The promotion of dietary behaviour change in healthy populations through digital interventions: A systematic literature review

Highlights:

- A systematic literature review on existing digital interventions for dietary behaviour change.
- Four major digital interventions strategies were revealed as personal digital assistant, video games, smartphones and web-based interventions.
- Tailored counselling and feedback services generally promote investigated interventions' effectiveness.

Abstract

Diet-related chronic disease is a global health epidemic giving rise to a high incidence of morbidity, disability and mortality. It comes at a considerable price, since it costs millions in national healthcare systems every year. Hence, diet management has gained immense importance in the modern world. With the rise of the digital revolution, there has been increased interest in using digital technology as a cost-saving and effective method in delivering behavioural change. However, evidence of its use in dietary behaviour change is relatively scarce. This review considers the digital interventions currently being used in dietary behaviour change studies.

A literature search was conducted in medical and health databases like PubMed, Cochrane Library, CINAHL, Medline and PsycInfo. Among 119 articles screened, 15 were selected for the study as they met all the inclusion criteria according to the PRISMA search strategy. From the search, four primary digital intervention methods were noted: use of personal digital assistants, use of the internet as an educational tool, use of video games and use of mobile phone applications. The efficiency of all the interventions increased when coupled with tailored feedback and counselling. It was established that the scalable and sustainable properties of digital interventions have the potential to bring about adequate changes in the eating behaviour of individuals. Further research should concentrate on the appropriate personalisation of the interventions, according to the requirements of the individuals, and proper integration of behaviour change techniques to motivate long-term adherence.

Keywords: Digital interventions; Dietary behaviour change; Healthy population; Systematic review

1. Introduction

Throughout their lifespan, human beings have to adjust to a continuum of changes. Science plays a significant role in bringing about social as well as behavioural changes in human populations. The scientific study of behaviour enriches the ability to change. Behavioural science helps in creating strategies to tackle the problems that emerge when people are faced with changes in behaviour, regardless of whether it is positive or negative, compulsory or voluntary. The behaviours that affect the health of human beings can be of two kinds, protective and risk behaviours. Studies have shown that most non-communicable diseases in the world, nowadays, are attributed to health behaviours (WHO, 2008; Lloyd-Jones *et al*., 2010).

There are multiple health risk behaviours which increase the chances of illness and prevent recovery. Of these, five have been identified as the riskiest and most capable of causing morbidity. They are: lack of physical activity (Fogelholm, 2010); substance (alcohol and drugs) abuse (Roerecke and Rehm, 2010; Stenbacka *et al*., 2010); consuming food low in nutrients but high in calories, fat and sodium (Mente *et al*., 2009); smoking (CDC, 2008) and risky sexual behaviour (Johnson *et al*., 2008). Conversely, protective health behaviours include: engaging in regular physical activities (Qin *et al*., 2010); including fruits and vegetables in the daily diet (Van and Pivonka, 2000; Riboli and Norat, 2003); and taking correctly prescribed medications (Cramer *et al*., 2008; Ho *et al*., 2009). Studies reveal that removal of health risk behaviours can avert 40% of cancers and 80% of cardiovascular diseases as well as type 2 diabetes (Institute of Medicine, 2001; Ezzati *et al*., 2004).

1.1 Dietary behaviour

It is evident that dietary behaviour is one of the groups of health risk behaviours that can have a major effect on a person’s health. A diet that is poor in nutrition can lead to ailments like diabetes, cardiovascular conditions, hypertension, osteoporosis, cancer (colorectal, stomach, lung, oesophageal and prostate) and even dental caries (Dietary Guidelines for Americans, 2015-2020).

An ideal diet should consist of whole grains, different kinds of fruits and vegetables, protein, oils and fat-free or low-fat dairy products. Apart from the above, ideal dietary behaviours include reducing the sodium content in food as well as avoiding solid fats, as they are the primary sources of trans fatty acids and saturated fatty acids (Myplate.gov, 2018). Departing from this wholesome diet can result in a calorie intake that is in excess of the calories being utilised by the body and this imbalance in calories, if left unchecked, ultimately results in obesity. In children and adolescents, lack of proper nutrition can lead to decreased cognitive performance as well as other developmental problems (CDC, 2017). Childhood obesity is detrimental to the proper development of the physical and mental health of children. Obesity can give rise to health problems like early puberty, respiratory conditions such as asthma, dermatological infections as well as predisposition to cancer (Public Health England, 2015). It can also lead to the development of type-2 diabetes (Lee *et al*., 2006). Obesity can also affect mental health by giving rise to psychological conditions like poor self-esteem, anxiety, eating disorders and being overly conscious about body image (Gable *et al*., 2009; National Obesity Observatory, 2011). Apart from the short-term effects, there are several long-term effects of childhood obesity. Children and adolescents who are obese have an increased likelihood of suffering from obesity into their adulthood, lowering life expectancy and compounding additional morbidities (Fontaine *et al*., 2003; Simmonds *et al*., 2015).

The UK is suffering from an obesity epidemic. According to reports from the National Health Services (NHS) England, in 2016, 27% of adults living in the UK were classified as obese as compared to 15% in 1993. In the year 2016/17, 617,000 patients admitted to the NHS had a primary or secondary diagnosis of obesity (NHS Digital, 2018). The UK has the worst rates of adult obesity among Western European countries, and the Organisation for Economic Co-operation and Development (OECD) report predicts that 50% of the UK population will be obese by the year 2050 if adequate steps are not taken (OECD, 2018). Childhood obesity levels in the UK are among the highest in the whole of Europe (National Obesity Forum, 2015). Levels increased steadily between 1995-2005 when the percentage of obese boys and girls (2-15 years) reached a peak level of 18% (Health and Social Care Information Centre, 2015). Figures show that 9.5% of 4-5 year-olds and 19.1% of 10-11 year-olds are obese. Obesity has also been observed to be strongly associated to social deprivation, as the rate of obesity among school leavers in economically backward areas was 24.7% while among those in the least disadvantaged regions it was 13.1% (Health and Social Care information Centre, 2014).

1.2 Changing dietary behaviour

The primary strategy to tackle the rise in obesity is to bring about a significant change in the dietary behaviour of children and adolescents, as well as adults. Behaviours do not occur in isolation but are part of a system. It is, therefore, challenging to change behaviours that are prevalent in everyday life. Historically, it was believed that dietary behaviour could be changed with knowledge of the nutritional value of food: this knowledge would automatically encourage people to be conscious of the diet they followed so that their own and their family's health could benefit from it. However, extensive studies of the available literature have indicated that educating people about the health benefits of nutritious food is not sufficient to bring about a dietary change (Contento *et al*., 1995). This is where behavioural science comes into play. It helps in the creation of specific strategies that are necessary to bring about behavioural changes by studying the problem from different angles.

Several factors play a role in the formation of dietary behaviours. These factors are known as mediating variables and can be personal, physical, environmental, behavioural and familial (Baranowski *et al*., 1996; 1997). The most effective way of bringing about a change in dietary behaviour is by changing one or more of the mediating variables (Baranowski *et al.*, 1997). An example is the inclusion of fruits and vegetables in the diet of young children. Most children eat fruits and vegetables that they are acquainted with or accustomed to (Baranowski *et al.*, 2000), which limits the variety of choices that are available to them. In this case, the mediating variable that can be targeted and changed is the environment. Strategies should be developed to change their environment so that they are exposed to a greater variety of fruits and vegetables. This can be achieved by increasing the availability at home or eating out at places where more variety is offered.

Designing interventions to change dietary behaviour is a complex process. Firstly, all the mediating variables need to be identified and prioritised, the type of changes that are necessary must be decided upon, and then policies need to be put into place. Change cannot be achieved without a great amount of qualitative research involving discussions with focus groups and exhaustive interviews with the target population (Kirby *et al*., 1995). Unfortunately, as there are no recommended or fixed strategies, most strategies are based on intuitions and study of the social, cultural and economic backgrounds of the target population. Even then, different individuals respond differently: the same message that can convince one parent to include fruits and vegetables in the child's diet might not work for another parent. Much research is still required in this area of behavioural research to come up with strategic policies that can work for most people in the community.

1.3 Digital behaviour change interventions (DBCI)

In today's digital age, a large number of people are connected to the internet by various technologies and it is estimated that between 20% and 80% of them use it to keep a check on their health as well as for some other sort of health benefit (Fox and Duggan, 2012; Kontos *et al*., 2014; Rock Health, 2015). It is therefore only natural that digital interventions should be employed to bring about the required changes in dietary behaviour. Digital behaviour change intervention (DBCI) can be defined as '…a product or service that uses computer technology to promote behaviour change' (West and Michie, 2016). Such interventions can be accessed by wearable devices, computer programmes, cellular phones, smartphone applications or various websites. Designing DBCIs involves an interdisciplinary approach, harnessing the expertise from disciplines like computer science as well as behavioural science to develop a collective approach to engage with the target population. An effective DBCI is designed by connecting knowledge of computer programming, content of the intervention, design of the interface and delivery by human-computer interaction (Perski *et al*., 2017).

Research shows that DBCIs can bring about individual changes by inspiring people to lead healthier lives, potentially helping millions. Change has been facilitated in a range of health behaviours like weight management (Liu *et al*., 2015), cessation of smoking (Whittaker *et al*., 2009; Civljak *et al*., 2013), increase in physical activity (Muntaner *et al*., 2015), decreasing consumption of alcohol (Nair *et al*., 2015), and self-management of chronic conditions (Jones *et al*., 2014). The effectiveness of the DBCIs, though, depends on some form of commitment to them and regular interaction with them (Donkin *et al*. 2011). For example, there are websites and mobile apps which have helped people to quit smoking, to manage anxiety disorders or to ensure the timely administration of medications. In many cases, these play the role of personal therapists by offering motivation, feedback and knowledge regarding certain matters in response to the lifestyle information that the patient puts in. Thus, DBCIs can prove quite valuable in providing interactive support services to public health campaigns (Webb *et al*., 2010).

1.4 Limitations of DBCIs

Notwithstanding the immense potential that a DBCI has for implementing changes in dietary behaviour, it does not come without drawbacks, the main one being the primary requirement of appropriate tools like a smartphone or a computer and a subscription to the internet. Also, there is a need for users to be able to utilise these technologies or be willing to spend time learning their operation.

Another major drawback is the commitment required for digital interventions to be effective. If the patient does not enter any data into the system, the DBCI will be rendered useless and no more beneficial than static content such as printed matter. The continuous updating of data by the user is a ‘hassle factor’ which can gradually wear away the intent to use DBCI for necessary interventions (Wantland *et al.*, 2004). This can be one of the many factors that make people drop out of these online programmes, as they lose motivation. DBCI must be used for a minimum amount of time to have any effect on behaviour, and it is necessary for the user to remain enthused towards the cause during that time period. Also, in matters of behavioural change, there is always an opportune moment when the user is most amenable to change or at risk of a setback. Digital interventions are unable to gauge these scenarios and act on them, which decreases their efficacy. Technological advancement has been able to address this problem partially, however, more research is needed. However, the introduction of sensor technology has in many cases reduced the ‘hassle factor’, and devices like GPS, accelerometers and galvanic skin response sensors have been able to sense the most favourable moment to act upon; for example, by gauging the moment when a user is susceptible to stress build-up and helping them to take steps to de-stress (Cugelman, 2018).

2. Rationale for study

In today's world, obesity and being overweight are considered the leading risk factors for fatality (WHO, 2017). Weighing more than normal can lead to cancers of the ovary, kidney, thyroid, breast, uterus, pancreas, gall bladder, stomach, oesophagus, bowel, liver and also myelomas and meningiomas. Prevalence of such types of cancers is on the increase due to the rise in obesity (Wang *et al*., 2011). According to the OECD, cancer causes about 221.9 deaths per 100,000 people in the UK, making it the 11th highest amongst the OECD countries in cancer mortality (OECD, 2018). Of these cancer cases, 6% of are due to obesity (Brown *et al.*, 2018). Also, figures reveal that in the UK, the number of caesarean births rose by 11% in five years to 28% in the year 2016-17, and this has been attributed partly to rising obesity as 1 in 5 women have a BMI above 30. About 25% of the total adult population in the UK are obese (Health and Social Care Information Centre, 2015) costing the NHS £14bn per year. In the absence of effective action to tackle the situation, this amount will rise to £50bn by 2050 (Butland *et al*., 2007).

There has also been a steady rise in childhood obesity in the UK. Since it is difficult to reverse obesity in adulthood, it is essential that steps be taken to prevent childhood obesity. Various environmental, behavioural and genetic factors cause childhood obesity (Karnick and Kanekar, 2012). Since genetic factors are not very common, it can be safely concluded that behavioural and environmental factors play a major role (Ebbeling *et al*., 2002). Sedentary lifestyles, lack of physical activity, addiction to video games, television and smartphones, and rapidly transforming dietary behaviours have all accelerated the obesity epidemic (WHO, 2015). It has been clearly demonstrated that the easy availability and intensive marketing of high-calorie food products aid in increasing obesity levels, as seen in developing countries like India, Mexico and Brazil (Popkin *et al*., 2012). In developed countries like the UK, the high purchasing potential of the customer, the availability of energy-rich food products which are comparatively cheap and the popularity of carbonated drinks which have high sugar content have accentuated the problem (Gupta *al*., 2012). In the absence of serious actions, the already struggling NHS will be unable to cope with this epidemic.

In 2006, the Department of Health in the UK estimated that it had spent £187bn per year in treating conditions that were preventable (National Consumer Council, 2006). In recent years. the realisation that money could be better spent on social campaigns for promoting healthy lifestyles has resulted in a government policy shift from curative to preventive medicine.

Public health promotional campaigns motivate the target population to change their behaviour, using the reward and punishment (or incentive and disincentive) method, such as preventing alcohol abuse in young people by portraying being drunk as uncool. Several strategies, tools and theories are used to create such campaigns, which are mainly based on the commercial marketing strategy of the 4Ps: product, price, place and promotion (Cugelman, 2018). Certain campaigns, apart from motivation and creating awareness of specific issues, also provide support, such as special telephone hotlines or referrals to health care centres or other facilities which can help with early diagnosis of conditions and increase survival rates in fatal conditions. Evidence suggests that health promotion social campaigns can influence around 5% of the population on average (Snyder, 2007). This percentage differs depending on the population or behaviour being targeted. Though 5% might seem quite a low number, even such small changes in the behaviour of a population can produce considerable impacts in the general health of the public.

Social campaigns, though, are not without their own set of limitations. Although social campaigns can create awareness and motivate people to change their habits, certain behavioural changes such as substance abuse, addictions, smoking, mental health and dietary changes are difficult to address. Initiating someone into a healthy lifestyle is far easier than maintaining their motivation to continue practising the healthy behavioural changes. For certain behavioural changes, the interventions need to be tailored according to personal lifestyle, tastes, habits, desires, time constraints and location. Social campaigns providing guidelines cannot attain this. A social campaign cannot help in the creation of a personalised healthy diet according to personal tastes, needs and preferences. In 2011, Cugelman *et al.* demonstrated that although social campaigns had the ability to affect 5% of the population, digital interventions could bring about behavioural change in 10% of the population. The advantage that the digital world provides in customisation and personalisation has a much more far-reaching effect in bringing about difficult behavioural changes like altering dietary habits. Apart from being more efficient, digital interventions are more cost-effective than other types of personalised support. As an example, a personalised digital intervention against smoking costs the least, with personalised print interventions costing 5-40 times more and personalised telephonic help being 150-250 times more expensive (Strecher *et al*., 2005). Thus, the efficacy, reach and low cost of DBCIs make them an ideal strategy to be followed to bring about dietary behavioural changes and improve public health.

This review considers the various studies present in the literature that demonstrate the effect of digital interventions on changing the dietary behaviour of individuals. The aims of this review are:

- Comparison of the different kinds of digital interventions available
- Gauging the efficacy of each kind of intervention on dietary behaviour changes by studying the effect size
- Recommendation of policies and formulation of strategies for further interventions.

3. Search strategy

Information sources were obtained from a literature search performed in the following medical and health-related databases: PubMed, CINAHL, PsycInfo, MedLine and trials available in the Cochrane Library. The search query used the terms ‘digital interventions’, ‘smartphone apps’, ‘diet’, ‘digital’, ‘behaviour’ and ‘dietary behaviour changes’. The search results obtained were downloaded and were then combined and sorted to remove duplicates. The articles obtained were then screened based on the pre-determined inclusion and exclusion criteria listed in Table 1. This systematic review was conducted following the guideline of PRISMA and has been registered on PROSPERO (registration number is CRD42019120085).

Table 1: The inclusion and exclusion criteria for the selection of articles

Inclusion criteria	Exclusion criteria
(i) Full-length articles published in peer-reviewed journals	(i) Reviews, incomplete trials and those where only the abstracts were available
(ii) Articles describing all kinds of clinical trials, randomised controlled trials as well as others were included	(ii) Sample population suffering from illness or disorders like diabetes, cardiovascular disease, depression or other mental health conditions as well as pregnant women
(iii) Use of any kind of digital intervention to change dietary behaviour	(iii) Studies where either diet or digital intervention was present but were not present together
(iv) Sample population selected were healthy adults, children or adolescents	(iv) Studies where there was no direct effect on change or intent to change dietary behaviour

Data was extracted and analysed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The flow diagram of the method followed is provided in Figure 1. Table 2 lists the articles which were selected for the review. Effect size of the studies performed was listed and for the studies in which it was not reported, effect size was calculated. Depending on the available data, effect sizes for the studies were calculated from means and standard deviations, T-test P-value and co-relation co-efficient using the formulae described by Lipsey and Wilson (2001).

Figure 1. Flow diagram showing the PRISMA strategy used to search the literature

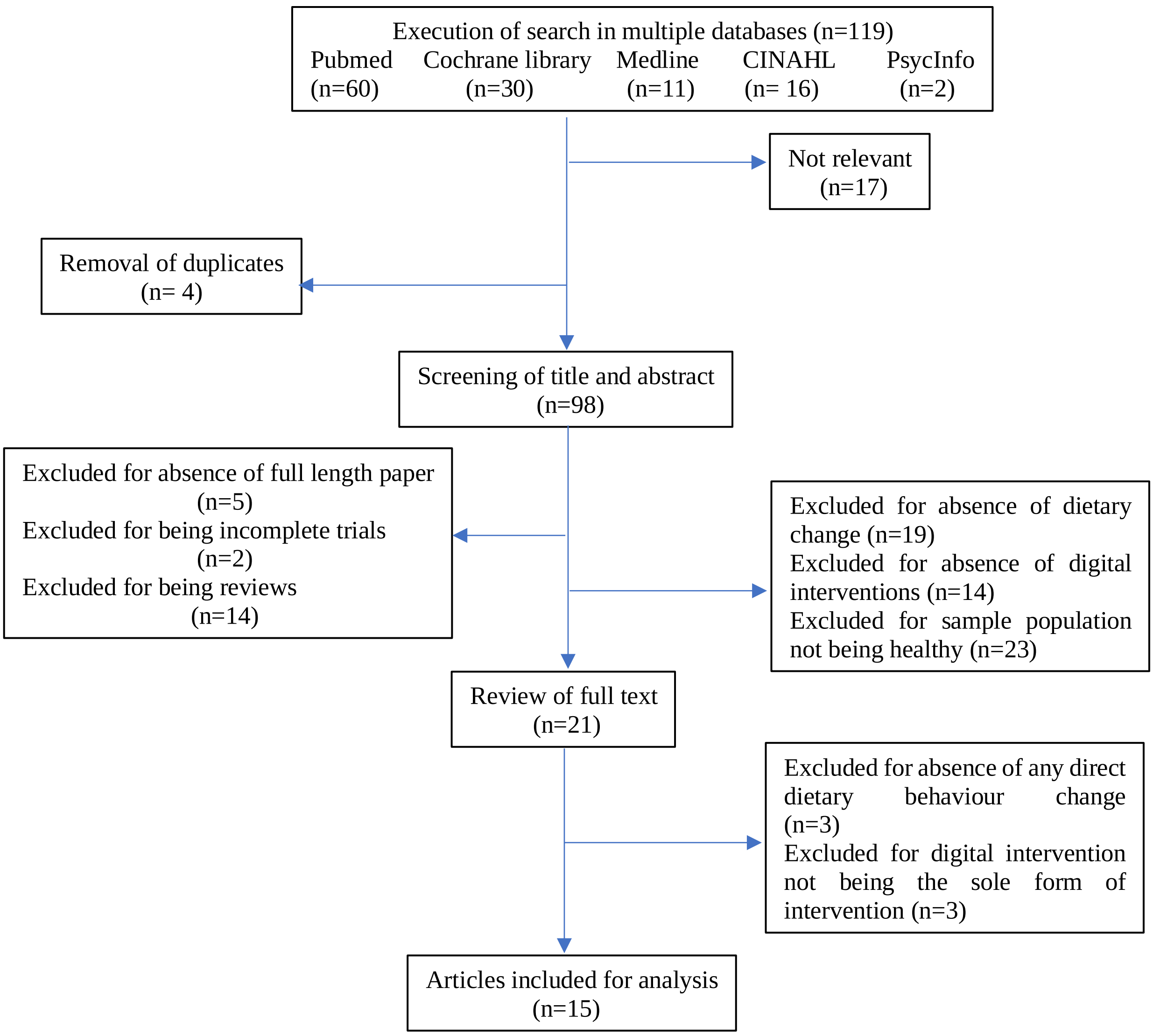

Table 2: Characteristics of the articles selected for analysis

Author, year	**Target population**	**Intervention type**	**Change in dietary behaviour**	**Effect size**
Personal Digital Assistant (PDA) as intervention				
Acharya *et al*., 2011	192 people with a mean age of 49 years and BMI of 34.0 kg/m^2	Self-monitoring PDA	Increased consumption of fruits, vegetables and less intake of refined grains	Effect size for fat intake was 0.25; for fruit servings 0.36; vegetable servings 0.32; whole grain servings 0.1 and refined grain servings was 0.2
Ambeba *et al*., 2015	Participants were 210 obese adults (BMI $\geq$ 34.0 kg/m^2)	Daily tailored feedback on diet intake using a PDA	Significant improvements in intake of fats and carbohydrates	Effect size calculated between group receiving feedback versus that not receiving feedback. (i) 0.32 for reduction of fat intake (ii) 0.34 for reduction of energy intake
Burke *et al*., 2011a	Healthy adults (18-59 years of age) with a BMI between 27 and 43 kg/m^2	Self-monitoring diet and exercise using a PDA with or without feedback	Higher proportion of the group using PDA and feedback had a significant weight loss (5%) after 6 months by monitoring calorie intake in their diets	An effect size of 0.3 in change in total fat intake was observed between the paper record group and group using PDA + feedback
Atienza *et al*., 2008	27 healthy adults aged $\geq$ 50 years	PDA monitoring their daily diet, providing feedback and answering questions	Target population reported higher intakes of vegetables and dietary fibres in their daily diet	Effect size of 0.9 for vegetable serving and 0.7 for dietary fibre intake was calculated
Olson *et al*., 2008	Adolescents visiting 5 rural primary care practices in the USA	Personal digital assistant (PDA)-mediated questionnaires, health behaviour assessments and counselling	Increased intake of milk	Effect size of change in milk intake between the PDA group and non-PDA group was 0.365.

Online education as intervention				
Schwarzer *et al*., 2016[#1]	454 adults (18-65 years of age)	Online platform delivering a lifestyle intervention to follow the Mediterranean diet	Overall improvements in Mediterranean diet	Various effect sizes on dietary behaviour was observed. R^2=0.14 for positive outcome expectancies; R^2=0.12 for dietary action control; R^2=0.13 for dietary planning and R^2=0.17 for stages of changes.
Kattelmann *et al*., 2014	1,639 college students	10-week intensive intervention focussing on eating behaviour, physical activity, stress management via e-mail and the internet	Small changes were observed in fat intake and inclusion of fruits and vegetables in the diet.	Effect size of fruits and vegetables consumption between control and experimental group was 0.05
O'Donnell *et al*., 2014	Students from 8 participating institutions in the USA (18-24 years of age), BMI $\geq$ 18.5.	10 online lessons with feedback, facts and interactive questions	Setting of goals increased intake of fruits and vegetables by the participants	Effect size of intake of fruits before goal setting and after 10 weeks of goal setting is η^2 = 0.09
Grimes *et al*., 2018	Child-parent dyads from 5 government schools in Australia	5-week intervention programme delivered weekly via an online education programme to reduce salt intake	Increased the knowledge, self-efficacy and behaviours related to salt in children but no reduction in salt intake was observed	An effect size of 1.08 was reported in change in dietary behaviour pre- and post-intervention
Video games as intervention				
Ortega *et al*., 2018	47 university students having an average age of 22.53 years	12-week intervention by active video and motor games.	Quality of diet was improved	Effect size of diet change post intervention as opposed to pre-intervention was 0.68.
Shiyko *et al*., 2016	47 healthy, highly educated women, 29.8 years of age on average with a BMI of 26.98 on average	A computer game called Spaplay with real world play patterns and linked to real-life activities like healthy snacking	60% of participants were contemplating 34% were preparing to and 4% demonstrated nutritional behaviour change	Effect size of nutritional knowledge was 0.86

Smart phone applications (apps) as intervention				
Duncan *et al.*, 2014	301 adult male participants between the age of 35-54 years	An IT based 9 months long intervention called ManUp influencing dietary behaviour and physical activity	Increased intake of high fibre bread and low-fat milk	Effect size was 0.07 for low fat milk intake and 0.2 for high fibre bread intake
Ipjian and Johnston, 2016[#2]	30 healthy adults (age 34.4 $\pm$ 15.7 years, BMI 25.3 $\pm$ 4.3 kg/m^2).	An app called MyFitnessPal aiding in reduced sodium intake	Those using the app reported lower urinary sodium levels	Effect size for the study was reported as $\eta^2 = 0.234$
Mummah *et al.*, 2017[#3]	135 overweight adults between 18-50 years of age, BMI = 28-40 kg/m^2	Vegethon mobile app enabling setting goals, self-monitoring and feedback	Significant increase in daily vegetable consumption in the intervention group	Effect size Cohen's d=0.18 for primary outcome measures after the 8-week trial and d=0.2 for 24h recalls
Wharton *et al.*, 2014	57 healthy adults (18-65 years of age, BMI= 25-40 kg/m^2)	Use of the diet tracking app called 'LoseIt!'.	Though weight loss was similar across groups using the app, memos or papers, healthy eating habit values fell for app users. Though more app users completed the trial.	Effect size of healthy eating index was 0.089

#1= Effect size is represented as R2 which is based on the variance; #2= Effect size is represented as η2 which is the ratio of the variance; #3= Effect size represented as Cohen's d which is the difference between the experimental and control mean divided by a standard deviation for the data.

4. Results and analysis

After screening the articles, 15 were selected to be included in this review. During the screening process, care was taken to include studies which demonstrated or targeted a direct change or intent to change the eating behaviours of the sample population. The studies mostly investigated the effect of the interventions on other behaviours, such as physical activity and self-monitoring, as well. Those in which changes in dietary behaviour were also responsible for weight loss of the experimental groups were preferred above others in which loss in weight was attributed to regular exercise or other behaviour changes. Though there are various intervention strategies employing the digital media, the articles selected revealed four broad categories: use of a personal digital assistant (PDA), use of smartphone applications, online education or web-based intervention and use of video games. The studies involving each of these interventions are discussed below.

4.1 PDA as an intervention

In 2008, in a novel randomised trial, Atienza *et al.* observed that use of PDA as opposed to written nutritional, educational material gave rise to a significant change in dietary behaviour. The intervention group was exposed for eight weeks to a hand-held device that not only monitored their intake of vegetable and whole grains twice daily, but also provided individualised feedback and support and helped to set goals,; the group demonstrated an increase in intake of vegetables and dietary fibre that had a high effect size. Use of PDA helped clinicians in the appropriate implementation of dietary interventions, as demonstrated by the 'Healthy Teens counselling approach' by Olson *et al.,* (2008). In the study, a screener based on PDA was used as an office intervention at primary care centres which were involved in the health behaviour counselling of adolescents. This 6-month long intervention resulted in an increased intake of milk as well as increased physical activity among the young people, though no other nutritional outcomes were obtained. The use of the PDA by the adolescents reduced time spent by the staff and clinicians in making individual reports and also enabled the clinicians to gain knowledge about and tackle sensitive issues concerning eating disorders.

Feedback is essential when using PDA. Several studies have demonstrated the improved effect of interventions that have used PDA coupled with feedback. In 2011, Acharya *et al.* reported an increase in fruit and vegetable intake and decrease in fat and refined grain intake in a group exposed to PDA as opposed to a paper record (PR) group. The software programme that was used by the PDA included immediate feedback to the user regarding the nutrient content of the food and calories ingested, so that the individual could make the necessary adjustments to the next meal to meet the daily target of nutrients. This resulted in greater adherence to the programme as well as attainment of goals. In the PR group, this self-monitoring had to be done manually and the time required increased with the number of target nutrients. The nutrient database included in the PDA made it easier for the users to learn about the value of food, while in the PR group acquiring knowledge about the food choices required much more effort. Also, the portability and social acceptability of PDA made it easier to use in any surroundings or environment.

In another study, Burke *et al.* (2011a) demonstrated a greater weight loss by a group using PDA coupled with feedback as compared to groups using PR and only PDA. Secondary analysis of a SMART trial in 2004 confirmed the importance of daily feedback in the use of PDA intervention. The trial conducted by Ambeba *et al.*, in 2015 reported reduction of calorie and fat intake over a 24-month period when the participants received remotely-sent daily feedback. A comparison of these articles is presented in Table 3. Effect size for increase in intake of fruits and vegetables and decrease in fat and energy remained between low to moderate (0.1-0.3) in most studies except that in Atienza *et al.*, where it was on the higher side (0.7-0.9). This data, though, should be carefully interpreted since this study had a very small sample size (27 adults).

Table 3. Summary of the results in the studies using PDA as digital intervention for dietary behaviour change

Articles	**Summary of Results**	**Drawbacks of the study**	**Strengths of the Study**
Atienza *et al.*, 2008	Greater intake of vegetable servings per 1000 kcal and increased fibre intake from grains in the PDA group	Small sample size, self-reported dietary intake and absence of generalisation to middle aged and older population and low retention rate	First RCT to study the effect of PDA in dietary behaviour change
Olson *et al*., 2008	Use of PDA among teens resulted in increased milk intake. Clinicians found PDA helpful in providing necessary counselling	Lack of precision in the recall measures may have led to obscure dietary changes. Height and weight were not measured.	Use of PDA helps clinicians in counselling, confirming the role of tailored counselling and monitoring in weight management

Acharya *et al.*, 2011	PDA group exhibited a higher intake of fruits, vegetables and lower intake of refined grains as compared to the PR group. Self-monitoring combined with PR reduced the intake of total fat, saturated and mono-unsaturated fatty acids.	Lack of extrapolation of the findings to a wider population than the homogenous, predominantly white, educated, full-time employed female population studied.	Comparison of PR and PDA system of interventions along with self-monitoring and a 91% rate of participant retention after 6 months
Burke, *et al.*, 2011a	Self-monitoring and median adherence was higher in the PDA group than the PR group. PDA group had a reduced fat and energy intake after 6 months. PDA+FB group demonstrated highest percentage of weight loss	Only 15.2% male representation in the population and data of only 6 months have been presented	First large RCT studying PR, PDA and PDA+FB with a 91% retention rate.
Ambeba *et al.*, 2015	Daily feedback (DFB) group exhibited significant decrease in total fat and energy intake as compared to no-DFB group after 2 years, proving the necessity of feedback. There was an initial increase in fat and energy intake but when the feedback messages were updated, the levels came down in the DFB group.	Fewer number of males, inclusion of participants of particular ages and BMI range and reliance on self-reported dietary intake	Daily, tailored and automated feedback in real time and ethnically diverse population studied for 2 years with a high retention rate

4.2 Online education as an intervention

Web-based intervention or nutritional education was seen to positively affect populations of different age groups. A study involving 1,639 college students, conducted by Kattelmann *et al.* in 2014, revealed that a 10-week intensive web-based intervention, consisting of 21 short lessons and regular e-mail messages called 'nudges', could increase the fruit and vegetable intake of the intervention group. Though no net change in BMI or weight was observed, this positive dietary behaviour change had an effect size of 0.05. A study by O'Donnell *et al.* (2014) explored the advantages of setting goals along with the effect of web-based interventions on changing dietary behaviour of students. The intervention consisted of 10 online lessons with data for weekly goals and behaviour. Intake of fruits and vegetables increased significantly with time in the intervention group ($P<0.001$), with an effect size which was moderate to large

(η^2 = 0.09). Time elapsed also had a significant effect (P<0.001) on goal, with a small to moderate effect size. Among adults, Schwarzer *et al*. in 2016 investigated the effect of lifestyle intervention delivered by an online platform which helped in addressing four psychological constructs that could lead to change in dietary behaviour. Using a Mediterranean diet adherence screener, it was observed that participants who had lower expectancies of positive outcomes gained more from the intervention. Grimes *et al*. (2018), studied the effect of web-based intervention in children by investigating the effect of a web-based salt reduction programme (DELISH) on knowledge, attitude and behaviour regarding salt-intake in the daily diet. The trial tested child-parent dyads and demonstrated a very high effect size (1.16 and 1.08) for increase in knowledge regarding high salt food and change in salt-related dietary behaviour among the children, respectively. The actual salt intake, though, was not changed, which might be because of the availability of specific food. A summary of the results of these studies is represented in Table 4. The overall effect sizes in the web-based intervention remained between low and medium. Increase in nutritional knowledge, though, showed a very high effect size (1.08; Grimes *et al*., 2018) confirming the importance of the web for disseminating knowledge.

Table 4. Summary of the results in the studies using online education as digital intervention for dietary behaviour change

Articles	**Summary of Results**	**Drawbacks of the study**	**Strengths of the Study**
Kattelmann *et al*., 2014	Experimental group reported small increase in fruit and vegetable intake though this increase was not maintained at follow up. Also, no decrease in weight but greater planning was observed amongst the intervention group	Self-selected samples, attrition rates, self-reported eating measures and physical activity	Intervention content was individually tailored to increase adherence, satisfaction and confidence in the intervention
O'Donnell *et al*., 2014	Goal-setting using online intervention increased intake of fruits and vegetables. Goal-setting is effective for behaviour change but not for maintenance of the change.	Goal-setting functions were not assessed. Options for goal-setting were limited. Self-reporting and the choice of a healthy population	One of the few studies where goal achievement has been linked to dietary behaviour change

Schwarzer *et al*., 2016	Significant change to Mediterranean diet. Individual psychological preferences should be considered and readiness for an intervention.	Lack of a control group and randomization, self-reported dietary intake, self-selected participants, no attempt at comparing cultural eating habits of the different countries	First study in which effect of online education on 4 social-cognitive constructs was examined which would help in studying the person-specific effect of interventions
Grimes *et al*., 2018	No change in salt intake but increase in knowledge about high salt food, salt efficacy and behaviour were bettered in children	Lack of a control group, small sample size from one region and self-reporting	Study confirmed that web-based educational programmes can increase awareness and knowledge

4.3 Video games as an intervention

The effect of a video games-based intervention on the dietary behaviour of university students was studied by Ortega *et al*., in 2018. The intervention lasted for 12 weeks and consisted of active and motor video games targeted at changing dietary behaviour. Adherence to a Mediterranean diet was observed at a moderate size effect in the students, though individual nutrients were not measured.

Another trial targeting adult, highly educated women showed a high effect size (0.86) for nutritional knowledge (Shiyko *et al*., 2016). The intervention, which was a video game known as 'SpaPlay', was a social online game motivating healthy eating and exercise to women. It provided the option of personalisation and individualisation of the content which resulted in a longer-lasting impact. It also combined the real and virtual, so that activities to be completed were real-life ones such as exercising and eating healthily. Table 5 summarises the results. Effect sizes for both nutritional knowledge and diet change were quite high (0.6-0.8).

Table 5. Summary of the results in the studies using video games as digital intervention for dietary behaviour change

Articles	**Summary of Results**	**Drawbacks of the study**	**Strengths of the Study**
Shiyko *et al*., 2016	Nutritional knowledge increased significantly, those in the action stage of behaviour showed better effects, need for individualising games, shorter activities were preferred to ones with a longer commitment	Small exclusive group already motivated to lose weight, self-report, lack of follow-up and lack of control group	One of the very few studies in which effect of serious video game on BMI and nutritional knowledge was investigated
Ortega *et al*., 2018	Decrease in fat mass and shift towards a Mediterranean diet was observed post-intervention but the problematic effect of video games was not improved	Lack of control group, limitation of the study to university students,	Demonstrates the potential of video games in weight management

4.4 Smartphone apps as an intervention

A randomised trial (RCT) looking at the effect of web-based and mobile phone-based intervention in changing dietary behaviour in middle-aged men was published in 2014 by Duncan *et al*. In this study, a challenge called 'ManUp' was delivered to the participants by both print and IT mediums. There was a low effect size change in the intake of dietary fibres and milk from the baseline to 3 months into the programmes; however, this change was not sustained through the study as at nine months the levels dropped to baseline once again. The trial also failed to show any difference between the group that was exposed to printed materials versus the one which formed the IT arm of intervention.

Another RCT by Mummah *et al*., in 2017, involving overweight adults exposed to the 'Vegethon' mobile app over a 12-month period, did demonstrate an increase in vegetable intake by the intervention group of an effect size equivalent to 0.18. This was the first study of the effect of a standalone mobile app on dietary behaviour change. The advantage of the app was its theory-based nature and the incorporation of feedback and goal setting. The high rates of adherence in this study could also be due to the fact that the participants were motivated to lose weight as they were already enrolled in weight loss programmes.

A small pilot study on the effect of the use of a mobile app called 'MyFitnessPal' on the sodium intake of 37 healthy people was published by Ipjian and Johnston in 2017. A moderate to high effect size of decrease in urinary levels of sodium was observed in the intervention group, proving that smartphone apps are capable of potentiating dietary behavioural changes. In an 8-week weight loss trial, Wharton *et al.* (2014) reported that smartphone apps were better suited for self-monitoring rather than bringing about an improvement in the quality of diet. In this study, a group using memo, another using paper and pencil and yet another using the mobile app 'LoseIt!' were studied for self-monitoring of their daily food intake. The paper and memo group were also provided with counselling while the app group only received feedback but no counselling. Results indicated excellent self-monitoring by the app users and more of the app users completed the trial. The weight loss across the group was also significant. However, healthy dietary behaviour decreased with time for the participants in the app group as opposed to the other two groups, indicating the importance of counselling in bringing about eating behaviour change. The results are summarised in Table 6. Effect size for this intervention, in general, ranged from low to medium but in two studies, sodium intake was significantly reduced (Ipjian and Johnston, 2017; Wharton *et al.* 2014).

Table 6. Summary of the results in the studies using video games as digital intervention for dietary behaviour change. *FFQs= Food frequency questionnaire

Articles	**Summary of Results**	**Drawbacks of the study**	**Strengths of the Study**
Duncan *et al.*, 2014	Increased intake of low fat milk and high fibre bread in both the print and IT groups after 3 months but the levels went back to the baseline level after 9 months	Very low retention rates limited number of observations, weight loss was not measured, and usage of print materials could not be assessed	Study of IT and print based interventions in male population
Wharton *et al.*, 2014	PR, memo and app group participants lost weight, but dietary self-monitoring was highest in the app group	App users might have used other methods for weight loss, feedback given only in the form of calories consumed.	Amongst the few studies which have revealed that smartphone apps can act as good self-monitors
Ipjian and Johnston, 2016	Greater adherence observed in the app group	Use of two different data analysis techniques,	Smartphone apps, when monitoring individual

	and significant decrease in urinary sodium levels were obtained though body weight remained the same.	direct comparison of intake of sodium over time could not be made, diet instructions differed in app and print group and weight loss not associated with the data	nutrients can bring about in dietary changes
Mummah *et al*., 2017	Participants demonstrated high engagement with the app and significant increase in consumption of vegetables and weight loss after 8 weeks. Outcome linked to frequency of app usage as well as individual participant characteristics.	Lack of longer follow-up and generalisation of findings to a larger population	Theory driven nature of the app along with goal-setting and self-monitoring resulted in greater adherence. Substantial sample size, randomised controlled study design, good FFQs* and 24-hour recalls.

5. Discussion

A sedentary lifestyle, combined with a diet abounding in food that is high in calories and added sugar, has resulted in the emergence of obesity as a major health problem which is globally associated with increased mortality and morbidity as well as increased occurrence of chronic diseases (Abelson and Kennedy, 2004; Lopez *et al*., 2006; Kelly *et al*., 2008). The number of obese people in the world is set to increase to 3.3 billion by the year 2025 (Kelly *et al*., 2008). Being overweight or obese takes a toll on the economic health of countries, as it accounts for 7% of all expenditures due to health care throughout the world (Withrow and Alter, 2011): in 2010 alone, a high BMI was the cause of 3.8% of disability and 3.4 million deaths, worldwide (Lim *et al*., 2010). Hence, maintaining a healthy weight is extremely important and research has shown that even small levels of weight loss can result in a considerable reduction in mortality, morbidity and health care costs associated with overweight (Knowler *et al*., 2002; Kaukua *et al*., 2003; Klein *et al*., 2004; Ryan and Kushner, 2010). As an example, it has been demonstrated that even a loss of 1 kg of body weight can reduce the risk of developing diabetes by 13% (Kriska *et al*., 2004). Lifestyle interventions required for weight management are improved quality of diet, increased physical activity and a restriction of the amount of calories being ingested.

In today's digital age, there is increased popularity in using digital interventions to effect lifestyle changes. This review presents various studies in which digital interventions have been used to bring about a dietary behaviour change. The 15 articles selected for analysis concentrate on specific categories of interventions, as only studies which described direct effect on dietary behaviour were included in the analysis. The parameters of change in dietary behaviour not being the same in all the studies, the overall effect size was not calculated, but individual effect size for each trial has been calculated and reported. Amongst the interventions, use of PDA coupled with personalised feedback seems to have had the best effects on the implementation of dietary changes. In general, all interventions exhibited better results when coupled with counselling and feedback. Adherence to the programme was a significant issue in all the trials. Hence, it is necessary to employ interventions which would sustain interest and motivation and support the users through each step.

A major component of the dietary behaviour change technique (BCT) is routine self-monitoring of one's daily diet (Baker and Kirschenbaum, 1993; Burke *et al*., 2005). It increases awareness of the food being consumed and helps in the elucidation of the impediments to positive dietary behaviour changes. Once these obstacles are identified steps can be taken to correct them which will help in achieving the goal of a better diet (Wadden *et al*., 2005). The conventional and most common manner of self-monitoring is using a PR or memo in which the individual records their daily dietary intake and other observations; this is presented to the interventionist weekly or once every two weeks for feedback. However, data indicates that over time it becomes difficult to sustain this routine of self-monitoring (Burke *et al*., 2011b). Thus, the directive and supportive feedback received is also reduced when self-monitoring is discontinued. Maintaining a PR also entails manual calculations and looking up information regarding the nutrient value of foods, which requires time and becomes tiresome for the user (Burke *et al*., 2005). Hence, substitutes for the paper record like PDA and an online diary have become popular. Studies indicate that PDAs have been used to keep records of food intake (McClung *et al*., 2009) and other data like total amount of energy consumed in 24 hours (Beaseley *et al*., 2005). In 2004, Glanz *et al*. revealed that PDAs consisting of dietary software programmes can be successfully employed in self-monitoring and consequently help in attaining the goals that are set for dietary behaviour change.

Advances in technology gave rise to devices originally known as Personal Information Management (PIM) gadgets, which gave access to a portable collection of data (Wiggins, 2004). These have evolved into PDAs which now include ‘smart’ watches, ‘smart’ pagers, internet appliances, cellular phones, palmtops, pocket computers, Tablet PCs, hand-held computers and wearable computers (Flanders *et al*., 2003; Webopedia). Since these devices now come with networking, voice recognition and wireless facilities, their value in the healthcare industry is on the rise. They are rapidly replacing the PR system of storing data. PDA does not come without limitations, though. Despite the immense potential to improve the quality of diet, make self-monitoring easier and increase the rate of adherence to the programmes, using a PDA can prove hard for the elderly and those with low literacy. However, with help from the interventionists, it is possible to overcome these difficulties.

Using the internet for the delivery of web-based behaviour change interventions has been reported in a number of studies where cessation of smoking behaviour and weight loss have been attempted (Winett *et al*., 2007; Chen *et al.*, 2008; Funk *et al*., 2010). It is an extremely popular manner of spreading health information (Kohl *et al*., 2013) and in the studies included in the review, internet use was found to increase the nutritional knowledge of the target population to a high degree (Grimes *et al*., 2018). However,, it is necessary to tailor the interventions according to the target population: for example, since, college students are known to spend on average 6.5 hours per day on the internet (Koff and Moreno, 2013), web-based interventions are more likely to meet with success in this population (Kattelmann *et al*., 2014; O'Donnell *et al.*, 2014).

Interactive video games combined with external counselling provide a very good means of intervention and are capable of increasing the adherence of the participants to the programme, as motivation and support are major issues faced by users. The limitation of video games remains the target population, who should exhibit an interest in such games or be technically skilled enough to use them, and this might be very specific, such as students or highly educated women (Shiyko *et al.*, 2016; Ortega *et al.*, 2018).

The ubiquitous presence of mobile apps make them a cost-effective form of intervention which can reach anybody at any time, can be personalised, deliver feedback and maximise interaction to increase effectiveness (Klasnia and Pratt, 2012) – even though, if not coupled with counselling, they do not seem to be able to sustain the effect (Wharton *et al.*, 2014). Increase in the number of apps that promote health has helped the user (Stephens *et al.*, 2011), though evaluation of these apps in RCTs is still pending and it is necessary to incorporate theory-based behaviour change strategies (Riley *et al.*, 2011; Azar *et al.*, 2013; Pagoto *et al.*, 2013).

6. Future directions

An integral part of dietary intervention in weight management is the user's role in self-monitoring, goal-setting and being aware of the nutritional value of the food being eaten. This review clearly indicates that no matter the kind of intervention being used, if it is not combined with appropriate feedback and counselling it does not sustain the required effect. Many of the trials indicated that delivery of personalised feedback messages in real-time is critical to support self-regulation during the weight loss programmes (Atienza *et al*., 2008; Olson *et al*., 2008; Burke *et al*., 2011a; Ambeba *et al*., 2016). A study by Spring *et al*. (2013) reported that when a diet-tracking system employing PDA was used in conjunction with a telephone-mediated counselling programme, the resulting weight loss of the participants was much more significant over a 12-month period than a counselling programme on its own. Thus, future research can be based on the use of mobile technology to deliver tailored feedback messages, which might cover other lifestyle changes like sleep and hygiene and can identify the improvements that happen in the behaviour even though goals are not met.

Digital interventions have the advantage of being (i) convenient to use; (ii) available in all geographic locations to a large number of people; (iii) able to be personalised; (iv) sustainable, i.e. by using suitable BCTs the platform can keep the users motivated and adherent to the programme, (v) cost-effective. Among these characteristics, the latter three require further development. The Transtheoretical Model of Behaviour Change (Prochaska, 1992; Prochaska *et al*., 1994) proposes that an intervention is most successful when it matches the behaviours and cognitions of the individuals. The personalisation of health behaviour interventions according to the readiness of the individual helps the person along the trajectory that leads to a change of behaviour. The human genome sequence and the fact that genotype influences one's health as well as diet has brought about the emergence of varied opportunities for individualisation of interventions depending on a person's genotype (Joost *et al*., 2007). Another matter for further study is the adherence to and sustainability of the intervention. The more a person gets involved with the programme, the more possibility of its completion. One strategy to ensure this is social interaction between participants (Kolt *et al.* 2013).

Thus, future research should concentrate on developing scalable and sustainable digital interventions which are tailored to the target population and integrate effective BCTs.

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Conflicts of Interest:

The authors declare no conflicts of interest.

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