Investigating emotion and reward processing using an associative matching task.

Toby Denholm-Smith

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Abstract

Evidence highlights a unique preference for stimuli with an emotional or rewarding connotation, compared to stimuli with no emotional or rewarding connotation. Known as a prioritisation effect, this phenomenon leads to enhanced memory, attention, reaction time and accurate responses to emotional and rewarding stimuli in participants. However, despite emotion and reward processing being well-documented in the literature, the relationship between processes is still largely unknown. The current research aims to address this issue and examine the relationship between reward and emotion processing through prioritisation effects. We used an associative matching task (AMT) where a basic geometrical shape was associatively *tagged* to motivationally significant information (e.g., a word signified by reward value or emotional valence). A sample of fifty adults (43 females; 6 males; 1 non-binary) with a mean age of 19.7 years old were recruited in the primary dataset. Results revealed two significant prioritisation effects, in the Medium reward-value (£25) and in the positive emotion-valence (happy) conditions, indicating that response time and accuracy scores were meaningful for Medium reward-value and Positive-valence conditions. However, the magnitude of positive emotion prioritisation effects was not directly related to the level of rewarding prioritisation effects. These findings were validated using an independent dataset that followed an identical experimental design as the primary dataset that consisted of fifty adults (44 females; 6 males) with a mean age of 20.7 years. Results in the independent dataset were similar to the findings in the primary dataset, with differences only occurring in regard to the magnitude of prioritisation effects in the reward condition. Significant prioritisation effects were discovered in the High reward-value (£50) and Positive emotion-valence conditions. The findings suggest that the processes of emotion and reward demonstrate some relationship, with the magnitude of motivational stimuli playing an important role. Implications of the present findings can be applied to various contexts including educational and clinical interventions to offer improved tailored treatments by considering both emotion and reward processes.

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1. Introduction

Cognition is a vital mental process that is involved in a plethora of different brain mechanisms that play a vital role in daily life, survival, and social interaction (Van Overwalle, 2009). Cognition can be defined as a vital form of mental processing that is involved in reasoning, acquisition and the manipulation of knowledge (Kiely, 2014). Cognition can be underpinned by different factors, for example, emerging literature highlights the role motivation can have on cognition (Braver et al., 2014; Grahek et al., 2019). Known as motivational drivers, recent literature highlights underlying neural and cognitive processes that contribute to the overall function of cognition. These two processes are emotion and reward processing (Sander, & Nummenmaa, 2021; Yankouskaya et al., 2022a).

Rewarding and emotional based stimuli have been suggested to have an impact on our day-to-day lives. For example, when a stranger may pay you a compliment or you win a large sum of money, equally when you are insulted or lose money, these simple examples provide anecdotal evidence to our encounters with emotion and reward processing. However, these emotional and rewarding events we encounter, frequently happen in conjunction to one another (Park et al., 2019). Recent theoretical and experimental literature has highlighted a gap in the literature regarding measuring emotion and reward processing (Chiew and Braver, 2011; Sander and Nummenmaa, 2021; Yankouskaya et al., 2022a). Specifically, literature surrounding emotion and reward processing frequently measure one process without considering the other (*emotion:* Hur et al., 2017, Pessoa and Adolphs 2010, and Tyng et al., 2017, *reward:* Clark 2013, Locke & Braver 2008, and Smith & Delgado 2015), this contributes to a gap in the literature, necessitating investigation into whether emotion and reward processing share similar underlying cognitive mechanisms or whether they occur independently to one another. Attempts have been made to establish an underlying theoretical model that better accounts for the role emotion and reward processing play on cognitive processes. For example, Northoff and Hayes, (2011) proposed three different models that aim to better explain the relationship between the self and reward processing developed from evidence that discusses their role on cognitive processes. The models suggest that the relationship between the self and reward processing is integrated, segregated, or occurs in parallel with one another. Evidence that facilitated the development of these models found similar results in terms of both emotion and reward processing and their relationship with the self. For example, enhanced responsiveness to the self and reward has consistently been noted alongside increased neural activity in specific brain areas such as the Ventral Striatum and Ventromedial prefrontal cortex (D'Argembeau, 2013; Dutcher et al 2020; Northoff, & Bermpohl, 2004). Similarly, Phan and colleagues (2004) identified when participants viewed emotional images, neural activity in the Ventromedial Prefrontal cortex and Ventral Striatum, was linearly dependent on the extent participants related the images to themselves. The involvement of these regions has been found across various tasks related to emotion, reward and self-processing, giving rise to a hypothesis that proposes a similar system is responsible for the basic properties of self-relevance and general affect (Heinzel & Northoff, 2014; Northoff & Hayes; 2011; Yankouskaya et al., 2022b). Emotion and reward processing have demonstrated a unique ability to influence cognitive processes including attention, memory and learning behaviours (Anderson et al., 2011; Dreisbach, 2006; Lang, & Bradley, 2013; Tyng et al., 2017). The cognitive processes influenced are the result of independent measurements that do not incorporate any theoretical framework. For example, Northoff (2016) and Yankouskaya et al., (2022b) to date are some of the only examples of attempts that have developed a theoretical ground that implies the relationship between emotion and reward processing. This however incorporated aspects of self-processing that do not directly link to understanding the relationship between emotion and reward processing.

Overcoming this can contribute to a greater understanding of the relationship between emotion and reward processing by allowing to make stronger inferences about the nature of their relationship (e.g. independent or related processes) and to help build a more inciteful understanding of different mental health disorders (Hobbs et al., 2023; Ryan, and Skandali, 2016; Sabharwal et al., 2016).

Dysfunctions and dysconnectivity in processing emotion and rewards have been linked to different mental health conditions, including PTSD (Lokshina et al., 2021; Nawijn et al., 2015), Schizophrenia (Barch, 2008) and Major Depressive Disorder (Ng et al., 2019). For example, Nawijn et al., (2015) identified patients with PTSD tend to exhibit lower satisfaction and expectancy when it comes to receiving rewards. This can therefore be considered a potential indicator that deficits in reward processing can be linked to PTSD. Similarly, Barch (2008) highlights a key diagnostic feature of schizophrenia that references key attributes of emotion processing. This includes the ability to display emotions through facial expressions or verbal communication and whether emotions are being displayed in the correct context. If there are indications that there is a relationship between emotion and reward processing, knowing the extent of their relationship will contribute to developing stronger treatments and interventions, reducing the persistence of symptoms in these mental health conditions. Understanding both processes together and individually will provide a better understanding of their relationship. However, to develop this understanding it is important to understand the mechanisms behind each process.

1.1 Emotion Processing

Emotion processing is a subjective experience, involving physiological change and behavioural response to emotional stimuli (Kauschke et al., 2019). Research orientated around emotion processing has predominately focused on the cognitive mechanisms that aid in the identification and discriminatory process of understanding different emotional expressions such as happiness, sadness, fear and anger (Adolphs, 2002; Ekman, 1993; Lindquist et al., 2016). For example, perception is believed to be a common underlying cognitive process of understanding different emotional expressions. Tsao and Livingstone, (2008) highlight the importance perception plays in interpreting emotional facial expressions and is the result of an underlying obligatory detection process in cognition that can lead to facial emotion recognition. Through understanding the facial shape of different emotions, (e.g. anger – narrowing of lip corners, eyebrows coming down, and eyes glare), perception can contribute to the facilitation of that individual's emotional expression. This is not the only contributing cognitive mechanism that aids in the identification and discriminatory process of understanding different emotional expressions. Individuals who suffer from blindness may process emotional expressions differently due to a lack of visual perceptive cues and may rely on hearing or touch (Gamond et al., 2017). Research that has been orientated on understanding the cognitive mechanisms of interpreting emotional expressions discusses the importance of the context in which the expression is being processed, this includes the type of emotion (e.g. happy, sad, fear) and origin of emotion (e.g. computer face, human face, object with a face). For example, Kätsyri and Sams (2008), highlight perceptual preferences when it comes to identifying emotional faces depending on whether they are static or dynamically moving into a specific emotion from a neutral expression. In all cases, human facial emotions were preferred over computer-animated faces. Interestingly, anger and fearful facial expressions for the computer-animated faces were identified quicker when they were dynamic compared to more positive emotions (Kätsyri & Sams, 2008). This highlights a potential preference bias in the interpretation of different emotional facial expressions.

Known as a prioritisation effect, emotion prioritisation effects reflect a biased response to emotional content, whereby emotionally connotated stimuli are considered to have higher relevance in processing and therefore take prioritisation over neutrally connotated stimuli (Sawada & Sato, 2015; Vuilleumier et al., 2001). This could be due to the evolutionary theories highlighting the importance of identifying different emotional expressions (Frijda, 1988). For example, identifying anger or fearful facial expressions with an increased level of speed and greater accuracy may increase the likelihood of survival due to a quick call to action based on the type of emotion displayed (Fox et al., 2000). The evolutionary theory also accounts for positive facial emotions, as this could facilitate socialisation and mating behaviours between individuals, optimising health and well-being (Ashby, & Isen, 1999; Diener et al., 1991). Alternative theories that further explain the prioritisation effects identified for emotional stimuli is the Arousal-Biased Competition (ABC) theory (Mather, & Sutherland, 2011). This theory proposes that arousal influences competition between stimuli depending on their emotional significance, implying that attentional, memory and perceptual processes prioritise emotionally connotated stimuli with a higher priority than for neutral stimuli (Lee et al., 2014; Mather & Sutherland, 2011). This leads to a preference bias for emotionally significant stimuli over neutral or non-emotional stimuli, explaining the nature of emotion prioritisation effects (Sawada, & Sato, 2015; Vuilleumier et al., 2001). The ABC theory explains why specific past events with a high-emotional significance are often remembered over past events with little to no emotional connotation (Kensinger, 2009). This theory alongside the evolutionary theory (Frijda, 1988) can be used to better explain the prioritisation bias for stimuli associated with an emotional connotation over neutral stimuli.

However, it does not fully explain why specific biases have been identified between emotional stimuli. In emotion processing, the presence of biases is stronger towards certain emotional stimuli over others. For example, literature suggests a positivity bias towards happy and positive emotions over sad, negative ones (Anderson et al., 2011; Gupta, 2019;

Kauschke et al., 2019), indicating that positive emotions have a distinct ability to capture an individual's attention. Calvo and Lundqvist (2008) investigated this using a perceptual-attention task that required participants to identify a series of seven different facial expressions that were quickly presented on a screen. Results found that participants' response times were significantly quicker and more accurate for the happy facial expressions over the remaining six facial expressions. This indicates that positive emotions had a distinct ability to capture an individual's attention. One explanation for this is the Broaden and Build model (Fredrickson, 2001), which implies positive emotions (e.g. Happiness) expands an individual's range of thought and action, promoting resource-building behaviour, linking to an evolutionary benefit of identifying emotionally positive stimuli over negative stimuli. Using theories of evolution and the Broaden and Build model provide a further explanation of the findings from Calvo and Lundqvist (2008). However, studies that have aimed to replicate this, have found conflicting results that counter the original findings, discovering the reverse effect that negative emotions were reacted to quicker than positive emotions (Fox et al., 2000; Nasrallah et al., 2009). Literature highlights a specific preference for negative emotions when recalling previous events (Baumeister et al., 2001; Finkenauer & Rimé, 1998), further indicating the prioritisation of negatively valenced stimuli over more positively valenced stimuli. This negativity bias towards emotions could be the result of evolutionary theories (Frijda, 1988) that imply negative emotions are easier to recall encouraging avoidance behaviours of that specific event, increasing the likelihood of survival.

However, recent evidence conflicts both proposed concepts of the nature of emotional prioritisation. For example, Yankouskaya et al., (2022a) through the use of an associative matching task (AMT) identified a preference in response time for both happy and sad facial expressions over neutral facial expressions. This conflicts the findings from the literature that indicated the prioritisation of emotional stimuli as having either a positive or negative preference. Whereas Yankouskaya et al., (2022a) highlights a prioritisation for both positive and negatively valenced stimuli equally. This disparity in the literature indicates the need for further research to help to identify prioritisation preferences between positive and negative emotions, facilitating a better understanding of the factors influencing biases associated with emotion processing (Stole et al., 2017).

Prioritisation effects for emotionally connotated stimuli have been identified in emotion processing literature, highlighting a specific bias towards emotional stimuli. Theories including the evolutionary theory (Frijda, 1988) and the ABC theory (Mather, & Sutherland, 2011) provide some understanding of why this prioritisation bias occurs. They also provide some explanation for why certain preferences occur between emotionally positive and negative stimuli. However, recent evidence conflicts this, indicating disparity within the research (Yankouskaya et al., 2022b).

1.2 Reward Processing

Several different definitions attempt to define reward processing. Although mostly successful, this is normally based on the context of their research, resulting in a limited perspective. In broader terms, reward processing can be defined as stimuli that induce learning, approach behaviour and decision-making (Schultz, 2015). This, however, is one definition of many that attempts to delineate reward processing. Reward processing, in a similar regard to emotion processing, is an important social factor driving individuals' basic behaviours. Emerging research concerning reward processing demonstrates that reward enhances perceptual, attentional, and executive control processes in order to achieve more efficient goal-related behaviours (Denny et al., 2012; Rushworth et al., 2011; Yantis et al., 2012). For example, Seitz and Watanabe (2009) found that participants could learn different perceptual tasks when correct responses were paired with a reward, even without participants conscious awareness. This suggests that rewards can influence individuals' perceptual abilities, regardless of their conscious awareness to the situation. Implying a potential preference in regard to rewarding stimuli to achieve more efficient goal-related behaviours. In the case of Seitz and Watanabe (2009), the optimal outcome being correct responses. Developments from this suggested that the intensity of the reward, particularly in terms of monetary gain as a form of reward stimuli, facilitated different preferential bias depending on the monetary gain level (e.g. high monetary gain vs low monetary gain). Compelling evidence signifies an improved behavioural performance in perceptual decision-making tasks with stimuli linked to monetary gain and that the effects of high-reward (high monetary gain) vs low-reward (low monetary gain) were consistently reported across the literature (Enzi et al., 2009; Sui et al., 2012). For example, Anderson et al., (2011) using a cognitive matching task between different shapes and different levels of monetary reward (high, low and no reward) discovered a biased preference for shapes associated with a higher monetary gain than low and no reward associated shapes. Findings further indicated participants were still more accurate and quicker in responding to shapes that had previously been associated with a higher reward, compared to shapes that have been paired with low or no reward. Therefore, implying a bias for highly rewarding stimuli in perception and attention priority, making them easier to discover in the future (Anderson et al., 2011; Wolf & Lappe, 2023). Indicating that reward prioritisation is highly value driven with the context of the history of reward stimuli having influence on outcome selection (Anderson, 2016). Similar results have been observed within the literature, for example Jahfari and Theeuwes (2017), found that participants attentional capture was strongest for high-value trials than for low-value trials when learning associations between different rewarding-values and colours. This could infer that reward prioritisation is highly value-driven regardless of the task used, influencing outcome selection (Anderson, 2016). This is supported by findings in the literature that have attempted using different tasks that have identified attentional prioritisation for high-value tasks over low and no rewarding tasks (e.g., Anderson, & Yantis, 2012; Chelazzi et al., 2013; Pearson, & Le Pelley, 2020). When encountering a rewarding experience, these findings infer that information associated with a higher reward receives a greater attentional priority, indicating a bias for reward prioritisation.

Theoretical frameworks have aimed to better explain these biases in prioritising high reward over low or no reward. The Expected Value of Control (EVC) theory (Shenhav et al., 2013) is one such framework that implies actions are under a constant valuation, determining whether the potential reward of an action is worth the cognitive effort. This contributes to a further explanation in regard to reward prioritisation biases for high rewarding stimuli over low or no rewarding stimuli, especially on the same task as the cognitive effort is the same across trials regardless of the intensity of the reward. However, this contradicts findings from Yankouskaya et al., (2020) that used an associative matching procedure that found equal response time scores for both the highest reward value (£9) and lowest reward value (£1) with no difference identified between them. This would imply no reward prioritisation bias depending on the reward intensity. This specific associative matching procedure, however, used 5 different reward values (£9, £7, £5, £3 and £1), whereby literature highlights specific memory biases for the highest and lowest outcomes associated with reward (Klingberg, 2010). Madan et al., (2014) argued memory biases from previous experiences results in overweighting for the largest reward gains and reward losses, causing a preference for relative gains over losses. This is consistent with Yankouskaya et al., (2022a) that used a similar matching task as Yankouskaya et al., (2020) but implemented only two reward value conditions (£8 and £2), in which this prioritisation bias for high reward value was observed, consistent with previous research (e.g. Anderson et al., 2011; Wolf & Lappe, 2023). Together these findings imply the importance to ensure a meaningful difference in monetary gains to encourage the engagement and attainment of reward in a cognitive task (Yankouskaya et al., 2022b; Zedelius et al., 2013). Biases in reward prioritisation are therefore likely a result due to a meaningful difference between a higher reward than a low reward.

Together, research indicates that reward processing enhances attentional, perceptual, and executive control processes, leading to more efficient goal related behaviour, even in cases when individuals may not be aware of the influence of the reward (e.g., Anderson et al., 2011). Within the scope of literature, findings suggest a specific bias in reward processing for higher rewards, particularly monetary gain, resulting in a unique attention capture for the more rewarding stimuli. Theories, such as the EVC theory (Shenhav et al., 2013) provides further reasoning for the prioritisation bias observed. However, some literature contradicts this and implies the need for a substantial difference in monetary rewards to truly influence behaviour. This suggests biases in reward prioritisation are likely a result of a notable difference between high and low rewards.

1.3 The Relationship Between Emotion and Reward Processing.

Understanding the relationship between emotion and reward processing has been predominately based on tasks that have measured each process independently from one another, making inferences on their relationship based on independent findings. For example, research has found similarities between emotion and reward processing tasks, including strong common effects on visual processing (Anderson et al., 2011; Anderson, & Yantis, 2013) and enhancing participant perceptual learning (Lang, & Bradley, 2013; Sui, & Humphreys, 2015). This demonstrates a common underlying relationship between these processes that, together, influence task performance (Dreisbach, 2006; Pessoa & Adolphs, 2010). Similar cognitive reappraisal tendencies have been linked to an enhanced responsiveness to rewarding stimuli (Kelley et al., 2019). Cognitive reappraisal is an antecedent-focused strategy that focuses on addressing emotions before they come to fruition. This is achieved by interpreting a potential emotional stimulus in a certain way that either enhances or lessens the emotional impact (Gross & John, 2003). The findings from Kelley et al., (2019) discovered that individuals that frequently engaged in cognitive reappraisal displayed a heightened responsiveness to rewarding cues. Whilst those that suppressed emotions were less likely to respond to rewarding cues. This indicates a proportional relationship between cognitive reappraisal and rewarding cues, with an inverse relationship between emotion suppression and rewarding cues. This suggests, the ability an individual has to interpret emotional stimuli that either heightens or lessens the emotional impact of that stimulus, appears to be directly related to their ability to respond to rewarding cues.

These findings were discovered using an electroencephalogram (EEG) that investigated the P300, an event-related potential which is associated with decision making. The P300 tends to be associated with higher-level cognitive processing that involves attention selection and resource categorisation (Polich, 2007).

These findings are supported by alternative EEG studies that identified similarities in the amplitude of P300 for both emotion and reward processing tasks. For example, Johnston et al., (1986) identified that the amplitude of the P300 varied proportionately to the intensity of emotional stimuli. Positive and negative emotional stimuli evoked a greater P300 response than stimuli with no emotional connotation. This effect was also observed for a reward processing task that investigated the P300. The magnitude of the reward was shown to enhance the amplitude of the P300, with a more positive response for larger rewards (Sato et al., 2005). This literature combined provides compelling evidence that at the biological level using neuroimaging there is reason to suggest a relationship between processes. To further this understanding, Yankouskaya et al., (2022a) investigated the neural connectivity underlying reward and emotion processing using fMRI. Results revealed that the brain established independent yet partially overlapping components within networks when prioritising emotion-valenced and reward-value processes. Positive emotion exhibited a stronger overlap with reward-value processing, when compared to negative emotion. These pivotal findings further indicate a relationship between emotion and reward processing at the neural level with implications using cognitive tasks. Due to the nature of the research, measuring both processes using an identical task, the relationship between processes may be the result of biases in emotion and reward prioritisation. This is because results found some level of prioritisation bias preference for positive emotion and high reward value. This is consistent with theoretical accounts on the relationship between emotion and reward processing. Sander and Nummenmaa (2021) highlight key concepts such as goal-relevance, appraisal and motivational relevance that are commonly used in emotional theories, can also be directly linked to theories of reward. This involves specific prioritisation preference biases that have been identified in both emotion and reward processing tasks.

Key evidence indicates that there is a relationship between emotion and reward processing due to both processes demonstrating similar effects on cognition. For example, previous research indicates that associations for rewarding and emotional stimuli that have been learnt in the past influence subsequent associations that use similar stimuli. Known as a *carryover effect*, literature has observed this effect in various contexts. For example, in a visual learning task, stimuli that were previously connotated with a high reward were responded to quicker than low rewarding stimuli (Krebs et al., 2010; Vartak et al., 2017). Meanwhile, similar *carryover effects* for emotions have been observed in both attention (Fiori & Shuman, 2017) and decision-making (Polyportis et al., 2020; Yates, 2007). The presence of these *carryover effects* for emotion and reward processing demonstrates a level of automatic control on cognition (Yankouskaya et al., 2022b). Emotion and reward processes may play a greater role in both conscious and unconscious (automatic) cognitive control than previously identified.

Findings above from both theoretical and experimental literature indicates a suggested relationship between emotion and reward processing. However, the true nature of the relationship between processes is not fully established due to disparities in the literature. This emphasises the need for further inquiry into the relationship between processes, especially due to the potential role both emotion and reward may play on conscious and unconscious processes.

Evidence disputes the suggested relationship between emotion and reward processing, indicating that these processes occur independently to one another. For example, Park et al., (2018) investigated emotional and motivational (rewards) manipulations on cognition through matched tasks. This was done via fMRI analyses looking at regions of interest (ROIs) that have been identified in emotional and motivational (reward) contexts, for example the anterior insula, ventromedial prefrontal cortex, and ventral striatum (D'Argembeau, 2013; Phan et al., 2004). Findings discovered no distinct common neural processes between emotional and motivational connotated stimuli, indicating independent processes. This account is supported by literature using similar experimental designs. This includes Dreisbach (2006), and Locke and Braver (2008), who reported significant differences in results between positive affect and reward processing. This reinforces the view that emotion and reward processing occur independently of one another. Similar disparities have been identified in neuroimaging studies that have investigated damage to specific brain areas associated with emotion and reward processing (e.g. amygdala), discovering impairments in emotional processing but not in reward processing (Adolphs et al., 1999; Berridge & Kringelbach, 2013). Dissociable patterns of brain activity have also been identified in emotion and reward-value tasks, indicating independent processes (Hare et al., 2008; Knutson et al., 2001). Specifically, research has identified unique brain activity in the nucleus accumbens being directly associated with reward processing (Knutson et al., 2001). Hare et al., (2008) discovered that emotion processing was predominately associated with brain areas including the amygdala and the ventrolateral prefrontal cortex. Findings would therefore identify unique independent brain areas associated specifically with either process. However, it should be considered these findings are predominately based upon independent assessments of the relationship between emotion and reward processing, meaning these findings should be interpreted with caution.

Based upon the lack of literature that assesses the relationship between emotion and reward processing and associated biases, Yankouskaya et al., (2022a) is an early attempt to measure both processes using the same experimental design, enhancing the current knowledge of the relationship between processes. However, there are some limitations within the research, for example, a lack of a control condition fails to account for the type of prioritisation effect present in the emotion and reward processing tasks. A control condition would determine whether effects observed are due to attentional or memory preferences. If prioritisation effects are observed in the control group, it would suggest that memory plays a more significant role than attention in determining prioritisation (Reuther & Chakravarthi, 2017). Due to the sparsity of literature on the topic, employing an independent dataset will contribute to the replicability of findings allowing further comparisons on the biases associated with emotion and reward processing expanding on their relationship. Doing this will also contribute to overcoming an emerging replication crisis identified in the literature (Pashler, & Wagenmakers, 2012).

1.4 Rationale

The aim of the present research is to investigate the relationship between emotion-valence and reward-value processing. This will be achieved by using an AMT that will measure emotion and reward processing together through response time and accuracy scores, calculating prioritisation effects. Specifically, the present design incorporates a third condition in the AMT as well as a control task to account for any undesirable prioritisation effects, aiming to provide further insight into the true nature of any prioritisation effects identified, allowing to distinguish between memory or attentional biases. Previously not accounted for in the literature (Locke & Braver, 2008; Park et al., 2019; Sander & Nummenmaa 2021; Yankouskaya et al., 2022a.). An additional condition was implemented for the emotion, reward, and control tasks. This third condition was a neutral or no-value connotated stimuli in the emotion and reward task (e.g., emotion – neutral face, reward - £0) and in the control condition, an additional abstract word was added. This third condition was then used in data analysis to calculate a baseline measurement. Two main hypotheses were developed: (i) participants will respond faster and more accurately to stimuli associated with reward or emotions compared to stimuli with no motivational values; (ii) there will be a relationship between the magnitude of reward and happy emotion prioritisation effect.

To test the replicability of the findings regarding the present hypotheses, an independent dataset will be employed to account for replication issues within the domain of cognitive psychology (Pashler & Wagenmakers, 2012). This data was collected via the precise same measurements employed in the current methodology. This includes using an identical experimental design and procedure using an independent group of participants, separate from the ones used in the current research.

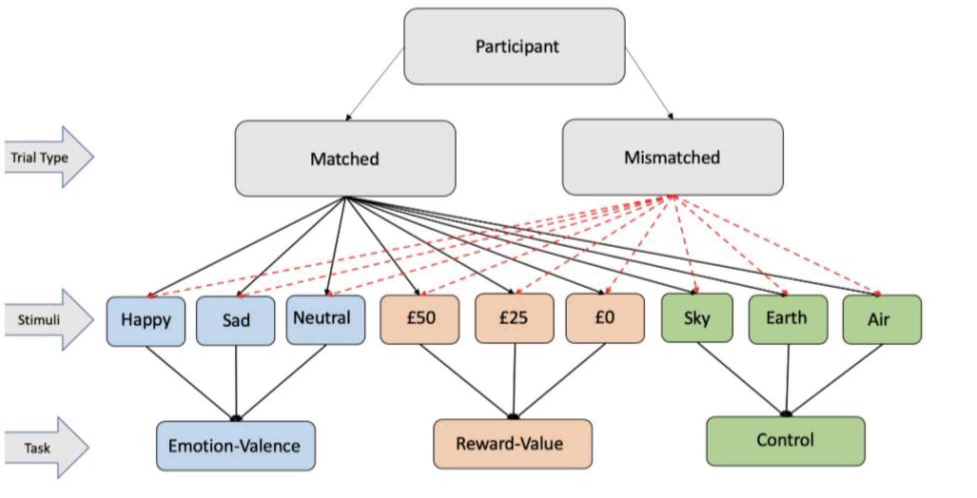
2. Method

2.1 Design

This research employs a factorial nested crossed design. A total of three factors were implemented: Task (Emotion-Valence, Reward-Value, Control), Trial type (Matched, Mismatched) and Stimuli (A geometrical shape and a fixed label for each task). The trial type is crossed with the stimuli, while the stimuli are nested to the task (see *Figure 1*.). While the Stimuli are nested with the Task, the levels of Stimuli within each task are not the same. This is due to the stimuli in each task being unique to each task (I.e. £50 to reward-value).

Figure 1

The factorial nested crossed design visualised consisting of the three implemented factors



Response time and accuracy, as dependent measures of the present research, will be used to calculate the magnitude of prioritisation effects for the comparison between tasks. To ascertain whether the prioritisation of emotionally valenced and reward-value information is based on its meaning or due to memory biases, it is necessary to eliminate the possibility that participants better remember associations that were presented earlier in the learning stage (Reuther & Chakravarthi, 2017). To account for this, a control task that is identical to the emotion and reward tasks in terms of cognitive processes involved but uses abstract stimuli (words) with no motivational connotation. This will help determine any memory prioritisation effect in the control task. Prioritisation effects in the control group would suggest memory-prioritisation over attention-prioritisation. This is because the control group is not exposed to any emotion-valence or reward-value stimuli, which rules out the possibility of attentional prioritisation being driven by emotional or rewarding stimuli.

2.2 Participants

A total of 50 participants (43 females; 6 males; 1 non-binary) were recruited via opportunity sampling from Bournemouth University, UK, with a mean age of 19.7 years old (ranging from 18-42 years old). Eligibility requirements consisted of English fluency, having normal or corrected to normal vision (e.g., prescription glasses, contact lenses) and no diagnosis of any mental health conditions. Participants were recruited via SONA (Sona Systems, 2023), an online participant recruitment website associated with the Department of Psychology, Bournemouth University, UK. Out of the 50 recruited participants, 43 were right-handed and 7 were left-handed. No participants withdrew from the study.

2.2.1. Independent Dataset Participants

The independent dataset consisted of 50 participants (44 females, 6 males), which were all recruited via opportunity sampling from Bournemouth University, UK via SONA (Sona Systems, 2023) with a mean age of 20.7 years old. All participants met the same eligibility requirements as in the original dataset. No participants withdrew from the independent dataset.

*2.2.2 G*Power Analysis*

To determine the minimum sample size necessary for the present research, a power analysis was conducted using G*Power (version 3.1.9.7) (Faul et al., 2007, 2009). A priori power analysis was done based upon a repeated measures ANOVA design with 2 groups and 3 measurements. Input parameters included a medium-effect size (Cohen's $f = 0.25$) $\alpha = .05$ with a desired power of .80. The analysis revealed a minimum sample of 28 participants was required to detect a significant effect in the present research. This was achieved as 50 total participants were recruited.

2.3 Materials

Prior to starting the study, participants received two documents: a participant information sheet and a participant agreement form. The information sheet outlined what was required to be done regarding the study, including the associative matching task, highlighting other areas where participant concerns may lay, including data protection and any cons associated with participation, of which there was none. After reading this and having the opportunity to ask questions, participants signed the agreement form, providing informed consent. Participants then provided personal details which included, age, gender, handedness, and their student email addresses to receive their Amazon gift card voucher.

2.3.1. Associative Matching Procedure

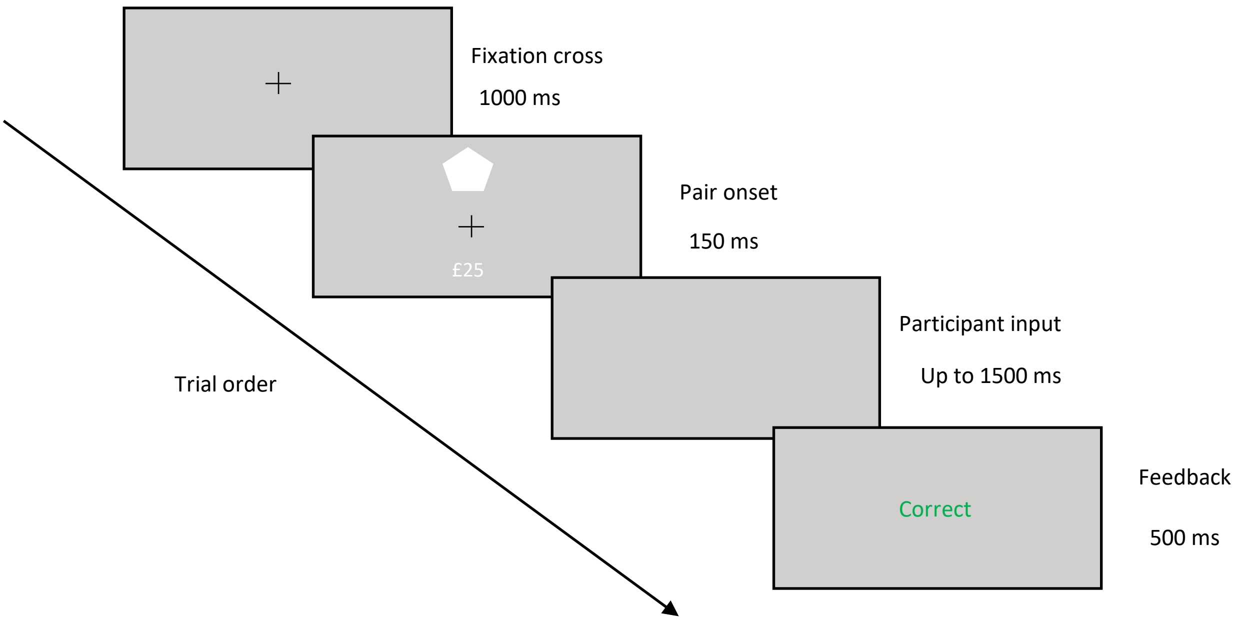
Participants completed an AMT for the emotion-valence, reward-value and control tasks respectively. This involved memorising three pairs of matched associations between a specific stimulus and a basic geometric shape for each task. With the idea that emotionally valenced, and reward-value stimuli will have enhanced responses based on the amount of reward or valenced stimuli present (Sui et al., 2012). For instance, in the reward-value task, participants could be asked to remember that £50 corresponded to a Circle, £25 to a Pentagon, and £0 to a Square, (see *Figure 2*), the stimuli in this case for reward-value being £50, £25, £0. The stimuli for the emotion-valence task included happy, neutral, and sad. Meanwhile, the control task consisted of abstract stimuli that had no emotionally valenced or rewarding meaning; the terms used were Sky, Earth and Air. After the initial stimulus-geometrical shape memorising phase, different variations of stimulus-geometrical shape pairings were presented, some of which being matched (what was learnt during the memorising phase) and some pairings being mismatched (random combinations of stimuli and geometrical pairings not previously memorised). Participants had to decide whether the pairings on screen either matched or mismatched the three original pairings learnt in the memorising phase. In total each task consisted of 360 trials taking 12-15 minutes to complete, totalling 1080 total trials for all three tasks, taking 45 minutes on average to complete.

Two randomised parameters were implemented into the AMT, allowing the present study to better account for any confounding variables (Skelly et al., 2012). Secondly, to avoid the possibility of participants getting 'lucky' with favourable repeated pairings (e.g., £0 - Circle), the pairs were randomised every time in the emotion-valence and reward-value tasks. This reduces the likelihood of responses being due to a fortunate, easy-to-remember pair and is actually due to attentional prioritisation.

After participants had learnt the taught matched pairs for the first task, they completed practice of 12 trials. This was aimed to help facilitate participant comprehension and minimise errors during the actual task (Freeman et al., 2014). At the beginning of each trial, a fixation cross was displayed in the centre of the screen ($0.8^{\circ} \times 0.8^{\circ}$) for 1000 ms, followed by a label (stimuli) and geometrical shape ($3.8^{\circ} \times 3.8^{\circ}$) displayed that lasted for 150 ms. Then, a blank interval appeared on the screen for 1500 ms, allowing participants to respond. After their response, a feedback message was presented for 500 ms, informing participants about their performance (e.g. *Correct!, Incorrect!* or *Too Slow!*). These feedback messages were assigned a colour, to help the convey the meaning of that feedback message (Kaya & Epps, 2004). For example, *Correct!* – green, *Incorrect- red, Too Slow! – yellow* (see *Figure 2.* for an example of a correct response). For the reward-value task, participants would receive an Amazon gift card voucher in relation to their performance on the reward-value task, was scaled to 0.01% in proportion to the value assigned to the geometrical shape, this was sent to their student email addresses after participation.

Figure 2

An example, visualised, of a correct trial in the reward-value task with the respective timing



PsychoPy (Version 2022.2.4) (Peirce et al., 2019) is an open-source piece of software that facilitates the running and creation of experiments. The present AMT was created and was run through PsychoPy (Version 2022.2.4) on a Hewlett-Packard EliteDesk 800 G1 SFF, 8GB RAM Operating system: Windows 7, 64bit Monitor: 24" BENQ XL2411, 1920 x 1080 pixels, with a 60 Hz refresh rate. This was done in a laboratory at Bournemouth University, UK in a sound-proof private booth.

2.4 Procedure

On arrival, participants were provided with an information and agreement form in order to provide informed consent. Participants provided some personal information, including age, handedness, gender, and student email address. The latter was required in order for participants to receive their Amazon gift card vouchers, which they were informed, their performance impacted their amount that they received (up to a maximum of £5). After this, they were informed of any instructions and started the computer-based AMT. Each task took approximately 15 minutes, and after completing the task, before moving onto the next one, participants had the opportunity to take a brief break before continuing. After completing the AMT, they were debriefed and provided a copy of the agreement form. They were also informed when they would receive the Amazon gift card voucher and that they must respond to the email with the voucher in order to obtain it.

2.5 Data pre-processing

Data pre-processing: Slow responses were removed for response time trials that were correct but exceeded the max time in the trial of 1.5 seconds. For each stimulus, the percentage of total trials were removed as slow responses: Air (0.3%), Earth (0.3%), Sky (0.3%), Happy (0.4%), Neutral (0.5%), Sad (0.5%), High-reward (0.4%), Medium-reward (0.4%) and No-reward (0.4%). This totalled to 3.4% of all trials being removed due to slow responses. A further .08% of all trials were removed for response time as fast guesses, which consists of response times quicker than 200ms.

2.6 Data Analysis

Assumption check: Normality of the data was assessed using Shapiro-wilk and using Mauchly's test of sphericity (see Appendix A, Appendix B and Appendix C) to identify and correct any violated assumptions of sphericity using Greenhouse-Geisser correction due to its robustness to violation.

Analysis accuracy and response time performance: 2 x 3 repeated measure ANOVA was used to test the effect of two within-subject factors (Trial Type: Match, Mismatch), Stimuli (e.g., Happy, Sad, Neutral in the Emotion Task) and interaction between Trial Type and Stimuli on percent of correct responses (accuracy) and correct response times. A Post Hoc comparisons using Bonferroni adjustments were performed to examine the effects of Stimuli and disentangle the interactions.

Analysis of prioritisation effect: We calculated the advantage (gain in performance) in accuracy and response time in each task as follows [No reward – Medium reward], [No reward – High reward], [Happy valence – Neutral valence], [Sad valence – Neutral valence], [Sky control – Earth control], [Earth control – Air control] and [Air control – Sky control]. Using a one-sample t-test we examined whether the magnitude of the gains was different from zero. The magnitude that was significantly smaller than zero indicated that there was no gain in performance.

The relationship between reward and emotion prioritisation effect: A Pearson's correlation was also employed to assess the direction and strength of the linear relationship between any prioritisation effects.

Testing the effects of dataset: A mixed 2 (Dataset: Original, Replication) x 2 (Gain-Stimuli) ANOVA was conducted to test the effects of Dataset as between-subject factor and Gain-Stimuli (within-subject factor) on gains measurement in each task. It has to be noted that in the Control task, we calculated three gains, yielding a 2x3 experimental design. This is due to the nature of the stimuli used, as in the emotion-valence and reward-value task, there are only two motivational connotated stimuli, and the control task uses three abstract stimuli.
Data were analysed using Jamovi (Version 2.3).

2.6.1 Replication Study

An independent dataset was implemented alongside the primary data to test the reliability of the primary dataset findings, to observe if similar prioritisation effects are present. This is because the replicated dataset used the exact same methodological design as the primary dataset, therefore results should be consistent between the two datasets.

2.7. Ethics

This study has been approved by Bournemouth University's Research Ethics Code of Practice board and all ethical considerations have been accounted for through this, following the Code of Ethics and Conduct (2018) by the British Psychological Society (2023). This ensures the present research does not break any ethical guidelines and upholds a high degree of sophistication regarding researcher professionalism and data protection. Participants were provided with a participant agreement form and information sheet, that outlines the aims and objectives of the research alongside further information about the study. The participant agreement form was to be signed and dated by participants to give informed consent to participate. As participants were required to provide some personal information, they were assigned a participant number to ensure no data protection breaches. Personal information required such as student email addresses were deleted from records after they had received their Amazon gift card vouchers, as is policy for the BU finance department. Digital eye strain (DES) is one concern associated with this research as participants were required to stare at a digital screen for forty-five minutes. Following recent literature by Kaur et al., (2022), after participants completed each condition, they had a five-minute break to reduce any symptoms of DES.

3. Results

3.1 Accuracy Analysis

3.1.1. Control Task Accuracy Analysis

In the Control Task, there was a main effect of trial type (*$F(1,45)=3.50$, $p=.068$*) indicating that participants showed no significant difference in accuracy responses for the matched condition (M= 83.8, SE= 1.47) when compared to the mismatched condition (M= 81.9, SE=1.74), indicating that trial type had no meaningful effect on accuracy.

In the main effect of stimuli (*$F(2,90)= 1.04$, $p=.356$*), no meaningful effects were found between Earth (M= 82.2, SE= 1.38), Air (M= 83.1, SE= 1.72) and the Sky condition (M= 83.5, SE= 1.71), showing the significant level was not reached for stimuli in the control task, ultimately having no effect on accuracy responses. Finally, the interaction effect between trial type and stimuli, showed no meaningful interaction ($F(2,90)= 1.12$, $p=.330$), between the trial type and stimuli for the control task. Overall, the control task had no recorded significant interactions on participant accuracy responses. See Appendix D for descriptive statistics.

3.1.2. Reward-Value Accuracy Analysis

In the Reward task, there was a main effect of trial type *($F(1,45)= 18.82$, $p< .001$, $\eta_p^2 = .295$)* (see *Figure 3)* indicating that participants' accuracy scores were higher for the matched trial type (M=80.9, SE= 2.1) than the mismatched trial type (M= 75.3, SE= 2.51). This indicates participants were more accurate in their responses for matched trials over mismatched trials.

The main effect of stimuli *($F(2, 90)= 9.84$, $p< .001$, $\eta_p^2 = .179$)* indicated that stimuli played an important role on participants accuracy scores. A post hoc analysis showed that participants accuracy for the Medium-reward condition (M= 81.5, SE= 2.2) was higher over the High-reward condition (M= 77.6, SEM= 2.4) *(MD= 3.5, SE= 1.19, t(45)= 2.93, p=.016)*. The difference between No-reward and High-reward conditions was non-significant *(MD= -2.2, SE= 1.4, t(45)= -1.53, p=.40).* Results suggest the Medium-reward condition had the strongest effect on participant accuracy scores over the No-reward and High-reward conditions.

There was an interaction between trial type and stimuli *(F(1.70, 76.71)= 3.32, p=.041,* η_p^2 *=.069*). Post-hoc comparison indicated that there was little difference in accuracy scores between matched No-reward (M=76.2, SE= 2) and mismatched No-reward (M=74.7, SE= 2.7) (*MD=1.5, SE=2.62, t(45)=.59, p= 1.0).* Further post-hoc analysis identified higher accuracy scores for the matched Medium-reward condition (M=85.5, SE= 1.9) over the mismatched Medium-reward condition (M= 76.8, SE= 2.5) (*MD=8.7, SE=2, t(45)= 4.7, p< .001).* Similar observations were discovered in the matched High-reward condition (M= 81, SE= 2.4) over the mismatched High-reward condition (M= 74.3, SE= 2.4) (*MD= 6.7, SE= 1.7, t(45)= 3.9, p=.01).* Post-hoc analysis using Bonferroni correction therefore revealed a meaningful effect between matched trial type and Medium and High reward values on participants accuracy scores *(Figure 3).*

Looking at the matched trial type and stimuli conditions, post-hoc using Bonferroni correction revealed better accuracy scores for the matched Medium-reward condition (M=85.5, SE= 2) over the matched No-reward condition (M= 76.2, SE= 2) (*MD= -9.23, SE= 1.24, t(45)= -4.56, p<.001).* While no meaningful significant effects were identified between the matched Medium-reward condition and matched High-reward condition (*MD= 4.45, SE= 1.81) (t(45)= 2.46, p= .267).* The identified effect between the matched stimuli conditions did not influence participants' accuracy scores. Similar was observed between matched No-reward condition (M= 76.2, SEM= 1.8) and matched High-reward (M= 81, SEM= 2.4) (*MD= -4.78, SE= 2.42, t(45)= 1.97, p=.822)*, indicating no significant effect on accuracy scores.

These results indicate that for matched trial type, Medium-reward value had the strongest effect on accuracy scores when compared with High- and No-reward values. This can be visualised in *Figure 3.* For mismatched trials see supplementary materials S5.1 and descriptive statistics see Appendix E.

3.1.3. Emotion-Valence Accuracy Analysis

In the emotion-valence task, there was a main effect of trial type ($F(1,45)= 5.17$, $p=.028$, $\eta_p^2=.103$) (see *Figure 3),* revealing that the matched trial type (M= 80.9, SE= 2.3) had a significant effect on participant accuracy scores over the mismatched condition (M=78.4, SE= 2.4) (*MD= 2.52, SE= 1.11,* $t(45)= 2.27$, $p= .028$). Therefore, the matched trial type had greater accuracy responses than the mismatched trial type.

The main effect of stimuli ($F(1.71,76.91)= 18.05$, $p<.001$, $\eta_p^2=.286$) identified a significant effect, indicating that stimuli had a meaningful effect on accuracy scores. Post-hoc analysis showed that participants' accuracy scores were higher for the Happy condition (M=83.6, SE= 2.5) over the Sad condition (M=75.4, SE= 2.2) (*MD= 8.24, SE= 1.57,* $t(45)= 5.24$, $p< .001$). Accuracy responses were also higher for the Neutral condition (M= 80.1, SE= 2.4) over the Sad condition (M=75.4, SE= 2.2) (*MD= 4.71, SE= 1.07,* $t(45)= 4.39$, $p< .001$). The difference between the Happy condition and the Neutral condition was non-significant (*MD= 3.53, SE= 1.44,* $t(45)= 2.46$, p=.053). These results demonstrate that both the Happy and Neutral conditions had a significant effect on participants' accuracy responses over the Sad condition.

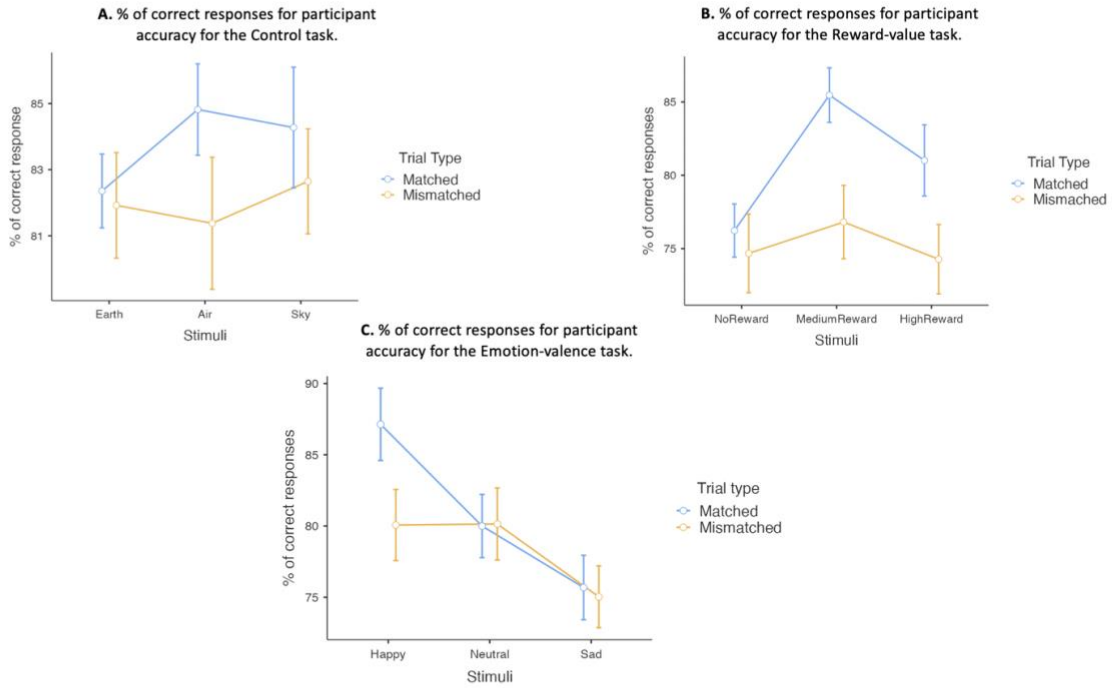
There was an interaction identified between trial type and stimuli ($F(2, 90)= 4.02$, $p= .021$, $\eta_p^2= .082$). Post-hoc analysis using Bonferroni correction identified that accuracy scores were higher for the matched Happy condition (M= 87, SE= 2.5) when compared to the mismatched Happy condition (M= 80, SE= 2.5) (*MD= 7.1, SE= 2.1,* $t(45)= 3.4$, $p=.02$).

There was no meaningful effect between matched Neutral condition (M= 80, SE= 2.2) and mismatched Neutral condition (M= 80.1, SE= 2.5) (*MD= -.14, SE= 1.7, t(45)=-.08, p= 1.0)* having no effect on participants accuracy scores. Similar findings were observed between matched and mismatched trial types for matched Sad condition (M= 75.7, SE= 2.3) and mismatched Sad condition (M= 75, SE= 2.2) (*MD= .65, SE= 2, t(45)= .32, p= 1.0).* Results indicate the strongest effect came from the matched Happy condition between matched trial type and stimuli on participants' accuracy scores when compared to the respective mismatched counterpart. No meaningful observations were discovered between matched and mismatched for the Neutral and Sad conditions.

Looking only at the matched trial type, using post-hoc analysis with Bonferroni correction, the matched Happy condition (M= 87.1, SE= 2.5) had the strongest effect on accuracy scores over the matched Sad condition (M= 75.7, SE= 2.3) *(MD= 11.45, SE= 2.51, t(45)= 4.56, p<.001),* indicating participants responded with greater accuracy for matched Happy conditions over matched Sad conditions. No meaningful differences were observed between the matched Happy condition and matched Neutral condition (*MD=7.14, SE= 2.42, t(45)=2.95, p=.075*). Equally, no meaningful difference was observed between the matched Neutral condition over the matched Sad condition (*MD=4.31, SE= 1.87, t(45)=2.29, p=.392*). Regarding matched trial type and different stimuli, these findings revealed participants were more accurate for the matched Happy condition than for matched Neutral and Sad conditions respectively. See supplementary materials S5.2. for the mismatched trials and Appendix F for descriptive statistics.

Figure 3

Proportion of correct responses visualised for the Control task (A), Reward-value task (B) and Emotion-valence task (C) for matched and mismatched trial type, including mean standard error bars for each stimulus.



3.2. Response Time Analysis

3.2.1. Control task response time analysis

There was a main effect of trial type in the control condition, (F (1,45) = 124.4, p<.001, η_p^2= *.734*) (See *Figure 4.*). This indicates that participants response times were faster in the matched condition (M= .75, SE= .01) than in the mismatched condition (M= .83, SE= .01).

The main effect for stimuli (F(2,90)= 2.7, p= .069) showed that the significant threshold was not met between stimuli and participant response time, indicating that the type of stimuli in the control task had no meaningful impact on participant response time. Looking at the interaction effect between stimuli and trial type ($F(2, 90)= .27$, $p= .759$), there was no notable interaction between trial type and stimuli on participant response time.

3.2.2. Reward-Value Response Time Analysis

For the reward-value task, there was a main effect of trial type ($F(1, 45)= 249.4$, $p,<.001$, $\eta_p^2= .847$) indicating the matched trial type ($M= .79$, $SE= .02$) had a significantly faster response time when compared to the mismatch condition ($M= .87$, $SE=.02$). Participants, therefore, responded quicker to matched trials over mismatched trials (*Figure 4.*).

There was a main effect on stimuli ($F(2, 90)= 3.58$, $p= .032$, $\eta_p^2= .074$). Post-hoc analysis revealed that there were no meaningful effects found in response time between No reward ($M=.85$, $SE= .02$) and Medium reward ($M= .83$, $SE= .02$) (*MD=.02, SE=.01, t(45)=-15.8, p=.07).* There was also a non-significant difference between No-reward and High-reward ($M= .83$, $SE= .02$) (*MD= .02, SE=.01, t(45)= 2.2, p=.09).* Medium reward and High-reward also showed no significant difference (*MD=.002, SE=.01, t(45)=-.19, p= 1.0).* Although a significant effect was found in the ANOVA, Post-hoc analysis revealed no meaningful results.

There was no meaningful interaction identified between trial type and stimuli ($F(2, 90)= .45$, $p= .641$) therefore there was no notable difference between matched and mismatched trial type and the levels of reward (£50, £25, £0) on participants response times.

3.2.3. Emotion-Valence Response Time Analysis

In the emotion-valence task, there was a main effect for trial type ($F(1, 45)= 188.3$, $p < .001$, $\eta_p^2= .807$) indicating that participants' response times were quicker for the matched condition ($M= .82$, $SE= .02$) over the mismatched condition ($M= .89$, $SE= .02$) (See *Figure*

4.). Participants therefore responded quicker to matched conditions over the mismatched conditions.

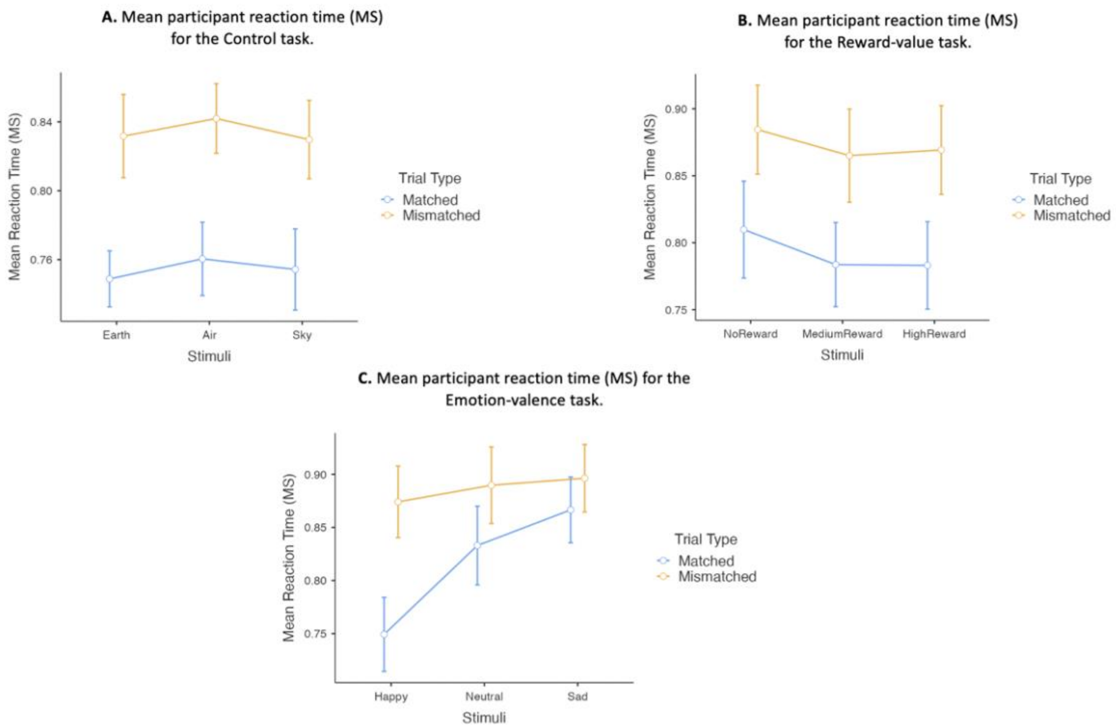
There was also a main effect for stimuli (F(2, 90)= 26.8, p <.001, $\eta_p{}^2$= *.373)*. Post-hoc analysis indicated that participants response times for the Happy condition (M= .81, SE= .02) was quicker than for the Neutral condition (M= .86, SE= .02) (*MD= -.049, SE= .01, t(45)= -5.21, p*<.001). Response times were also quicker for the Happy condition over the Sad condition (M=.88, SE= .02) (*MD= -.69, SE= .01, t(45)= -6.45, p<.001).* A non-significant difference was found between the Neutral (M= .86, SE= .02) and Sad condition (M=.88, SE= .02) (*MD= -.02, SE= .01, t(45)= -2.23, p= .093).* Overall, this suggests that participant response times were quickest for the happy condition over the Neutral and sad conditions.

There was a significant interaction identified between trial type and stimuli (F(2, 90)= 29.9, p<.001, $\eta_p{}^2$=*.399*). Post-hoc analysis using Bonferroni correction revealed that response time was quickest for the matched Happy condition (M= .75, SE=.02) over the mismatched Happy condition (M= .87, SE= .02) (*MD=-.12, SE=.01, t(45)= -15.1, p< .001),* therefore indicating a significant difference between matched trial type and Happy stimuli on participants response times. Further analysis revealed participants responded quicker to the matched Neutral condition (M= .83, SE= .02) over the mismatched Neutral condition (M= .89, SE= .02) (*MD=-.06, SE=.01, t(45)=-6.1, p< .001).* Similar observations were made that showed participants responded faster to matched Sad conditions (M= .87, SE=.02) than mismatched Sad conditions (M= .90, SE= .02) (*MD=-.02, SE=.01, t(45)= -3.2, p=.04).* Together these findings indicate that participants response times were faster for matched conditions over mismatched conditions.

Looking at matched trial type, post-hoc analysis with Bonferroni correction revealed that participants' response times were quicker for the matched Happy condition than the matched Neutral condition (*MD=.08, SE= .01, t(45)= -6.61, p,.001)*. Matched Happy condition also had faster response times than the matched Sad condition (*MD= -.11, SE= .01, t(45)= -8.24, p<.001)*, indicating that matched stimuli influenced participants' response times. There was no meaningful effect on response time between matched Neutral and matched Sad conditions *(MD= .03, SE= .01, t(45)= 2.48, p= .251).* These findings suggest that the matched Happy conditions had the quickest response times over the Neutral and Sad conditions.

Figure 4

Mean participant response time visualised for the (A) Control task, (B) Reward-value task and (C) Emotion-valence task for matched and mismatched trial types, including mean standard error bars for each stimulus

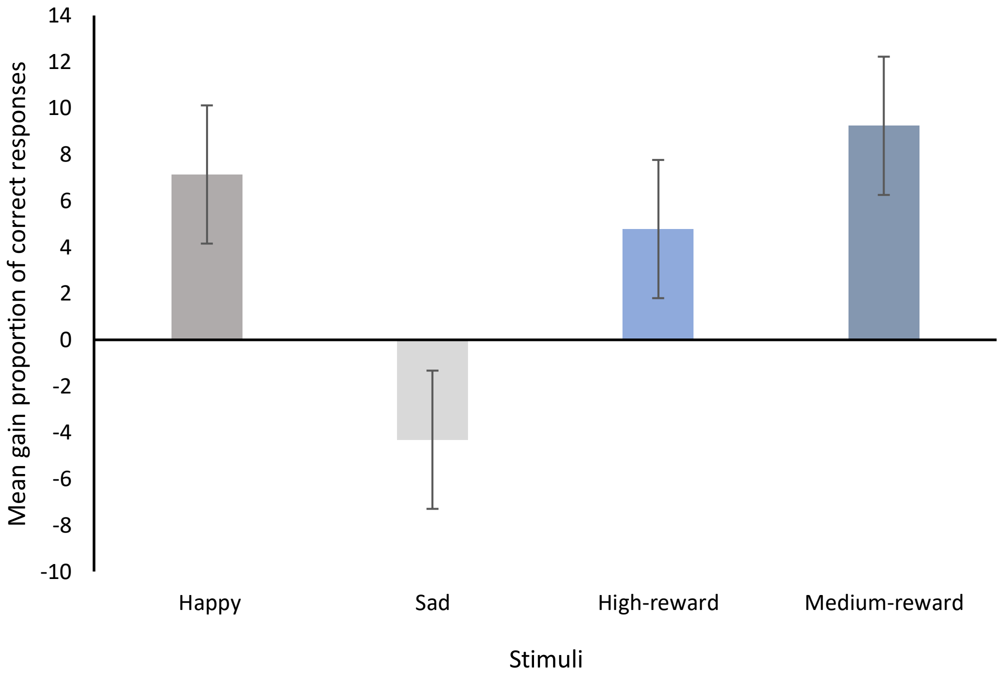


3.3. Prioritisation Effects in Emotion-Valenced and Reward-Value Tasks

A one sample t-test was employed to test whether the magnitude of 'gains' is significant against zero for accuracy and identified one prioritisation effect. Only medium reward ($t(45)= 4.56$, $p<.001$), showed a response time bias that was significantly different from zero, indicating a prioritisation effect. No other prioritisation effects were observed in High-reward or No-reward conditions. A significant effect was found in the emotion-valence task for the Sad condition ($t(45)= -2.3$, $p= .026$), however, this mean difference indicates no prioritisation effect (See *Figure 5.)*. No prioritisation effects were observed in the Control task. No further analysis was done, as there was only one prioritisation observed.

Figure 5

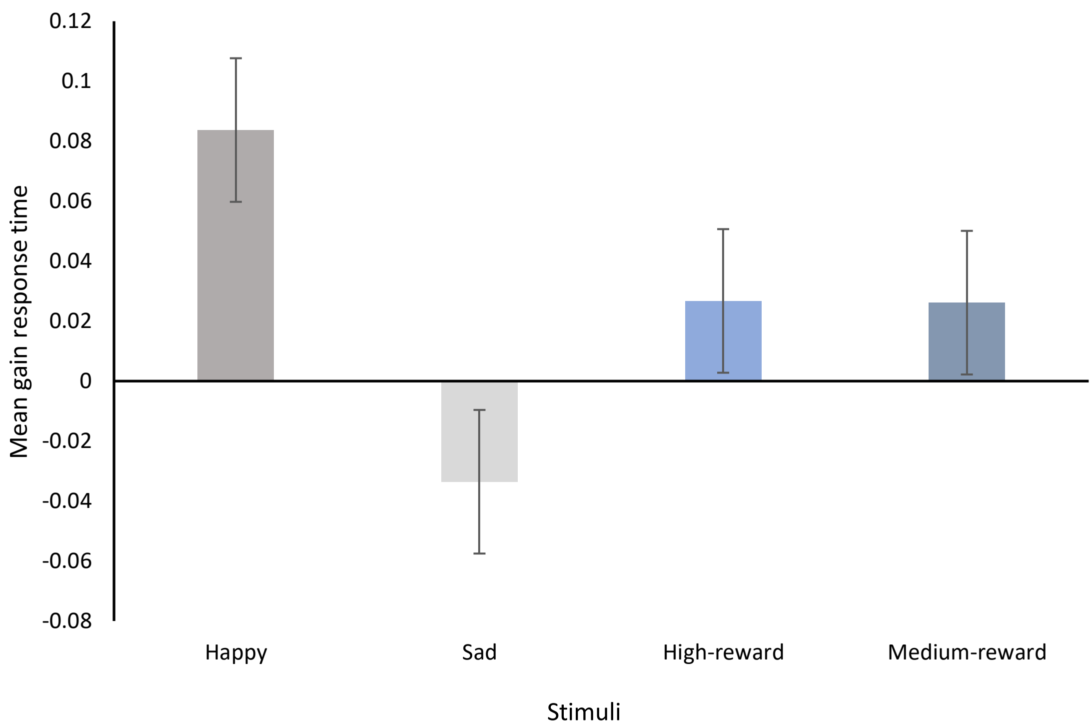
Mean gain proportion of correct responses for matched stimuli including error bars



Regarding response time, only one meaningful significant prioritisation effect was observed, in the emotion-valenced task. This was in the Happy condition ($t(45)= 6.61$, $p <.001$) with a large effect size (ES= .97), implying participants' response times were quicker for the Happy condition over the other conditions. A significant effect was observed in the Sad condition (t(45)= -2.48, p=.017), there was no prioritisation effect, however, due to a negative mean difference. Meanwhile, no further significant prioritisation effects were found in the reward-value or control task for response time (see *Figure 6.)*. No further analysis was done, as there was only one prioritisation observed.

Figure 6

Mean gain response times for matched stimuli including error bars



3.4. Independent Replication Data Analysis

Table 1

Descriptive statistics for accuracy responses in the independent dataset

Conditions	*n*	*M*	*SE*	95% CI		*SD*
				LL	*UL*	
Control Match						
Earth	45	83	2.2	78.7	87.3	14.7
Sky	45	80.7	2.7	75.5	85.9	17.8
Air	45	83	2.2	78.7	87.2	14.6
Control Mismatch						
Earth	45	79.9	2.2	75.6	84.2	14.7
Sky	45	78.2	2	74.1	82.3	13.9
Air	45	80.3	2.1	76.2	84.5	14.1
Reward Match						
No reward	45	71.7	2.6	66.7	76.8	17.3
Medium reward	45	86.3	2	82.4	90.3	13.5
High reward	45	84.6	2	80.6	88.6	13.7
Reward Mismatch						
No reward	45	74.5	2.65	69.3	79.7	17.8
Medium reward	45	76.6	2.3	72	81.1	15.5
High reward	45	76.6	2.4	71.9	81.3	16
Emotion-Valence Match						
Happy	45	87.1	1.8	83.5	90.6	12.1
Neutral	45	75.9	2.8	70.4	81.4	18.9
Sad	45	74.7	2.8	69.2	80.2	18.8
Emotion-Valence Mismatch						
Happy	45	79.1	2.1	75	83.2	14.1
Neutral	45	79.2	2.2	74.9	83.6	14.9
Sad	45	75	2.2	70.6	79.3	15

Note. *n* = number of participants, *M* = mean, *SE* = Standard error of the mean, CI = confidence intervals; *LL* = lower limit; *UL* = upper limit, *SD* = Standard Deviation.

Table 2

Descriptive statistics for response time in the independent dataset

Conditions	*n*	*M*	*SE*	95% CI		*SD*
				LL	*UL*	
Control Match						
Earth	46	.75	.01	.73	.77	.05
Sky	46	.75	.01	.73	.78	.08
Air	46	.76	.01	.74	.78	.07
Control Mismatch						
Earth	46	.83	.01	.81	.86	.08
Sky	46	.83	.01	.81	.85	.08
Air	46	.84	.01	.82	.87	.07
Reward Match						
No reward	46	.81	.02	.78	.85	.12
Medium reward	46	.78	.02	.75	.81	.11
High reward	46	.78	.02	.75	.82	.11
Reward Mismatch						
No reward	46	.88	.02	.85	.92	.11
Medium reward	46	.87	.02	.83	.90	.12
High reward	46	.87	.02	.84	.90	.11
Emotion-Valence Match						
Happy	46	.75	.02	.72	.78	.12
Neutral	46	.83	.02	.80	.87	.13
Sad	46	.87	.02	.84	.90	.10
Emotion-Valence Mismatch						
Happy	46	.87	.02	.84	.91	.11
Neutral	46	.89	.02	.86	.93	.12
Sad	46	.90	.02	.87	.93	.11

Note. *n* = number of participants, *M* = mean, *SE* = Standard error of the mean, CI = confidence intervals; *LL* = lower limit; *UL* = upper limit, *SD* = Standard Deviation.

3.4.1. Prioritisation Effects in Emotion-Valenced and Reward-Value Tasks –Independent Dataset

A one-sample t-test was conducted to test whether the magnitude of calculated 'gains' is significant against 0 for response time only. In total, two prioritisation effects were identified, the strongest of which was the emotional-valenced task, specifically for the Happy stimuli ($t(44)= 4.07, p< .001$) over the Neutral stimuli, reporting a small to medium effect size (ES= .33). In the emotion-valenced tasks no prioritisation effect was found between Sad stimuli and Neutral stimuli.

The other prioritisation effect was discovered in the High-reward condition ($t(44)= 2.21, p< .033$) over the No-reward condition, reporting a medium to large effect size (ES= .61). This suggests a significant prioritisation effect in participants' response time for High-reward over No-reward. No further prioritisation effects were found in the reward-value task. Importantly, in the control task no significant prioritisation effects were identified between Air, Earth, and Sky conditions.

A paired-sample t-test was used to calculate the magnitude of the differences between the two prioritisation effects identified above. No significant effect was identified between them ($t(44)= -1.30, p= .199$).

3.4.2. Relationship Between Emotion and Reward Processing.

A Pearson's correlation analysis was performed to identify any correlation between the prioritisation effect and response time for the High Reward-value condition vs No Reward-value and Happy Emotionally-valenced stimuli vs Neutral Emotionally-valenced stimuli. Results revealed no significant correlation between them ($r(44)$= .06, p=. 693), this suggests that High Reward-value and Happy emotionally valenced processes could occur independently from one another.

3.5. Primary vs Replication Gains Data Analysis

Gain scores for both the present research (Primary) and from the independent sample (Replication) were calculated and tested against one another, to account for any biases between the two datasets using a mixed ANOVA, measuring a main effect of stimuli and an interaction effect between stimuli and dataset. This was done for the control, emotion-valence and reward-value tasks respectively.

3.5.1. Control Task

For the control task, a 2(dataset: Primary, Replicated) x 3(stimuli: Earth, Air, Sky) mixed ANOVA was performed to test differences between the primary and replicated data. Main effect analysis of stimuli revealed ($F(2, 178)= .33, p= .72$) no significant effect between stimuli. Further, the interaction effect of stimuli and dataset also revealed no meaningful differences ($F(2, 178)= 1.47, p= .23$), therefore stimuli in both the primary and independent dataset did not differ significantly (see **Figure 7.**).

3.5.2. Emotion-Valence Task

A 2(dataset: primary, replication) x 2(stimuli: Happy, Sad) mixed ANOVA was performed to test any significant differences between the factors. For the main effect of stimuli ($F(1, 89)= 96.55, p<.001, \eta_p^2 = .52$) a significant effect was observed for the gain scores between the stimuli. Specifically, response time from gain scores was faster for the happy condition over the sad condition.

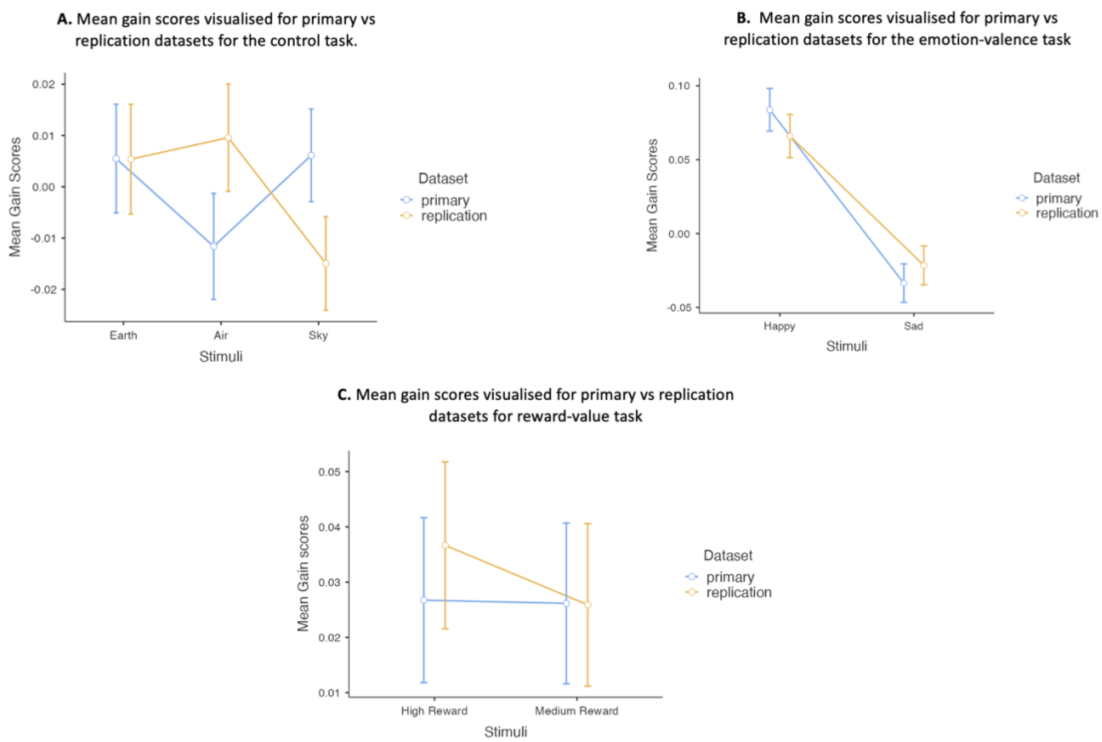
The interaction effect between stimuli and dataset showed ($F(1, 89)= 2.03, p= .157$), no significant interaction was identified for the gain scores between the stimuli and dataset. Despite a significant effect found in the stimuli main effect, this only shows an effect between Happy and Sad stimuli (see **Figure 7.**), therefore the findings of the replication dataset are still valid to be used with the primary dataset.

3.5.3. Reward-Value Task

Using a 2 (dataset: Primary, Replicated) x 2(stimuli: Medium-reward, High-reward) mixed ANOVA was performed to test differences between primary and replicated data. The main effect of stimuli revealed no significant effect ($F(1, 89)= .56, p=.45$) showing no difference in stimuli. Similarly, the interaction effect between stimuli and dataset showed no significant findings ($F(1, 89)= .46, p=.50$). This suggests no meaningful interaction was observed between the primary and replicated dataset (see **Figure 7.**) in response time for the Reward-value condition.

Figure 7

Mean gain scores visualised for primary vs replication datasets including standard error bars for the (A) Control task, (B) Emotion-valence task and (C) Reward-value task



The findings from the independent dataset mostly confirm the findings from the primary dataset, indicating a level of robustness of the prioritisation effects identified in the emotion-valenced and reward-value tasks. For the emotion-valence task, both datasets identified significant response time prioritisation effects for the Happy condition and not for the Sad condition. In the reward-value task, a meaningful prioritisation effect was discovered in the Medium-reward condition for the primary dataset. The replication dataset found a prioritisation effect in the High-reward condition, not in the Medium-reward condition. When comparing the ‘gains’ from both datasets, no significant differences were found in the control, emotion-valence or reward-value task indicating similarity between datasets.

4. Discussion

The current study aimed to investigate the relationship between emotion-valence and reward-value processing through prioritisation effects, calculated through reaction time and accuracy scores. This was completed using an AMT. An AMT that specifically included a third condition was also introduced in the AMT as well as a control task to better account for the type of prioritisation effect present. Using this method, our findings suggest some relationship between emotion-valence and reward-value processing in terms of prioritisation effects, but the extent of this relationship is highly influenced by the magnitude of rewarding or emotionally relevant stimuli.

4.1. Associations With Motivational Stimuli: Enhancing Accuracy and Response Time

Our findings demonstrated that participants responded faster and more accurate to stimuli associated with Medium reward-value compared to High reward-value and No reward-value. Similarly, we found that responses and accuracy were faster for stimuli associated with Happy conditions in the emotion task. These finding are in line with our first hypothesis and with previous research reporting facilitation effects of motivational stimuli compared to stimuli with no motivational connotation (Dreisbach, 2006; Pessoa & Adolphs, 2010; Yankouskaya et al., 2022a). In the emotion-valence condition, there were no differences in response time between the Sad and Neutral conditions, implying no preference for stimuli connotated with Neutral or negative valence. Evidence in the literature implies similar responses for both Happy and Sad connotated stimuli (e.g. Sawada, & Sato, 2015; Vuilleumier et al., 2001; Yankouskaya et al., 2022a), reasoning that positive and negative valenced stimuli are detected equally due to their emotional relevance over neutral stimuli. The present findings are in line with literature that implies that Happy-emotion has a unique ability to capture an individual's attention over Sad-emotions (Anderson et al., 2011; Gupta, 2019; Kauschke et al., 2019). One explanation of the present findings is the Broaden and Build model (Fredrickson, 2001), suggesting participants may have preferred the positively valenced stimuli over neutral and negativity valenced stimuli, promoting more constructive behaviour. This is one such explanation for the current observed result.

Medium reward-value that had the highest accuracy scores over both High reward and No reward-value and is mostly inconsistent with the literature. While many studies have observed a linear relationship in the processing of shapes tied to emotions, the processing of reward values often exhibits a U-shaped curve instead which could provide an explanation of the present findings. For example, Yankouskaya et al., (2020) identified that participants responded distinctly to extreme reward values of the highest and lowest monetary gain (e.g., £1 and £9) in comparison to monetary values that were between the highest and lowest amount (e.g., £5 and £7). These findings have been previously noted in research by Klingberg (2010) and Madan & Spetch (2012). Subsequent findings have tied the memory biases, that stem from participants' previous experiences with rewards, to decision-making processes (Madan et al., 2014; Wimmer & Buchel, 2016). It is then suggested that these memory biases may enhance performance specifically for the highest and lowest reward values, as indicated in multiple studies (Klingberg, 2010; Madan & Spetch, 2012; Yankouskaya et al., 2020). For instance, Madan et al. (2014) posited that memory biases based on past experiences lead individuals to overweight the most significant gains and losses, prompting them to prioritize relative gains over relative losses. However, the opposite pattern was obsereved in the current findings where participants showed faster response time to shapes associated with medium reward. Although this effect is inconsistent, this may reflect the difference between reward and emotion processing as introducing emotions linked to simple shapes might alter the typical response dynamics (e.g. Yankouskaya et al., 2020). Future studies would therefore need to manipulate different reward values and the relative 'baseline or zero-point of non-rewarding value.

This is important as different patterns of prioritisation have been identified in the emotion-valence and reward-value tasks. Specifically, Medium reward having a quicker response time and Happy emotion having improved accuracy responses on the same AMT.

4.2. Differences Between Emotion and reward Prioritisation Effects on Cognition.

Regarding the present research, calculating the prioritisation effect has proved a more nuanced understanding of participant performance in terms of emotion-valence and reward-value tasks. The prioritisation effect was calculated via gains, accounting for the baseline, specifically a level of performance without any influencing factors such as emotion or reward. For example, an increase in accuracy or a decrease in response time, when compared to this baseline, provided the 'gain' or prioritisation effect due to either the reward-value or emotional-valence task. The baseline specifically was the result of a neutral or non-rewarding condition that had no motivationally driven connotation. The prioritisation effect calculation in this instance catered well to individual differences, as participants' performances were compared to this baseline developed from their independent results. This better accounts for individual biases offering a more specific understanding of the relationship between emotion and reward processing. The baseline used in the present research was appropriate, therefore an absent prioritisation effect was not the result of an inappropriate baseline.

The present findings and the appropriateness of the baseline used to calculate the prioritisation effects would indicate that emotion and reward processing exert to some extent the same prioritisation effect on cognition. The prioritisation effect identified only in the Happy valence condition is not fully consistent with prioritisation effects identified in the literature (For example, Yankouskaya et al., 2022a), which implies prioritisation for both Happy and Sad emotions. Reasons for the present findings could be due to the nature of negatively valenced stimuli. Negatively valenced stimuli (e.g., sadness) have been found to capture attention to less of an extent than positively valenced stimuli, however, this is context driven (Strauss, & Allen, 2009). For example, the present research implemented a Neutral-valence condition, whereby literature has recorded that Neutral faces are frequently misinterpreted as being negatively valenced (Lee et al., 2008). In this context, it could explain why no prioritisation effect was observed in the Sad-valence condition, as participant attention for negative valence could have been spread between the Neutral and Sad conditions. In the AMT, stimuli appeared on screen during emotion-valence task for 150ms, this therefore may have not of been enough time to effectively differentiate between Neutral and Sad faces. Literature highlights the processing time in which individuals identify different emotional expressions, with sad facial expressions suggested to take 250ms (Martinez & Du, 2010). This could indicate the need for a longer stimuli onset time to account for 250ms. However, this is contradicted by literature that suggests sad facial expressions can be observed earlier than 250ms. For example, Du and Martinez, (2013), looked at the minimum exposure time needed to successfully classify six classical facial expressions, sadness being one. Their findings suggested that processing sad faces can take between 70ms-200ms. This evidence would therefore suggest in some cases participants would have had enough time to differentiate between neutral and sad faces.

The finding of a prioritisation effect on the happy valence condition implies a preference bias in participants for stimuli associated with positive valence over neutral valence. This prioritisation effect is somewhat consistent with evolutionary theories (e.g., Frijda, 1988) that suggest positive emotions may facilitate socialisation and mating behaviours between individuals optimising health and well-being (Ashby, & Isen, 1999; Diener et al., 1991). This could explain why prioritisation was found in the Happy condition but does not fully explain the lack of prioritisation in the Sad condition. From an evolutionary perspective, the context of a laboratory setting when completing the AMT may not be considered an environment where one needs to take precaution, indicating participants may have had a more positive outlook and thus only prioritised emotionally positive information.

The prioritisation effect identified in the Medium-reward condition opposes previous literature that has highlighted a bias for a preference for higher monetary-value rewards over lower-monetary rewards (Berridge & Kringelbach, 2013; Yankouskaya et al 2022). Reasoning for this may be due to participants preferring relative gains over losses (Madan et al., 2014), and the difference between £50 and £25 may not have been deemed meaningful enough. This would therefore cause participants to prioritise Medium reward to ensure some level of reward gain. However, this effect has predominantly been observed in literature that has used a broader range of rewarding stimuli (e.g., Yankouskaya et al., 2020). Literature that has only used two conditions for the reward-value task, for example, Yankouskaya et al., (2022) did not observe this effect. Therefore, including a third condition such as Medium reward-value may have facilitated this effect. This finding may be better explained by the over-justification effect (Lepper et al., 1973). This is when using an external rewarding stimulus (in this case rewards in the form of Amazon gift vouchers), can have an inverse effect that demotivates individuals' motivation (Peters & Vollmer, 2014). If participants were previously already motivated to do well in the AMT and then being informed that they will receive an Amazon gift voucher based upon their task performance, this could have resulted in them to perform worse-off in the high-reward condition, which would explain why a prioritisation effect was discovered in the Medium-reward condition. An alternative explanation could be a lack of motivation, specifically receiving an Amazon gift card voucher in relation to performance, scaled to 0.01% in proportion to the value assigned to the geometrical shape may have not been deemed rewarding enough. This could explain why a prioritisation effect was observed in the Medium-reward condition over the High-reward condition, as participants may have not been motivated to perform as well. This links to the EVC theory (Shenhav et al., 2013) whereby actions are under a constant valuation, determining whether the potential reward of an action is worth the cognitive effort. In this context, a value of £25 may be easier to identify in 150ms than £50, requiring less cognitive effort and some level of reward, compared to more cognitive effort for only slightly more reward-value, indicating the effort required not deemed to be worth it. Further, the No-reward condition (£0) and High reward condition (£50) both contained the number of £0, therefore during stimuli onset of 150ms participants may have not fully processed the value of the stimuli properly. Whereby £25 may be easier to identify, leading to the prioritisation effect observed. This also provides an explanation to why the prioritisation effect was observed in accuracy and not response time as it took longer for participant to process the stimuli. One reason as of why this may have occurred could be due to the nature of the reward-value stimuli, as participants may have taken longer to react to the rewarding stimuli in the hopes of choosing a correct outcome. This is because the level of monetary gain is determined by the number of correct responses, not based on the speed of response time.

No prioritisation effects were observed in the control task, which indicates the effects identified in the emotion-valence and reward-value task are due to attention rather than memory biases (Humphreys, & Sui, 2016; Sui et al., 2016). Although no prioritisation effects were observed, the Air condition had a p-value of p= .05, the same as the alpha threshold for the present analysis. This was not considered a prioritisation effect as doing so could be the result of influences by random variation in the sample (Madjarova et al., 2022), with little generalisability to the wider population. Despite this not being a prioritisation effect, it is important in understanding the proximity of the p-value to the alpha threshold. One explanation could be the Air condition in the control task might have inadvertently induced a bias previously unidentified and therefore unaccounted for. Unbeknownst at the time of data collection, participants may have a unique and different perspective to the word ‘Air’, therefore inducing some level of motivational connotation to the word. This could be the common theme between stimuli in the control task that are all fundamental aspects of the natural world. This underlying common theme may have been identified by participants and led to subconscious visual awareness of the natural world (Lupyan, & Ward, 2013). Potentially facilitating some level of motivational connotation to what was originally believed to be abstract stimuli with no meaningful connotation, better explaining the proximity to the prioritisation threshold. There was also a lack of randomisation between pairings in the control task. Unlike for reward-value and emotion-valence tasks, pairings in the control task were not randomised between participants. Therefore, participants may have been subject to a ‘lucky pairing’ between geometrical shape and word used, for example, circle-Earth.

4.3. The Relationship Between Prioritisation Effects for Emotion and Reward Processing.

The second hypothesis, (ii) there will be a relationship between the magnitude of reward and happy emotion prioritisation effect, was rejected. This is despite prioritisation effects identified in the Happy emotion-valence and Medium reward-value tasks. This is due to the present prioritisation effects being due to either accuracy or response times independent to one another. As no prioritisation effects were observed in accuracy responses for emotion-valence and in response time for reward-value, further statistical and correlational analysis could not be conducted to test the direct relationship for emotion-valence and reward-value tasks for both accuracy and response times. Therefore, no direct comparison between processes can appropriately be made.

Despite this, the present research is one of the earliest to investigate emotion and reward processing together using the same cognitive task accounting for inconsistencies within the literature. These findings however are in support of the notion that emotional and reward processing is linked to an enhancement in learning (Lang, & Bradley, 2013; Sui, & Humphreys, 2015) as evidence suggests individuals' response time is quicker, and accuracy is higher for stimuli connotated with emotionally or rewarding information. This indicates to some degree a relationship between processes, that influence task performance (Dreisbach, 2006; Pessoa & Adolphs, 2010). Yankouskaya et al., (2022) found a relationship between positive emotion and reward-value processing. Our results support this as prioritisation effects were identified for both positive emotion and reward-value processing. Although rejecting the second hypothesis, this further implies some relationship between emotion and reward processing that is not dependent on the magnitude of reward or emotional intensity. Rather adopting a similar approach as theoretical accounts such as Sander and Nummenmaa (2021) that infer the relationship between emotion and reward processing is interwound but each process to some extent operates independently from one another. For example, this independent operation could be individuals process rewarding stimuli with greater accuracy than emotional stimuli. Similarly, individuals may process emotionally connotated stimuli quicker than rewarding stimuli. However, together these processes capture an individual's attention with emotional and rewarding stimuli intensity corresponding to a specific prioritisation over alternatives. From this, both emotion and reward processing contribute to an individual's goal-relevance, appraisal, and motivation towards a certain outcome. Similar to what was highlighted by Sander and Nummenmaa (2021) that imply theories of emotion can also be directly linked to theories of reward.

Despite the rejection of the second hypothesis as there was no relationship between the magnitude of reward and happy emotion prioritisation effects, the present findings do indicate some evidence that suggests a level of interwovenness between processes that also offers independent functioning. For example, processing rewarding stimuli with greater accuracy and processing emotional stimuli quicker, but both processes together enhance performance on the same task. However, looking at the independent dataset may further expand the primary findings not only looking at the replicability of them, but the relationship between processes.

4.4. Replication Dataset Discussion

The replication dataset, similar to the primary dataset identified two main prioritisation effects. These prioritisation effects were for the Happy emotion condition and the High reward-value condition. Beginning with the Happy emotion condition, this is in line with the primary dataset findings for response time. These findings support the validity and reliability of the primary dataset as similar outcomes were observed for the positive valence task. Secondly, these findings from the replicated dataset support that a positive bias occurs in regard to response time for a positively valenced task. These findings are consistent with literature (Yankouskaya et al., 2017; Neta & Tong, 2016) that implies there is a cognitive bias that prioritises positive valenced stimuli over negatively valenced stimuli (Gupta, 2019; Kauschke et al., 2019). This finding also gives rise to support why no prioritisation effect was observed in the Sad emotion condition. Specifically, 150ms may have not been enough time for participants to identify a sad facial expression. It also gives support to the evolutionary theory behind emotion processing (Frijda, 1988) as these findings replicated the primary dataset findings.

The other prioritisation effect observed was in the high-reward condition in the reward-value task. This contradicts the findings in the primary dataset, as they primary dataset found a prioritisation effect for Medium reward-value, providing contrasting evidence to the over-justification effect (Lepper et al., 1973). This implies participants were more motivated for the higher reward than the medium reward. The reasoning behind these differences could be due to individual bias when it comes to reward sensitivity in participants.

Overall, participants demonstrated similar prioritisation effects in both the emotion-valence and reward-value tasks for the replicated dataset. This implies that the cognitive processes that underly emotion and reward processing show some level of interconnectivity and are not entirely separate to one another. Due to the nature of the replication dataset adopting an identical methodological design to the primary dataset, the findings present that emotion and reward processing have some relationship to one another but can operate independently from one another. The extent of which depend on the context of the intensity of the rewarding or emotionally connotated stimuli.

4.5. Primary vs Replication Discussion

Further analysis was done between both the primary and replication dataset to test for any differences between them. Through parametric testing, no significant differences were observed between datasets, besides in the main effect of stimuli in the emotion-valence comparison. This finding was between the happy and sad valence conditions, implying response time was faster for positive valence over negative valence which is consistent with what has been discussed. Importantly however, no meaningful findings were discovered for the interaction effect between stimuli and datasets. Interestingly, there was little difference between datasets in the control task for the term 'Earth' (see Figure 7.), which could indicate a bias in participants across datasets. This could be due to a programming error during the creation of the experiment where during the learning phase, the order of learning the pairs in the control condition did not change between participants. This could have resulted in the serial position effect whereby participants have a stronger memory recall for stimuli that appears first and last on a list presented to them (Glanzer, & Cunitz, 1966; Murdock Jr, 1962). As Earth was learnt first by every participant, the serial position effect explains why there is a little difference between datasets, assuming a bias in participants' memory. Interestingly, this observation due to a programming error indicates that prioritisation effects may occur from what was learnt first. Literature that has used an AMT discovered that participants response times were quicker for stimuli associated with themselves first (Yankouskaya et al., 2022b), therefore indicating more testing on this is required on whether learning order can facilitate prioritisation effects. Learning order should be considered as a potential confounding variable for future research when investigating prioritisation effects.

Overall, the replication dataset does indeed replicate the findings of the primary dataset, with differences regarding stimuli intensity. Similar findings between datasets in the control task as the result of a programming error have provided an observation previously not identified in the literature regarding the role learning order has on prioritisation effects. Using and independent dataset to validate the primary findings is something that has previously not been considered and provides interesting insights into the mechanisms that underly emotion and reward processing together.

4.6. Limitations

The present research, albeit one of the earliest to overcome certain limitations within the literature, has some limitations that future research should address when investigating emotion and reward processing. As a prioritisation effect was observed in both high- and medium reward-value conditions in the findings from both datasets, future investigative literature should identify a potential threshold limit for rewarding stimuli deemed meaningful enough. This is to avoid participants preferring relative gains over losses (Madan et al., 2014) which is believed to be the reasoning behind the discrepancies between datasets. The present design should be replicated but using different monetary values and gain to identify whether this intensity resulted in the different outcomes between datasets.

Another limitation is the lack of consideration for individual biases in emotional state and reward sensitivity prior to participation. The importance of context is justified within the literature, particularly emotional and reward intensity tends to be unique to individuals (Berridge & Kringelbach, 2008; Eisenberg et al., 2000). Implementing questionnaires to measure the emotional state and reward sensitivity of individual participants and integrating this into data analysis would better account for individual emotional and reward bias. In particular, the subjective value of high and medium rewards needs to be accounted for due to subjectivity surrounding the magnitude of rewards. For example, the highest reward value of £50 may not be considered as much by one participant compared to another. This is because reward sensitivity is relative. Although the present design did not incorporate this direct measurement of individual relativity, it did account for individual differences in the data by comparing participants' performances to a baseline developed from their independent results.

As aforementioned, no prioritisation effects were observed in the control conditions, however, the Air condition had a p-value of $p = .05$, the same as the alpha threshold. This may have occurred due to a lack of full randomised pairings between stimuli and geometrical tasks in the control task. Future research should implement this alongside emotion and reward tasks. This will help to improve the standardisation of randomising pairings across all three tasks in the AMT. Alternative randomised abstract words in the control condition should be introduced to help account for any subjective bias for control stimuli that may have some unknown motivational connotation.

In the emotion valence task, three conditions were employed, Happy, Neutral and Sad. In which, the Happy and Sad conditions are seen as polarities to one another, unlike in the reward condition which could raise concern as emotions in general are more complex than polarities between happy and sad. Future research should therefore consider using positive and negative priority valence, a similar approach to Yankouskaya and Sui, (2022). This will allow to incorporate more positively and negatively valenced emotions giving more breadth to the term of emotion processing. This could also be achieved by using arousal to measure emotion processing but doing this requires strict control of experimental variables as arousal is harder to control and maintain than valence which is always either positive or negative.

Overcoming the outlined limitations will help provide a better understanding of the intricate relationship between emotion and reward processing and enhance the precision of the present experimental design.

4.7. Implications

The present findings have real world implications that contribute to our understanding of the relationship between emotion and reward processing. Specifically, the findings illustrate a relationship between processes in prioritisation effects that indicated greater accuracy with reward processing and quicker response times to emotions. This has an application to education, as task performance was improved in emotion and reward tasks when compared to a control task. Manipulating rewarding and emotional stimuli could be implemented in revision and teaching techniques to help retain important information in students.

These findings also have implications for different mental health conditions. As outlined, dysconnectivity between emotion and reward processing has been linked with different mental health conditions. Clinical interventions that aim to treating these mental health conditions should consider the suggested relationship between emotion and reward processing to better tailor interventions to treat these conditions. Specifically, knowing that emotion may influence reward and vice versa, treatments and interventions should consider both processes, rather than focusing on one.

4.8. Conclusion

These findings are consistent with current literature on the topic, specifically identifying prioritisation effects in both emotion and reward processing, implying that both processes may not be entirely independent. Despite this consistency with previous literature, this research overcomes different methodological challenges and inconsistencies that have not previously been accounted for. For example, measuring emotion and reward processing using an AMT, implementing a control condition, and calculating prioritisation effects from an established baseline with no emotional or rewarding connotation. This provides an early attempt at investigating emotion and reward processing together looking at the relationship between them. Our findings support accounts of common influences of rewarding incentives and positive emotion on cognitive functioning and the important role this has on human behaviour, decision making and general well-being (Pessoa, 2017). The findings also have implications to educational and clinical contexts in offering alternative treatment and intervention options that considers both processes. Using an independent dataset, has not only validated the primary dataset findings but has identified the potential impact learning order can have on prioritisation effects. This indicates the need for further research on this, to better account for potential confounding variables.

In conclusion, the present study indicates some relationship between emotion and reward processing using valence and monetary gain as motivational stimuli, through meaningful prioritisation effects identified in the high-reward value, medium-reward value, and positive valence tasks. These pivotal findings imply some level of underlying mechanisms that impact emotion and reward processing at the cognitive level, specifically using an AMT. By addressing any limitations associated with the present study, this will develop human advancement in the understanding of these two cognitive processes.

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Appendices

Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Trial Type	1.000	NaN [a]	1.000	1.000
Stimuli	0.876	0.055	0.890	0.924
Trial Type ✻ Stimuli	0.874	0.052	0.888	0.922

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels

Appendix A. Tests of Sphericity assumptions for the control condition.

Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Trial Type	1.000	NaN [a]	1.000	1.000
Stimuli	0.948	0.312	0.951	0.992
Trial Type ✻ Stimuli	0.827	0.015	0.852	0.882

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels

Appendix B. Tests of Sphericity assumptions for the reward-value condition.

Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Trial type	1.000	NaN [a]	1.000	1.000
Stimuli	0.830	0.017	0.855	0.885
Trial type ✻ Stimuli	0.944	0.284	0.947	0.988

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels

Appendix C. Tests of Sphericity assumptions for the emotion-valence condition.

	Earth_M	Sky_M	Air_M	Earth_MM	Sky_MM	Air_MM
N	46	46	46	46	46	46
Missing	0	0	0	0	0	0
Mean	82.4	84.3	84.8	81.9	82.6	81.4
Std. error mean	1.12	1.83	1.38	1.60	1.59	2.00
95% CI mean lower bound	80.2	80.7	82.1	78.8	79.5	77.5
95% CI mean upper bound	84.5	87.9	87.5	85.0	85.8	85.3
Standard deviation	7.58	12.4	9.38	10.8	10.8	13.6
Shapiro-Wilk W	0.927	0.807	0.915	0.840	0.950	0.902
Shapiro-Wilk p	0.007	< .001	0.003	< .001	0.046	< .001

Appendix D. Descriptive statistics for matched (M) and mismatched (MM) stimuli for accuracy on the control task.

	NoRM	MediumRM	HighRM	NoRMM	MediumRMM	HighRMM
N	46	46	46	46	46	46
Missing	0	0	0	0	0	0
Mean	76.2	85.5	81.0	74.7	76.8	74.3
Std. error mean	1.81	1.86	2.43	2.68	2.50	2.36
95% CI mean lower bound	72.7	81.8	76.3	69.4	71.9	69.6
95% CI mean upper bound	79.8	89.1	85.8	79.9	81.7	78.9
Standard deviation	12.3	12.6	16.5	18.2	17.0	16.0
Shapiro-Wilk W	0.959	0.872	0.853	0.853	0.862	0.959
Shapiro-Wilk p	0.107	< .001	< .001	< .001	< .001	0.100

Appendix E. Descriptive statistics for matched (M) and mismatched (MM) stimuli for accuracy on the Reward-value (R) task.

	HappyM	NeutralM	SadM	HappyMM	NeutralMM	SadMM
N	46	46	46	46	46	46
Missing	0	0	0	0	0	0
Mean	87.1	80.0	75.7	80.1	80.1	75.0
Std. error mean	2.54	2.22	2.26	2.49	2.53	2.17
95% CI mean lower bound	82.2	75.6	71.3	75.2	75.2	70.8
95% CI mean upper bound	92.1	84.4	80.1	85.0	85.1	79.3
Standard deviation	17.2	15.1	15.3	16.9	17.1	14.7
Shapiro-Wilk W	0.670	0.870	0.929	0.889	0.854	0.901
Shapiro-Wilk p	< .001	< .001	0.008	< .001	< .001	< .001

Appendix F. Descriptive statistics for matched (M) and mismatched (MM) stimuli for accuracy on the emotion-valence task.

5. Supplementary materials

5.1. Mismatched Reward-Value Trials for Accuracy

The mismatched No-reward condition (M= 74.7, SE= 2.7) had no meaningful difference on the proportion of correct responses when compared to the mismatched Medium-reward condition (M= 76.8, SE= 2.5) (*MD= -2.13, SE=1.6, t(45)= -1.3, p= 1.0)* and when compared to the mismatched High-reward condition (M= 74.3, SE= 2.4) (*MD=.40, SE= 1.9, t(45)= .2, p= 1.0).* No meaningful effects were discovered between mismatched Medium-reward (M= 76.8, SE= 2.5) and the mismatched High-reward conditions (M= 74.3, SE= 2.4) (*MD= 2.5 , SE= 1.5, t(45)= 1.6 , p= 1.0).*

5.2. Mismatched Emotion-Valence Trials for Accuracy

The mismatched conditions revealed looking at *Figure 3,* the mismatched Happy condition (M=80.1, SE= 2.5) had no significant effects with the mismatched Neutral condition (M=80.1, SE= 2.5) (*MD= -0.07, SE= 1.71, t(45)= -0.04, p=1.00).* There was also no meaningful results observed between the mismatched Happy condition and the mismatched Sad condition (M= 75, SE= 2.2) (*MD=5.03, SE= 1.71, t(45)= 2.94, p=.076*). There was however a significant effect observed between the mismatched Neutral condition (M= 80.1, SE= 2.5) and the mismatched Sad condition (M= 75, SE= 2.2) (*MD= 5.11, SE= 1.33, t(45)= 3.85, p= .006).* Therefore, revelling for the mismatched conditions accuracy scores were highest for the Neutral condition.

5.3. Mismatched Emotion-Valence Trials for Response time

The mismatched Happy condition (M=.87, SE=.02) revealed no meaningful effect with the mismatched Neutral condition (M= .89, SE= .02) (*MD= .015, SE= .009, t(45)= -1.59, p= 1.0).* There was also no significant effect on response time between the mismatched Happy condition and mismatched Sad condition (M=.90, SE= .02) (*MD= -.02, SE= .01, t(45)= -*

2.12, p= .590). No significant difference identified between the mismatched Neutral condition (M= .89, SE= .02) and the mismatched Sad condition (M=.90, SE= .02) (*MD*= -*.006, SE= .01, t(45)= -.793, p= 1.00).*