individuals who feel negative need education or information on how to manage their intakes healthily. Moreover, there were comments in the qualitative study that regarded sugar reduction as of low priority, individuals who agreed less with statements in the ‘personal management’ component of the questionnaire and individuals who agreed strongly with statements in the ‘perceived nonautonomy’ component. These individuals who take on a passive approach towards their intake behaviours may require specific strategies aimed at encouraging them towards taking an active role. The variations in perception and priorities of individuals from both chapters show the importance of providing different strategies for different groups.

Furthermore, individuals could hold different attitudes concurrently, as demonstrated in Chapter 4. Likewise, Chapter 5 identified three latent sub-populations with distinct attitude combinations and strengths within the study sample. For example, individuals who felt ill-equipped were less apathetic and less negative towards sweet-tasting foods, sugar and sweeteners and their intakes, but also perceived their understanding and autonomy to be low; whereas individuals who were actively engaged were more apathetic and negative but perceived their understanding and autonomy to be high. Assessing their associations with demographic and lifestyle characteristics showed that age and highest education qualification attained could influence the likelihood of which attitudes individuals had. Findings from Chapters 4 and 5 suggested the value of tailoring sugar-reduction strategies to different sub-populations to maximise their effectiveness.

8.2. Understanding underlying mechanisms

8.2.1. Sweet taste exposure and health

Researchers have reported that adults and children of different weight statuses did not differ in their dietary exposure to sweet-tasting foods (Kamil et al., 2021; Puputti et al., 2019; Teo et al., 2022), with the exception of dietary energy intake assessed in two studies, where individuals with normal weight consumed more energy from sweet-tasting foods than individuals with overweight and obesity (Bawajeeh et al., 2022; van Langeveld et al., 2018). The estimated intake frequencies of total sweet food groups in the diets of 581 adults living in the UK did not show any difference between BMI categories (Chapter 5). Considering sweet taste exposure in the diet as a whole, Chapter 3 also did not find any association between exposure and weight status. Furthermore, sweet taste exposure was not associated with total fat in tissue, another indicator of obesity which is even postulated as a more precise measure (Bays et al., 2013). This implies that dietary sweet taste exposure by itself is not related to obesity. Dietary sweet taste exposure also did not exhibit any association with average blood glucose level over the past three months and parameters of short-term glucose variability in Chapter 3. Experimental studies with sweetened solutions were similar in their findings, where neither sucralose solutions (Dalenberg et al., 2020; Grotz et al., 2017; Khan & Sievenpiper, 2021) nor sucrose or saccharin solutions impaired insulin responses (Just et al., 2008). There may simply be a lack of association between dietary sweet taste exposure and glucose variability, regardless of sources of sweet taste.

Referring back to the common narrative introduced in Chapter 1, there does not seem to be a direct association between sweet taste exposure and health outcomes; the first and last aspects of ‘exposure–preference–sugar intake–health’. One might then question if sweet taste exposure is indirectly associated with health outcomes through sweet taste preference. However, looking at the baseline sweet taste exposure and preference of participants in the intervention trial, sweet taste exposure does not appear to be correlated with sweet taste preference. In Chapter 3, both absolute judgement and relative impression of sweet taste preference were measured, by average liking across the sweet-tasting test foods and average preferred level of sweetness in these foods respectively, and neither measures were associated with exposure to sweet taste in the diet. This supports the conclusion of a systematic review on the impact of dietary sweet taste exposure on sweet taste acceptance, preference, choice and intake in the diet; that evidence for the effect of longer-term exposure was limited and equivocal (Appleton et al., 2018). In one study, adults with higher intake frequencies of sweet-tasting foods preferred higher sucrose concentrations in liquid, semi-solid and solid test-foods; but did not differ from adults with lower intake frequencies in their sweet taste liking of sucrose solutions (Holt et al., 2000). Holt and colleagues also did not find differences in intake frequencies of sweet-tasting foods between sweet-likers and sweet-dislikers. Similarly, sweet-liker status was ascertained in Chapter 3 and sweet-likers, neutral-likers and sweet-dislikers did not differ in their estimated dietary sweet taste exposure. Nonetheless, other researchers have reported considerable differences in intakes of sugar-sweetened beverages and added sugar, where sweet-likers had higher intakes than sweet-dislikers (Garneau et al., 2018). It is plausible that when looking at sweet taste in totality, not just from sugar as a source, dietary exposure is not associated with preference. The findings from this thesis does not support the narrative that sweet taste exposure is associated with sweet taste preference and perhaps could be removed from the 'exposure–preference–sugar intake–health' narrative.

8.2.2. Adaptability of sweet taste preference

By the same token, since the variations in baseline dietary sweet taste exposure across individuals were not related to the variations in sweet taste preferences across these individuals in Chapter 3, it seems unlikely that sweet taste preference may be adapted through varied sweet taste exposure. Nevertheless, the randomised controlled trial (Chapter 2) investigating this hypothesis is still underway and its findings will provide concrete evidence on the adaptability of sweet taste preference.

8.2.3. Individual/consumer factors

Research on attitudes of individuals towards sweet-tasting foods, sugar or sweeteners and their intakes have been focused on one or the other of these food items; such as consumer attitudes toward sweet-tasting treats (Forde & Solomon-Moore, 2019; Harricharan et al., 2014; Morel et al., 2019), consumer attitudes towards sugar and sugar-sweetened foods (Fadupin et al., 2015; Ortega-Avila et al., 2019; Zytnick et al., 2015), or parental attitudes towards sweeteners (Sylvetsky et al., 2014). Research on these food items and their intakes have also been conducted in America, while research that took place in the UK focused on attitudes towards the Soft Drinks Industry Levy (SDIL), more commonly known as the 'sugar tax' (Pell et al., 2019; Thomas-Meyer et al., 2017). In Chapter 4 of this thesis, various attitudes towards all three items – sweet-tasting foods, sugar and sweeteners, towards their intakes and towards related policies were collected in a sample of adults living in the UK and the prevalence of these attitudes was assessed in a larger sample in Chapter 5. Their results compared well with the range of attitudes identified in previous studies (Fadupin et al., 2015; Forde & Solomon-Moore, 2019; Morel et al., 2019; Ortega-Avila et al., 2019; Palmedo & Gordon, 2019; Pielak et al., 2019; Zytnick et al., 2015). The three latent populations with distinct combinations and strengths of attitudes identified in Chapter 5 demonstrated the value of studying attitudes in combination instead of separately, especially when assessing the association between attitudes and intake. A review on associations between attitudes towards and intakes of sugar concluded that an association was inconclusive (Gupta et al., 2018). It is plausible that a combination of attitudes, as could be elucidated by latent profile analysis, is needed to drive intake behaviours in certain directions.

Nonetheless, the role of attitudes is limited and if not, small. As discussed in Chapter 5, the questionnaire did not assess actual knowledge of participants, but rather, how well they perceived their knowledge to be. It is possible that a good grasp of knowledge could encourage healthier dietary sweet taste and sugar intakes. Nonetheless, pertaining to dietary sugar intake, the systematic review performed by Gupta and colleagues (2018) showed that knowledge and attitudes are limited in their effectiveness of driving healthier behaviours in adults. Introduced in Chapter 1, the reasoned action approach posits that in addition to the attitudes an individual may have, their perceived capacity, autonomy, descriptive norms and injunctive norms also predict their behaviour (Fishbein & Ajzen, 2009; Stok et al., 2014). Both descriptive and injunctive norms in social influences such as eating with family and friends and the household size (Coxon et al., 2019; Hattersley et al., 2009; Hermans et al., 2010; Higgs & Thomas, 2016; Marinho et al., 2020) and cultural or political factors such as the promotion of foreign media or advertisement and sugar taxes, have also been found to drive intakes of sugar, sugar-sweetened beverages or sweet-tasting snack foods. Social and environmental influences may further activate approval goals, which may also predict behaviour (Ajzen & Kruglanski, 2019). Moreover, preferential pricing and availability were mentioned by consumers to influence their intakes of sweetened beverages and sweeteners (Hattersley et al., 2009; Kamarulzaman et al., 2014). While this thesis focused on attitudes towards sweet-tasting foods, sugar and sweeteners as drivers of their intakes, other social, political, physical and economic factors ought to be considered as well, to better understand the positioning of sweet taste at the individual and population level.

At the same time, individuals naturally vary in their demographic and lifestyle characteristics at a population level. These variations explain the variations in attitudes, such as an increase in age decreasing the odds of an individual being actively engaged compared to feeling ill-equipped and being unopinionated, and also explain the variations in intakes, such as an increase in age correlating with an increase in the intake frequency of total sweet-tasting food groups per day (Chapter 5). Since several attitudes identified in this thesis were related to intake frequencies, variations in intake may be affected by individual characteristics, attitudes, or both concurrently.

8.2.4. (Sweet) taste exposure in the diet

In the evaluation of dietary exposures to sweet-tasting foods, sugar and sweeteners and their links to health risks, traditional food-borne exposure assessments have focused on sources of sweet taste (Debras et al., 2022; Ebrahimpour-koujan et al., 2018; Farsad-Naeimi et al., 2020; Kamil et al., 2021; Martyn et al., 2018; Takehara et al., 2022; Yin et al., 2021). In studying dietary sweet taste in its entirety, Bawajeeh and colleagues (2022) focused on the presence of sweet taste and not the intensity of it. However, given that a higher intensity of sweet taste may result in an earlier meal termination and consequently, reduce food intake (Lasschuijt et al., 2021; Lucas & Bellisle, 1987; Vickers et al., 1998, 2001), it is important to also consider the intensity of sweet taste. Dietary taste patterns based on taste intensity have been shown to be associated with weight status. In both Western and Asian populations, individuals with obesity tended to consume more energy from foods in the cluster high in 'salt, umami and fat' intensity and less from foods in the cluster high in 'sweet and fat' intensity, as compared to individuals with normal weight (Teo et al., 2022; van Langeveld et al., 2018). These results conveys that weight status is not related to dietary sweet taste and instead, dietary salt, umami or fat exposure in the diet.

Putting everything back into context (Chapter 1), Chapters 2 and 3 sought to better understand underlying mechanisms related to the ‘exposure–preference–sugar intake–health’ narrative; by investigating if manipulations to sweet taste exposure may result in adaptations to sweet taste preference, and whether sweet taste exposure itself is directly associated with sweet taste preference and health outcomes separately, at the individual level. Chapters 4 and 5 considered several factors that may influence the relationships that consumers have with sweet taste, both at the individual and population levels, and assessed if individual characteristics and attitudes may relate to their intakes of sweet-tasting foods, sugar and sweeteners. By identifying sub-populations in greater need for dietary intervention, such as tailored sugar-reduction strategies, Chapter 5 also informed on the target groups. If the trial in Chapter 2 concludes that sweet taste preferences can be changed with varied sweet taste exposure, information from Chapter 5 will help identify the groups to be targeted for varied sweet taste exposure. Chapters 6 and 7 looked into the quantification of sweet taste exposure in the diet both at the population and global levels, and how these dietary taste exposures and patterns could be compared across diets. By doing so, it revealed whether changes to sweet taste exposure should be identical across diets and/or populations. Should the trial in Chapter 2 conclude that sweet taste preferences can be adapted, information from Chapter 7 will help inform how sweet taste preferences can be adapted differently across diets and/or populations. Figure 8.1. on the right illustrates where each chapter stands in the thesis and how the chapters are related.

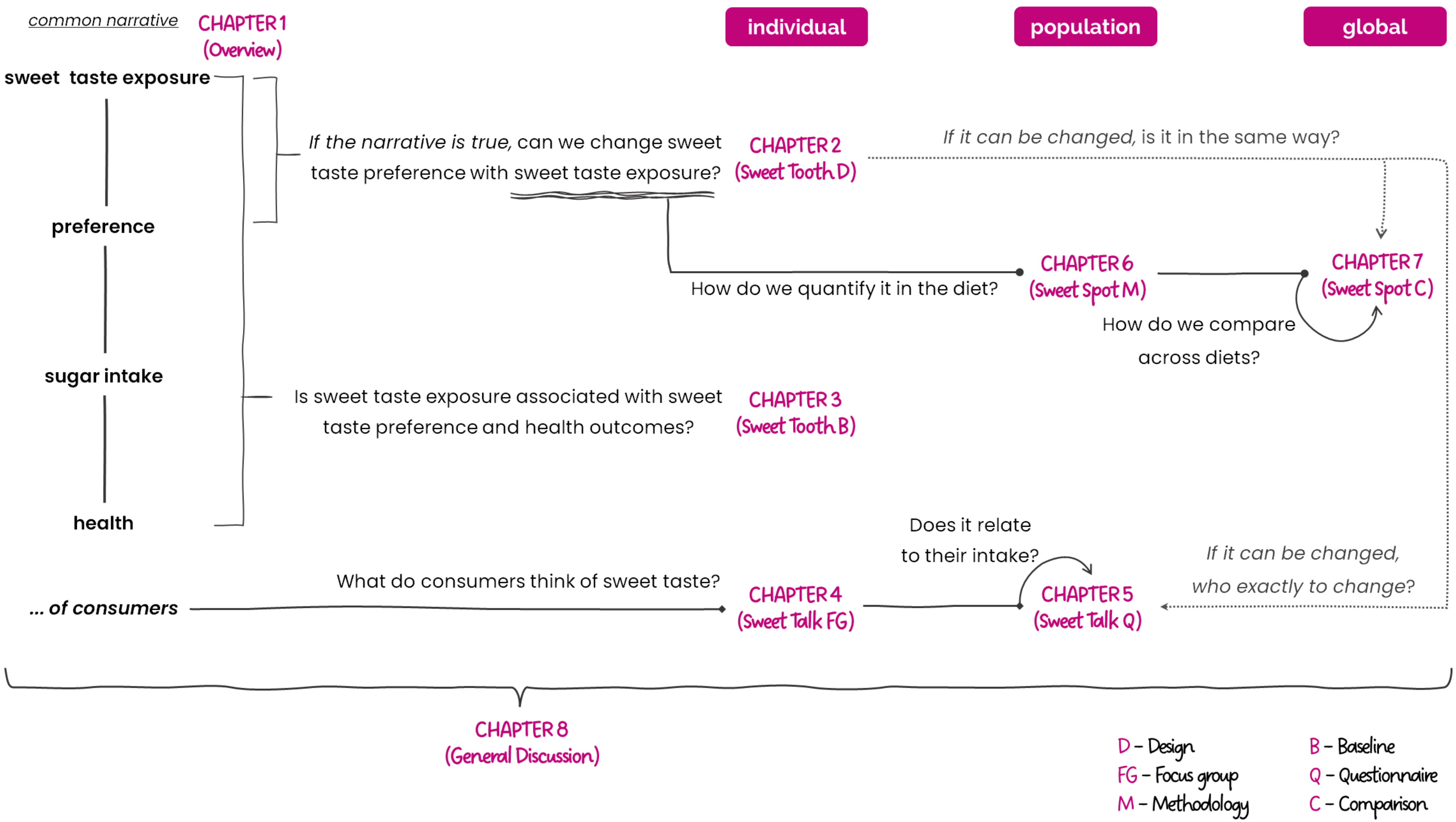

Figure 8.1. Structure of the thesis – where each chapter stands and how the chapters are related.

8.3. Limitations

8.3.1. Design

All data analyses were based on cross-sectional studies, which could be subjected to occasion factors that bias measures in a similar manner and to a lack of temporal elements in the research that prevents any causal inference to be drawn (Spector, 2019). The use of cross-sectional design has often been criticised in analytical studies of association, especially if the variables of interest may change with time or periodically. Data used in Chapters 6 and 7 were also not collected by the postgraduate researcher, since secondary data from national diet surveys were used. Nonetheless, the purpose of data analysis in these two chapters were to elucidate taste exposure in the diet, which may be considered as stable over time, and not meant to analyse associations between an exposure and an outcome (Kesmodel, 2018). Chapter 6 was also a comparison of methods to assign taste values to food intake data and to quantify taste exposure, which benefited from larger sample sizes that cross-sectional national surveys could provide. To avoid making any causal inference, the variables of interest in each chapter were set beforehand and all results sections were carefully worded to focus on the presence, direction and strength of associations between these variables.

Moreover, a cross-sectional design is advantageous and even optimal (Spector, 2019) when assessing the effect of a condition previously experienced by individuals (sweet taste exposure in the diet in Chapter 3), in evaluating the prevalence of attitudes (qualitative study in Chapter 4 and questionnaire in Chapter 5), in exploring patterns of relationship (attitudes towards and intakes of sweet-tasting foods, sugar and sweeteners in Chapter 5) and in assessing the prevalence of stable variables or traits (dietary taste exposure in Chapters 6 and 7). Cross-sectional studies can inform on variables that may be important to focus on, be the basis of theoretical formation and even be the target of intervention in future studies. For instance, latent profile analysis in Chapter 5 showed the value in profiling study participants based on their attitudes when researching on the influence of attitudes on intakes, among other factors such as demographic and lifestyle characteristics. Given the merits of cross-sectional studies and efforts taken to correctly analyse and interpret the data in this thesis, the limitations of a cross-sectional design on the thesis findings is likely to be minimal.

In investigating any association between dietary sweet taste exposure and sweet taste preference, health outcomes and intakes of sweet-tasting foods, sugar and sweeteners, dietary sweet taste exposure of individuals were estimated from frequencies of intake (Taste FFQ in Chapter 3 and intake frequency questionnaire in Chapter 5) rather than from actual quantities, such as 24-hour dietary recall or food diary. The two questionnaires were selective in terms of the foods they included and did not represent dietary intake of a full day. Sensitivity analyses of food records were also not possible within the scope of the studies. Thus, dietary sweet taste exposure could have been underestimated in both chapters. That being said, numerous research studies have demonstrated that a FFQ is able to capture habitual food intake, including episodic foods, while dietary recall and food diary only capture recent food intake (Evans et al., 2022; Subar et al., 2020; Watson et al., 2009). Sugar-sweetened and artificially-sweetened beverages (including coffee and tea), vegetable and fruit juices, sweetened milk and plant-based beverages and alcohol are considered as episodically-consumed foods which may require a FFQ for a better gauge of sweet taste exposure in the diet (Brassard et al., 2019; Rochefort et al., 2022). Additionally, daily intake of sucrose has large within-person and between-person coefficients of variation requiring several repeated days to give an accurate estimate, which makes a FFQ a more suitable dietary intake assessment (Willett, 2012). Nonetheless, traditional dietary assessments such as 24-hour dietary recall, FFQ and food records are all subjected to reactivity, whereby individuals adapt their dietary behaviours, either intentionally or unintentionally (Gurinović et al., 2017; Welch & Mulligan, 2023).

The foods in the Taste FFQ of Chapter 3 were shortlisted as the most frequently consumed foods of dominant tastes and taste combinations set by van Langeveld and colleagues (2018); in other words, the majority of foods that would contribute the most to sweet taste exposure in the diet were shortlisted and further additions might not have made considerable difference to the estimated dietary sweet taste exposure. Likewise, in Chapter 5, the top National Diet and Nutrition Survey food groups that contributed to total sugar intakes relevant to the sugar reduction programme in the UK (Tedstone et al., 2015), further split into ‘sugar-free’ and ‘not sugar-free’ groups, as well as the addition of sugar, honey and sweetener in coffee, tea and homecooked dishes, could be considered together as an adequate estimate of exposure to sweet-tasting foods, sugar and sweeteners. Therefore, despite its shortfalls, using frequency of intake in this thesis was suitable and added to its findings.

8.3.2. Generalisability

This thesis focused on the Netherlands in Chapters 2 and 3, the UK in Chapters 4 and 5 and Australia, France, the Netherlands, the UK and the US in Chapters 6 and 7. Its findings may only be generalised to these populations. On the one hand, most of these countries were studied due to their high sugar consumption (Chapter 7) for which investigation on the common narrative introduced in Chapter 1 is relevant, and some of these countries, such as the UK, have their sugar reduction guidelines based on the common narrative (Pan American Health Organisation, 2016; Public Health England, 2018a). On the other hand, these countries do not represent non-western populations and diets. Despite some evidence for diets around the world converging to the western diet (Le et al., 2020; Tilman & Clark, 2014), mainly associated with global urbanisation (da Costa et al., 2022), there has also been evidence for the transition towards other diets in countries that previously followed a western diet (Azzam, 2021). Thus, the application of findings from this thesis may be limited to diets characterised by high intakes of sugars, refined carbohydrates, fats, processed foods and foods of animal-origin and low intakes of coarse grains, fruits and vegetables (Popkin et al., 2012).

In the sample of adults living in the Netherlands (Chapter 3), there were more females, older adults and the mean BMI was lower than that of the population (van Rossum et al., 2020). These individuals also had relatively low sweet taste exposure and sweet taste preference as compared to the maximum values possible. It is likely that this sample is not representative of the Dutch adult population and cannot be generalised to the whole population. Similarly, the sample of adults living in the UK (Chapter 5) were not representative of the UK population, as there were more females, younger adults, fewer adults belonging to a Black ethnic group, more adults with O levels, A levels, college diploma or equivalent while less adults with no formal education or a university degree, more adults in socio-economic class 2 or 4 while less adults in class 1 or 5, and more adults with underweight, healthy weight or morbid obesity while less adults with overweight or obesity. The dietary taste exposures and patterns elucidated from Chapter 7 were from nationally-representative diets of the Netherlands and the UK. It would have been preferable for the samples in Chapters 3 and 5 to be nationally-representative, to better correspond with findings from each chapter, and to better understand these populations accurately. Be that as it may, the sample in Chapter 5 consisted of participants across all age groups, ethnic groups, highest education level attained, socio-economic classifications and BMI groups. This allowed for data from different persons to be collected including those in minority numbers. Even though there were only six participants who identified as non-binary, this research was a step towards better gender-based analysis in health research (Day et al., 2016; Gogovor et al., 2021). Thus, despite not representing the national population ratios of demographic characteristics, the sample was able to represent persons of different demographic characteristics.

8.3.3. Theoretical reasoning vs. statistical evidence

There were several research steps in this thesis that required subjective decision-making to either analyse data, make inferences or draw conclusions. The formation and naming of sub-themes and themes (Chapter 4); the questions on attitudes per sub-theme and the naming of attitude components (Chapter 5); the assignment of taste values to untested foods (Chapters 6 and 7); the allocation of foods to one of four texture categories with corresponding average eating rates (Chapters 6 and 7); the selection of clusters and their names (Chapters 6 and 7); the matching of existing taste databases to countries without their own taste database and the matching of foods in taste databases to food intake data of these countries (Chapter 7) were all based on theoretical reasonings instead of irrefutable statistical evidence, such as the significance of an association based on its p-value (Chapters 3 and 5). Notably, each of these decisions were made in consultation with other researchers using systematic reasoning and documentation, and if applicable, with advice from statisticians and statistical results. Statistics as evidence also requires statistical literacy, scientific reasoning and argumentation skills in understanding and applying scientific methods and findings (Berndt et al., 2021; He & Lin, 2020; Vorholzer et al., 2022). Therefore, subjective decision-making in this thesis would likely have limited implications on its findings. Nonetheless, it is important to acknowledge that the choice of an alternative in any of the above-mentioned research steps could have led to different outcomes and conclusions.

8.4. Strengths and originality

8.4.1. Design

This thesis investigated dietary sweet taste and its associations in an individual (Chapters 2, 3 and 4), in a population (Chapters 5 and 6), and globally (Chapter 7). With reference to the overview, most associations between sweet taste exposure and preference were studied at an individual and a population level, either by conducting experiments or by analysing data of cohort studies (Chapter 1.3). Researchers have attempted to examine different populations on their genetic basis of sweet taste preference, but by comparing across studies rather than within a study. Similarly, research on sweet taste exposure and health outcomes has focused on individuals or on clinical populations (Chapter 1.4). Research on attitudes towards sweet taste has also focused on specific sub-populations, such as parents; and cross-country research has focused on sub-populations as well, such as dietitians (Chapter 1.5). While dietary taste patterns have been studied at a population level, attempts to study at a global level have not been successful due to methodological differences (Chapter 1.5). In comparison, recommended dietary sugar intakes and suggestions to achieve it have been put forth similarly across the world (Pan American Health Organisation, 2016; Tedstone et al., 2015; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016) and total sugar intakes as a percentage of total dietary intakes have also been compared across the world (Walton et al., 2021). Prior to setting universal guidelines related to sweet taste, such as the common narrative on reducing sweet taste exposure to lower sweet taste preference, the role of sweet taste in the diet, in relation to other tastes and mouthfeel, to health outcomes, and to attitudes, ought to be clarified from different angles as well. By examining individuals and populations, across countries, this thesis was able to provide a more comprehensive understanding of sweet taste and its associations with attitudes, health outcomes and dietary intake and exposure.

In order to clarify the position of sweet taste from different perspectives, this thesis is composed of different study designs. In Chapter 2, a randomised controlled trial was designed and began in 2020. In Chapter 3, a cross-sectional design was used by obtaining baseline data from the trial, which involved sensory evaluations, biological samples and quantitative questionnaires. A qualitative and quantitative approach was taken to examine attitudes towards and intakes of sweet-tasting foods, sugar and sweeteners, in Chapters 4 and 5; where an exploratory qualitative study was first conducted, followed by the development of a quantitative questionnaire from thematic analysis of the qualitative work and a cross-sectional study on attitudes and estimated intake frequencies of the general public living in the UK. The study in Chapter 5 also performed latent profile analysis, a recent method in behavioural research to identify latent sub-populations (Oberski, 2016; Spurk et al., 2020; Williams & Kibowski, 2016). To elucidate the most suitable and feasible method to quantify taste exposure in the diet, Chapter 6 employed various statistical techniques to evaluate distance measures and clustering methods. Finally, in Chapter 7, nationally-representative dietary surveys were obtained for a cross-sectional assessment of dietary taste exposures and patterns.

8.4.2. Perspective

As reviewed in Chapter 1, most of the research related to sweet taste focused either on specific sources of sweet taste, such as sucrose, non-nutritive sweeteners or sugar-sweetened beverages. Otherwise, research on sweet taste as a whole was undertaken at a population level by assessing dietary taste patterns. This thesis considered all sources of sweet taste in the diet when studying any associations of sweet taste exposure with preference, health outcomes and attitudes. Using the Taste FFQ developed for the randomised controlled trial, an estimation of dietary sweet taste exposure could be made in Chapter 3 and analysed against preference for sweet-tasting foods that varied in their structural properties (liquid, semi-solid and solid). In Chapter 5, dietary sweet taste exposure was estimated from intake frequencies of both sugar- and sweetener-sweetened foods and beverages, to study its associations with attitudes.

This thesis also incorporated elements of oral processing behaviours in quantifying taste exposure in the diet. The duration of taste experienced in the mouth has been established as an important driver for food intake and satiety (de Graaf, 2012; Lasschuijt et al., 2021); yet, taste at a dietary intake level and across diets have been focused on the intensity of taste experienced in the mouth. By accounting for the structural properties of foods and their rates to be consumed by individuals, the foods in the Taste FFQ could be categorised as either liquid, semi-solid, soft-solid or hard-solid and assigned the average eating rate of that category. This novel method of considering both taste intensity and duration enabled dietary sweet taste exposure of individuals to be quantified and studied for its association with sweet taste preferences and health outcomes in Chapter 3. By the same token, food intake data of the five countries in Chapter 7 were also categorised in a similar manner and assigned their corresponding eating rates. This enabled the quantification and comparison of dietary taste exposures and patterns across these countries.

8.5. Directions for future research

8.5.1. Other tastes and behaviours

Research on taste patterns in the diet have consistently shown the disassociation between sweet taste in the diet and energy intake. Instead, savoury-tasting and/or fatty foods are more predictive of higher and excessive energy intake (Cox, Hendrie, Lease, et al., 2018; Teo et al., 2022; van Langeveld et al., 2018). The findings from this thesis also mirrored findings from previous studies that dietary sweet taste exposure was not associated with indicators of obesity and Type 2 diabetes. It might be of value to shift the research focus towards dietary salt, umami and fat exposure instead.

Moreover, this thesis demonstrated that intake frequencies of sweet-tasting foods, sugar and sweeteners may be associated with individual characteristics and separately, with attitudes that individuals may have. At the same time, individual characteristics were associated with attitudes. The research could be extended by investigating whether individual characteristics moderate the relationships between attitudes and intakes. This would require a larger sample of participants with varying demographic and lifestyle characteristics, and a range of attitudes.

8.5.2. Methods

The Taste FFQ developed for the randomised intervention trial in Chapter 2 is a novel way of using traditional dietary assessments, such as food frequency questionnaires, to assess dietary intakes from a taste perspective. That being said, this questionnaire was created to cluster individuals according to high or low dietary sweet taste exposure, rather than their absolute taste exposures. Absolute magnitudes of dietary taste exposures were obtained from 24-h dietary recalls in Chapter 7, but this dietary assessment method may not have captured episodically-consumed foods. As discussed in section 8.3., using a FFQ may be more suitable when assessing dietary sweet taste exposure. Therefore, one suggestion for future research would be to expand the current Taste FFQ to comprise not only foods that contribute to dominant tastes in the diet, but all foods that may be consumed by the population. These foods could be assigned to texture categories to estimate their taste durations and assigned their taste intensities using a taste database. To improve the estimations of taste duration and intensities of foods, more foods could be consumed and rated by trained sensory panellists. Importantly, this Taste FFQ may then be validated with biomarkers of sources of sweet taste, such as urine biomarkers on sucrose and non-nutritive sweeteners (Logue et al., 2020; Muli et al., 2021). The resultant Taste FFQ would be a valid tool to quantify dietary taste exposure and patterns.

A more accurate estimation of dietary sweet taste exposure from the Taste FFQ would enable a better investigation into its associations with relative and absolute judgements of sweet taste preference, indicators of obesity, parameters of glucose variability, attitudes and demographic or lifestyle characteristics. Such endeavour would strengthen the findings of this thesis. Moreover, the magnitudes and patterns of dietary taste exposure could be evaluated for their associations with health risks. Notably, it would still be a challenge to incorporate non-caloric foods. Energy intake could be statistically controlled for, but its impact on diets with high non-caloric food intake remains unclear. Further research on how to incorporate dietary taste exposure into nutritional epidemiology would be valuable.

8.5.3. Study population

A better understanding of sweet taste exposure and its associations investigated in this thesis would require a broader range of study population. As seen in the cross-country comparisons of dietary taste exposures and patterns, five countries following a westernised diet had considerable differences in some of the exposures and patterns. A natural progression of this work would be to study other diet types, such as those of other countries or clinical populations within a country. In one study, dietary taste patterns of bariatric patients were assessed before and after Roux-en-Y gastric bypass or sleeve gastrectomy (van der Burgh et al., 2022). After surgery, the percentage of energy intake from sweet and sour foods increased, while that of other tastes decreased, independent of weight lost from surgery. It would be of interest to monitor clinical populations on their dietary taste exposures to promote healthier eating behaviours without sacrificing their enjoyment of foods (Cox, Hendrie, & Lease, 2018; Teo et al., 2022).

The inconsistent use of usage of “gender” and “sex” is common in health research (Day et al., 2016; Gogovor et al., 2021; Johnson et al., 2009) and in research on sweet taste, focus has been placed on sex instead of gender differences (Armitage et al., 2021; Walton et al., 2021). Yet, the diets of individuals of different gender expression and sexual orientation differ in diet quality (Prestemon et al., 2022; VanKim et al., 2019) and risk for Type 2 diabetes (Corliss et al., 2018). It would be beneficial to conduct research on sweet taste exposure and its associations investigated in this thesis, across genders. While the sample in Chapter 5 included different genders, there were only six individuals who identified as non-binary and further investigations of the differences in their attitudes could not be made. Targeted recruitment may be helpful in reaching out to these sub-populations.

8.6. Societal relevance

8.6.1. Segmentation and prioritisation of consumer (sub-)groups for strategies

This thesis provided evidence for individual variations in perceptions, motivations and priorities with regards to sweet-tasting foods, sugar and sweeteners, and their intakes. Consequently, sugar-reduction strategies ought to be varied accordingly. In the UK, the SDIL has been in place since 2018. However, from the qualitative study in Chapter 4, it was clear that some consumers were still uninformed of its implementation and varied in their need for information and education or suggestions to manage their priorities. The current Eatwell Guide provided by Public Health England (2018a) may be helpful to individuals who are already actively engaged. These individuals tend to be of a younger age and do not have a university degree (Chapter 5) and might benefit from guidance on how to use the Eatwell Guide or replace sugar with sweeteners in home cooking (Chapter 4). Conversely, older individuals with or without a university degree may feel ill-equipped to use the Eatwell Guide, or simply remain unopinionated (Chapter 5). Individuals who feel ill-equipped would most likely need to be empowered to feel that they have the autonomy over these food items. Empowerment strategies may utilise media to equip these individuals on ways to manage their intakes and to process information from various channels, such as the programme on BBC Two, “Trust me, I’m a Doctor”, where researchers cover different viewpoints from the industry, media and science (BBC, 2020). Individuals who remain unopinionated may also appreciate advice and suggestions on how to manage their various commitments or other priorities so that they are still able to have healthy dietary sweet and sugar intakes. The thesis findings showed that the segmentation and prioritisation of sugar-reduction strategies can be made by seeking out the demographic and lifestyle characteristics of individuals that are directly associated with intake, or that are associated with attitudes which in turn drive intake.

8.6.2. (Sweet) taste exposure and guidelines

The common narrative of ‘sweet taste exposure – preference – sugar intake – health’ introduced in Chapter 1 has been the basis of numerous public health initiatives aimed at reducing sugar intakes to lower the prevalence of obesity and Type 2 diabetes. However, the findings of this thesis did not support this narrative. Cross-sectional evaluation of dietary sweet taste exposure was not associated with sweet taste preference nor health outcomes. As such, further investigation on the plausibility of this narrative to successfully reduce sugar consumption and lower the prevalence of obesity and Type 2 diabetes is warranted. This investigation is currently underway by the dietary intervention trial described in Chapter 2. It would also be value for public health institutes to practice caution when recommending changes to dietary sweet taste, since the common narrative has not yet been proven true. In the meantime, the present findings could prompt the investigation into other ways of reducing sugar intakes, rather than focusing on sweet taste.

Upon controlling for dietary nutrient and energy intake, researchers found that diets scoring low in diet quality could have the same contributions by each taste to diets scoring high in diet quality

(Cox, Hendrie, & Lease, 2018). Correspondingly, diets with a lower ratio of core to discretionary foods could have similar dietary taste patterns to diets with a higher ratio of core to discretionary foods (Cox, Hendrie, Lease, et al., 2018). This suggests that dietary taste patterns of individuals could still be maintained when switching from a less healthy to a more healthy diet. Given the importance of taste in determining dietary patterns (Chapter 1), and even as a factor in food choice that cannot be compromised (Chapter 4), it would be valuable to consider dietary taste exposures of individuals when formulating strategies to reduce excessive energy intakes, to maintain these dietary taste patterns. This appears to be a plausible approach, since the predominant taste pattern has been found to be consistent throughout quartiles of dietary energy intake (Teo et al., 2022). Thus, dietary energy intake could potentially be reduced by switching to healthier sources across taste exposures.

At the same time, such strategies and related recommendations may need to differ with country, given the country differences shown in this study, where they varied in dietary taste exposures and patterns. The current recommended sugar intake is similar across numerous countries (Kromhout et al., 2016; Pan American Health Organisation, 2016; World Health Organisation, 2015; World Health Organisation Regional Office for the Eastern Mediterranean, 2016). Recommendations on healthier alternative sources across taste exposures, in contrast, may have to differ across countries. Their predominant taste exposures and patterns may be different, for which policy makers have to first assess and then adjust their recommendations accordingly. Population-specific research is valuable in this regard, to ensure consumers have their needs met while effecting behavioural change. Consequently, the outcomes from the ongoing randomised controlled trial may require deeper inquiry on its transferability to other populations. The outcomes of this trial would inform researchers and policy-makers on the potential influence of long-term dietary exposure on sweet taste preferences, particularly the direction, duration and effect size. However, as found in Chapter 6, the dietary sweet taste exposure of the Dutch diet was found to be significantly lower than those of Australia, France, the UK and the US. The findings from this trial may have to be calibrated according to the baseline sweet taste exposures of respective countries.

Finally, the findings from this thesis could help with the current challenges faced by regulatory compliance committees. The joint Food and Agricultural Organization-World Health Organization Food Standards Program has been developing a standard to limit the amount of sweet taste from carbohydrates in drinks for young children (Starkey et al., 2022). However, their research found numerous analytical measures of sweet-tasting molecules in foods and no measure of sweet taste, hence, concluding that there is “no way to determine compliance for such a requirement.” (Starkey et al., 2022, p. 334). The approaches to quantify dietary taste exposure in this thesis could help to determine the perceived sweetness of carbohydrate sources in liquid, semi-solid, soft-solid and hard-solid foods; while the cross-country comparisons could also inform on how to assess sweet taste in panels globally.

8.7. Conclusion

There is a narrative that a greater exposure to sweet taste would increase the preference for sweet taste and consequently, increase sugar intake and lead to a higher prevalence of negative health outcomes. It has set the parameter for numerous sugar reduction recommendations, despite remaining unproven and unclear. In response, this thesis explored the dietary sweet taste intake and exposure with health outcomes, at the individual, population, and global levels. A randomised controlled trial was designed in the Netherlands to assess the adaptability of sweet taste preference through dietary intervention with varied sweet taste exposures. While the trial is ongoing, baseline dietary sweet taste exposure of the participants showed no association with their sweet taste preference, nor with indicators of obesity and Type 2 diabetes.

Concurrently, focus groups and interviews were conducted in a small sample of the general public in the UK, which identified possible attitudes towards sweet-tasting foods, sugar, and sweeteners, towards their consumptions and towards related policies. Individuals varied in their perceptions, motivations, and concerns towards these food items. Subsequently, a structured questionnaire was developed to assess associations between attitudes and intakes, and to identify individual characteristics that may influence the prevalence of attitudes. Individual variations in attitudes remained in this larger sample of consumers in the UK. Individuals who felt they could manage their intakes, added sugar and consumed sugar food groups and total sweet-tasting food groups more frequently; individuals who felt they were unaffected, also consumed sugar food groups and total sweet-tasting food groups more frequently. Through latent profile analysis, three sub-populations with distinct combinations of attitudes of different strengths were identified: feeling ill-equipped, actively engaged or unopinionated.

In addition, approaches to quantify sweet taste exposure in the diet, amongst other tastes, were evaluated for their suitability and feasibility to characterise dietary taste exposure patterns in and across populations. These taste exposures and patterns were subsequently compared between Australia, France, the Netherlands, the UK, and the US. These countries mostly had similar taste combinations but differed in the percentage contributions from these clusters to total energy intake. They also differed in their absolute dietary taste exposure, although some of their patterns displayed similarities, such as dietary sweet taste exposure contributing the most to total exposure in the diets of Australia, the UK, and the US.

This thesis challenged the common narrative of ‘sweet taste exposure – preference – sugar intake – health’, by looking at the direct relationship between exposure and preference, and health. It provided insights into individual, population and global variations in dietary sweet taste exposure and attitudes towards and intake of sweet taste. While further investigation into the adaptability of sweet taste preference and the aforementioned associations in more representative samples is required, this thesis suggested the value for segmentation and prioritisation of specific sugar reduction strategies in distinct sub-populations.

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Appendix 1. Examples of daily menu for different intervention groups.

		Food product	Item brand/type
LOW SWEET EXPOSURE	Breakfast	Bread	Any
		Margarine	Low fat margarine 40% fat
		Vegetable spread	Mister Kitchen vegetable spread
		Egg salad	Johma Eisalade
		Cheese	Milner Belegen kaas 30+
		Skimmed milk	AH Magere melk
	Snack	Coffee/tea/water	Any
		Fruit	Any
		Savoury biscuits	Sultana Crunchers
	Lunch	Bread	Any
		Margarine	Low fat margarine 40% fat
		Vegetable spread	Heunz Dandwich spread naturel
		Pepper spread	Zonnatura Paprika spread
		Meat	Any
		Skimmed milk	AH Magere melk
	Snack	Coffee/tea/water	Any
		Fruit	Any
		Unsalted cashew nuts	AH Cashewnoten ongezouten
	Dinner	Spaghetti Bolognese	
		Water	
	Snack	Coffee/tea/water	Any
		Sparkling water	Spa Intense bruisend mineraalwater
		Neutral mini crackers	LU Mini crackers naturel
REGULAR SWEET EXPOSURE	Breakfast	Bread	Any
		Low fat margarine 40% fat	Low fat margarine 40% fat
		Peanut butter	Calve Pindakaas
		Fruit Jam with less sugar	Hero Minder zoet jam
		Kaas	Any
		Skimmed milk	AH Magere melk
	Snack	Coffee/tea/water	Any
		Fruit	Any
		Fruit biscuits	Sultana Fruit biscuit
	Lunch	Bread	Any
		Margerine	Low fat margarine 40% fat
		Celery salad	Joma Selleriesalade
		Pepper spread	Zonnatura Paprika spread
		Meat	Any
		Skimmed milk	AH Magere melk
	Snack	Coffee/tea/water	Any
		Fruit	Any
		Unsalted nuts with cranberries	AH Cranberrymix ongezouten
	Dinner	Spaghetti Bolognese	
		Water	
	Snack	Coffee/tea/water	Any
		Flavoured water	Spa Touch bruisend
		Rice cracker chocolate flavour	Rijstwafels met chocolade

		Food product	Item brand/type
HIGH SWEET EXPOSURE	**Breakfast**	Bread	Any
		Margarine	Low fat margarine 40% fat
		Peanut butter & coconut maple	Mister Kitchen Pindakaas kokos maple
		Fruit jam	Hero fruit jam
		Chocolate milk	AH Choc drink
	Snack	Coffee/tea/water	Any
		Fruit	Any
		Fruit and yogurt biscuits	Sultana YoFruit
	Lunch	Bread	Any
		Margarine	Low fat margarine 40% fat
		Chocolate spread	Nutella
		Apple syrup	AH Biologisch Appelstroop
		Yogurt drink	Optimel Drinkyoghurt 0% vet
	Snack	Coffee/tea/water	Any
		Fruit	Any
		Unsalted nuts with cranberries	AH Cranberrymix ongezouten
	Dinner	Spaghetti Bolognese	
		Water	
	Snack	Coffee/tea/water	Any
		Flavoured water	Spa Touch bruisend
		Rice cracker chocolate flavour	Rijstwafels met chocolade

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Appendix 2. Provided foods for the three dietary intervention groups.

LOW SWEETNESS EXPOSURE

REGULAR SWEETNESS EXPOSURE

HIGH SWEETNESS EXPOSURE

Figure 1. Intervention foods delivered on a biweekly basis including solid, semi-solid and liquid foods for the three exposure groups.

Appendix 3. Materials used during focus groups and interviews.

Moderator Guide.

Questions will focus on participants' beliefs about sugar and sweeteners, which would you choose to consume and why, your considerations towards natural versus artificial versus synthetic and non-caloric versus low-calorie sweeteners, your thoughts on reducing sugar versus sweetness intake, as well as your opinions on current and potential strategies to reduce free sugar intake.

Opening

Build rapport; help with voice identification during transcription. Broad; aims to access the general discourse on sweet-tasting foods.

- ➔ *Are there negative connotations to it?*
- ➔ *Do they feel like it is necessary?*
- ➔ *Are they frequent consumers?*

- o Everyone to introduce yourselves: name and favourite dessert
- o Tell me the most recent time you consumed a memorable dessert
- o What came to your mind immediately when I asked about 'sweet foods' or 'desserts'?

Introduction

Preference for sugar or sweetener.

- o Which type of drink is your favourite and why?
  - o Regular soft drink, diet soft drink, juice, etc.
- o When you consume foods and drinks, do you usually consume with sugar or with sweeteners? Why?

Sugar

Influencing factors for sugar consumption.
Opinions and/or beliefs towards sugar.
Influencing factors for sugar reduction.
Assess knowledge on current recommendations.
Thought-provoking to stimulate discussion; potentially generate novel/unexpected perspectives; cover what we might miss out
Opinions on current/potential strategies to reduce sugar consumption; link to next section.

- o Pertaining to sugar, can you share with me what factor(s) will drive you to choose to consume sugar over sweeteners?
- o What are the concerns, you have about consuming foods or drinks with sugar?
  - o Do you think there are any advantages or disadvantages to consuming foods or drinks with sugar?
- o Have you ever thought about cutting down on sugar? Why?
- o Are you aware of the health reasons for cutting down on sugar?
  - o Obesity?
  - o Diabetes?
  - o Tooth decay and loss?
  - o Will you cut down on sugar consumption for the above reasons?
- o If you had to provide a rough estimate, what do you think is the Public Health England recommended daily sugar allowance?

- 30 grams is the correct answer, which is roughly 7 sugar cubes. A single can of Coca-Cola contains 35 grams/ a 360ml bottle of Innocent 'Spark' smoothie contains 43.2grams/ a Starbucks signature hot chocolate in venti size contains 60grams (refer to print-out). How does that make you feel knowing it is about twice over the recommended allowance?
  - Does this new knowledge make you want to drink less of these sugar-sweetened drinks?
- A recent report stated that 2017 was the first time that bottled water sales have been bigger than Coca Cola sales. Why do you think people are switching to a water option?
  - Will you switch to a water option? Are there other options you will switch to?

(Time check: we have completed the section on sugar, we have three more sections to go ☺)

Sweetener

Preference for sweetened drink.
Assess knowledge on sweeteners.
[Influencing factors for sweetener consumption.
Opinions and/or beliefs towards sweeteners.
[Considerations towards artificial versus natural and non-caloric versus low-calorie sweeteners.

- Would you go for a bottle of water or diet soft drink? Why?
- Are you familiar with the variety of sweeteners currently available? (refer to print-out)
  - Natural versus artificial versus synthetic sweeteners, do you know what they are? What they are made from?
  - Do you know that there are non-caloric and also low-calorie sweeteners? Do you know which ones are which?
- Can you share with me what factor(s) will drive you to choose to consume sweeteners over sugar?
- What are the concerns you have, about consuming foods or drinks with sweeteners?
  - Do you think there are any advantages or disadvantages to consuming foods or drinks with sweeteners?
  - Do you ever consider potential health issues which could arise from long-term consumption of sweeteners? (Artificial or synthetic sweeteners?) If so, what?
- Do you consider artificial versus natural versus synthetic, non-caloric versus low-calorie sweeteners differently? How so?
  - Are you more concerned with one type over another?
  - Are you more motivated to consume one type over another?

Sweetness

Thought-provoking to stimulate discussion; potentially generate novel/unexpected perspectives on dietary sweetness versus dietary sugar consumption

➔ *is sugar or sweetness the issue?*

Potential barriers or support if we were to suggest strategies in the future to reduce sweetness in the diet.

- Given that both sugar and sweeteners seem to have their own sets of issues, do you think we should reduce the amount of sugar in our diet, or reduce the amount of sweet foods and drinks (regardless of source of sweetness: sugar or sweetener) in our diet?
- Do you think you will face difficulty in reducing sweetness in your diet?

(Time check: we are now down to the final section on strategies ☺)

Strategies

Opinions on current and potential strategies to reduce free sugar intake.
How to deal with the dilemma of sugar or sweetener; desired strategies in the future to reduce sweetness in the diet.

- Going into reducing the amount of sugar in our diet, what do you think would be the best method for trying to reduce sugar consumption?
    - Product labelling like traffic light system or "low sugar"? Do you trust labels?
    - Scare tactics? (refer to print-out)
    - Regulations similar to those placed on cigarettes and alcohol?
    - Education? Particularly in schools and/or workplace?
- The sugar tax is one method. "A 20% tax on sugary drinks would prevent 3.7 million people becoming obese in the UK over the next decade." (refer to print-out) What are your initial thoughts when hearing this quote?
    - What effect do you think this will have on the consumption of sugary and sweetener products?
    - Do you think it should be manufacturers or consumers that should pay the soft drinks tax? Why?
- Chocolate bars are shrinking in size and drink manufacturers are reducing their sugar amount due to the taxes, have you personally noticed these changes when consuming these products and what effect has it had on your shopping behaviour?
- How do the words 'diet' or 'zero calories' impact your choice of beverage?
- Do you think strategies/policies/recommendations should be about replacing sugar with sweeteners?
    - Earlier on, some of you think that we should only reduce sugar intake, while some of you think that we should reduce sweetness in the diet, regardless of source of sweetness. What societal-changes or methods do you think will be beneficial?

Conclusion

Influencing factors for sugar or sweetener consumption.
Ensure accuracy of moderator's understanding.
Allow for anything relevant that has not been covered to be addressed.
Possible perspectives (subjectivity) on this topic that may inform analysis.

- Of all the things we discussed, what to you is the most important factor in deciding to consume sugar or sweetener?
    - If health, which aspect of health (illness like diabetes, or weight management, or dental health etc.)?
- With all things considered (like taste, health, accessibility etc.), which would you prefer to consume the most and least?
  (Change of) preference after focus group discussion
    - if sweetener – specify natural/artificial/synthetic/non-caloric/low-calorie
- (Give a brief oral summary) Is this an adequate summary?
- Is there anything which has not been discussed that you feel strongly about and would like to bring up now?
- Can you share with me why you decided to participate in this focus group?

Thank you very much for all your input.

Figure 1. Recommended free sugars intake per day by Public Health England, and sugar contents in popular drinks, all portrayed with number of sugar cubes (The Coca-Cola® Company, 2020; Innocent Drinks, 2019; amended from Newman, 2020).

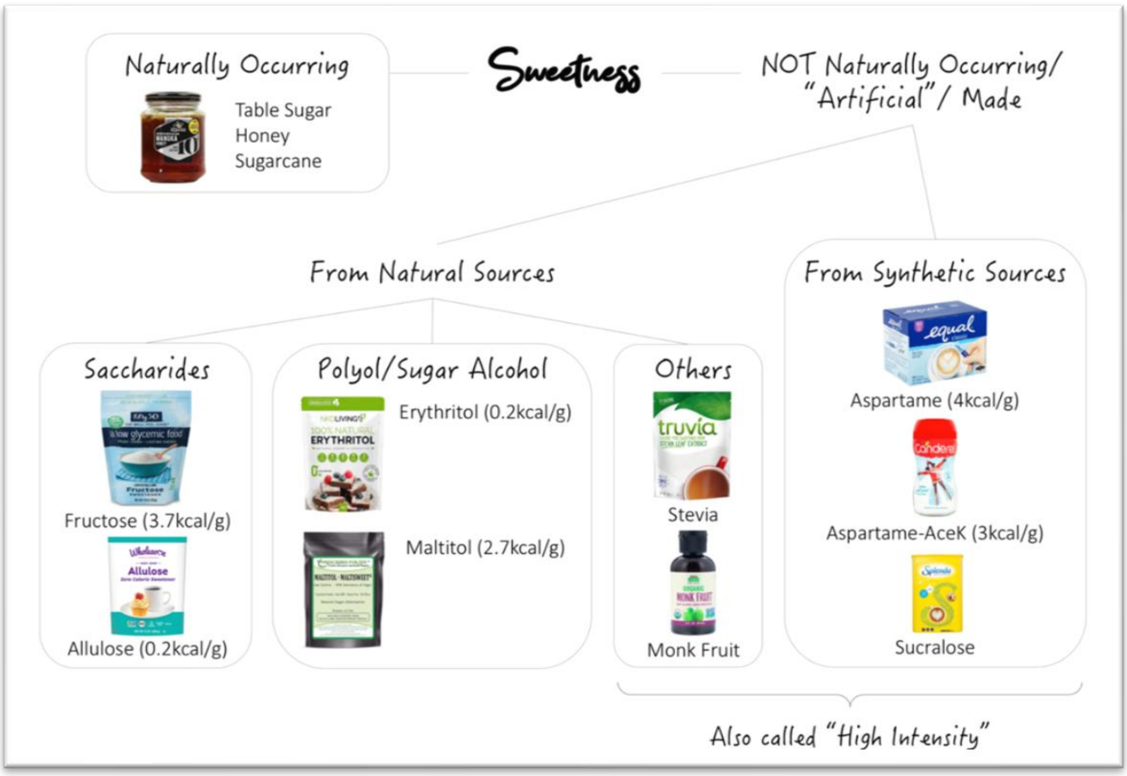
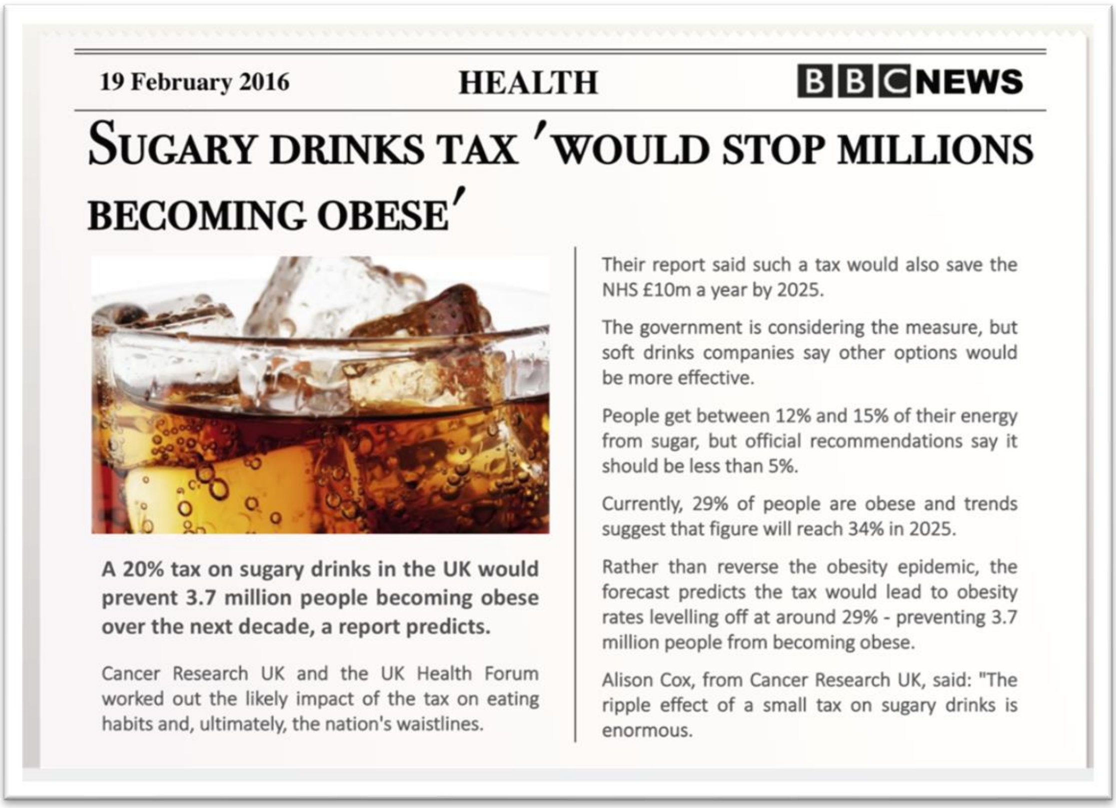


Figure 2. Various sources of sweetness (Fifty50® Foods, 2020; NKD Living, 2018; NOW® Foods; 2018; Prescribed For Life, 2018; Rowse Honey, 2020; Splenda®, 2019; The Truvia® Company, 2016; Equal, 2018; Canderel®, 2019; Wholesome Sweeteners, 2019).

Figure 3. Examples of what plain packaging can look like on products containing sugars (Britcliffe, 2012; Depositphotos Inc., 2012; Habbick 2013; iStock, 2017).



19 February 2016 HEALTH BBC NEWS

SUGARY DRINKS TAX 'WOULD STOP MILLIONS BECOMING OBESE'

A 20% tax on sugary drinks in the UK would prevent 3.7 million people becoming obese over the next decade, a report predicts.

Cancer Research UK and the UK Health Forum worked out the likely impact of the tax on eating habits and, ultimately, the nation's waistlines.

Their report said such a tax would also save the NHS £10m a year by 2025.

The government is considering the measure, but soft drinks companies say other options would be more effective.

People get between 12% and 15% of their energy from sugar, but official recommendations say it should be less than 5%.

Currently, 29% of people are obese and trends suggest that figure will reach 34% in 2025.

Rather than reverse the obesity epidemic, the forecast predicts the tax would lead to obesity rates levelling off at around 29% - preventing 3.7 million people from becoming obese.

Alison Cox, from Cancer Research UK, said: "The ripple effect of a small tax on sugary drinks is enormous.

Figure 4. An actual BBC News article illustrated as a newspaper clipping (Gallagher, 2016; Thinkstock, 2016).

Appendix 4. Definitions and quotes of each theme and sub-theme.

Table 1. Definitions and quotes for each theme and sub-theme.

Value | What sweet-tasting foods, sugar and sweeteners can provide.		
Taste	The sensation of sweet-tasting foods, sugar, or sweeteners	"It still has to taste good I think that's the thing." (DI1, P2) "Does the natural, yes I definitely consider them? Um, it obviously comes down to taste? Um I probably want and, get it and make put it in my own recipes and see how it (pause) changes things from having sugar in them?" (FG3, P3) "And the taste of soda is better when is with sugar and if is (pause) if there's no sugar, then is isn't worth drinking it." (FG2, P3) "The taste, sweeteners are disgusting (laughs) in my opinion they taste very different and I, I don't like it." (I1, P1) "You wouldn't think that would be drinkable! Would you. You'd think it would just be so over sweet!" (FG7, P4) "I just don't like sugar in my coffee but that's about it. I do eat sugar all the time, so (laughs)." (FG2, P6)
Pleasure	The enjoyment and satisfaction derived from experience with sweet-tasting foods, sugar, or sweeteners	"The fact that people just enjoy th- their drink, with sugar. Is just that is something that you cannot change because some people most people, to be fair, don't even care about the (pause) Health impact." (FG2, P6) "They just, just lookin' at them they come in a lil plastic box. Just don't like the look of it I just don't like the idea of it? Um (pause) yeah I don't use sugars, um in my coffee anyway I and I don't cook so, um (pause) yeah I don't really have a sugar in my in my house. But um, if I had to, I'd go for sugar not a sweetener I just don't like the look of them I don't know. Just look like little pills (laughs) something puts me off." (FG1, P4) "Let's say we're not gonna have cake anymore because you can't make cake without either sugars or sweeteners alright so, if we get rid of both those things there's no more cake. (pause) To me, th- the life is too short, to do away with, good things in life." (DI1, P2) "When you love something, you can-not let go, right? (laughs) You will make excep-exceptions for the thing that you really love." (FG2, P3) "I always go full fat, full sugar. You know if, again is about taking responsibility. If you decide to put something in your mouths, you want to have an experience of it. It's it's fine, with it. Just take th- the real thing as opposed to artificial things and, just eat less of it and just appreciate what you have!" (I1, P1) "Although I do like a Jager bomb… Yeah so if I'm going out then it's a bit different, but all my inhibitions go out the window and I just let loose if I'm drinking." (FG6, P2)
Special	Not an everyday affair with sweet-tasting foods or sugar	"That taste of Cadbury's chocolate? Um… it it just relaxing. It feels like a treat." (FG3, P3) "But for me I would rather not buy diet or reduced sugar things I would make the sugary things more of a treat and have less often." (FG7, P3) "So I never really (pause) m-my mom's always been sort of health, conscious so we (pause) it's probably bad on a Sunday night we

		used stop off at this local shop, and just get so much. So many sweets and (pause) and, bad things but. Yeah and just our day to, to have that and that was after we'd, been on, been round to my grandparent's for Sunday dinner so it was, sort of like our, cheat day y'know? But (pause) yeah I don't do that, too often." (FG1, P1) "Yeah about it being novelty? When coke you know and all those, sugary drinks. Yeah. When they became novelty and everybody wanted, to have it type of thing and, it wasn't so readily available before so everybody jumped on the bandwagon really." (FG1, P4)
Emotion	Sentiments and feelings derived from sweet-tasting foods or sugar; influence of mood on intake	"For me I think happy uh like this sounds weird. But like happy thoughts? I'm like, pudding is a good thing." (DI1, P2) "I think that in the psychology aspect? Uh some people looking for sweetness when they are sad or depressed." (FG2, P2) "It makes me happy and that's all I care about so (laughs)" (FG2, P6) "Yeah like I don't really mind, I would rather be a bit curvy and happy and enjoy what I eat rather than obsessively worry all the time and restrict myself of things that I want." (FG6, P1) "When I drink juice? I always feel much more healthier." (FG2, P4) "It depends yeah, depends on the mood." (FG4, P4)
Worth	Weighing of cost and benefit, for sweet-tasting foods, sugar, or sweeteners	"And they had this coffee cake or whatever (pause) on fifty percent off. So I thought I'll have that. And uh, yeah of price. Price. And it was a pretty big slab." (FG1, P2) "I maybe care about the price! Rather than discriminate between sugar and sweetener." (FG3, P1) "it's to understand what the health benefits if there are any or there are, and I assume there'll be a cost impact as well? And then it's not like we're running out of sugar? (laughs) So, it's not gonna help the planet. So I need to an angle to really think why why would I want to, change and if (pause) if I saw in, products that are on sale? (pause) I would look it up first and think okay, again why? And then I'll think about it." (FG3, P3) "Yeah I associate it to weight loss and it's better when I'm counting calories." (FG6, P3) "Let's say you need uh, a a boost for, the energy boost you can get but you can get it in other ways but (pause) uh sort of nutritionally as far as I understand there's not much benefit to (pause) unlike sh- salt, where people need, a little bit of salt in their diet." (FG1, P2)

Angle | Negativity surrounding sweet-tasting foods, sugar and sweeteners.

Disinterest	Indifference towards negativity surrounding sweet-tasting foods, sugar, or sweeteners	"Yeah, balanced rather than just the sugar or just the fat but you know, in order to keep ourselves healthy. We need to do this. we need to have that. we need to sleep. We- a package rather than (pause) sugar." (FG3, P1) "Like I don't think it's necessary in this case but I mean, personally, yeah I-I'd I have some biscuits, I'd chocolate here and there, and (pause) ... (pause) there are- so what I find myself, doing (pause) is, a chocolate bar is a chocolate bar and, you can get one without sugar if you want, but I don't go around looking for that particularly. (pause) Uh so when I have one I have one." (FG1, P2)

		"I think people do have do have sugar just because they like it but if they didn't have to have it, they wouldn't, have sort of withdrawal symptoms and, and what not, from, from not having sugar." (FG1, P1) "I don't think that it's necessarily is uh (pause) I don't think it's necessarily the case that because something we can label it and call it uh because it is and we call it artificial or synthetic, it is necessa- that necessarily means, that it is (pause) less uh or, it's not as good or it is worse than something natural." (FG1, P2) "To me, eating sweet things, is just, quite normal! Um I-I don't necessarily look upon it as a treat. It's like I fancy something sweet, I'm gonna have that." (FG3, P2) "N-nothing really comes, comes to my mind (pause) cause I'm not always thinking when's my next, cake coming or something (pause) so it's not, really I don't really have a (pause) it doesn't mean I don't enjoy it sometimes when I have it but." (FG1, P2)
Disfavour	Serious and strong negativity or disapproval towards negativity surrounding sweet-tasting foods, sugar, or sweeteners	"Yeah I think we mainly covered the (pause) um, so for example, both the sugar, table sugar and artificial sweetener, they're both artificial." (FG2, P5) "I think I think people need professional help! You know for sugar? Cause of the fact that I've I- I- y-yeah. I think she's right. It is a drug (pause) and when I when I need, I need it. It's not like (pause) uh, oh I should have a cake, oh I shouldn't have. It's more like, I NEED A CAKE… So yeah I feel I feel (inaudible) education, but I think people are not really aware of the fact that it is quite addictive? And it it is quite, um harmful to your body? It is important but also professional help, might, yeah. Help people." (FG2, P6) "Sugar's a highly addictive substance." (FG1, P2) "And that's the one that, a couple of years had a lot of bad press. Alright and it was like, y'know people were saying oh it can cause (pause) illness like serious illness something as even like people were saying like… It can cause, cancer and all those kinda stuff." (DI1, P2) "It's delivered, to refineries in, in tankers with the skull and crossbones, symbol on it… Because of the chemical contents within it." (FG3, P2) "Yeah I think there's chemicals in them um (pause) same what they put in diet, um things so I just stay away from it, d- yeah it puts me off." (FG1, P4) "You're just basically fooling your brain into like, your body's like having sugar but it's not actually? So it's actually making everything worse? (pause) So that's what I heard." (FG2, P6) "Yeah because you kinda get addicted as well to the sweet taste you know? Um, I think if you are on a, low-sugar diet for a- awhile, even for a week and I've heard that from, from people you know once they go back, and go back to their normal diet, everything taste so much sweeter and I think it's just, our brain kind of get ad- not addicted but used to it." (I1, P1) "They're consuming things, and probably getting hooked onto a taste (pause) without really realising it. Um and then it's difficult for them to shake that off as they get older." (FG3, P2)

Relativity	Whether sweet-tasting foods, sugar, or sweeteners are good or not, is relative to what you are comparing it with	"The reason I don't pick diet is because I heard about aspartame and I've heard people get tumours. It might be a myth thing but both options are bad and it's better to do better the devil I know than I don't." (FG4, P1) "Um, the fact that it's more naturally processed. So I would, go, on sugar rather than sweeteners just because it's, it's less processed really. (pause) So you know, the less, th-th-the less processed it is the better. I think it is, for me." (I1, P1) "Yeah I go for normal as well, I really hate the taste of diet stuff and I think it's more natural even though it's probably still not good for you." (FG4, P4) "Advantages? As in you're getting the sweetness without the sugar." (FG5, P1) "It's just if you'd like the sweet taste. Like my dad for example, has sweeteners in his tea and coffee, as he couldn't have a coffee without anything in it. He chooses a sweetener over sugar as he feels it is healthier for him. (pause) Oh I guess if you have got for example younger children or even yourself who massively react to sugar and you notice a change in their personality then maybe sweeteners would be better in that situation." (FG7, P4)
Personal Relevance | To be concerned personally and/or to change one's own behaviour.		
Health and Body Image	How a person thinks he/she looks in terms of body size and skin; how healthy a person thinks he/she is	"I am eating way too much sugar. but I'm also doing way more exercise than the average person (pause) I would say average. Um (pause) so is there actually a link? Am I actually safe to eat the amount of sugar I'm eating or is there actually a problem and I shouldn't be? I don't know the answer to that but because, I'm not having any problem as you were saying as well. Then you know, th-there's nothing to spur you to change..." (FG3, P3) "I think it depends on, on the individual! Because I do think they-they have theor (pause) advantages if, if you take someone that is (pause) morbidly obese (pause) would you be more concerned about the chemicals that you're puttin' in their body? Or if the sole aim for them would the most important thing factor was them to lose weight, (pause) then perhaps uh (pause) a sugar alternative might be the, the best solution in that (pause) in that case? If they were tryin' to lose weight, because they were at risk of, some kind of serious heart disease or something?" (FG1, P1) "There's a lot of messages around and I think now, there's more of an emphasis on (pause) people (pause) lookin' at it thinking right what do I do? But th-then some people think that'll never happen to me. Whoosh! Shall eat what I want." (FG3, P1) "Nowadays (pause) well I am aware of (pause) like sugar-related issues health issues. Um but I don't think I eat so much sugar that I should (pause) cut it down? Uh I would say that nowadays, my (sigh) food, um (pause) i-if I was to change, anything, it would be (pause) related to fat rather than sugar? (pause) I think?" (FG1, P3)
Generation and Age	Whether a person identifies with being a child, a	"I do, for the children? (Laughs) [But, not (laughs) but not for ourselves!] Not for ourselves yeah." (DI1, P1 and P2) "Um, so I think also (pause) embeddin' and implementin' education that type of education into schools would be really, helpful cause,

	youth, an adult, or an elderly; belonging to a "younger" or "older" generation	back then, there was nothing, nothing like that, say you don't even think about the implication of it actually w-what you doin', to your body? Um, but (pause) you know, as I got older, my you know, my -my taste changed and I don't crave sweets as much." (FG1, P4) "I do think it's um, (pause) needed in workplaces cause I think you've got a generation (pause) perhaps slightly older than us? So it may be into you- into your forties and fifties. Who, haven't had any awareness of any of this, haven't been really affected by kinda social media drives because they are not really a social media generation. So I think there is a, a generation above us, that is kind of like, I don't know kinda hang on, we-we've missed them and actually you could capture them with some workplace intervention." (DI1, P2) "For elder people I don't know like maybe, only for label, it's good for them because they know already, at their age. Because of low sugar is better for them. (pause) But for like um (pause) young age, have to like educate more. (pause) Yeah. Give information?" (FG2, P1) "But it isn't that bad for you, and children's brains are still developing but older bodies are not as affected by these chemicals but for young children to be drinking aspartame every day." (FG5, P1)
Socio-Economic Position	The measure of a person's economic and social class in relation to others; a combination of his/her income, education and occupation	"I'm sure someone somewhere has done this. (pause) But if you were to say okay who are the, leading consumers of foods and drinks that are high in sugar? I'm guessing we would find that it's the people that there are. Have less money." (DI1, P2) "I don't mean to sound judgmental but the people I see who usually consume high energy and high sugar drinks are usually people who look quite rough and poor." (FG6, P3) "It's got to be a holistic approach, because we are sat here as essentially comfortable financial group, but I think you have to educate the masses and peoples dietary budgets are very different. The problem is you can buy a burger king for two pounds against buying fresh fruit and vegetables which are much more expensive. Unfortunately, people are always going to default to the cheaper, easier option. Changes need to be made at the legislation level, hitting the source, who make it so readily available. We need to put more emphasis on the suppliers so that they take responsibility for it." (FG7, P2)
Stake	The involvement and interest in the process and outcome, of consuming or reducing sweet-tasting foods, sugar, or sweeteners	"You know, cause [participant name] sees it as a, a treat. Whereas I will kinda see it more as like a staple, like something you have every day. Yeah or, or at least more often than not. Maybe not every day. But more often than not." (DI1, P2) "Although there are a notable amount of people now who are kinda you know driving the healthy lifestyle, there is still a lot of people who are, you know, probably more in line with where I am, and slightly beyond, which is like pffttt! Yeah, if you make it easy for me maybe but I've got other fish I need to fry right now and I'm not gonna get there." (DI1, P2) "I don't use them. I mean (pause) since I don't add stuff anyway, I'm not um, don't add sugar or artificial sweetener." (FG1, P2)

		"No I don't have any problem like cause I don't have cravings for it so I'm, I'm good." (I1, P1) "I don't add sugar really to anything. (pause) and um, I, for me personally I wouldn't ever stop to think about whether a sweetener was good bad or indifferent I just don't use them so they're not really on my radar." (FG3, P1) "I feel like all of the things I prioritise in my shopping list low sugar isn't really (pause) something I would think of." (FG5, P2) "And maybe relating it to their experience for example if you're talking with people who are, very much into putting sugar in their coffee. You (pause) kind of shape your, education, based on that. Because they are interested in that one. If you talk about something else and if they don't already consume it they won't listen but if you relate it to their, experience they will listen." (FG2, P5)
Personal Responsibility | One has an active relationship with sweet-tasting foods, sugar and sweeteners.		
Informed Choice	The ability to understand each option and make the decision	"I don't think it works telling people these days, don't do this. (pause) Because you know, if someone said to me don't do that, I'd just gonna ignore you and do it. (pause) If someone said hey, I know you like that and that's fine. But just so you know, this is a better option. And this is better for you and here is why. But I you know what, I'd listen to that." (DI1, P2) "But until such point is I know, what are the sweeteners I can use and how they work versus sugar, I would still carry on with sugar until I have that knowledge." (DI1, P2) "It's so hard to identify these days what is really, bad for you what is not so bad because you have to go and read it all. You know um whether that would be an easier way to do it maybe that, would it be a step too far, could we do something in in between? But I think it would be beneficial to help consumers identify more easily (pause) what what's in food and (pause) what's bad for you." (FG1, P4) "There's a lot of (pause) questions about (pause) uh how far (pause) the difference between providing information about what people might want to do and actually trying to get them to do something else (pause) now I find that it's actually intervening in their, in their own private life, for example." (FG1, P2) "I think you have to be s-sort of consciously aware of the quantities and the (pause) macronutrients that's (pause) in a product. Um (pause) when you're readin' reading those labels and and trying to make a sort of, an informed decision on on what you then buy I think that I think that's one of the real issues?" (FG1, P1) "No I don't think so, but because I'm I don't know what's in it and I've never kind of I always never curious cause I always knew what's in the cube so I always use the cube. I guess it's it's kind of what you know about it and familiarity." (FG2, P5) "Because at the end of the day, its' a free world and and we cou we're all at liberty to make our own choices. But (pause) the information just needs to be. A bit clearer." (FG3, P2)

		"Yeah like it's education isn't it? But they can't just put that out there as, we think you should eat less without explaining why and who it affects and what." (FG3, P3) "I don't think that's (pause) that's gonna be an answer to take something and replacing with something else. So, as I said we don't know the effect long term of all those artificial sweeteners in our bodies as well! So why would you do that?" (I1, P1) "I think a combination would work well, like education and scare tactics would work together, because people would understand the reasons behind it rather than just being told 'don't do this'." (FG6, P3) "Yeah but at the end of the day if the customer wants it then surely they should pay for it? They aren't forcing them to consume it." (FG6, P1) "There should definitely be traffic light thing, it's good cause it's a rule and you can see it on everything and it's consistent over all foods, education need to be a simple rule so they can work out in the shop like you say you're not going to get your phone out if you're in a hurry." (FG5, P4)
Self-Regulation	Managing one's own consumption; modifying own behaviour such as intake or exercise accordingly	If I, yeah doing sport and I think oh! I can afford to, have a can of Fanta because. You know? I've just done three hours on the court!" (FG3, P3) "Um, if I've got something sweet in the house (pause) I'll eat it and that's possibly why I don't buy, that sort of thing from (pause) from the supermar- if I want something sweet, I'll get it." (FG1, P1) "The traffic light system, occasionally I'll, if I think I'll, all I'll measure it by is like adding up what's red in the sugar zone, I'll just go 'oh okay, that meal is mostly red for sugar so I'll make sure the other meals are not red in other areas' so I make sure it's like lower, a different colour for anything else I buy, and that they don't add up. I could be buying four fucking things in the red zone and be like 'oh yeah that's fine cause I've had like seven things in the orange or green'." (FG4, P1) "Well I buy basic cornflakes and cut up a banana really thinly and I never eat raisins cause they're unappealing I do that now cause I know I've got to eat more fibre and fruit helps it carry it through I have chocolate one or two times a week, not a big bar, it's going on average like I binge and then I don't touch anything for two weeks." (FG4, P1) "I really like home cooking so I don't like to buy things cause actually when you look at the content of sugar say in a, pre-made Bolognese sauce or something, it's really really high. Um (pause) and I uh (pause) so I-I like to like, just cook things like make them, from the ingredients, rather than using a tin of food or whatever or a bottle of food." (DI1, P1) "And I get them in bulk from those other things that I shouldn't have too much of? I kinda take them out of (pause) th- the healthier options." (FG3, P3) "When um this meal I drink water, next meal I will like, treat myself like have a cup of (pause) um soft drink? Yeah. (FG2, P1)

		"I try and balance it, some days I think I have way over two thousand but the next day I'll be healthier and have a salad or something." (FG6, P1) "And if I need to have one KitKat, I will have that KitKat because. It won't affect me that much. Cause it's just once a month or something." (FG2, P5) "I programme myself to like it too I think I'm used to it, a lot of people say they can't taste it but I don't really care, you get used to bitter tastes, like I've got used to black tea, I used to hate it and now I love it." (FG5, P1) "To be fair I started using honey instead of sugar in tea and coffee so I started doing that and it doesn't even taste that different. I bought sweetener for the first time yesterday, Canderal." (FG5, P2)
Internal Conflict	Struggling to balance out motives, feelings and behaviours; pull and tug between two opposing voices	"Whether I'll ever completely get away from it? I don't know. But I think I'd probably move towards, kinda the way that [participant name] has Innocent smoothies which is, you have them every so often, because it's nice. But it's not part of your staple day to day. Um, so I think it'd probably be more towards that I can't ever act- can't see myself ever completely ditching it?" (DI1, P2) "I honestly don't know because I do eat a lot of sugar (laughs) So, uh removing from my life I think that would be very very challenging for me." (FG2, P6) "Some of the time that will be a fact that people (pause) are gonna consider when going to cause if you say oh it's the same you think, do I want to be healthy? Or do I not? But I, don't know what that is, thirty pence cheaper?" (FG1, P1) "Let's say we're not gonna have cake anymore because you can't make cake without either sugars or sweeteners alright so, if we get rid of both those things there's no more cake. (pause) To me, th- the life is too short, to do away with, good things in life." (DI1, P2) "Yeah or a bit of fruit but I don't always want a bit of fruit, I don't want that sort of sweet I want a bit of naughty sweet." (FG5, P3) "You feel you being demonised cause actually you deserve that treat cause you've worked for it." (FG3, P3) "I do crave fizzy drinks, but like, and I know they're bad, and I try not to do it that much but like, I don't really care even though I know they're bad, cause I want it." (FG4, P4) "Yeah I definitely have, I know I eat too much sugar, I'm always trying to go on a diet but I usually end up back at square one as I give in too easily." (FG6, P1)
Motivation	The extent of the drive or desire that stimulates behavioural change	"Well for sure the educating the people but sometimes you know no matter how much knowledge you have it's more about changing the behaviour." (I1, P1) "It's more about a caring for yourself. Rather than oh I don't want to do that because it's gonna be bad." (I1, P1) "Yeah. Um but there is a lot of temptation around us all the time everywhere um and I guess, it's um it's just making small adjustments and, and maybe different choices rather have a piece of fruit, um instead of a biscuit or, something like that." (FG1, P4)

		"Yeah I agree, there seems to be a sudden health kick in our generation and everyone is trying to be healthier than each other, it's actually quite competitive I guess." (FG6, P2) "I lack the willpower, at the moment to do it. I think this stage of life we're at at the moment, with two young children, where you're constantly tired. And I know, the answer to get natural energy and all the rest of it, is to eat healthily and do exercise. But when you're coming off the back of about two hours sleep, you don't really want those things." (DI1, P2)
Understanding | Acquiring, comprehending and applying insights sweet-tasting foods, sugar and sweeteners.		
Delivery of Information	How information on sweet-tasting foods, sugar, or sweeteners is disseminated and received	"Catchy infographics, I find those really, like impactful advertising, just on visual, you know when they have like heaps of sugar to display to everyone on those stupid diet programs, to be fair that is more impactful than the traffic light system." (FG4, P1) "But, so basically all those packaging, like they mostly use like bright colours like red and stuff. I think that's kind of like sending that sort of, um, yeah. Idea to your brain that that you should be that that is kind of, you know attractive. For the consumer, that's how it's designed." (FG2, P6) "I think schools do quite well, because my kids are a lot more aware of sugar than we ever were when we were kids. They even asked me to put an app on my phone where you can scan food bar codes and it tells you the number of sugar cubes in it." (FG7, P5) "The news and stuff the press has been released about it. But I just know, there is a negative undertone." (DI1, P2) "Where's you said the World Health Organisation uh where, um I mean, you know (pause) presumably the the the broad sheets would have it but where else would you get uh a World Health Organisation message?" (FG3, P1) "I think more of, th-the leaflets visual leaflets like that you know, if if they were put around schools or organisations you know to actually have a visual because, you don't really think about that? When you havin' the drink while you don't realise that necessarily? Um, so it-it makes you realise? It-it's there in your face?" (FG1, P4) "People are heavily influenced by their parents so maybe also (pause) gettin', well yeah. Just you tackle it at every angle I guess. Schools, parents, workplace." (FG1, P1) "What was interesting to me was when Jamie Oliver went into schools and he said to the kids choose your lunch. He then said to them before you can eat this you need to burn off the calories around the running track that this food contains. I thought that was brilliant for visualising how much they have got to do to burn off their chosen food." (FG7, P2) "The news media pack up on the headline and they don't really fully explain it and everybody just sees the headline and (pause) and and (pause) just changes habits, sometimes unnecessarily." (FG3, P2) "How do we get our information and how much time do we spend and where do we get reliable sources about you know just, you have somebody on the internet who's an influencer or whatever

		and it has in the background a bottle of something uh and you know and there's people looking at that how do we choose our reliable sources to find out about these things so, it takes a lot of time and uh you'll have to look at these things and spend time, really trying to understand." (FG1, P2)
Awareness	A general knowledge of, being conscious about, sensing issues related to sweet-tasting foods, sugar, or sweeteners	"When people talk think about sugar, they think about like adding sugar to tea, or you know, coffee and stuff like that maybe, some cookies, cakes, sweet things. And they don't realise how much sugar is in (in overlap) other type of food? So they they, they (pause) you know they- they they eat so much (pause) like, processed food." (FG1, P3) "In the sort of the whole process of promoting a balanced diet, then (pause) it's not necessarily, just about (pause) uh cutting down on sugar cane cutting down on coke because it's got too much sugar in it. It's about an awareness sort of. (pause) all the other products that don't look like sugary products." (FG3, P2) "Yeah yeah I think people are wisening up because information is out there in a way which is more accessible, not just kinda studies going on behind everyone's back." (FG4, P1) "If you had asked me two years ago I would have assumed if it was labelled no added sugar then it would have no sugar in it. It is only more recently that I suspect sweeteners have been added." (FG7, P4) "Yeah I have definitely cut down, I put on quite a lot of weight a few years ago and I made a conscious effort to change my diet and I lost quite a lot of weight, it was definitely related to how much sugar I consumed." (FG6, P2) "Thing is I feel like I don't really understand it but I always go for low fat or low sugar or no added sugar like I would always go for that if I had a choice." (FG5, P2) "But people are so oblivious to it and there's no stuff on the news about it like with kids you need to cut back because parents just don't really realise how bad it really is for children when they just give them sweets and stuff." (FG5, P3) "Also I don't think people are aware of the damage that they are doing to their health because there's so much out there, or maybe people just turn a blind eye to it." (FG6, P1) "I know that it's generally considered bad for you but if, you wanted me to go into specifics before you answered that truthfully, I couldn't have given you, the specifics other than saying I know it's bad for me on a general level." (DI1, P2) "I think instead of preventing it, they should encourage them and then help them see other options other than saying oh this is too expensive you can't buy it now... Cause I've seen it, after Brexit, in some shops (pause) For example there's a certain thing, sausage or whatever I buy, and there's five or ten p difference. People don't realise is just because I always buy that one, I will realise. But I won't know the reason behind it. I will just assume it's Brexit. But it might be, the sugar tax in that sausage. (pause) You don't know." (FG2, P5)

Perception	The way one interprets or regards information related to sweet-tasting foods, sugar, or sweeteners	"But brown rice is better for you so surely brown sugar is." (FG5, P2) "It doesn't count! Cause it's a drink!" (FG1, P1) "Well the key is, is when they follow it with the word drink… because there's orange juice (pause) drink, then its' like uh oh [it's got something else]." (FG3, P1 & P2) "It's a natural fruit. It's a natural sugar! It's natural sugar I think it's different sugar." (FG1, P4) "I mean, the general idea of sugar like I know uh glucose, fructose, like um lactose, like all the, um types of… Yeah where you get sugar from. And for example some of them your body doesn't produce and, um so you need to get them for example glucose, and things. But I don't know about the general sweeteners." (FG2, P5) "If I have the chance between sugar and honey? Yeah I will choose honey because it's natural." (FG2, P2) "Uh, so if you have like (pause) wholemeal food, it contains different types of sugar different types of carbs, (pause) as compared to fruits. Cause th-the fruit, um, they contain a lot of glucose and fructose which are like, simple sugars?... i-in fruit you-you've got th-th-the type of sugar that you actually use quite quickly?... So uh (pause) as compared to, let's say, whole-grain, um (pause) pasta or whatever, which also contains a lot of (pause) carb, that's that is a different type… from what I know, it's for your health, it's better to eat vegetables, rather than fruits? Or grains? If you if you need carbs. If you need this type of uh (pause) thing. It's better to eat grains or y'know cereals, without, added sugar. Uh, rather than fruit?" (FG1, P3) "Oh yeah white is so bad for you, they have to bleach it and put sugar in it." (FG5, P2)
Proficiency	The deeper knowledge and expertise in matters related to sweet-tasting foods, sugar, or sweeteners	"Thing is they're always like no added sugar but I didn't realise as soon as you blend fruit that your body treats it as white sugar, out the packet, and also like if you made a smoothie with like two bananas, one apple, that would only count as one of your five a day, as soon as you blend it the sugar becomes free radicals or something and your body just treats it as sugar." (FG5, P2) "It's a lot of lack of education in, like, knowing that actually if you, cook a tomato sauce or something like the sugars within the tomato, or you know there's a, the fruit and food and vegetables have, naturally occurring stuff in them. So you don't actually need to add, anything to it. So you will still get a feeling of like oh like in a cake you could add some banana or something, and you get some sweetness instead of (laughs) instead of adding sugar you know there's lots of things like that." (DI1, P1) "The addition of sugar on proteins (inaudible). You know, um help cancer cells to, (sigh) um metabolise certain uh things such as collagen for example you know when if the cancer cells can degrade collagen better. They um, they can go from one tissue to another so that's uh, that's for example. An example of study." (I1, P1)

		"People just don't realise it's not only about like, sugar cubes or something like that." (FG1, P3) "I feel like coke is the drink where people are very educated on, like everyone knows it's bad." (FG5, P3) "I think a lot has been done to educate people on sugar, but there seems to be no education on sweeteners and what they are." (FG7, P4)
Reasoning	To apply logic while processing information, in order to form inferences about sweet-tasting foods, sugar, or sweeteners	"There's a lot of messages around and I think now, there's more of an emphasis on (pause) people (pause) lookin' at it thinking right what do I do? But th-then some people think that'll never happen to me. Whoosh! Shall eat what I want." (FG3, P1) "Yeah like I don't know what to believe any more because there are so many of this fad diets and all that I like don't know who to trust." (FG5, P4) "I think you might be replacing one bad thing with another bad thing!" (FG7, P1) "I think my concern would be if people, mis-interpreted the message that said sweeteners are okay, and sugars are less okay. People might think, well I won't bother exercising now and they think then if if I just turn to sweeteners." (FG3, P1) "I would buy, the normal one? But just eat less? Probably? So if if I if I (pause) did buy, a lite version of something I would probably (pause) be thinking that okay I can eat more because it's lite?" (FG1, P1) "How do we get our information and how much time do we spend and where do we get reliable sources about you know just, you have somebody on the internet who's an influencer or whatever and it has in the background a bottle of something uh and you know and there's people looking at that how do we choose our reliable sources to find out about these things so, it takes a lot of time and uh you'll have to look at these things and spend time, really trying to understand." (FG1, P2) "I-I think it's something complex debate about, just because something technically could be called natural whether or not that it is it's actually is more beneficial (pause) than something that was (pause) i-in effect (pause) cooked up in a lab, that doesn't necessary follow that that's better than that, simply. Bu-but it's quite a complex matter." (FG1, P2) "I think maybe if you suffer from diabetes or something like that there are possibly some sweeteners that are better for blood sugar regulation, I don't really know. Yeah, I think that would maybe be an advantage, but from my point of view, someone that doesn't have a condition, I don't see any advantage." (FG7, P3) "But is this being considered? Because what now what I'm thinking is, um obviously uh there're other stuff that are quite (pause) you know, not so beneficial even harmful, uh in the shops. So it's not just bout sugar, but if we actually, go for this, these regulations in terms of what every single thing we eat (pause) then it would be the end of an era. Of marketing and brands and everything." (FG2, P6)

It's Not Up to Me | One takes a passive approach towards sweet-tasting foods, sugar and sweeteners, because intake is subject to other factors.

Beyond Individual Control	Factors beyond the control of an individual, including external influences	"They probably just have one, so they make that choice for you really, in terms of sweeteners." (FG1, P4) "Fair enough if you're big and you're top of reasonable BMI and that's the way, like I know someone who's got a thyroid problem and it doesn't matter how clean she eats she will put on weight and she'll go running every week but she's still a big woman and she can't help it, probably really depressing and crappy on their self-esteem." (FG4, P1) "But also, it depends on your, previous experiences. For example. Up your upbringings, what they drink what they eat. And then you see what they eat and you do the same so." (FG2, P5) "Yeah as a kid I had way more sugar than my children have now. Every time I was picked up from school or play group my mum would give me a bag of sweets. Golden syrup on my porridge." (FG7, P3) "I think we're lucky in this country as well cause I've travelled a lot and m- orange juice for example over here (pause) if it says natural, pure orange juice it is a hundred percent pure orange juice in America for example, you try finding orange juice, That doesn't have added sugar (pause) it used to be very hard they are getting better but they used to be yeah. Not available!" (FG3, P3) "Yeah but at the same time you might want baked beans but you're not asking for all the extra added sugar which has gotten has increased drastically over the years like it didn't used to have that much sugar in it, and you can't really get ones without the enormous amount of sugar in it and that's not necessarily their fault, baked beans are supposed to be healthy for you, it's the manufacturers' fault for putting that much in there in the first place." (FG5, P1) "I think the nation is starting to become a lot healthier in general, like I'll admit I used to be someone who would always buy a fizzy drink, thinking about it now I don't really know why but I always did, now I rarely even look at them and I usually buy water." (FG6, P1) "I think people need professional help! You know for sugar? Cause of the fact that I've I- I- y-yeah. I think she's right. It is a drug (pause) and when I when I need, I need it." (FG2, P6) "I think the trouble is, I only noticed it when I went on a sugar-free diet, is that you don't realise how accustomed your palate is to sweetness. So with ketchup and other things like that you wouldn't imagine are loaded with sugar they are. You don't realise how your palate has become accustomed to such a sweet taste in everything and then when you remove the sugar completely everything becomes so bland." (FG7, P2)
Strategies and Regulations	Legislations; official large-scale measures put in place	"I think some places they (pause) cause it's less (pause) you sort of automatically get th-the diet? Because it's cheaper? As opposed to getting I think if you asked for, a coke they almost I-I don't know how true this is." (FG1, P1) "You know, if it's really a health issue problem, it has to be you know, peep-people can't take responsibility most of the time, so

		you know that's, that's a lot to do with that! You know, teaching people how to take responsibilities… But, at the end of the day, you know, if that doesn't work, is like people are children you know, you have to tell them off and the only way is punishment! Isn't it?" (I1, P1) "It's a government's responsibility to make sure companies are in like, and if there's a UK health crisis aa best method of treating best method of disease or not is prevention, so you need to, you need to set the standard, you can't just rely on people to know what's best for them." (FG4, P1) "IF there were more taxes which manufacturers had to fork out for then maybe they'd actually stop filling their products with so much sugar, that's the message which is trying to be achieved at the end of the day." (FG6, P2)
Deception	The idea of traps, tricks or temptations by manufacturers; distrust of food industry	"I think people don't really think about what they're putting in their shopping baskets, there's so many brands of the same stuff and so many adverts, it's easy to fall into the trap of buying things rather than sticking to a plan/shopping list." (FG6, P2) "I think it's sneaky how much they put in stuff, it can be hard to stick to your plan or keep things in moderation when companies load things with sugar and fat." (FG6, P3) "Some big companies are being um getting paid by some of the big companies to the doctors and they are giving kind of (pause) prejudice or kind of biased advice? So you shouldn't always trust the professionals as well. I just like, do some research, ask people, what are their opinion, and stuff. So don't just go to professionals." (FG2, P5) "Well I'm a cynic with this kinda stuff and I work in marketing. So (pause) y'know, I know first-hand, that, it is spin city you know? Everything is being spun. So it's just that oh no sugar, uhhuh? What else is in it then? Because I'm tasting sweetness somewhere, and unless you're some kind of magician, you've put something in it to make it sweet, so you saying no sugar it's just like okay, well how're you harming me (pause) somewhere else?" (DI1, P2) "Cause obviously they're not allowed to lie on the tables but I feel like they deliberately make it confusing cause obviously it's in their interest that you don't understand." (FG5, P2) "I feel tricked, how much was there already if there's no added sugar." (FG5, P4)

Appendix 5. Questions per sub-theme and per food item.

Six themes, 24 sub-subthemes → 38 statements

A total of 82 questions: 23 questions focused on sweet-tasting foods (SF), 29 focused on sugar (SU), 26 focused on sweeteners (SW), and 4 focused on both sugar and sweeteners.

Theme 1: Angle | The approach to view sweet-tasting foods, sugar and sweeteners. **6 statements: 3 sweet-tasting foods, 6 sugars, 6 sweeteners (15 questions in total)**					
Sub-theme	**Definition**	**Questions**	SF	SU	SW
Disinterest	Indifferent towards sugar/ sweeteners/ sweet foods	People are too concerned about cutting down on __. I feel indifferent towards __.	✓ ✓	✓ ✓	✓ ✓
Disfavour	Negativity and disapproval towards sugar/ sweeteners/ sweet foods	Adding __ in food products is unnecessary. __ is physically addictive.	 ✓	✓ ✓	✓ ✓
Relativity	Whether sugar/ sweetener is good or not, is relative to what you are comparing it with	__ is not as bad as fat for your health. __ is worse for your health than salt.		✓ ✓	✓ ✓
Theme 2: Personal Relevance | The presence or absence of reasons to personally be concerned and/or change behaviour. **5 statements: 5 sweet-tasting foods, 5 sugars, 5 sweeteners (15 questions in total)**					
Sub-theme	**Definition**	**Questions**	SF	SU	SW
Health and Body Image	How a person thinks he/she looks in terms of body size and skin; how healthy a person thinks he/she is	My health or body image will determine whether I modify my __ intake or not. Only people with obesity or diabetes need to modify their __ intake.	✓ ✓	✓ ✓	✓ ✓
Generation and Age	Whether a person identifies with being a child, a youth, an adult, or an elderly; belonging to an "younger" or "older" generation	Desire or need for __ changes with age.	✓	✓	✓
Socio-Economic Status	The measure of a person's economic and social class in relation to others; a combination of his/her income,	*Demographic questions on level of education and employment.*			

	education and occupation				
Stake	The involvement and interest in the process and outcome, of consuming or reducing sugar/sweeteners	I want to reduce my intake of __. I tend to crave ___.	✓ ✓	✓ ✓	✓ ✓
Theme 3: Personal Responsibility | One has an active relationship with sweet-tasting foods, sugar and sweeteners. **4 statements: 3 sweet-tasting foods, 4 sugars, 4 sweeteners (11 questions in total)**					
Sub-theme	**Definition**	**Questions**	SF	SU	SW
Informed Choice	The ability to understand each option and make the decision	I put little or no thought into my consumption of __. My choice and/or consumption of __ depends on how much knowledge I have of it.	✓	✓ ✓	✓ ✓
Self-Regulation	Managing one's own consumption; modifying own behaviour such as intake or exercise accordingly	When I consume ___, I balance out my diet through exercising and/or eating other healthy foods.	✓	✓	✓
Internal Conflict	Struggling to balance out motives, feelings and behaviours; pull and tug between two opposing voices	I feel guilty whenever I consume __.	✓	✓	✓
Motivation	The extent of the drive or desire that stimulates behavioural change				
Theme 4: It's Not Up to Me | One takes a passive approach towards relationship with sweet-tasting foods, sugar and sweeteners, subjected to other things. **7 statements: 4 sweet-tasting foods, 6 sugars, 5 sweeteners (15 questions in total)**					
Sub-theme	**Definition**	**Questions**	SF	SU	SW
External Influences	Factors beyond an individual's control, outside of self	The manufacturers are to blame for the amount of __ in food these days. The food environment hinders me from reducing my intake of __. The people that I am with (family, friends, colleagues) influence my intake of __.	 ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
Strategies and Regulations	Legislations; official large-scale measures put in place	Governing bodies are responsible for the influence of __ on people's health. The current recommendations on sugar intake are realistic.	✓	✓ ✓	✓

Deception	The idea of traps, tricks or temptations by manufacturers; distrust of food industry	I am distrustful of what goes into sweet food products these days.	✓		
		Labels are misleading and deceptive.		✓	✓
Theme 5: Understanding | The presence or absence of acquiring, comprehending and applying insights on sweet-tasting foods, sugar and sweeteners. **10 statements: 2 sweet-tasting foods, 9 sugars, 7 sweeteners (18 questions in total)**					
Sub-theme	**Definition**	**Questions**	SF	SU	SW
Delivery of Information	How information on sugar/ sweeteners/ sweet foods is disseminated and received	I know where to find credible information on __.	✓	✓	✓
Awareness	A general knowledge of, being conscious about, sensing issues related to sugar/ sweeteners/ sweet foods	I am able to state what is the recommended intake of sugars.		✓	
		I know what strategies or policies have been put in place to reduce sugar consumption in the UK.		✓	✓
Perception	The way of regarding or interpreting things related to sugar/ sweeteners/ sweet foods	There is/are “good” versus “bad” __.		✓	✓
		Unsweetened fruit juices are healthy sources of sugars.		✓	
		__ intake increases risk for cancer.		✓	✓
Education	The knowledge and proficiency in matters related to sugar/ sweeteners/ sweet foods	I know how to replace sugar with sweeteners in cooking and/or baking.		✓	✓
		If someone asks me, “what is/are __?”, I am able to explain to him/her.		✓	✓
Reasoning	To apply logic while processing information, in order to form inferences	I can consume more sweet foods if they are made from sweeteners than from sugar.	✓		
		I do not know whether to consume sugar or sweeteners.		✓	✓
Theme 6: Value | What sweet-tasting foods, sugar and sweeteners can provide. **6 statements: 6 sweet-tasting foods, 3 sugars, 3 sweeteners (12 questions in total)**					
Sub-theme	**Definition**	**Questions**	SF	SU	SW
Taste	The flavour of sweet foods with sugar/ sweeteners	Drag and re-arrange the following, according to their importance to you in deciding your choice of a sweet food. The top will be ranked as the most important, while the bottom will be ranked as the least important. Cost, Health, Pleasure, Presentation, Taste	✓		

Pleasure	The enjoyment and satisfaction derived from experience with sugar/ sweeteners/ sweet foods	It is impossible to completely eliminate __ out of my diet.	✓	✓	✓
Special	Not an everyday affair	I categorise my intake of sweet foods into “special” and “normal”. I only consume __ during special occasions.	✓ ✓	 ✓	 ✓
Emotion	Sentiments and feelings derived from sugar/ sweeteners/ sweet foods; influence of mood on intake	The presence or absence of __ in my diet influences my mood.	✓	✓	✓
Worth	Weighing of cost and benefit	I would rather be bigger in size and happy, than restrict myself and be sad.	✓		

→ Checking Questions (randomized with the other questions):

9. All sugar is dug out from sugar mines at least 50 metres deep.
10. All sugar comes from the sea.

Appendix 6. Questionnaire used in Sweet Talk II.

Start of Block: Consent

Consent to Participate

A) I confirm that I have read and understood the information provided.
B) I agree to take part in the study on the basis set out in the Information Sheet.

(validation: unable to proceed unless both boxes are checked)

Start of Block: Inclusion Criteria

Before we proceed, please answer the following questions:

Age: _____
(validation: unable to proceed unless age 18 or above)

Number of years residing in the UK: _____
(Validation: unable to proceed unless 1 year or above)

Start of Block: Introduction

Introduction

In this questionnaire, you will be asked on your intake of certain foods.

You will also be asked questions on 'sweet foods' 'sugar', 'sugars' and 'sweeteners'. Please read the following definitions. **Importantly, there is a distinction between 'sugar' in singular form and 'sugarS' in plural form.** These definitions will be listed at the bottom of each page for your reference.

The term 'sweet foods' refers to all sweet-tasting foods, including fruits, sweet biscuits, cereals, spreads, confectionery, pastries, ice-cream etc, regardless of whether these are sweetened naturally, sweetened with sugar or sweetened with sweeteners.

The term 'sugar' refers to "regular" table sugar, i.e. sucrose. This may take the form of sugar grain/crystal, sugar cube, sugar sachet or sugar stick.

The term 'sugar**S**' refers to both 'sugar' and the sugars present in honey, syrups, unsweetened fruit juices and fruit juice concentrates. This excludes sugar from intact fruits and vegetables.

The term 'sweeteners' refers to low or no calorie sweeteners that are used in place of sugar in many foods and drinks as a reduced or no calorie alternative. For example, sucralose used in Splenda, stevia leaf extract used in Truvia, aspartame used in Canderel etc. This excludes honey and syrup.

Finally, you will be asked to provide some basic information such as gender, height, ethnicity etc.

Please complete the questions as honestly and as accurately as you can ☺
There are no right or wrong answers – we are interested purely in your opinions!

Sources:
(https://www.sugar.org/sugar/sugars/)
(https://www.who.int/mediacentre/news/releases/2015/sugar-guideline/en/)
(https://www.sweeteners.org/category/11/sweeteners/54/what-are-low-calorie-sweeteners)

Start of Block: Food Questions

Food Questions
The following questions ask about some foods & drinks you might have during a 'typical' week, over the past month or so. Do not be concerned if some things you eat or drink are not mentioned.

1. Please select how often you add at least one portion of SUGAR into the following foods / drinks: (a portion includes: one cube, one teaspoon, one sachet).

	Rarely or never	Less than 1 a Week	Once a Week	2-3 times a Week	4-6 times a Week	1-2 times a Day	3-4 times a Day	5+ a Day
Coffee	☐	☐	☐	☐	☐	☐	☐	☐
Tea	☐	☐	☐	☐	☐	☐	☐	☐
Homecooked Dishes	☐	☐	☐	☐	☐	☐	☐	☐

2. Please select how often you add at least one portion of HONEY into the following foods / drinks: (a portion includes: one tablespoon, one pump/squeeze the size of your thumb).

	Rarely or never	Less than 1 a Week	Once a Week	2-3 times a Week	4-6 times a Week	1-2 times a Day	3-4 times a Day	5+ a Day
Coffee	☐	☐	☐	☐	☐	☐	☐	☐
Tea	☐	☐	☐	☐	☐	☐	☐	☐
Homecooked Dishes	☐	☐	☐	☐	☐	☐	☐	☐

3. Please select how often you add at least one portion of SWEETENER into the following foods / drinks: (a portion includes: one sachet, one tablet, one teaspoon, one pump/squeeze the size of your fingertip).

	Rarely or never	Less than 1 a Week	Once a Week	2-3 times a Week	4-6 times a Week	1-2 times a Day	3-4 times a Day	5+ a Day
Coffee	☐	☐	☐	☐	☐	☐	☐	☐
Tea	☐	☐	☐	☐	☐	☐	☐	☐
Homecooked Dishes	☐	☐	☐	☐	☐	☐	☐	☐

4. Please select how often you eat at least ONE portion of the following foods & drinks: (a portion includes: a piece of scone, a biscuit, a scoop of ice-cream, a glass of pop etc).

	Rarely or never	Less than 1 a Week	Once a Week	2-3 times a Week	4-6 times a Week	1-2 times a Day	3-4 times a Day	5+ a Day
Biscuits e.g. cereal bars, toaster pastries (Pop Tarts), gluten free biscuits.	☐	☐	☐	☐	☐	☐	☐	☐
Breakfast Cereal e.g. ready to eat cereals, granola, muesli, porridge oats.	☐	☐	☐	☐	☐	☐	☐	☐
Cakes & Morning Goods e.g. cake bars and slices, American muffins, flapjacks, Swiss rolls, croissants, crumpets, English muffins, pancakes,	☐	☐	☐	☐	☐	☐	☐	☐

buns, teacakes, scones, waffles, Danish pastries, fruit loaves, bagels.								
Chocolate & Sweet Confectionery (**not** sugar free or diet) e.g. chocolate bars, filled bars, assortments, seasonal chocolate, all sweets except sugar-free sweets/ chewing gum.	☐	☐	☐	☐	☐	☐	☐	☐
Chocolate & Sweet Confectionery (sugar free or diet) e.g. carob, diabetic and low-calorie chocolate, all sugar-free sweets/ chewing gum.	☐	☐	☐	☐	☐	☐	☐	☐
Ice Cream, Lollies & Sorbets (**not** sugar free or diet) e.g. dairy and non-dairy, choc ices, arctic roll.	☐	☐	☐	☐	☐	☐	☐	☐
Ice Cream, Lollies & Sorbets (sugar free or diet) e.g. sugar-free or diet versions of dairy and non-dairy, choc ices, arctic roll.	☐	☐	☐	☐	☐	☐	☐	☐
Puddings e.g. canned, chilled, frozen puddings.	☐	☐	☐	☐	☐	☐	☐	☐
Sweet Spreads & Sauces e.g. confectionery branded chocolate spreads, peanut butter, flavoured peanut butter, almond butter, cashew butter, coulis, compotes, cream-based toppings, brandy sauce.	☐	☐	☐	☐	☐	☐	☐	☐
Yogurts (**not** sugar free or diet) e.g. sugar-sweetened dairy yogurt, fromage frais products, soya, goat sheep products except natural yogurt and unsweetened yogurt or fromage frais.	☐	☐	☐	☐	☐	☐	☐	☐
Yogurts (sugar free or diet) e.g. artificially-sweetened or diet dairy yogurt, fromage frais products, soya, goat sheep products.	☐	☐	☐	☐	☐	☐	☐	☐
Fruit juice & Smoothies e.g. unsweetened fresh fruit juice, fruit concentrate, unsweetened smoothies.	☐	☐	☐	☐	☐	☐	☐	☐
Non-alcoholic fizzy drinks/pop (**not** sugar free or diet) e.g. coke, Lucozade.	☐	☐	☐	☐	☐	☐	☐	☐
Non-alcoholic fizzy drinks/pop (sugar free or diet) e.g. diet coke, diet lemonade.	☐	☐	☐	☐	☐	☐	☐	☐

Start of Block: Attitudes Questions: Sweet Foods

You will now answer some questions about **sweet foods**.

This refers to <u>all sweet-tasting foods</u>, including fruits, sweet biscuits, cereals, spreads, confectionery, pastries, ice-cream etc, regardless of whether these are sweetened naturally, sweetened with sugar or sweetened with sweeteners.

Please complete the questions as honestly and as accurately as you can :-) There are no right or wrong answers - we are interested purely in your opinions!

People are too concerned about cutting down on sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I feel indifferent towards sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Sweet taste is physically addictive.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

My health or body image will determine whether I modify my sweet foods intake or not.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Only people with obesity or diabetes need to modify their sweet foods intake.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Desire or need for sweet foods changes with age.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I want to reduce my intake of sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I tend to crave sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I put little or no thought into my consumption of sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

When I consume sweet foods, I balance out my diet through exercising and/or eating other healthy foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I feel guilty whenever I consume sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

The food environment hinders me from reducing my intake of sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

The people that I am with (family, friends, colleagues) influence my intake of sweet foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Governing bodies are responsible for the influence of sweet foods on people's health.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I am distrustful of what goes into sweet food products these days.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I know where to find credible information on sweet foods.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I can consume more sweet foods if they are made from sweeteners than from sugar.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

It is impossible to completely eliminate sweet foods out of my diet.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I categorise my intake of sweet foods into “special” and “normal”.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I only consume sweet foods during special occasions.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

The presence or absence of sweet foods in my diet influences my mood.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I would rather be bigger in size and happy, than restrict myself and be sad.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Drag and re-arrange the following, according to their importance to you in deciding your choice of a sweet food. The top will be ranked as the most important, while the bottom will be ranked as the least important.

- Cost, Health ,Pleasure, Taste, Presentation

Start of Block: Attitude Questions: Sugar(s)

You will now answer some questions about **sugar** or **sugars**.

The term 'sugar' refers to "regular" table sugar, i.e. sucrose. This may take the form of sugar grain/crystal, sugar cube, sugar sachet or sugar stick.

The term 'sugarS' refers to both 'sugar' and the sugars present in honey, syrups, unsweetened fruit juices and fruit juice concentrates. This excludes sugar from intact fruits and vegetables.

Again, please complete the questions as honestly and as accurately as you can :-) There are no right or wrong answers - we are interested purely in your opinions!

People are too concerned about cutting down on sugars.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I feel indifferent towards sugars.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Adding sugar in food products is unnecessary.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Sugar is physically addictive.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Sugar is not as bad as fat for your health.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Sugar is worse for your health than salt.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

My health or body image will determine whether I modify my sugar intake or not.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Only people with obesity or diabetes need to modify their sugar intake.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Desire or need for sugar changes with age.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I want to reduce my intake of sugars.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I tend to crave sugars.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I put little or no thought into my consumption of sugars.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

My choice and/or consumption of sugars depends on how much knowledge I have on them.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

When I consume sugars, I balance out my diet through exercising and/or eating other healthy foods.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I feel guilty whenever I consume sugars.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

The manufacturers are to blame for the amount of sugar in food these days.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

The food environment hinders me from reducing my intake of sugars.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

The people that I am with (family, friends, colleagues) influence my intake of sugars.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Governing bodies are responsible for the influence of sugars on people's health.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

The current recommendations on sugars intake are realistic.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I know where to find credible information on sugars.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I am able to state what is the recommended intake of sugars.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

There is "good" versus "bad" sugar.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Unsweetened fruit juices are healthy sources of sugars.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Sugar intake increases risk for cancer.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

If someone asks me, “what is sugar?”, I am able to explain to him/her.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

It is impossible to completely eliminate sugar out of my diet.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I only consume sugars during special occasions.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

The presence or absence of sugars in my diet influences my mood.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

All sugar is dug out from sugar mines at least 50-metres deep.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

All sugar comes from the sea.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Start of Block: Attitude Questions: Sweeteners

You will now answer some questions about **sweeteners**.

This refers to low or no calorie sweeteners that are used in place of sugar in many foods and drinks as a reduced or no calorie alternative. For example, sucralose used in Splenda, stevia leaf extract used in Truvia, aspartame used in Canderel etc. This excludes honey and syrup.

Once again, please complete the questions as honestly and as accurately as you can :-) There are no right or wrong answers - we are interested purely in your opinions!

People are too concerned about cutting down on sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I feel indifferent towards sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Adding sweeteners in food products is unnecessary.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Sweeteners are physically addictive.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Sweeteners are not as bad as fat for your health.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Sweeteners are worse for your health than salt.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

My health or body image will determine whether I modify my sweeteners intake or not.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Only people with obesity or diabetes need to modify their sweeteners intake.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Desire or need for sweeteners changes with age.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I want to reduce my intake of sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I tend to crave sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I put little or no thought into my consumption of sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

My choice and/or consumption of sweeteners depends on how much knowledge I have on them.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

When I consume sweeteners, I balance out my diet through exercising and/or eating other healthy foods.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I feel guilty whenever I consume sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

The manufacturers are to blame for the amount of sweeteners in food these days.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

The food environment hinders me from reducing my intake of sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

The people that I am with (family, friends, colleagues) influence my intake of sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Governing bodies are responsible for the influence of sweeteners on people's health.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I know where to find credible information on sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

There are "good" versus "bad" sweeteners.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Sweeteners intake increases risk for cancer.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

If someone asks me, “what are sweeteners?”, I am able to explain to him/her.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

It is impossible to completely eliminate sweeteners out of my diet.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I only consume sweeteners during special occasions.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

The presence or absence of sweeteners in my diet influences my mood.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Labels are misleading and deceptive.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I know what strategies or policies have been put in place to reduce sugar consumption in the UK.
- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

I know how to replace sugar with sweeteners in cooking and/or baking.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

I do not know whether to consume sugar or sweeteners.
- o Strongly agree (1)
- o Somewhat agree (2)
- o Neither agree nor disagree (3)
- o Somewhat disagree (4)
- o Strongly disagree (5)

Start of Block: Demographics/ Lifestyle Characteristics Questions

You will now answer a few questions about yourself.

Gender:
(We use this information to better understand the profile of our participants.)
- o Male (1)
- o Female (2)
- o Non-Binary (3)
- o Prefer not to say (4)

Height:
(please enter in your preferred system of measurement and put '0' in the others.)
- o Feet (ft) (1) ________________________
- o Inches (in) (2) ___________________________
- o Centimetres (cm) (3) ____________________________

Weight:
(please enter in your preferred system of measurement and put '0' in the others.)
- o Stones (st) (1) ____________________
- o Pounds (lb) (2) ______________________
- o Kilograms (kg) (3) _____________________

Are you currently suffering from any serious health condition which you feel influences your eating and food intake choice? (e.g., diabetes)
- o Yes (please specify) (1) ___________________
- o No (2)

Do you have intolerances or allergies to foods (especially sugar, sweetener, wheat, gluten, rice, cereal and fruits)?
- o Yes (please specify) (1) ___________________
- o No (2)

Are you currently following any diet program? (e.g., restricting your diet for weight loss)
- o Yes (please specify) (1) ___________________
- o No (2)

Choose one option that best describes your ethnic group or background:
(We use this information to better understand the profile of our participants.) (This question is developed by the GOV.UK Design System team)

- English/ Welsh/ Scottish/ Northern Irish/ British (1)
- Irish (2)
- Gypsy or Irish Traveller (3)
- Any other White background, please describe (4) ________________________________
- White and Black Caribbean (5)
- White and Black African (6)
- White and Asian (7)
- Any other Mixed/ Multiple ethnic background, please describe (8) __________________
- Indian (9)
- Pakistani (10)
- Bangladeshi (11)
- Chinese (12)
- Any other Asian background, please describe (13) ________________________________
- African (14)
- Caribbean (15)
- Any other Black/ African/ Caribbean background, please describe (16) ______________
- Arab (17)
- Any other ethnic group, please describe (18) ____________________________________
- Prefer not to say (19)

What is the highest degree or level of school you have completed?
(We use this information to better understand the profile of our participants.)
(This question is adapted from the Office for National Statistics)

- No formal qualifications (1)
- O-Levels, GCSEs or equivalent (2)
- A-Levels, college diploma or equivalent (3)
- University degree (4)
- Post-graduate degree or higher (5)
- Vocational or other qualifications (6)
- Prefer not to say (7)

Occupation:
Please tick one box to show which best describes the sort of work you do. If you are not working now, kindly tick a box to show what you did in your last job.
(We use this information to better understand the profile of our participants.)
(This question is adapted from the National Statistics Socio-economic classification (NS-SEC))

- Managerial, administrative and professional occupations: teacher – nurse – physiotherapist – social worker – welfare officer – artist– musician – police officer (sergeant or above) – software designer – accountant – solicitor – medical practitioner – scientist – civil/mechanical engineer– finance manager – chief executive – office manager – retail manager – bank manager – restaurant manager – warehouse manager – publican (1)
- Intermediate occupations: non-manager or non-supervisor in secretary – personal assistant – clerical worker – office clerk – call centre agent – nursing auxiliary – nursery nurse (6)
- Small employers and own account workers: small organisations or self-employed (3)
- Lower supervisory and technical occupations: supervisor of motor mechanic – fitter – inspector – plumber – printer – tool maker – electrician – gardener – train driver – postal worker – machine operative – security guard – caretaker – farm worker – catering assistant – receptionist – sales assistant – HGV driver – van driver – cleaner – porter – packer – sewing machinist – messenger – labourer – waiter/waitress – bar staff (4)
- Semi-routine and routine occupations: non manager non supervisor as postal worker – machine operative – security guard – caretaker – farm worker – catering assistant – receptionist – sales assistant – HGV driver – van driver – cleaner – porter – packer – sewing machinist – messenger – labourer – waiter/waitress – bar staff (5)

End of Questionnaire

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Appendix 7. Factor loadings and questions removed in Sweet Talk II analysis.

Table 1. PC1 to PC6 statements, their factor loadings, and their (sub-)theme in Chapter 4.

PC1: Personal impact		***From Chapter 4:***	
Question	**Loading**	**Sub-theme**	**Theme**
I tend to crave sweet foods.	0.784	stake	personal relevance
I tend to crave sugars.	0.756	stake	
I tend to crave sweeteners.	0.407	stake	
I want to reduce my intake of sweet foods.	0.485	stake	
The presence or absence of sweet foods in my diet influences my mood.	0.740	emotion	value
The presence or absence of sugars in my diet influences my mood.	0.691	emotion	
The presence or absence of sweeteners in my diet influences my mood.	0.445	emotion	
I feel indifferent towards sweet foods.	0.430	disinterest	angle
Sweet taste is physically addictive.	0.556	disfavour	
Sugar is physically addictive.	0.489	disfavour	
Cronbach's Alpha:	**0.813**		
Rotated % of variance:	**7.93**		

PC2: Personal management		***From Chapter 4:***	
Question	**Loading**	**Sub-theme**	**Theme**
When I consume sugars, I balance out my diet through exercising and/or eating other healthy foods.	0.631	self-regulation	personal responsibility
When I consume sweeteners, I balance out my diet through exercising and/or eating other healthy foods.	0.606	self-regulation	
When I consume sweet foods, I balance out my diet through exercising and/or eating other healthy foods.	0.622	self-regulation	
My choice and/or consumption of sugars depends on how much knowledge I have on them.	0.469	informed choice	
My choice and/or consumption of sweeteners depends on how much knowledge I have on them.	0.393	informed choice	
I only consume sweet foods during special occasions.	0.533	special	value
I only consume sugars during special occasions.	0.527	special	
I only consume sweeteners during special occasions.	0.446	special	
I categorise my intake of sweet foods into "special" and "normal".	0.392	special	
My health or body image will determine whether I modify my sugar intake or not.	0.569	health body image	personal relevance
My health or body image will determine whether I modify my sweet foods intake or not.	0.538	health body image	
My health or body image will determine whether I modify my sweeteners intake or not.	0.474	health body image	
The people that I am with (family, friends, colleagues) influence my intake of sweeteners.	0.391	external influences	it's not up to me
Cronbach's Alpha:	**0.763**		
Rotated % of variance:	**7.71**		

PC3: Apathy		*From Chapter 4:*	
Question	**Loading**	**Sub-theme**	**Theme**
People are too concerned about cutting down on sweet foods.	0.711	disinterest	angle
People are too concerned about cutting down on sugars.	0.695	disinterest	
People are too concerned about cutting down on sweeteners.	0.512	disinterest	
Sugar is not as bad as fat for your health.	0.404	relativity	
Adding sugar in food products is unnecessary.	0.323	disfavour	
Cronbach's Alpha:	**0.689**		
Rotated % of variance:	**6.58**		

PC4: Negativity		*From Chapter 4:*	
Question	**Loading**	**Sub-theme**	**Theme**
Sweeteners are worse for your health than salt.	0.626	relativity	angle
Sweeteners are physically addictive.	0.570	disfavour	
Sweeteners are not as bad as fat for your health.	0.579	relativity	
Adding sweeteners in food products is unnecessary.	0.572	disfavour	
I feel guilty whenever I consume sweeteners.	0.558	internal conflict	personal responsibility
Labels are misleading and deceptive.	0.401	deception	it's not up to me
The food environment hinders me from reducing my intake of sweeteners.	0.378	external influences	
Cronbach's Alpha:	**0.676**		
Rotated % of variance:	**6.38**		

PC5: Perceived understanding		*From Chapter 4:*	
Question	**Loading**	**Sub-theme**	**Theme**
I know where to find credible information on sugars.	0.800	delivery of info	understanding
I know where to find credible information on sweet foods.	0.771	delivery of info	
I know where to find credible information on sweeteners.	0.762	delivery of info	
If someone asks me, "what are sweeteners?", I am able to explain.	0.634	education	
If someone asks me, "what is sugar?", I am able to explain.	0.551	education	
I do not know whether to consume sugar or sweeteners.	0.471	reasoning	
I know how to replace sugar with sweeteners in cooking/ baking.	0.466	education	
I know what strategies or policies have been put in place to reduce sugar consumption in the UK.	0.417	awareness	
Cronbach's Alpha:	**0.777**		
Rotated % of variance:	**5.96**		

PC6: Perceived Nonautonomy		*From Chapter 4:*	
Question	**Loading**	**Sub-theme**	**Theme**
Desire or need for sweet foods changes with age.	0.759	generation age	personal relevance
Desire or need for sugar changes with age.	0.743	generation age	
Desire or need for sweeteners changes with age.	0.575	generation age	
It is impossible to completely eliminate sugar out of my diet.	0.492	pleasure	value
It is impossible to completely eliminate sweet foods out of my diet.	0.484	pleasure	
Cronbach's Alpha:	**0.663**		
Rotated % of variance:	**4.52**		

Table 3. Cross-loading items.

Question	*From Chapter 4:* Sub-theme	Theme
I want to reduce my intake of sugars.	stake	personal relevance
I want to reduce my intake of sweeteners.	stake	
I feel guilty whenever I consume sweet foods.	internal conflict	personal responsibility
I feel guilty whenever I consume sugars.	internal conflict	
I put little or no thought into my consumption of sugars.	informed choice	
I put little or no thought into my consumption of sweet foods.	informed choice	
I put little or no thought into my consumption of sweeteners.	informed choice	
Governing bodies are responsible for the influence of sugars on people's health.	strategies regulations	understanding
Governing bodies are responsible for the influence of sweet foods on people's health.	strategies regulations	
I am able to state what is the recommended intake of sugars.	awareness	
The food environment hinders me from reducing my intake of sweet foods.	external influences	it's not up to me
The food environment hinders me from reducing my intake of sugars.	external influences	
The manufacturers are to blame for the amount of sweeteners in food these days.	external influences	
The people that I am with (family, friends, colleagues) influence my intake of sugars.	external influences	
I am distrustful of what goes into sweet food products these days.	deception	
I feel indifferent towards sugars.	disinterest	angle

Table 4. Items that had less than 0.32 coefficients.

Question	*From Chapter 4:* Sub-theme	Theme
There is "good" versus "bad" sugar.	perception	understanding
There are "good" versus "bad" sweeteners.	perception	
Unsweetened fruit juices are healthy sources of sugars.	perception	
I can consume more sweet foods if they are made from sweeteners than sugar.	reasoning	
It is impossible to completely eliminate sweeteners out of my diet.	pleasure	value
I would rather be bigger in size and happy, than restrict myself and be sad.	worth	
The manufacturers are to blame for the amount of sugar in food these days.	external influences	it's not up to me
The current recommendations on sugars intake are realistic.	strategies regulations	
Sugar is worse for your health than salt.	relativity	angle
I feel indifferent towards sweeteners.	disinterest	

Appendix 8. Estimated intake frequencies from Sweet Talk II responses.

Table 1. Estimated intake frequencies across ranking of consideration factors (n=581).

Number of times a day (range: 0-5)	**Cost (n=75)**	**Health (n=99)**	**Pleasure (n=103)**	**Taste (n=297)**	**Presentation (n=7)**
Add **sugar**	0.59±1.13	0.97±1.68	1.26±2.00	1.13±2.10	0.27±0.67
Add **honey**	0.27±1.00	0.20±0.57	0.13±0.43	0.29±1.08	0.08±0.16
Add **sweeteners**	0.41±1.01	0.55±1.83	0.59±1.59	0.64±1.59	0.07±0.14
Sugar food group	1.72±1.96	1.74±2.06	1.87±1.88	1.86±1.73	1.58±0.79
Sugar-free group	0.20±0.28	0.42±1.12	0.19±0.31	0.31±0.67	0.51±0.47
Total **sweet** group	1.92±1.93	2.16±2.57	2.06±1.87	2.16±1.96	2.09±0.93

Table 2. Number of responses per choice of frequency of adding sugar, honey and sweeteners into coffee, tea, or homecooked dishes; consuming a portion of sugar[1] or sugar-free food group.

Food item(s)	Rarely or never	Less than 1 a Week	Once a Week	2-3 times a Week	4-6 times a Week	1-2 times a Day	3-4 times a Day	5+ a Day
SUGAR								
Coffee	398	40	22	30	21	46	29	12
Tea	422	33	12	25	20	40	32	14
Homecooked Dishes	360	105	42	65	18	4	2	2
HONEY								
Coffee	566	9	2	8	3	6	3	1
Tea	252	29	11	15	4	6	8	0
Homecooked Dishes	395	102	46	32	12	6	4	1
SWEETENER								
Coffee	486	19	13	14	17	27	12	10
Tea	503	17	7	20	9	20	14	8
Homecooked Dishes	519	30	14	23	6	4	0	2
A portion of:								
Biscuits	102	113	76	167	75	54	6	5
Breakfast Cereal	127	99	58	116	110	78	1	9
Cakes & Morning Goods	135	166	124	113	41	16	2	1
Chocolate & Sweet Confectionery	40	87	79	198	108	71	7	8
Ice Cream, Lollies & Sorbets	246	226	75	41	6	4	0	0
Puddings	277	167	96	46	9	1	1	1
Sweet Spreads & Sauces	244	128	78	105	33	10	0	0
Yogurts	272	118	67	98	29	12	2	0
Fruit Juices & Smoothies	208	104	70	112	61	34	7	2
Non-alcoholic fizzy pop	335	88	55	64	32	18	5	1
Sugar-free Chocolate & Sweet Confectionery	396	77	40	53	15	11	4	2
Sugar-free Ice Cream, Lollies & Sorbets	476	89	22	10	0	1	0	0
Sugar-free Yogurts	353	87	49	78	23	6	0	2
Sugar-free Non-alcoholic fizzy pop	271	74	65	79	47	35	17	10

[1] Top National Diet and Nutrition Survey food groups that contributed to total sugar intakes relevant to the sugar reduction programme in the UK, from 2012 to 2014 (Tedstone et al., 2015).

Appendix 9. Response patterns and characteristics of latent classes.

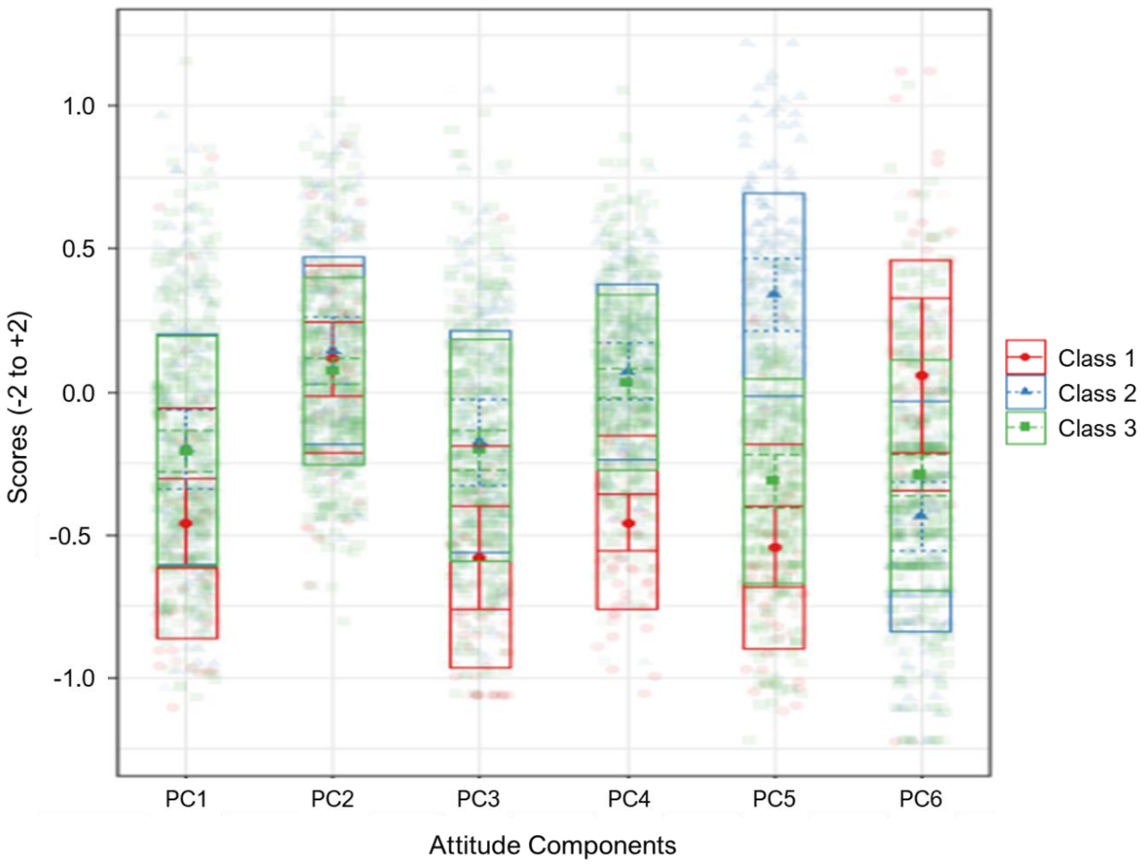

Figure 1. Response patterns to the attitude components based on a 3-Class Model. Class 1: Not bothered. Class 2: Actively engaged. Class 3: Unopinionated.PC1: personal impact, PC2: personal management, PC3: nonchalance, PC4: negativity, PC5: perceived understanding, PC6: perceived nonautonomy.

Class 1 felt significantly less impacted, as compared to Class 2, t(569) = -4.88, p < .001, and to Class 3, *t*(569) = -4.53, *p* < .001. Class 2 was significantly more in the direction of personal management than Class 3, *t*(567) = 2.62, *p* = .0268, while Class 1 was not different from both Class 2 or Class 3 on how much they were into personal management (*p* ≥ .893). Class 1 was significantly less nonchalant compared to Class 2, t(567) = -6.17, *p* < .001, and to Class 3, *t*(567) = -6.79, *p* < .001. Once again, Class 1 was much less negative towards these food items as compared to Class 2, t(567) = -11.4, p < .001, as well as to Class 3, *t*(567) = -11.6, *p* < .001. Class 1 perceived their understanding of the food items to be lower than Class 2, t(575) = -18.3, p < .001, and to Class 3, *t*(575) = -4.61, *p* < .001. Class 2 perceived their understanding to be higher than Class 3, *t*(575) = 23.5, *p* < .001. Class 1 perceived themselves as not having the autonomy over their intakes of these food items, hence their perceived nonautonomy was higher than Class 2, *t*(577) = 8.28, *p* < .001, and Class 3, *t*(577) = 6.50, *p* < .001. Class 2 perceived themselves as having autonomy over their intakes of these food items and their perceived nonautonomy was lower than Class 3, *t*(577) = -3.85, *p* = .004.

Table 1. Participant characteristics across latent classes (N=581).

Percentage (n=) in a category, unless otherwise stated.	**Class 1: Not bothered (n=52)**	**Class 2: Actively engaged (n=162)**	**Class 3: Unopinionated (n=367)**
Male, %	36.5 (19)	30.9 (50)	46.9 (172)
Age, year, mean ± SD	41.8 ± 13.1	33.8 ± 15.5	39.5 ± 15.0
White[1], %	88.5 (46)	95.7 (155)	89.4 (328)
Asian[2], %	3.8 (2)	1.2 (2)	4.4 (16)
Black[3], %	5.8 (3)	1.2 (2)	3.3 (12)
Mixed or Multiple, %	1.9 (1)	1.9 (3)	1.4 (5)
Others[4], %	0 (0)	0 (0)	1.6 (6)
No Formal Qualifications, %	3.8 (2)	2.5 (4)	1.4 (5)
O Levels / GCSEs – equivalent, %	13.5 (7)	19.1 (31)	20.2 (74)
A Levels / Diploma – equivalent, %	36.5 (19)	53.1 (86)	42.2 (155)
University Degree, %	17.3 (9)	14.8 (24)	19.9 (73)
Postgraduate Degree, %	25.0 (13)	6.2 (10)	9.5 (35)
Vocational or Other, %	3.8 (2)	4.3 (7)	6.8 (25)
NS-SEC Class 1, %	36.5 (19)	20.4 (33)	28.1 (103)
NS-SEC Class 2, %	23.1 (12)	39.5 (64)	20.7 (76)
NS-SEC Class 3, %	11.5 (6)	5.6 (9)	8.2 (30)
NS-SEC Class 4, %	7.7 (4)	13.0 (21)	19.9 (73)
NS-SEC Class 5, %	21.2 (11)	21.6 (35)	23.2 (85)
BMI, kg/m^2, mean ± SD	28.1±7.22	26.1±6.85	26.4±6.59
Presence of health condition, %	15.4 (8)	8.6 (14)	11.7 (43)
Adherence to diet, %	28.8 (15)	13.6 (22)	13.9 (51)
Presence of allergy, %	25.0 (13)	9.3 (15)	14.2 (52)

Appendix 10. Scatterplots of clusters formed with different distance measures.

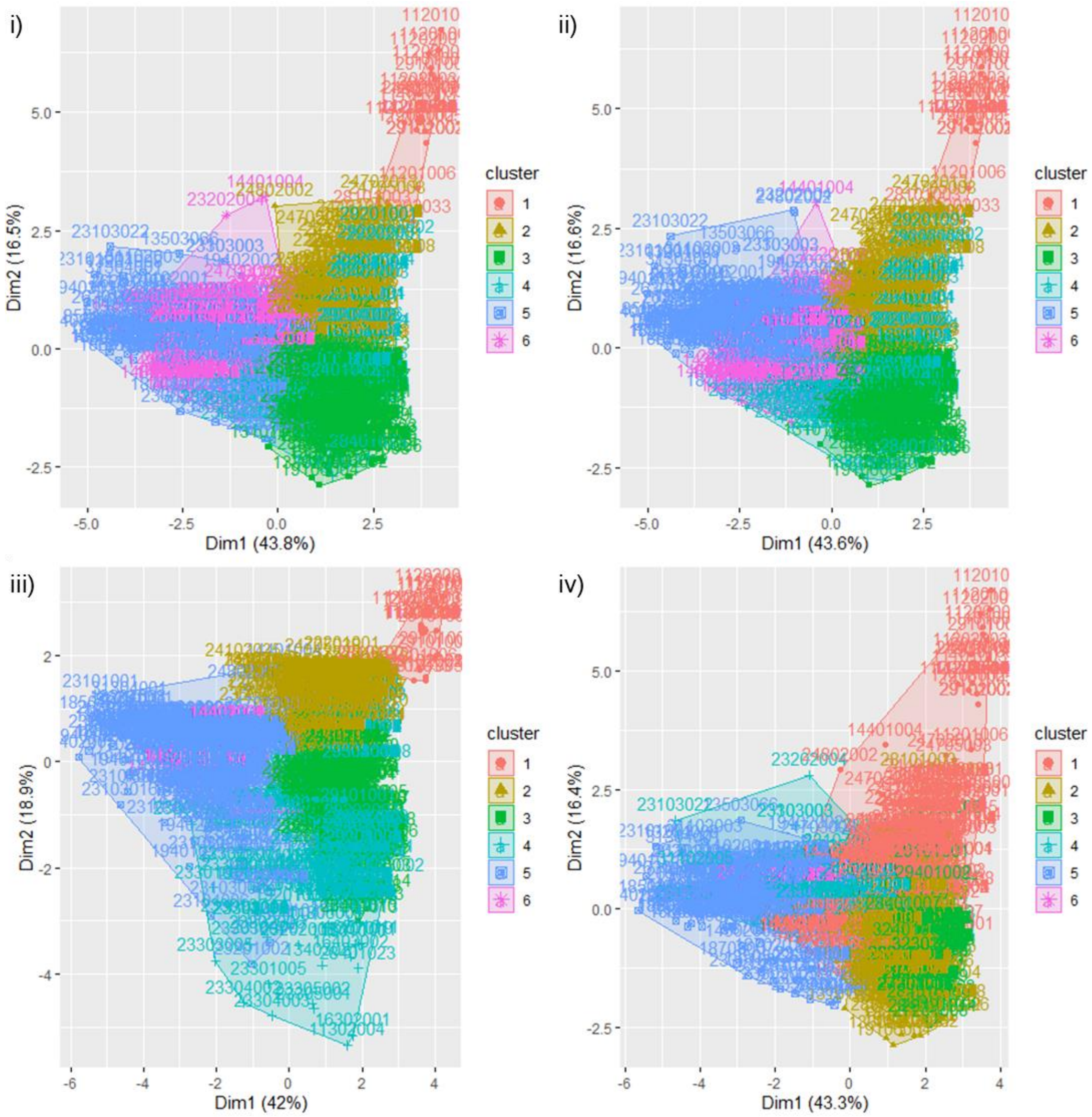

Figure 1. Scatterplot of six clusters formed by Ward’s clustering method with (i) Euclidean, (ii) Manhattan, (iii) Maximum, and (iv) Canberra distance measures.

Appendix 11. Food groups in clusters formed with different distance measures.

Table 1. Minor food groups in each cluster formed by Ward's Linkage with either A) Euclidean, B) Manhattan or C) Maximum distance measures.

	A) Euclidean	B) Manhattan	C) Maximum
Cluster 1: Bitter	Tea, Coffee and coffee substitutes, Beers	Tea, Coffee and coffee substitutes, Beers	Tea, Coffee and coffee substitutes, Beers
Cluster 2: Neutral	Tea, Waters, municipal and bottled, unflavoured, Flours and other cereal grains and starches, Regular breads, and bread rolls, English-style muffins, flat breads, and savoury and sweet breads, Pasta and pasta products (without sauce), Breakfast cereals, ready to eat, Savoury biscuits, Dry soup mix, Seeds and seed products, Nuts and nut products, Gravies and savoury sauces, Cabbage, cauliflower and similar brassica vegetables, Carrot and similar root vegetables, Leaf and stalk vegetables, Peas and beans, Tomato and tomato products, Other fruiting vegetables, Other vegetables and vegetable combinations, Dishes where vegetable is the major component, Mature legumes and pulses, Mature legume and pulse products and dishes, Spirits, Other alcoholic beverages, Intense sweetening agents, Herbs, spices, seasonings and stock cubes	Tea, Waters, municipal and bottled, unflavoured, Flours and other cereal grains and starches, Regular breads, and bread rolls, English-style muffins, flat breads, and savoury and sweet breads, Pasta and pasta products (without sauce), Breakfast cereals, ready to eat, Savoury biscuits, Dry soup mix, Nuts and nut products, Gravies and savoury sauces, Cabbage, cauliflower and similar brassica vegetables, Carrot and similar root vegetables, Leaf and stalk vegetables, Peas and beans, Tomato and tomato products, Other fruiting vegetables, Other vegetables and vegetable combinations, Dishes where vegetable is the major component, Mature legumes and pulses, Mature legume and pulse products and dishes, Spirits, Other alcoholic beverages, Intense sweetening agents, Herbs, spices, seasonings and stock cubes	Waters, municipal and bottled, unflavoured, Flours and other cereal grains and starches, Regular breads, and bread rolls, English-style muffins, flat breads, and savoury and sweet breads, Pasta and pasta products (without sauce), Breakfast cereals, ready to eat, Breakfast cereals, hot porridge style, Savoury biscuits, Pastries, Mixed dishes where cereal is the major ingredient, Batter-based products, Eggs, Dishes where egg is the major ingredient, Beef, sheep and pork, unprocessed, Poultry and feathered game, Dairy milk (cow, sheep and goat), Cream, Cheese, Dairy milk substitutes, unflavoured, Seeds and seed products, Nuts and nut products, Potatoes, Cabbage, cauliflower and similar brassica vegetables, Carrot and similar root vegetables, Leaf and stalk vegetables, Peas and beans, Other fruiting vegetables, Other vegetables and vegetable combinations.Dishes where vegetable is the major component, Mature legumes and pulses, Mature legume and pulse products and dishes, Intense sweetening agents, Herbs, spices, seasonings and stock cubes
Cluster 3: Sweet	Fruit and vegetable juices, and drinks, Soft drinks, and flavoured mineral waters, Other beverage flavourings and prepared beverages, English-style muffins, flat breads, and savoury and sweet breads, Breakfast cereals, ready to eat, Sweet biscuits,	Fruit and vegetable juices, and drinks, Soft drinks, and flavoured mineral waters, Electrolyte, energy and fortified drinks, Other beverage flavourings and prepared beverages, English-style muffins, flat breads, and savoury and sweet breads,	Soft drinks, and flavoured mineral waters, Other beverage flavourings and prepared beverages, English-style muffins, flat breads, and savoury and sweet breads, Breakfast cereals, ready to eat, Sweet biscuits, Cakes, muffins, scones, cake-type desserts,

	Cakes, muffins, scones, cake-type desserts, Pastries, Batter-based products, Pome fruit, Stone fruit, Tropical and subtropical fruit, Other fruit, Mixtures of two or more groups of fruit, Dried fruit, preserved fruit, Mixed dishes where fruit is the major component, Frozen milk products, Custards, Other dishes where milk or a milk product is the major component, Flavoured milks and milkshakes, Dairy milk substitutes, flavoured, Soy-based ice confection, Carrot and similar root vegetables, Other fruiting vegetables, Sugar, honey and syrups, Jam and lemon spreads, chocolate spreads, sauces, Dishes and products other than confectionery where sugar is the major component, Chocolate and chocolate-based confectionery, Fruit, nut and seed-bars, Muesli or cereal style bars, Other confectionery, Formula dietary foods	Breakfast cereals, ready to eat, Sweet biscuits, Cakes, muffins, scones, cake-type desserts, Pastries, Batter-based products, Pome fruit, Stone fruit, Tropical and subtropical fruit, Other fruit, Mixtures of two or more groups of fruit, Dried fruit, preserved fruit, Mixed dishes where fruit is the major component, Dairy milk (cow, sheep and goat), Frozen milk products, Custards, Other dishes where milk or a milk product is the major component, Flavoured milks and milkshakes, Dairy milk substitutes, unflavoured, Dairy milk substitutes, flavoured, Soy-based ice confection, Soy-based yoghurts, Carrot and similar root vegetables, Other fruiting vegetables, Sugar, honey and syrups, Jam and lemon spreads, chocolate spreads, sauces, Dishes and products other than confectionery where sugar is the major component, Chocolate and chocolate-based confectionery, Fruit, nut and seed-bars, Muesli or cereal style bars, Other confectionery, Formula dietary foods	Pastries, Batter-based products, Tropical and subtropical fruit, Mixtures of two or more groups of fruit, Dried fruit, preserved fruit, 169Frozen milk products, Custards, Other dishes where milk or a milk product is the major component, Flavoured milks and milkshakes, Dairy milk substitutes, flavoured, Soy-based ice confection, Carrot and similar root vegetables, Other fruiting vegetables, Sugar, honey and syrups, Jam and lemon spreads, chocolate spreads, sauces, Dishes and products other than confectionery where sugar is the major component, Chocolate and chocolate-based confectionery, Fruit, nut and seed-bars, Muesli or cereal style bars, Other confectionery, Formula dietary foods
Cluster 4: Sweet & Sour	Fruit and vegetable juices, and drinks, Cordials, Soft drinks, and flavoured mineral waters, Electrolyte, energy and fortified drinks, Pome fruit, Berry fruit, Citrus fruit, Stone fruit, Other fruit, Dried fruit, preserved fruit, Yoghurt, Cream, Cheese, Soy-based yoghurts, Pickles, chutneys and relishes, Salad dressings, Wines, Cider and perry	Fruit and vegetable juices, and drinks, Cordials, Electrolyte, energy and fortified drinks, Pome fruit, Berry fruit, Citrus fruit, Stone fruit, Other fruit, Dried fruit, preserved fruit, Yoghurt, Cream, Cheese, Salad dressings, Tomato and tomato products, Wines, Spirits, Cider and perry	Tea, Fruit and vegetable juices, and drinks, Cordials, Electrolyte, energy and fortified drinks, Pome fruit, Berry fruit, Citrus fruit, Stone fruit, Tropical and subtropical fruit, Other fruit, Dried fruit, preserved fruit, Yoghurt, Cream, Cheese, Soy-based yoghurts, Gravies and savoury sauces, Salad dressings, Leaf and stalk vegetables, Tomato and tomato products, Other fruiting vegetables, Wines, Spirits, Cider and perry, Other alcoholic beverages

Cluster 5: Salt & Fat	Regular breads, and bread rolls, Pasta and pasta products (without sauce), Pasta and pasta products (without sauce), Savoury biscuits, Pastries, Mixed dishes where cereal is the major ingredient, Fin fish, Crustacea and molluscs, Other sea and freshwater foods, Packed (commercially sterile) fish and seafood, Fish and seafood products, Mixed dishes with fish or seafood as the major component, Beef, sheep and pork, unprocessed, Mammalian game meats, Organ meats and offal, products and dishes, Sausages, frankfurts and saveloys, Processed meat, Mixed dishes where beef, sheep, pork or mammalian game is the major component, Mixed dishes where sausage, bacon, ham or other processed meat is the major component, Mixed dishes where poultry or feathered game is the major component, Cheese, Meat substitutes, Dishes where meat substitutes are the major component, Soup, homemade from basic ingredients, Soup, prepared from dry soup mix, Canned condensed soup (unprepared), Soup, commercially sterile, prepared from condensed or sold ready to eat, Soup, not commercially sterile, purchased ready to eat, Nuts and nut products, Gravies and savoury sauces, Dips, Potatoes, Tomato and tomato products, Other fruiting vegetables, Dishes where vegetable is the major component, Potato snacks, Corn snacks, Extruded or reformed snacks, Other snacks, Yeast, and yeast vegetable or meat extracts	English-style muffins, flat breads, and savoury and sweet breads, Pasta and pasta products (without sauce), Savoury biscuits, Pastries, Mixed dishes where cereal is the major ingredient, Mixed dishes with fish or seafood as the major component, Sausages, frankfurts and saveloys, Processed meat, Mixed dishes where beef, sheep, pork or mammalian game is the major component, Mixed dishes where sausage, bacon, ham or other processed meat is the major component, Mixed dishes where poultry or feathered game is the major component, Cheese, Meat substitutes, Dishes where meat substitutes are the major component, Soup, homemade from basic ingredients, Soup, prepared from dry soup mix, Canned condensed soup (unprepared), Soup, commercially sterile, prepared from condensed or sold ready to eat, Soup, not commercially sterile, purchased ready to eat, Gravies and savoury sauces, Pickles, chutneys and relishes, Salad dressings, Dips, Tomato and tomato products, Dishes where vegetable is the major component, Potato snacks, Extruded or reformed snacks, Other snacks, Yeast, and yeast vegetable or meat extracts	Regular breads, and bread rolls, Pasta and pasta products (without sauce), Savoury biscuits, Pastries, Mixed dishes where cereal is the major ingredient, Fin fish, Crustacea and molluscs, Other sea and freshwater foods, Packed (commercially sterile) fish and seafood, Fish and seafood products, Mixed dishes with fish or seafood as the major component, Mammalian game meats, Organ meats and offal, products and dishes, Sausages, frankfurts and saveloys, Processed meat, Mixed dishes where beef, sheep, pork or mammalian game is the major component, Mixed dishes where sausage, bacon, ham or other processed meat is the major component, Mixed dishes where poultry or feathered game is the major component, Cheese, Meat substitutes, Dishes where meat substitutes are the major component, Soup, homemade from basic ingredients, Soup, prepared from dry soup mix, Canned condensed soup (unprepared), Soup, commercially sterile, prepared from condensed or sold ready to eat, Soup, not commercially sterile, purchased ready to eat, Nuts and nut products, Gravies and savoury sauces, Pickles, chutneys and relishes, Dips, Potatoes, Other fruiting vegetables, Dishes where vegetable is the major component, Potato snacks, Corn snacks, Extruded or reformed snacks, Other snacks, Herbs, spices, seasonings and stock cubes

Cluster 6: Fat	Breakfast cereals, hot porridge style, Pastries, Batter-based products, Butters, Dairy blends, Margarine and table spreads, Plant oils, Unspecified fats, Fish and seafood products, Eggs, Dishes where egg is the major ingredient, Beef, sheep and pork, unprocessed, Poultry and feathered game, Dairy milk (cow, sheep and goat), Cream, Dairy milk substitutes, unflavoured, Soup, homemade from basic ingredients, Nuts and nut products, Potatoes, Other fruiting vegetables	Flours and other cereal grains and starches, Regular breads, and bread rolls, Pasta and pasta products (without sauce), Breakfast cereals, ready to eat, Breakfast cereals, hot porridge style, Savoury biscuits, Pastries, Mixed dishes where cereal is the major ingredient, Batter-based products, Butters, Dairy blends, Margarine and table spreads, Plant oils, Fin fish, Crustacea and molluscs, Other sea and freshwater foods, Packed (commercially sterile) fish and seafood, Fish and seafood products, Eggs, Dishes where egg is the major ingredient, Beef, sheep and pork, unprocessed, Mammalian game meats, Poultry and feathered game, Organ meats and offal, products and dishes, Processed meat, Mixed dishes where poultry or feathered game is the major component, Dairy milk (cow, sheep and goat), Cream, Soup, homemade from basic ingredients, Nuts and nut products, Potatoes, Other fruiting vegetables, Mature legume and pulse products and dishes, Corn snacks, Other snacks, Yeast, and yeast vegetable or meat extracts	Butters, Dairy blends, Margarine and table spreads, Plant oils, Unspecified fats, Nuts and nut products

Appendix 12. Standard for evaluating eating rate categories.

Table 1. Standard for evaluating eating rate categories.

No.	Food or Food Category	Category[1]	Code
1	Bread except bun, roll, muffin, untoasted white bread	hard	4
2	Croissant e.g., chocolate croissant, croissant with ham and cheese	hard	4
3	Breakfast cereal e.g., Kellogg’s special K	hard	4
4	Rice/oat/cereal porridge e.g., rolled oats porridge	soft	3
5	Aged/ hard cheese [2] e.g., Gouda 48+, Emmental	hard	4
6	Fish e.g., salmon; <u>except</u> fried	soft	3
7	Meat [2] e.g., pork fillet; <u>except</u> minced or processed (sausage etc.)	hard	4
8	Minced meat	soft	3
9	Processed meat e.g., sausage; except deep fried	soft	3
10	Cooked meals e.g., curry, wrap, hamburger, sandwich, mixed dishes	soft	3
11	Sushi e.g., maki roll	soft	3
12	Egg e.g., omelette	soft	3
13	Vegetables raw e.g., rucola, spinach, lettuce, parsley	hard	4
14	Salad e.g., Russian salad; <u>except</u> egg salad and Dutch ‘salad’ spreads	hard	4
15	Cooked/tinned vegetables e.g., boiled swede, steamed broccoli, canned beans; <u>except</u> sprouts, corn	soft	3
16	Hard fruit e.g., apple, pineapple, melon	hard	4
17	Soft fruit e.g., strawberry, avocado	soft	3
18	Dried fruit e.g., dried mango	hard	4
19	Fruit puree	semi	2
20	Potato/bean puree e.g., mashed potato	soft	3
21	Relish e.g., Piccalilli	soft	3
22	Compote e.g. berry compote	soft	3
23	Preserve e.g. marmalade	soft	3
24	Jam	semi	2
25	Jelly e.g. fruit jelly	soft	3
26	Wine gum/ jelly [2] e.g. fruit gum	hard	4
27	Infant food puree e.g. infant 6 months fruit puree	semi	2
28	Infant food sieved e.g. infant sieved broccoli	soft	3

29	Paste e.g. tahini	soft	3
30	Gravy e.g. gravy powder prepared	semi	2
31	Dip e.g. avocado dip	soft	3
32	Dressing e.g. salad dressing	semi	2
33	Sauce e.g. apple sauce, chili sauce	semi	2
34	Pasta sauce e.g. ready-made Bolognese sauce in jar	soft	3
35	Pre-diluted syrup e.g. pancake syrup, fruit syrup	semi	2
36	Diluted syrup	liquid	1
37	Custard e.g. vanilla-chocolate duo custard	semi	2
38	Pudding e.g. butterscotch pudding	soft	3
39	Mousse e.g. chocolate mousse	soft	3
40	Powders e.g. cocoa powder, curry powder	hard	4
41	Instant/pre-mix e.g. herb mix, rice mix to add	hard	4
42	Soup without pieces e.g. instant soup made from dry mix	semi	2
43	Soup with pieces e.g. chicken soup with noodles and chicken	soft	3
44	Oil/ cooking spray e.g. olive oil, sesame oil	semi	2
45	Butter/ margarine e.g. unsalted butter, dairy blend	soft	3
46	Baked treats e.g. cakes, eclairs, strudel, crumble, donut, pancake, waffle	soft	3
47	Puff pastry e.g. pot pie with puff pastry, apple turnover	hard	4
48	Ice cream e.g. Neapolitan	semi	2
49	Ice cream with nuts/ biscuits e.g. cookies and cream ice-cream	soft	3
50	Thick drinks e.g. smoothie, milkshake	liquid	1
51	Beer/ wine e.g. rose, lager	liquid	1
52	Cocktail e.g. gin and tonic, whisky sour	liquid	1
53	Hard alcohol [2] e.g. gin, whisky, liqueur	semi	2

[1]Definitions as follows – liquid: foods that flow and do not require chewing before swallowing; semi-solid: foods that are predominantly processed by squeezing between tongue & palate; soft-solid: foods that require (initial) chewing between the molars but without crisp; hard-solid: crispy foods that require chewing between molars, generally producing sound. [2]Categorised based on tested eating rates (van den Boer, Werts, et al., 2017), instead of category definition.

Appendix 13. Reference solutions and products used by taste databases.

Table 1. French taste database reference solutions and products shown per taste and mouthfeel.

	Solution references		Food references	
	Concentration	**% scale**	**Product name and brand**	**% scale**
Sweet	Sucrose 20 g/l (R1)	13.33#	White sandwich bread, Harris®	11.5
	Sucrose 50 g/l (R2)	33.33#	Sourdough bun, Pasquier®	23.9
	Sucrose 100 g/l (R3)	66.67#	Actimel, Danone®	32.6
			Chamallows, Haribo®	59.8
			Nutella spread, Ferrero®	68.0
			Sweetened condensed milk, Nestlé®	73.3
Salt	NaCl 2·00 g/l (R1)	16.67#	Cracotte (crispbread), LU®	18.4
	NaCl 3·50 g/l (R2)	33.33#	Vache qui rit (processed cheese), Bel®	32.1
	NaCl 5·00 g/l (R3)	56.67#	Cracker Tuc original, LU®	48.0
			Salted butter (salt crystels from Guérande), Paysan breton®	61.2
			Soy sauce, Kikkoman®	81.8
Sour	Citric acid 0·50 g/l (R1)	13.33#	Petit suisse, Gervais®	20.9
	Citric acid 0·80 g/l (R2)	33.33#	Dehydrated tomato soup, Royco®	24.2
	Citric acid 1·50 g/l (R3)	66.67#	Yogurt Velouté, Danone®	33.7
			Tomato Ketchup, Heinz®	56.4
			Lemon juice (fresh and plain)	93.2
Bitter	Caffeine 0·50 g/l (R1)	13.33#	Mineral water, Volvic®	4.7
	Caffeine 0·80 g/l (R2)	33.33#	Camembert, Lepetit®	24.6
	Caffeine 1·50 g/l (R3)	66.67#	Marmelade of bitter orange, Bonne maman®	32.3
			Black chocolate 70% cocoa, Lindt Excellence®	38.6
			Beer (alcohol-free), Buckler®	52.6
			Black chocolate 90% cocoa, Lindt Excellence®	60.2
Umami	MSG 1·20 g/l (R1)	13.33^	Pâté, Hénaff®	15.5
	MSG 3·00 g/l (R2)	33.33^	Strasbourg sausage, Knacki Herta®	22.9
	MSG 7·00 g/l (R3)	66.67^	Surimi stick, Coraya®	41.7
			Soy sauce, Kikkoman®	61.6
Fat			Single cream 15% fat, Pâturage®	13.3
			Strasbourg sausage, Knacki Herta®	24.6
			Vache qui rit (processed cheese), Bel®	34.3
			Camembert, Lepetit®	45.6
			White chocolate, Galak Nestlé®	60.0
			Mascarpone, Fiorini®	72.0
			Unsalted butter, Président®	90.0

Adapted from Muñoz, Civille and Carr (1992). ^ Adapted from Martin and colleagues (Martin et al., 2009).

% scale refers to the value to which a specific concentration corresponds to on the 1-100 scale.

Table 2. The Dutch Taste, Fat and Texture database reference solutions and products shown per taste and mouthfeel.

	Solution references		Food references	
	Concentration	**% scale**	**Product name and brand**	**% scale**
Sweet	Sucrose 20 g/l (R1)	13.33[#]	Knappertjes (biscuits), Verkade®	20
	Sucrose 50 g/l (R2)	33.33[#]	Vanilla vla (Vanilla custard), Friesland Campina®	33
	Sucrose 100 g/l (R3)	66.67[#]	Sponge cake, Albert Heijn home brand®	50
			Marshmallow, Haribo®	67
			Sweetened condensed milk, Friesland Campina®	88
Salt	NaCl 2·00 g/l (R1)	16.67[#]	Cracotte natural (crispbread), LU®	14
	NaCl 3·50 g/l (R2)	33.33[#]	Potato chips natural, Pringles®	48
	NaCl 5·00 g/l (R3)	56.67[#]	Old cheese 48 + , Old Amsterdam®	74
			Soy sauce, Kikkoman®	94
Sour	Citric acid 0·50 g/l (R1)	13.33[#]	Rye bread, Bolletje®	15
	Citric acid 0·80 g/l (R2)	33.33[#]	Buttermilk, Albert Heijn Puur en Biologisch®	38
	Citric acid 1·50 g/l (R3)	66.67[#]	Biogarde (yogurt), Albert Heijn home brand®	50
			Sour pickles, Albert Heijn home brand®	78
			Bottled lemon juice, Albert Heijn home brand®	97
Bitter	Caffeine 0·50 g/l (R1)	13.33[#]	Grapefruit juice, Albert Heijn home brand®	57
	Caffeine 0·80 g/l (R2)	33.33[#]	Black chocolate 85% cocoa, Lindt Excellence®	70
	Caffeine 1·50 g/l (R3)	66.67[#]		
Umami	MSG 1·20 g/l (R1)	13.33[^]	Non-fried natural seaweed, Nori®	28
	MSG 3·00 g/l (R2)	33.33[^]	Crab sticks, Vici®	43
	MSG 7·00 g/l (R3)	66.67[^]	Parmesan cheese, Grana Padano®	69
			Soy sauce, Kikkoman®	86
Fat			Melba® toast	0
			Snackcups natural round (crackers), Haust®	9
			Slagroomvla (cream custard), Friesland Campina®	55
			Cream cheese original, Philadelphia®	72
			White chocolate, Verkade®	73
			Unsalted butter, Friesland Campina®	97

[#] Adapted from Muñoz, Civille and Carr (1992). [^] Adapted from Martin and colleagues (Martin et al., 2014).

% scale refers to the value to which a specific concentration corresponds to on the 1-100 scale.

Appendix 14. Further descriptions on dominant taste clusters from Sweet Spot II.

The population diet from Australia resulted in six clusters, with ‘Salt and Fat’ contributing the most to total energy intake (32.8%), then ‘Sweet’ (21.8%), ‘Fat’ (18.1%), ‘Neutral’ (17.3%), ‘Sweet and Sour’ (11.0%) and lastly, ‘Bitter’ cluster (7%). The French diet resulted in seven clusters and its ‘Sour, Salt and Fat’ cluster was unique compared to other countries. Its ‘Salt’ cluster was the highest in energy contribution (32.6%), followed by ‘Umami, Salt and Fat’ (27.3%), both ‘Sweet and Fat’ and ‘Sweet and Sour’ contributed equally (13.4%), ‘Sweet’ (12.8%), ‘Sour, Salt and Fat’ (3.3%) and lastly, ‘Bitter’ cluster (3.1%). The Dutch diet also consisted of seven clusters – ‘Neutral’ (28.5%), ‘Umami, Salt and Fat’ (19.1%), ‘Salt and Fat’ (14.0%), ‘Sweet and Sour’ (10.7%), ‘Fat’ (8.2%) and ‘Bitter’ cluster (7.0%). The population diet from the UK resulted in six clusters similar to that from Australia – ‘Neutral’ (25.4%), ‘Sweet’ (21.9%), ‘Fat’ (21.8%), ‘Salt and Fat’ (17.0%), ‘Sweet and Sour’ (9.1%) and ‘Bitter’ cluster (6.2%). Like France and the Netherlands, the population diet from the US consisted of seven clusters. Its ‘Salt and Fat’ cluster contributed the most to total energy intake (32.4%), followed by ‘Sweet’ (20.8%), ‘Umami, Salt and Fat’ (14.6%), ‘Neutral’ (14.4%), ‘Sweet and Sour’ (11.0%), ‘Fat’ (9.5%) and lastly, ‘Bitter’ cluster (7.0%).

Table 1. Minor food groups from each country in each cluster.

Cluster: Neutral	
AU	Tea; Waters, municipal & bottled, unflavoured; Flours & other cereal grains & starches; Regular breads, & bread rolls; English-style muffins, flat breads, & savoury & sweet breads; Soup mix; Seeds & seed products; Gravies & savoury sauces; Cabbage, cauliflower & similar brassica vegetables; Carrot & similar root; Leaf & stalk vegetables; Peas & beans; Tomato & products; Other fruiting vegetables; Dishes where vegetable is the major component; Mature legumes & pulses & products & dishes; Other alcoholic beverages;Yeast, & yeast vegetable or meat extracts; Infant cereal products; Breakfast hot porridge; Breakfast cereals; Cheese; Dips; Dried fruit, preserved fruit; Eggs; Fin fish; Mixed dishes where cereal is the major ingredient; Muesli or cereal style bars; Nuts & products; Packed fish & seafood; Pasta & products; Pome fruit; Potatoes; Poultry & feathered game; Savoury biscuits; Soup, homemade; Sweet biscuits; Tropical & subtropical fruit
FR	
NL	Vegetables; Cereals & cereal products; Fruits; Nuts & seeds; Bread; Pastry & biscuits; Milk & milk products; Non-alcoholic beverages; Sugar; sweets & sweet sauces; Meat substitutes & dairy substitutes; Potatoes & tubers; Legumes
UK	Other cereals; Other rice incl homemade dishes; Beans & pulses incl ready meal & homemade dishes; Other pasta incl homemade dishes; Brown granary & wheatgerm bread; Other bread; White bread; Wholemeal bread; Other breakfast cereals; High fibre breakfast cereals; Biscuits mfg; Other eggs & egg dishes incl homemade; Skimmed milk; Other milk; Other potatoes incl homemade dishes; Other chicken incl homemade recipe dishes; Other white fish incl homemade dishes; Other shellfish incl homemade dishes; Other vegetables incl homemade dishes; Green beans not raw; Meat alternatives incl ready meals & homemade dish; Salad & other raw vegetables; Leafy green vegetables not raw; Peas not raw; Other fried / roast potatoes incl homemade dishes; Other potato products & dishes mfg; Tomatoes not raw; Nuts & seeds; Savoury sauces pickles gravies & condiments; Mfg oily fish products incl ready meals; Other canned tuna incl homemade dishes; Tap water only; Herbal tea; Chocolate confectionery; Bottled water still or carbonated; Soft drinks not low calorie carbonated; Pasta products & ready meals; Other fruit not canned; Yogurt
US	Milk, nonfat; Milk substitutes; Chicken, whole pieces; Fish; Shellfish; Vegetable mixed dishes; Poultry mixed dishes; Eggs & omelets; Beans, peas, legumes; Processed soy products; Pasta, noodles, cooked grains; Nuts & seeds; Yeast breads; Bagels & English muffins; Rolls & buns; Biscuits, muffins, quick breads; Tortillas; Cookies & brownies; Crackers, excludes saltines; Grits & other cooked cereals; Oatmeal; Rice; Ready-to-eat cereal, lower sugar; Other sandwiches; Soups; White potatoes, baked or boiled; Mashed potatoes & white potato mixtures; Dark green vegetables, excludes lettuce; Lettuce & lettuce salads; Other vegetables & combi; Other red & orange vegetables; Tomato-based condiments; String beans; Onions; Mustard & other condiments; Coffee; Tea; Tap water; Bottled water

Cluster: Bitter	
AU	Coffee & coffee substitutes; Beers; Chocolate & chocolate-based confectionery; Leaf & stalk vegetables; Tea
FR	Confectionery incl chocolate; Water based beverages; Beer & beer-like beverage; Mixed alcoholic drinks; Wine & wine-like drinks; Coffee, cocoa, tea & herbal drinks; spirits & liqueurs
NL	Vegetables; Alcoholic beverages; Non-alcoholic beverages; Herbs & spices
UK	Coffee; Tea; Beers & lagers; Low alcohol & alcohol free beer & lager; Salad & other raw vegetables
US	Dark green vegetables; Lettuce & salads; Mustard & other condiments; Red, orange & other vegetables; Salad dressings; Coffee; Tea; Flavored or carbonated water; Beer; Liquor & cocktails
Cluster: Fat	
AU	Breakfast cereals, hot porridge style; Butters; Dairy blends; Margarine & table spreads; Plant oils; Other fats; Eggs; Dishes where egg is the major ingredient; Beef, sheep & pork, unprocessed; Poultry & feathered game; Dairy milk; Dairy milk substitutes, unflavoured; Nuts & nut products; Potatoes; Batter-based products; Breakfast cereals, ready to eat; Cabbage, cauliflower & similar brassica vegetables; Carrot & similar root vegetables; Cheese; Corn snacks; Cream; Crustacea & molluscs; Dips; Dishes where vegetable is the major component; Fish & seafood products (homemade & takeaway); Flavoured milks & milkshakes; Leaf & stalk vegetables; Meat substitutes; Mixed dishes where cereal is the major ingredient; Other fruiting vegetables; Other vegetables & vegetable combi; Pasta & pasta products (without sauce); Pastries; Seeds & seed products
FR	
NL	Fats & oils; Savoury bread spreads; Cheese; Meat & poultry
UK	Pasta mfg products & ready meals; White bread (not high fibre not multiseed bread); Cream; Other cheese; Butter; Other cooking fats & oils not pufa; Block margarine; Pufa oils; Other beef & veal incl homemade recipe dishes; Other lamb incl homemade recipe dishes; Other chicken / turkey incl homemade recipe dishes; Liver & dishes; Mfg beef products incl ready meals; Burgers & kebabs purchased; Meat alternatives incl ready meals & homemade dish; White fish coated or fried; Mfg shellfish products incl ready meals; Other vegetables incl homemade dishes; mfg vegetable products incl cream; Chips purchased; Other mfg potato products fried/ baked; Nuts & seeds; Pizza; Pufa low fat spread; Buns cakes & pastries mfg; Mfg lamb products incl ready meals; Reduced fat spread; Rice mfg products & ready meals; Mfg pork products incl ready meals; Other white fish incl homemade dishes; Mfg coated chicken products incl ready meals; Other pork incl homemade dishes; Low fat spread not pufa; Ready meals based on bacon & ham; Other cereals
US	Milk, reduced fat; Milk, whole; Milk, lowfat; Milk substitutes; Cream & cream substitutes; Ice cream & frozen dairy desserts; Cottage/ricotta cheese; Beef, excludes ground; Butter & animal fats; Chicken, whole pieces; Chicken patties, nuggets & tenders; Fish; Dips, gravies, other sauces; Processed soy products; Nuts & seeds; Nutrition bars; Turnovers & other grain-based items; Pasta mixed dishes; French fries & other fried white potatoes; White potatoes, baked or boiled; Mashed potatoes & white potato mixtures; Carrots; Tomatoes; Vegetable mixed dishes; Onions; Margarine; Salad dressings & vegetable oils; Candy containing chocolate
Cluster: Salt and Fat	
AU	Pasta & pasta products (without sauce); Savoury biscuits; Pastries; Mixed dishes where cereal is the major ingredient; Unspecified fats; Crustacea & molluscs; Other sea & freshwater foods; Packed fish & seafood; Fish & seafood products; Mixed dishes with fish or seafood as the major component; Mammalian game meats; Organ meats & offal, products & dishes; Processed meat; Mixed dishes where beef, sheep, pork or mammalian game is the major component; Mixed dishes where sausage, bacon, ham or other processed meat is the major component; Mixed dishes where poultry or feathered game is the major component; Cheese; Meat substitutes; Dishes where meat substitutes are the major component; Soup, homemade from basic ingredients or prepared from dry soup mix or prepared from condensed or sold ready to eat; Canned condensed soup; Gravies & savoury sauces; Dips; Potato or corn snacks; Extruded or reformed snacks; Other snacks; Yeast, & vegetable or meat extracts; Beef, sheep & pork, unprocessed; Cheese substitute; Dishes where vegetable is the major component; English-style muffins, flat breads, & savoury & sweet breads; Fin fish; Flours & other cereal grains & starches; Seasonings & stock cubes; Mature legume & pulse products & dishes; Nuts & nut products; Other fruiting vegetables; Other vegetables & vegetable combi; Pickles, chutneys & relishes; Potatoes; Poultry & feathered game; Regular breads, & bread rolls; Salad dressings; Stuffings

FR	Bread & similar products; Breakfast cereals; Cereals & cereal primary derivatives; Pasta, doughs & similar products; Dishes, incl. Ready to eat meals (excluding soups & salads); Soups & salads; Fine bakery wares; Milk, whey & cream; Milk & dairy powders & concentrates; Cheese; Dairy dessert & similar; Fat emulsions & blended fats; Condiments (incl table-top formats); Animal & vegetable fats/oils; Preserved fat tissues; Fats & oils & primary derivatives thereof; Unprocessed eggs; Processed eggs; Mammals & birds meat; Canned-tinned meat; Animal meat dried; Fish (meat); Fish & seafood processed; Animal other slaughtering products; Fruiting vegetables; Processed or preserved vegetables & similar; Root & tuber vegetables; Flowering brassica; Stems/stalks eaten as vegetables; Herbs & edible flowers; Processed legumes, nuts, oilseeds & spices; Legumes; Starches; Starchy roots & tubers; Processed fruit products; Nuts, oilseeds & oilfruits; Drinking water; Water based beverages; Fruit / vegetable juices & nectars; Unsweetened spirits & liqueurs; Hot drinks & similar (coffee, cocoa, tea & herbal drinks); Savoury extracts & sauce ingredients; Extracts of plant origin; Meat & dairy imitates
NL	Vegetables; Eggs; Meat & poultry; Savoury snacks; Nuts & seeds; Cereals & cereal products; Meat substitutes & dairy substitutes; Fish; Potatoes & tubers; Cold cuts; Fats & oils; Cheese; Bread;
UK	Other pasta incl homemade dishes; Rice mfg products & ready meals; Other cereals; Biscuits mfg / retail; Crisps & savoury snacks; Other cheese; Cheddar cheese; Other bacon & ham incl homemade dishes; Other pork incl homemade recipe dishes; Mfg coated chicken / turkey products; Mfg chicken products incl ready meals; Homemade meat pies & pastries; Mfg meat pies & pastries; Other meat incl homemade recipe dishes; Other sausages incl homemade dishes; Other meat products mfg incl ready meals; Baked beans; Other rice incl homemade dishes; Mfg beef products incl ready meals; Other oily fish incl homemade dishes; Mfg oily fish products incl ready meals; Mfg canned tuna products incl ready meals; Other shellfish incl homemade dishes; Other fruit not canned; Nuts & seeds; Fruit juice; Savoury sauces pickles gravies & condiments; Soup mfg/ retail; Soup homemade; Pasta mfg products & ready meals; Other chicken / turkey incl homemade recipe dishes; Other beef & veal incl homemade recipe dishes; White bread (not high fibre not multiseed bread); Other mfg vegetable product; Mfg egg products incl ready meals; Mfg white fish products incl ready meals; Meat alternatives incl ready meals & homemade dish; Reduced fat spread (not pufa); Ready meals based on sausages; Soft drinks not low calorie rtd still
US	Dips, gravies, other sauces; Cheese; Cottage/ricotta cheese; Pizza; Soups; Beef, excludes ground; Ground beef; Pork; Cold cuts & cured meats; Lamb, goat, game; Chicken, whole pieces; Turkey, duck, other poultry; Liver & organ meats; Fish; Shellfish; Stir-fry & soy-based sauce mixtures; Poultry mixed dishes; Pasta sauces, tomato-based; Meat mixed dishes; Rice mixed dishes; Burritos & tacos; Burger; Chicken/turkey sandwiches; Other sandwiches; Frankfurter sandwiches; Beans, peas, legumes; Processed soy products; Nuts & seeds; Rolls & buns; Yeast breads; Crackers, excludes saltines; Turnovers & other grain-based items; Doughnuts, sweet rolls, pastries; Saltine crackers; Tortilla, corn, other chips; Popcorn; Pasta, noodles, cooked grains; Other Mexican mixed dishes; Nachos; Pasta mixed dishes, excludes macaroni & cheese; Macaroni & cheese; Egg rolls, dumplings, sushi; Other vegetables & combi; Potato chips; Mashed potatoes potato mixtures; French fries & other fried potatoes; Lettuce & salads; Corn; Vegetable mixed dishes; Mayonnaise
Cluster: Umami, Salt and Fat	
AU	
FR	Bread & similar products; Cereals & cereal primary derivatives; Cheese; Milk, whey & cream; Fermented milk or cream; Meat & dairy imitates; Dishes, incl. Ready to eat meals (excluding soups & salads); Processed eggs; Mammals & birds meat; Marinated meat; Animal meat dried; Canned-tinned meat; Processed meat products; Sausages; Meat specialties; Preserved fat tissues; Fish (meat); Fish offal; Amphibians, reptiles, snails, insects; Fish & seafood processed; Crustaceans; Molluscs; Animal other organs; Animal other slaughtering products; Animal liver; Animal kidney; Fungi, mosses & lichens; Processed or preserved vegetables & similar; Sprouts, shoots & similar; Soups & salads; Nuts, oilseeds & oilfruits; Processed fruit products; Fried or extruded cereal or root-based products; Fine bakery wares; Savoury extracts & sauce ingredients; Condiments
NL	Meat & poultry; Fish; Savoury snacks; heese; Cold meat cuts; Non-alcoholic everages; Savoury sauces; Herbs & spices; Misc foods; Nuts & seeds; Savoury bread spreads; Mixed dishes; Fruits; Meat substitutes & dairy substitutes; Soups; Bread; Fats & oils
UK	
US	Dips, gravies, other sauces; Cheese; Cream cheese, sour cream, whipped cream; Cold cuts & cured meats; Ground beef; Bacon; Chicken, whole pieces; Chicken patties, nuggets & tenders; Frankfurters; Sausages; Fish; Shellfish; Meat mixed dishes; Pasta sauces, tomato-based; Poultry mixed dishes; Seafood mixed dishes; Fried rice & lo/chow mein; Soups; Tortilla, corn, other chips; Soy-based condiments; Processed soy products; Nuts & seeds; Yeast breads; Turnovers & other grain-based items; rackers, excludes saltines; Pretzels/snack mix; Egg rolls, dumplings, sushi; Pasta mixed dishes, excludes macaroni & cheese; Potato chips; Vegetable juice; Mustard & other condiments; Olives, pickles, pickled vegetables

Cluster: Sour, Salt and Fat	
AU	
FR	Bread & similar products; Cereals & cereal primary derivatives; Cheese; Fish; Molluscs; Fish & seafood processed; Crustaceans; Processed or preserved vegetables; Bulb vegetables; Algae & prokaryotes organisms; Stems/stalks eaten as vegetables; Fruiting and leafy vegetables; Fruit; Flowering brassica; Milk, whey & cream; Herbs & edible flowers; Sprouts, shoots & similar; Legumes with pod; Soups & salads; Legumes; Processed legumes, nuts, oilseeds & spices; Condiments; Root & tuber vegetables; Processed fruit products; Flowers used as vegetables
NL	
UK	
US	
Cluster: Sweet and Fat	
AU	
FR	Fine bakery wares; Bread & similar products; Dairy dessert & similar; Confectionery incl chocolate; Coffee, cocoa, tea & herbal ingredients; Processed fruit products
NL	Pastry & biscuits; Milk & milk products; Sugar, sweets & sweet sauces; Fruits; Cereals & cereal products; Bread; Nuts & seeds; Savoury snacks; Meat substitutes & dairy substitutes
UK	
US	
Cluster: Sweet and Sour	
AU	Tea; Fruit & vegetable juices, & drinks; Cordials; Electrolyte, energy & fortified drinks; Berry fruit; Citrus fruit; Stone fruit; Other fruit; Yoghurt; Cream; Soy-based yoghurts; Pickles, chutneys & relishes; Salad dressings; Beers; Wines; Cider & perry; Cabbage, cauliflower & similar brassica vegetables; Cakes, muffins, scones, cake-type desserts; Carrot & similar root vegetables; Cheese; Custards; Dips; Dried or preserved fruit; Frozen milk products; Gravies & savoury sauces; Mixed dishes where cereal is the major ingredient; Mixtures of two or more groups of fruit; Other beverage flavourings & prepared beverages; Other confectionery; Pastries; Savoury biscuits; Soft drinks, & flavoured mineral waters; Tomato & tomato products; Tropical & subtropical fruit
FR	Bread & similar products; Fine bakery wares; Cheese; Fermented milk or cream; Milk, whey & cream; Molluscs; Fruit used as fruit; Processed fruit products; Stems/stalks eaten as vegetables; Soups & salads; Nuts, oilseeds & oilfruits; Confectionery incl chocolate; Sugar & other sweetening ingredients (excluding intensive sweeteners); Dessert sauces/toppings; Herbs & edible flowers; Table-top sweeteners formulations; Drinking water; Water based beverages, licorice flavour; Water based beverages; Fruit / vegetable juices & nectars; Conc or dehydrated fruit/vegetables juices; Mixed alcoholic drinks; Beer & beer-like beverage; Wine & wine-like drinks; Processed or preserved vegetables & similar
NL	Fruits; Vegetables; Milk & milk products; Meat substitutes & dairy substitutes; Non-alcoholic beverages; Sugar, sweets & sweet sauces; Pastry & biscuits; Cheese; Fats & oils
UK	Buns, cakes & pastries homemade; Other milk; Cream; Other cheese; Cottage cheese; Yogurt; Salad & other raw vegetables; Beans & pulses incl ready meal & homemade dishes; Other fruit not canned; Fruit juice; Canned fruit in juice; Sugar confectionery; Preserves; Soft drinks not low calorie conc; Soft drinks low calorie conc; Soft drinks not low calorie still; Soft drinks low calorie still; Cider & perry; Wine; Fortified wine; Savoury sauces pickles gravies & condiments; Other vegetables incl homemade dishes; Alcoholic soft drinks; Smoothies 100% fruit &/or juice; Soft drinks not low calorie carbonated; Beers & lagers; Low alcohol & alcohol free wine; Tomatoes raw
US	Milk, reduced fat; Yogurt, regular; Yogurt, Greek; Dips, gravies, other sauces; Ice cream & frozen dairy desserts; Cream cheese, sour cream, whipped cream; Cottage/ricotta cheese; Cheese sandwiches; Other sandwiches; Egg/breakfast sandwiches; Mustard & other condiments; Peanut butter & jelly sandwiches; Fruit drinks; Cakes & pies; Ready-to-eat cereal, lower sugar; Turnovers & other grain-based items; Citrus fruits; Citrus juice; Other fruit juice; Dried fruits; Other fruits & fruit salads; Apples; Grapes; Berries; Apple juice; Vegetable juice; Tomatoes; Olives, pickles, pickled vegetables; Tomato-based condiments; Mayonnaise; Salad dressings & vegetable oils; Tea; Soft drinks; Beer; Wine; Sport & energy drinks; Diet sport & energy drinks

Cluster: Sweet	
AU	Soft drinks, & flavoured mineral waters; Other beverage flavourings & prepared beverages; Breakfast cereals, ready to eat; Sweet biscuits; Cakes, muffins, scones, cake-type desserts; Batter-based products; Pome fruit; Tropical & subtropical fruit; Mixtures of two or more groups of fruit; Dried fruit, preserved fruit; Mixed dishes where fruit is the major component; Frozen milk products; Custards; Other dishes where milk or a milk product is the major component; Flavoured milks & milkshakes; Dairy milk substitutes, flavoured; Soy-based ice confection; Sugar, honey & syrups; Jam & lemon spreads, chocolate spreads, sauces; Dishes & products other than confectionery where sugar is the major component; Chocolate & chocolate-based confectionery; Fruit, nut & seed-bars; Muesli/ cereal bars; Other confectionery; Breakfast cereals, hot porridge style; Carrot & similar root vegetables; Citrus fruit; Cordials; Dairy milk (cow, sheep & goat); Dairy milk substitutes; English-style muffins, flat breads, & savoury & sweet breads; Fruit & vegetable juices, & drinks; Gravies & savoury sauces; Other fruit; Other fruiting vegetables; Pastries; Stone fruit
FR	Bread & similar products; Fine bakery wares; Breakfast cereals; Dairy dessert & similar; Cereals & cereal primary derivatives; Pasta, doughs & similar products; Dishes, incl. Ready to eat meals (excluding soups & salads); Processed fruit products; Water-based sweet desserts; Root & tuber vegetables; Fruit used as fruit; Fruiting vegetables; Nuts, oilseeds & oilfruits; Confectionery incl chocolate; Processed legumes, nuts, oilseeds & spices; Sugar & other sweetening ingredients (excluding intensive sweeteners); Beverages concentrates; Drinking water; Water based beverages; Fruit / vegetable juices & nectars; Mixed alcoholic drinks; Beer & beer-like beverage; Unsweetened spirits & liqueurs; Wine & wine-like drinks; Hot drinks & similar
NL	
UK	Cereal based milk puddings homemade; Buns cakes & pastries mfg; White bread (not high fibre not multiseed bread); High fibre breakfast cereals; Other breakfast cereals (not high fibre); Biscuits mfg / retail; Biscuits homemade; Buns cakes & pastries homemade; mfg egg products incl ready meals; Other cereal based puddings homemade; Other cereal based puddings mfg; Fruit pies mfg; Fruit pies homemade; Sponge puddings homemade; Cereal based milk puddings mfg; Ice cream; Whole milk; Semi skimmed milk; Other milk; Cream; Salad & other raw vegetables; Carrots raw; Carrots not raw; Peas not raw; Other vegetables incl homemade dishes; Apples & pears not canned; Other fruit not canned; Canned fruit in syrup; Canned fruit in juice; Bananas; Citrus fruit not canned; Nuts & seeds;Sugar; Sweet spreads fillings & icing; Preserves; Chocolate confectionery; Sugar confectionery; Beverages dry weight; Fruit juice; Soft drinks not low calorie carbonated; Dairy desserts homemade; Fromage frais & dairy desserts mfg; Sponge puddings mfg; Soft drinks low calorie carbonated; Soft drinks not low calorie conc; Bottled water still or carbonated; Yogurt; Soft drinks not low cal rtd still
US	Flavored milk, whole; Milk substitutes; Yogurt, regular; Ice cream & frozen dairy desserts; Flavored milk, nonfat; Flavored milk, reduced fat; Flavored milk, lowfat; Milk shakes & other dairy drinks; Smoothies & grain drinks; Cream cheese, sour cream, whipped cream; Pudding; Cakes & pies; Nuts & seeds; Yeast breads; Doughnuts, sweet rolls, pastries; Bagels & English muffins; Biscuits, muffins, quick breads; Cookies & brownies; Pancakes, waffles, French toast; Cereal bars; Oatmeal; Ready-to-eat cereal, higher sugar; Ready-to-eat cereal, lower sugar; Dried fruits; Apples; Bananas; Melons; Other fruits & fruit salads; Peaches & nectarines; Berries; Gelatins, ices, sorbets; Other starchy vegetables; Carrots; Other vegetables & combi; Other red & orange vegetables; Tomatoes; Corn; Vegetable mixed dishes; Soups; Other fruit juice; Sugars & honey; Jams, syrups, toppings; Candy not containing chocolate; Candy containing chocolate; Coffee; Soft drinks; Diet soft drinks; Fruit drinks; Other diet drinks; Enhanced or fortified water; Nutritional beverages

AU: Australia. FR: France. NL: the Netherlands. UK: the United Kingdom. US: the United States. Mfg.: manufactured. Incl.: including.

Appendix 15. Absolute and percentage dietary taste exposure from Sweet Spot II.

Table 1. Absolute and percentage contributions of dietary taste exposure from nationally representative diets of Australia (AU), France (FR), the Netherlands (NL), the United Kingdom (UK) and the United States (US).

score g min (%)	AU	FR	NL	UK	US
Sweet	189441 ± 927 (23.6 ± 0.085)	135939 ± 1788 (18.0 ± 0.167)	77065 ± 1835 (21.5 ± 0.172)	125913 ± 2143 (24.9 ± 0.203)	185059 ± 1176 (23.2 ± 0.107)
Sour	90024 ± 576 (11.1 ± 0.058)	121403 ± 1132 (16.9 ± 0.118)	64984 ± 1149 (15.3 ±0.126)	59431 ± 1339 (11.6 ± 0.140)	89201 ± 731 (11.4 ± 0.073)
Bitter	83479 ± 512 (11.5 ± 0.076)	75780 ± 965 (10.9 ± 0.147)	43150 ± 995 (11.5 ±0.153)	60806 ± 1165 (13.0 ± 0.179)	79795 ± 651 (11.3 ± 0.095)
Umami	74084 ± 557 (9.50 ±0.050)	67183 ± 1076 (8.57 ±0.100)	27578 ± 1100 (7.33 ± 0.103)	48319 ± 1284 (9.21 ± 0.121)	73160 ± 712 (9.89 ± 0.064)
Salt	173994 ± 1102 (21.4 ± 0.074)	173048 ± 2194 (23.4 ± 0.151)	54060 ± 2193 (14.9 ± 0.153)	100703 ± 2559 (19.2 ± 0.180)	180458 ± 1408 (22.9 ± 0.094)
Fat	149004 ± 832 (19.0 ± 0.062)	154296 ± 1634 (20.7 ± 0.125)	99373 ± 1657 (25.7 ± 0.133)	104023 ± 1927 (20.6 ± 0.151)	142090 ± 1048 (18.1 ± 0.079)
Total	1033503 ± 8822	838303 ± 17764	393327 ± 18284	643388 ± 21428	1059880 ± 11163
Consumed quantity per day, g	3086 ± 11.2	2946 ± 22.2	2939 ± 22.9	2845 ± 26.8	2968 ± 14.3
Energy intake per day, kcal	1959 ± 7.20	2088 ± 14.5	2160 ± 15.0	1907 ± 17.3	2006 ± 9.16

Appendix 16. Sum of percentage contributions by clusters per taste.

Table 1. Energy contribution per taste across the countries calculated by summing up percentages of clusters in which the taste appears in.

(%)	AU	FR	NL	UK	US
Sweet	32.8 *(21.8+11.0)*	39.6 *(13.4+12.8+13.4)*	25.5 *(14.8+10.7)*	43.0 *(21.9+21.1)*	31.8 *(20.8+11.0)*
Sour	11.0	16.7 *(3.3+13.4)*	10.7	9.1	11.0
Bitter	7.0	3.1	7.0	6.2	7.0
Umami	-	27.3	19.1	-	14.6
Salt	32.8	63.2 *(3.3+27.3+32.6)*	33.1 *(19.1+14.0)*	17.0	47.0 *(14.6+32.4)*
Fat	50.9	76.6 *(3.3+13.4+ 27.3+32.6)*	56.1 *(14.8+19.1+ 8.2+14.0)*	38.8 *(21.8+17.0)*	56.5 *(14.6+9.5+32.4)*

AU: Australia. FR: France. NL: the Netherlands. UK: the United Kingdom. US: the United States.

Appendix 17. Publications from thesis.

1. Tang, C.S.; Mars, M.; James, J.; and Appleton, K.M. (2021). Sweet Thoughts: Attitudes towards sugar, sweeteners and sweet-tasting foods amongst British consumers. (Abstract). The British Feeding and Drinking Group 45th Annual Meeting, Online, UK. *Appetite*. doi:10.1016/j.appet.2021.105529.

Abstract: Public health efforts to reduce sugar intake, including guidelines on sweeteners and sweet-tasting foods, may influence individual perceptions of these foods. This study aimed to explore consumer attitudes towards sugar, sweeteners, sweet-tasting foods, and related policies. Seven focus groups, two dyadic interviews and one solo interview were conducted in Southern England, with 29 participants (5 males, ages: 18-65 years). Using an inductive approach, thematic analysis resulted in the identification of six themes reflecting how participants viewed sugar, sweeteners and sweet-tasting foods, related policies, or their relationship with these foods. The presence or absence of reasons to be personally concerned ('Personal Relevance'), and the assumption of responsibility towards these foods ('Personal Responsibility'), were reported to affect intakes. This active relationship relied on the acquisition, comprehension and application of insights surrounding these foods. In the theme 'Understanding', participants expressed both clarity and confusion towards various information. Conversely, the theme 'It's Not Up to Me' saw a passive approach to dietary intakes of these foods, stemming from feelings of being subjected to circumstances beyond one's control. In theme 'Angle', there was a lack of positive perceptions towards these foods; yet a 'Value' to the consumption of all these foods was also reported. Future work will look at these attitudes in association with dietary intakes.

Keywords: Sweet taste, attitudes, sugar, sweeteners, thematic analysis, qualitative, focus groups, perceptions.

2. Tang, C.S.; Mars, M.; Cox, D.N.; Hendrie, G.; James, J.; de Graaf, K.; and Appleton, K.M. (2022). Spot the pattern: Methods towards the characterisation of dietary taste patterns. (Abstract). The British Feeding and Drinking Group 46th Annual Meeting, Online, UK. *Appetite*. doi:10.1016/j.appet.2022.106207.

Dietary taste exposure at a population level is difficult to characterise, due to the lack of taste intensity values across all foods consumed, and a lack of agreement as to how to quantify taste exposure. The current work aimed to characterise Dutch dietary taste patterns and explored different methods to do this. The National Food Consumption Survey 2012-16 and a database of 500 foods with sweet, sour, bitter, umami, salt taste and fatty mouthfeel values assigned by a trained panel were used. To assign values to un-tested foods, two methods were investigated: 1- Best Fit (BF): assigning exact values of a best-matched tested food within each sub-group based on expert knowledge, 2- Group Average (GA): assigning mean values of tested foods within that sub-group (e.g., root vegetables). They yielded significant yet small differences (smallest t=2.17(1847), p=0.03); Bland-Altman analyses revealed that BF systematically assigned smaller values and was more subjective compared to GA. Two methods of quantifying dietary taste exposure were also explored: A) Cluster analyses: foods most similar in taste intensities were grouped to elucidate their contribution to energy intake (7-28.5%), B) analyses based on Sensory Amount: summation of taste intensity values per food multiplied by amount consumed. Clustering provided dominant taste combinations but depend on the data provided; Sensory Amount revealed the magnitudes of all basic tastes within the diet. To conclude, dietary taste patterns can be best characterised using the GA method combined with Sensory Amount.

Keywords: Taste, sensory, dietary assessment, methodology.

3. Tang, C.S.; Mars, M.; Cox, D.N.; Hendrie, G.; James, J.; and Appleton, K.M. (2023). Comparison of dietary taste exposure across Australia, France, the Netherlands, the United Kingdom and the United States of America. (Abstract). The 10th European Conference on Sensory and Consumer Research, Turku, Finland. *Food Quality and Preference*.

Abstract: Taste exposure in the diet, facilitated by taste intensity and duration, may influence dietary intake, diet quality, and associated health outcomes. This work aimed to assess dietary taste exposure patterns of Australia, France, the Netherlands, the UK and the US. Dietary records from respective national consumption surveys were assigned sweet, sour, bitter, umami, salt taste and fatty mouthfeel values from Australian, Dutch or French sensory databases. Each food was also categorised as liquid, semi-solid, soft-solid or hard-solid and assigned the average eating rate of its category to account for exposure duration. The magnitudes of sweet, sour, bitter, umami, salt, fat, total taste exposure, and contributions of each taste to total taste exposure were separately compared; adjusted for BMI, sex, energy intake and consumed quantity. Countries differed in their total taste exposure (R^2=0.43, F(8,14717)=1372, p<.001). Pairwise comparisons with Bonferroni correction revealed differences between each country except between the US (1060±11x10^{+3} score g min) and Australia (1034±9x10^{+3} score g min). These diets also had similar sweet (23.2-23.6%), sour (11.1-11.4%) and bitter (11.3-11.5%) contributions to total exposure. Sweet taste contributed the most to total exposure in the UK (24.9±0.2%), the US (23.2±0.1%) and Australia (23.6±0.1%). Although the Netherlands had the lowest fatty mouthfeel exposure (99±2x10^{+3} score g min), fatty mouthfeel contribution to total exposure was the highest (25.7±0.1%). French fatty mouthfeel exposure was the highest (154±2x10^{+3} score g min) and significantly higher than the UK (104±2x10^{+3} score g min); however, contributions to total exposure were similar. Bitter taste exposure differed between each country (R^2=0.47, F(8,13272)=1482, p<.001), yet contribution to total exposure was similar between Australia (11.5±0.1%), the Netherlands (11.5±0.2%) and the US (11.3±0.1%). To conclude, variations exist in total taste exposure across the countries, and in the contribution of each taste to total taste exposure within the diet.

Keywords: Taste exposure, dietary intake, cross-country, sensory databases.

4. Tang, C. S., Mars, M., James, J., de graaf, K., & Appleton, K. M. (2021). Sweet talk: A qualitative study exploring attitudes towards sugar, sweeteners and sweet-tasting foods in the united kingdom. *Foods*, *10*(6). doi:10.3390/foods10061172.

Abstract: Worldwide initiatives currently aim to reduce free sugar intakes, but success will depend on consumer attitudes towards sugar and the alternatives. This work aimed to explore attitudes towards sugar, sweeteners and sweet-tasting foods, towards consumption and related policies, in a sample of the general public of the UK. Focus groups and interviews were conducted with 34 adults (7 males, ages: 18–65 years). Thematic analysis identified six themes: ‘Value’ (e.g., pleasure, emotions), ‘Angle’ (e.g., disinterest), ‘Personal Relevance’ (to be concerned and/or change one’s own behavior), ‘Personal Responsibility’ (one has an active relationship with these food items), ‘Understanding’ (the acquisition, comprehension and application of information) and ‘It’s Not Up to Me’ (a passive approach, because intake is subjected to other factors). Both positive and negative attitudes towards sugar, sweeteners and sweet-tasting foods were expressed in all themes. Participants also reported varied engagement with and motivations towards all food items, with implications for intakes. Suggested challenges and potential strategies for reducing free sugar intakes highlighted the need for differing approaches. Future work should assess associations between attitudes and intakes. For greatest population benefit, evidence of the dominant attitudes in those in greatest need of reduced free sugar intakes would be of value.

Keywords: sweet taste; sweetness; perceptions; focus groups; qualitative research; thematic analysis