The Cognitive and Neural Mechanisms of Dietary Decision-Making

Elektra Schubert

ORCID: 0000-0003-4670-8234

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Abstract

Dietary decisions are influential on both physical and mental health. Unhealthy choices can have many negative consequences, including obesity, heart disease, diabetes, and cancer. This thesis investigated the role of tastiness and healthiness in dietary decisions and interventions, with three specific research questions. The first involved neural representations of tastiness and healthiness: more specifically, how these attributes are represented in the brain during the early stages of dietary decisions. The second question was centred on whether health warning labels (HWLs) can reduce sugary drink consumption. Finally, the third question involved how the experience and regulation of incidental emotions impacts dietary decisions. These questions were addressed in the three empirical chapters of this thesis.

In Study 1, we investigated neural representations of tastiness and healthiness during the first second of rating food images (Experiment 1) or consumption decisions (Experiment 2). The results showed that fine-grained taste and health ratings could be decoded from electroencephalography data using multivariate pattern analysis. This suggests that during dietary decisions, tastiness and healthiness representations are present in the brain from an early stage, even without explicit instructions to consider them. In Study 2, we investigated whether HWLs encouraged healthier choices regarding sugar-sweetened beverages. In a laboratory-based task, participants viewed HWLs, then indicated their willingness to consume various beverages. The HWLs referred either to consequences of a poor diet (general) or sugary drinks (specific). The results showed that both types of HWLs decreased willingness to consume drinks, compared to a control condition. For general HWLs, this effect was weaker for drinks perceived as healthy, whereas the effect of specific HWLs remained constant regardless of perceived healthiness. Overall, our results suggest that HWLs may be effective at prompting behaviour change, and product-specific messages may

reduce consumption of a wider range of drinks. In Study 3, we examined how dietary decisions are influenced by emotions and the regulation of these emotions. Participants completed an online task which involved experiencing and regulating emotions before making hypothetical dietary decisions. The results showed that negative emotions decreased willingness to consume foods, whereas positive emotions led to an increase, particularly for healthy foods. Regulating negative emotions did not change dietary decisions; however, actively increasing and decreasing positive emotions via reappraisal led to respective increases and decreases in desire for food. These results may suggest that people appraise stimuli in a way that matches their emotional state (e.g., feeling positive leads people to view foods as more pleasant).

Overall, these findings highlight the importance of both healthiness and tastiness for dietary decision-making, support the effectiveness of HWLs for promoting healthier choices, and deepen our understanding of the effects of incidental emotions and emotion regulation on dietary decisions. This thesis may inform interventions to improve dietary decisions, and provides a strong basis for future studies that aim to evaluate interventions through examining changes to neural representations of taste and health attributes.

Declaration

I declare that:

(i) this thesis comprises only my original work towards the Doctor of Philosophy, except where indicated in the preface;

(ii) due acknowledgement has been made in the text to all other material used; and

(iii) the thesis is fewer than 100 000 words in length, exclusive of tables, figures, references and appendices.

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Elektra Schubert

Preface

For each study reported herein, experimental data was collected by the PhD candidate with assistance from members of the Decision Neuroscience Laboratory at the University of Melbourne. Three chapters of this thesis are presented in article format: Chapter 2 presents an article published by *Neuropsychologia* on 12/11/2021; Chapter 3 presents an article published by *Appetite* on 01/06/2021; and Chapter 4 presents an article submitted for publication to *Appetite* on 16/05/2022. Each empirical manuscript was drafted entirely by the PhD candidate, and was then revised and edited with the assistance of the manuscript's named co-authors. No third-party editorial assistance was provided in preparation of the thesis.

All co-authors have agreed to the use of these manuscripts in this thesis, and have provided signed copies of the co-author authorisation form. The work in this thesis was supported by an Australian Government Research Training Program Scholarship awarded to Elektra Schubert.

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List of Abbreviations

ATF. Appraisal Tendency Framework.

BED. Binge-Eating Disorder.

BMI. Body Mass Index.

EEG. Electroencephalography.

ERP. Event-Related Potential.

fMRI. Functional Magnetic Resonance Imaging.

HWL. Health Warning Label.

LPP. Late Positive Potential.

MVPA. Multivariate Pattern Analysis.

OFC. Orbitofrontal Cortex.

SSB. Sugar-Sweetened Beverage.

SVR. Support Vector Regression.

vmPFC. Ventro-Medial Prefrontal Cortex.

WTC. Willingness to Consume.

Chapter 1: General Background

In everyday life, people make constant dietary decisions, each involving a complex, multi-layered process. For example, an individual may first decide whether to eat a snack at all in between meals. If they decide to eat this snack, they might then deliberate over a chocolate bar or a piece of fruit. In this decision, a wide range of factors may be considered, including tastiness, health, convenience, price, and familiarity (Januszewska et al., 2011; Steptoe et al., 1995). Two factors are particularly important: taste and health. Taste strongly drives food choice, with people usually choosing to eat foods that they consider to be tasty (Dana et al., 2021). However, foods considered to be tasty are often also unhealthy (e.g., chocolate), which may lead to a taste preference for unhealthy foods, labelled the "unhealthy-tasty intuition" (Garaus & Lalicic, 2021; Luomala & Leipamaa, 2004; Raghunathan et al., 2007). Due to the importance of tastiness in dietary decisions, the unhealthy-tasty intuition may reduce a person's healthy food consumption (e.g., vegetables), and instead prompt them to eat unhealthy foods (Briers et al., 2020), even if this conflicts with their personal health goals (Baumeister, 2002).

Repeated decisions to consume unhealthy foods can lead to a wide range of negative consequences (Meldrum et al., 2017). An unhealthy diet that is high in ultra-processed foods, fat, and sugars, is associated with excess body weight (overweight; Askari et al., 2020; Mozaffarian, 2016). In its extreme, this can lead to obesity, a serious medical condition often diagnosed if an individual has a body mass index (BMI) of more than 30 (Kopelman, 2000). Obesity has been identified as a risk factor for several other health conditions, including type 2 diabetes, heart diseases such as coronary artery disease and hypertension, osteoarthritis, asthma, and many types of cancer, including those of the colon, rectum, breast, uterus, esophagus, pancreas, kidney, and gallbladder (Hruby et al., 2016; Kopelman, 2000; Meldrum et al., 2017; Mozaffarian, 2016). In addition to medical conditions, obesity is associated with

negative psychological consequences such as depression, low self-esteem, poor body image, stress, and victimisation due to weight stigma (Chu et al., 2019; Emmer et al., 2020). Since the 1980s, rates of obesity have been increasing in Western countries, including the United States of America (Hales et al., 2018; Ogden et al., 2006), United Kingdom (Wang et al., 2011), and Australia (Keramat et al., 2021). From 1990 to 2017, the worldwide prevalence of overweight (high BMI) increased by approximately 70% (GBD 2017 Risk Factor Collaborators, 2018). These increasing trends led to the declaration of a global obesity epidemic, formally recognised by the World Health Organisation in 1997 (Caballero, 2007). This epidemic has brought substantial economic costs worldwide (Tremmel et al., 2017; Wang et al., 2011). Therefore, it is important to investigate ways to reduce obesity, to improve the mental, physical, and economic health of societies worldwide. Although obesity is a complex issue that is also influenced by other factors that are not related to food (e.g., exercise levels; socioeconomic status), a key risk factor is a poor diet (Meldrum et al., 2017), which arises due to repeated unhealthy food choices. Therefore, understanding food choices is important for developing interventions to combat obesity.

The focus of this thesis is on individual dietary decisions. There are two primary goals: first, to investigate the neural processes involved in dietary decisions; and second, to explore two ways of changing these processes: (a) health warning labels (HWLs) as an intervention; and (b) the experience and regulation of emotions. The influential attributes of perceived health and taste will be important for addressing both goals. In the subsequent chapters, I report three studies to examine the underlying neural processes and influences on dietary decisions. To address the first primary goal, Study 1 was focused on the neural representations of tastiness and healthiness attributes during dietary decision-making. This involved presenting visual food cues (images) while participants' neural activity was recorded, and examining whether and when perceptions of taste and health attributes were

present in the neural activity. To address the second goal of investigating influences on dietary decisions, two further studies were conducted. Study 2 investigated graphic HWLs as an intervention to improve dietary choices for sugar-sweetened beverages (SSBs) in particular. Finally, Study 3 was focused on the effects of negative and positive emotions and the regulation of these emotions on dietary choices. Participants completed an online task in which they were induced with emotions, and on some trials attempted to regulate these emotions. They then made a hypothetical dietary choice, and we examined whether these choices differed according to whether emotions were induced and whether these emotions were regulated.

In this chapter, I will begin by reviewing the existing literature on how taste and health attributes are cognitively and neurally processed and integrated into dietary decisions. I will then review the literature on the effectiveness HWLs as an intervention for dietary decisions. The final section of the literature review will be focused on the effects of both positive and negative emotional experience, as well as emotion regulation, on dietary decisions. To end the chapter, I will describe the focus of the current thesis, including the aims and specific research questions, and will finally describe the three empirical studies designed to address these questions.

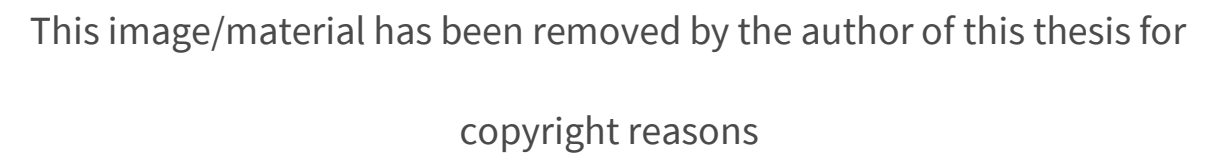
1.1 Cognitive and Neural Processing of Food Cues

Food choice is a complex process that is influenced by both individual and situational factors. Furst et al. (1996) proposed a conceptual model that groups food choice into three major components (see Figure 1). First, a person's *life course*, which comprises personal background and previous experiences, influences the development of their preferences, values, and ideals. These qualities, along with the person’s personal resources, environment, and social framework, form the second part of the model, *influences*. These influences then feed into the *personal system*, which is the final component of the model and includes two

parts. The first is *value negotiations*, which involves weighing up various considerations about the food, including sensory perceptions (e.g., taste, texture), quality, managing relationships (e.g., considering foods to be shared with family members), health and nutrition, convenience, and monetary considerations. When such deliberations become habitual (e.g., a person decides that a sandwich is a healthy lunch choice, then selects that food on a daily basis), they form the second component of the personal system, *strategies*, which are recurrent food choice patterns based on these habitual deliberations. Other models have extended and added to Furst's (1996) original model, but have retained the three key components of life course, influences, and the personal system (Gorton & Barjolle, 2013; Sobal & Bisogni, 2009). In this thesis, I focus primarily on the value negotiations component of the personal system. That is, although there are other important factors, such as environmental context, pre-existing individual differences, and habits that might influence food choices, these will not be considered in depth. Instead, the focus will be on two specific components of the value negotiations process: the sensory perception of taste, and consideration of health and nutrition (i.e., health and taste attributes).

Figure 1

Conceptual Model of Food Choice



Note. A person's life course influences their ideals, personal factors, resources, social framework, and food context. These factors then form the person's personal system for deciding on the subjective value of food choices. Value negotiations involve the consideration of sensory perceptions, money, convenience, health, quality, and managing relationships. Over time, value negotiations can become habitual, forming strategies. The final food choice is determined by both strategies and individual occasions of value negotiations. From "Food Choice: A Conceptual Model of the Process," by T. Furst et al., 1996, *Appetite*, *26*(3), 246-266. Copyright by Academic Press Limited.

When faced with a food choice, people are often prompted by a visual cue of the food under consideration – for example, they might see a chocolate bar in the supermarket before deciding whether to buy it. There is evidence that vision drives food consumption, with previous studies suggesting that viewing food leads to greater desire for the food (Ouwehand & Papies, 2010) and consumption (Linné et al., 2002). Visual food cues have been found to elicit stronger neural responses than other types of food cues, such as odors (Huerta et al., 2014). Therefore, there has been a widespread focus on visual food cues in both cognitive and neural studies in the dietary decision-making literature (Huerta et al., 2014; van der Laan et al., 2011). In the following paragraphs, I will review this literature, discussing findings on how the attributes of taste and health are processed and integrated into decisions when visual food cues are presented.

The differences in processing between taste and health attributes can be understood using Construal Level Theory (Trope & Liberman, 2003) as a framework. This theory rests on the assumption that objects can be interpreted or *construed* at different levels, with lower levels being more concrete, contextualised, and unstructured, and higher levels more abstract, schematic, and decontextualised (Trope & Liberman, 2003). Applying this to a dietary decision, a focus on the perceived or expected taste of a food can be considered a lower-level construal (e.g., "This chocolate bar looks delicious"), whereas considering its health constitutes a higher level (e.g., "Chocolate bars are not good for my long-term health"). Construal Level Theory then proposes that increased psychological distance, which can involve both space and time, will lead to higher level construal (Trope & Liberman, 2003). For example, considering a food to eat in the immediate future involves low temporal distance, which means that lower-level construal, such as a focus on tastiness, is more likely. If one considers a food to eat in the more distant future, Construal Level Theory would instead predict a higher-level construal, which may involve focusing on the healthiness of the food. While food choices can be foreshadowed with meal preparation or grocery shopping, many individual decisions are made immediately before the food is consumed. Further, the low-level construal of food items is often highly desirable– tastiness has a highly hedonic nature, which can bias people toward focusing on taste instead of longer-term health consequences (Trope & Liberman, 2003). In studies on the cognitive processes involved in dietary decision-making, there has therefore been a large focus on taste and health attributes (Lim et al., 2018; Sullivan et al., 2015), and how the focus on each attribute can be shifted.

Existing literature on the processing of taste and health attributes has focused primarily on how they differ in speed of processing (Sullivan et al., 2015) and the automatic capture of attention (Motoki et al., 2018). Sullivan et al. (2015) investigated the relative processing speed of taste and health attributes using a hypothetical binary food choice

paradigm. While participants chose between a healthy or unhealthy food using a computer mouse, the researchers tracked the mouse trajectory toward the chosen food. The trajectory was then used to determine the earliest time at which taste or health information began to influence the decision. This analysis showed that taste information began to influence the decision-making process approximately 195 ms (9%) earlier than health, which suggests that taste is cognitively processed more quickly. Using a similar paradigm, Lim et al. (2018) replicated this result, showing that taste was processed about 230 ms more quickly than health. In further support of the quick processing of taste attributes, Motoki et al. (2018) found that automatic visual attention was captured by the tastiness of foods, but not healthiness. Using eye-tracking analyses, they found that when participants viewed neutral images with food items as distractors, the extent to which their gaze was drawn to the food items was predicted by perceived taste but not health. Overall, the evidence from previous studies using mouse- and eye-tracking techniques suggests that the cognitive processing of taste attributes occurs quickly, automatically, and sometimes without conscious awareness. Health, on the other hand, is processed more slowly and deliberately, in line with the predictions of Construal Level Theory regarding high-level construal.

1.1.1 Neuroimaging Studies on Food Attributes

Neuroimaging studies give further insight into the underlying cognitive mechanisms involved in the processing of visual food cues. Several studies have used functional magnetic resonance imaging (fMRI) studies to examine differences in brain regions that are activated in response to foods with high- versus low-caloric value (Frank et al., 2010; Geliebter et al., 2013; Schur et al., 2009; Siep et al., 2009). These studies showed that when participants viewed foods classed as “high-calorie”, "fattening", or "palatable", they showed increased activity in several brain regions, including the orbitofrontal cortex (Coletta et al., 2009; Frank et al., 2010; Geliebter et al., 2013; Goldstone et al., 2009; Siep et al., 2009), brainstem

(Geliebter et al., 2013; Schur et al., 2009), amygdala (Goldstone et al., 2009; Schur et al., 2009), fusiform gyrus (Frank et al., 2010; Geliebter et al., 2013; Siep et al., 2009), and striatum (Goldstone et al., 2009; Siep et al., 2009). This might suggest that these regions, which have also been implicated in reward and emotional processing (Kennis et al., 2013; Rolls, 2019; Seabrook & Borgland, 2020), are involved in encoding information about the caloric value of food cues. Moving beyond a focus on high- versus low-calorie foods, Tusche and Hutcherson (2018) found that fMRI-recorded representations of perceived tastiness and healthiness could be decoded from the right superior frontal gyrus and right lateral prefrontal cortex, respectively. This suggests that in these regions, the brain encodes personal perceptions of food attributes, which are important factors in dietary decisions (Dana et al., 2021).

Existing electroencephalography (EEG) studies have provided information on the timing of the neural processing of taste and health attributes. There is evidence that some event-related potential (ERP) components differ when elicited by high- versus low-calorie foods, including the N1 (Meule et al., 2013; Rosenblatt et al., 2018b; Schwab et al., 2017; Toepel et al., 2009), which occurs approximately 100 ms after the presentation of a stimulus and is typically measured in occipital electrode sites (Meule et al., 2013; Vogel & Luck, 2000). The N1 may reflect early, automatic allocation of attention (Vogel & Luck, 2000), therefore, the fact that this component reflects caloric value might suggest that high-calorie foods draw attention quickly and automatically. If high-calorie foods are considered tastier, this conclusion aligns with Motoki et al.'s (2018) finding that taste attributes attract automatic attention. However, another study found that although the N1 differed between high- and low-calorie foods (Meule et al., 2013), there was no difference in subjective tastiness between these categories. Therefore, the observed difference in the N1 component may have been driven by healthiness, rather than tastiness.

Although the comparison of high- versus low-calorie foods is common in existing dietary decision-making studies (Carbine et al., 2018), this approach makes it difficult to determine whether observed differences in the ERP components reflect differences in the processing of taste, health, or both attributes. People's food choices are strongly driven by individual preferences and health perceptions (Dana et al., 2021). These perceptions may not always align with caloric value, as people may use other aspects of food to judge healthiness, such as nutrient contents (Gandhi et al., 2022) and expected satiety (Buckland et al., 2015). Therefore, examining differences in neural responses to foods that vary along subjective attributes may be more appropriate for understanding the neural mechanisms of food choices than comparing high- and low-calorie foods. Rosenblatt et al. (2018) took this approach and found further evidence for health-related effects on the N1, showing that subjective healthiness ratings positively predicted N1 amplitudes. In the same study, there was no difference in the N1 component between foods of high versus low perceived tastiness. Therefore, although behavioural and eye-tracking studies suggest that taste is processed earlier than health (Lim et al., 2018; Motoki et al., 2018), some neuroimaging studies show that early indices of automatic attention reflect an opposite pattern.

Taste attributes have been associated with some later ERP components (Asmaro & Liotti, 2014; Rosenblatt et al., 2018b), most notably the P3 and late positive potential (LPP; Carbine et al., 2018), which are both typically measured in the frontal, central, and parietal electrode regions (Polich, 2007; Schupp et al., 2000). The P3 occurs approximately 300 ms after a stimulus appears, whereas the LPP occurs 350 to 750 ms after stimulus presentation but can show sustained effects for up to 6000 ms (Cuthbert et al., 2000; Schupp et al., 2000). Previous studies have shown that the P3 reflects the processing of novel stimuli and evaluation of their significance (Friedman et al., 2001), while the LPP is associated with emotional and highly arousing stimuli and is thought to reflect motivational activation

(Hajcak et al., 2010; Schupp et al., 2000). The strongest evidence that the P3 and LPP reflect perceptions of tastiness was found by Rosenblatt et al. (2018), who showed that subjective taste, but not health ratings, predicted P3 and LPP amplitudes when participants viewed images of snack foods. This suggests that information on tastiness perception may be present in the brain during the first second of viewing a food cue. Notably, existing studies on taste and health attribute processing have almost all focused on food cues; however, beverage choice is another important component of dietary decision-making, with sugary drink consumption contributing toward excess calories in one's diet (Malik & Hu, 2011). It is unclear whether packaged visual drink stimuli also elicit similar neural responses that reflect perceptions of tastiness and healthiness.

It is also important to understand how taste and health attributes are integrated into decisions. According to dietary decision-making models, during a food choice the subjective value of each basic food attribute is weighed up, and these attributes are then integrated to form an overall measure of subjective value which determines the outcome of the decision (Furst et al., 1996; Rangel & Hare, 2010). This theory has been supported by several fMRI studies (Hare et al., 2009; Pelletier & Fellows, 2019; Suzuki et al., 2017). For instance, Hare et al. (2009) examined the neural correlates of food *goal value*, defined as the expected level of reward from consuming a food. They measured goal value by having participants choose between two food items based on previously given subjective health and taste ratings: a reference food, which was neutral on both attributes; and a food was closer to the upper or lower end of the perceived health and taste spectrum. Goal value was quantified as the strength of their decision to eat one food over the other. They found that this measure was associated with activity in the ventromedial prefrontal cortex (vmPFC). Further, vmPFC activity was predicted by subjective health and taste ratings for participants who were classed as "self-controllers" (i.e., those whose decision-making patterns appeared to be influenced by

both taste and health, rather than primarily by taste). These findings suggest that after taste and health are processed, they are integrated into decisions in the vmPFC.

Similarly, other studies have suggested that health and taste contribute toward a cognitive evidence accumulation process, whereby an overall value signal moves between two potential food choices (e.g., a healthy or unhealthy food, or a decision to eat or not eat one food; Hajihosseini & Hutcherson, 2021; Harris et al., 2018). As taste and health are processed, subjective values for each attribute are computed, which move the overall value signal toward one choice or another (Hajihosseini & Hutcherson, 2021; Harris et al., 2018). There is also evidence that this value signal is reflected in EEG-recorded neural activity, including alpha frequency (Hajihosseini & Hutcherson, 2021) and ERP components from 500 to 1000 ms after the presentation of a food stimulus (Harris et al., 2018). Overall, the evidence suggests that taste and health are evaluated in the brain, and this process contributes toward an overall value signal that determines whether a food is consumed.

1.2 Dietary Decision-Making Interventions: Health Warning Labels

The existing literature on the neuro-cognitive processing of taste and health attributes provides a foundation for examining interventions to improve dietary decision-making. Several studies have already examined how the processing of taste and health attributes changes when caloric and nutritional information is placed on foods, using mouse-tracking and fMRI techniques (Grabenhorst et al., 2013; Lim et al., 2018). An important advantage of using such cognitive and neural techniques is that they may not only reveal whether personal and public health interventions are effective, but also give insight into how such interventions work at a deeper, cognitive level. The current thesis will examine two different approaches for changing food choices, namely HWLs (covered in this section), and the regulation of incidental emotions (see Section 1.3). I will begin by focusing on HWLs, as they are currently of high policy interest, are relatively easy to implement by public health authorities,

and have been thoroughly researched, particularly in relation to tobacco, alcohol, and food consumption (Clarke et al., 2020a; Noar et al., 2016). HWLs may also alter the cognitive and neural processing of taste and health attributes, although there is minimal empirical evidence on this matter. As HWLs explicitly mention the health consequences of products, they may make cognitive representations of health attributes more salient, and may lead to negative associations that alter perceptions of tastiness. In this section, I will review the existing literature on the effectiveness and underlying cognitive mechanism of HWLs for tobacco, snack food, and finally, sugary drink consumption.

HWLs are messages displayed on a product that warn of the negative consequences of consuming it (Hammond, 2011; Pechey et al., 2020). For almost 20 years, these have been displayed on cigarette packets to discourage tobacco consumption worldwide, including in Australia, the United Kingdom, and the United States (Borland, Wilson, et al., 2009). There is substantial evidence for their effectiveness, showing that displaying HWLs on cigarette packages is associated with reductions in negative attitudes toward smoking (Noar, Hall, et al., 2016), thoughts and intentions to quit (Blanton et al., 2014; Hammond et al., 2003; Noar, Hall, et al., 2016), and real attempts to quit (Borland, Yong, et al., 2009; Cho et al., 2018). There is a smaller amount of existing literature on the impact of HWLs on real-world smoking behaviours, as opposed to intentions (Noar, Hall, et al., 2016). There is some evidence that HWLs are associated with decreased population smoking rates (Azagba & Sharaf, 2013; Jung, 2016), and led to reduced smoking behaviours in a four-week randomised clinical trial (Brewer et al., 2016). However, another randomised clinical trial found that although HWLs reduced positive perceptions of smoking and health concerns, they did not reduce real-world smoking behaviours over a three-month period. Therefore, although HWLs affect behavioural intentions, their lasting effects on smoking behaviours are unclear.

Nonetheless, based on the evident success of HWLs for affecting behavioural intentions around smoking, more recent studies have suggested that they may also be useful for reducing the purchase and consumption of unhealthy foods (Clarke et al., 2020b) and beverages (Grummon et al., 2019a; Gupta et al., 2021). This suggestion is based on similarities between smoking and unhealthy food consumption. Most notably, both are widespread behaviours despite having negative health consequences (Lauer et al., 2010; Jayedi et al., 2020; West, 2017; World Health Organisation, 2018), activate similar reward-related regions of the brain (Tang et al., 2012), and require cognitive self-control resources in attempts to quit (Shmueli & Prochaska, 2009). However, smoking and unhealthy food consumption are not completely analogous. Food is necessary for survival, and the definition of "unhealthy" food is not always clear, as various measures can be used to estimate healthiness (e.g., calorie, fat, sugar, or micronutrient content). Even foods widely considered unhealthy may have some nutritional benefits; for example, ice cream, despite being high in sugar, also contains calcium, an important micronutrient (Titchenal & Dobbs, 2007). This complexity does not apply to tobacco, which is not necessary for survival, has no nutritional benefits, and comes with health risks even if consumed socially or via secondhand smoke (Öberg et al., 2011; Schane et al., 2009). Nonetheless, due to the similarities between smoking and unhealthy food and drink consumption, HWLs may be useful for discouraging the purchase of products that are high in calories and refined sugars, while carrying little other nutritional value.

1.2.1 Health Warning Labels for Food and Beverage Products

A growing body of experimental evidence has attempted to identify the most effective types of HWLs for food and beverage products (Clarke et al., 2020; Rosenblatt et al., 2018a). Studies of HWLs on cigarette packaging have suggested that pictorial HWLs are most effective, that is, those accompanied by often graphic images depicting the adverse health

consequences associated with smoking, such as an image of a damaged set of lungs (Brewer et al., 2016; Noar, Francis, et al., 2016; Noar, Hall, et al., 2016b). Compared to text-only HWLs, text-and-image HWLs have been found to induce greater negative emotionality and increased intention to quit smoking in experimental studies (Noar, Hall, et al., 2016b), and decreased rates of smoking in randomised clinical trials (Brewer et al., 2016). Some studies have investigated whether text-and-image HWLs are also the most effective type of label for changing dietary decisions, in online and laboratory experiments (Clarke et al., 2020a; Clarke et al., 2020b). An overwhelming finding from these studies is that when HWLs are accompanied by an image, they decrease unhealthy dietary choices more strongly than text-only warnings, as measured by the likelihood of energy-dense snack selection in hypothetical vending machine tasks (Clarke et al., 2020a) and self-reported motivation to change dietary behaviour (Rosenblatt et al., 2019).

Further, HWLs seem to be most effective when they are negatively framed. In a laboratory-based task, Rosenblatt et al. (2018) showed that negatively-framed HWLs (i.e., warnings about the health risks of eating unhealthy foods) changed self-reported dietary self-control more effectively than positively-framed HWLs (i.e., messages emphasizing the benefits of a healthy diet). Therefore, the most promising type of HWLs for promoting healthier dietary choices seem to be those that include both text and graphic images, with an emphasis on adverse health risks.

Other studies have examined the mechanisms by which HWLs may change dietary behaviour. First, studies of HWLs on cigarette packaging and alcohol have suggested that they work by eliciting negative emotions, including fear (Byrne et al., 2015), disgust (Hammond et al., 2004), and worry (Yong et al., 2014). These emotions then act as mediators, prompting changes in behaviour such as quit attempts (Cho et al., 2018) and hypothetical alcoholic drink selection (Clarke et al., 2021). Studies specifically focusing on

HWLs on foods and beverages have produced similar findings, with several studies showing that participants report more negative emotion after viewing foods with negatively-framed graphic HWLs, compared to no labels or text-only labels (Clarke et al., 2020a; Pechey et al., 2020; Rosenblatt et al., 2019). Donnelly et al. (2018) extended on this finding by explicitly testing negative emotion as a mediator in the relationship between HWLs and sugary drink consumption. Their results showed that, compared to no warning, graphic HWLs increased negative affect, which in turn predicted participants' intention to purchase water instead of a sugary drink in an online hypothetical purchasing task. However, although negative emotions are one mechanism through which HWLs work, it is also important for the content of the negative stimuli to be linked to the food under consideration. A recent study found that aversive, negative emotion-eliciting image labels alone (e.g., a dog lying dead on the ground) did not change motivation toward food as effectively as HWLs that communicate a clear causal relationship between the food and the aversive image (Ventsel et al., 2022). Therefore, the existing literature suggests that the elicitation of negative emotions is one mechanism involved in the effectiveness of HWLs on food and drink products, but not the only one.

Another mechanism by which HWLs may work is by changing the cognitive processing of food cues and attitudes toward foods (Asbridge et al., 2021; Rosenblatt et al., 2018b). Rosenblatt et al. (2018) examined ERP responses to food images in two experimental stages. In the first stage, participants viewed and rated food images. They were then allocated to one of two groups and viewed either negatively-framed graphic HWLs or neutral control images. In the second experimental stage, participants made consumption decisions about the foods. The results showed that from the first to second experimental stage, participants in the HWL group showed reduced P3 and LPP amplitudes for tasty foods, whereas the control group showed no change. As both components have been found to reflect the appetitive value, tastiness, and craving for foods (Carbine et al., 2018), this result may suggest that

viewing HWLs changes the cognitive processing of unhealthy food cues, prompting these foods to be considered less appealing. In support of this idea, Asbridge et al. (2021) found evidence that HWLs change implicit attitudes toward energy-dense snack foods. In their study, participants who viewed graphic HWLs did not change in their selection of healthy or unhealthy food in hypothetical decisions, but showed more negative implicit attitudes toward unhealthy foods compared to those who viewed no HWLs. Therefore, the existing evidence suggests that HWLs may change a person's view of unhealthy foods, potentially beyond conscious awareness.

Although many studies have focused on using HWLs to reduce the consumption of unhealthy foods, HWLs may be even more useful for discouraging the purchase and consumption of SSBs, including soft drinks, fruit drinks (e.g., juices, packaged smoothies), and sports drinks. Unlike unhealthy foods, which contain some nutrients and can contribute toward a balanced diet in moderation, SSBs contain little nutritional value and are often high in calories and added sugar. Further, calories consumed in liquid form may be less satiating than solid foods (Chambers et al., 2015). Therefore, despite being high in calories, SSBs are not likely to make consumers feel full, which may lead to overconsumption of other foods (Mourao et al., 2007). Accordingly, SSB consumption has been linked to adverse health effects, most notably including type 2 diabetes (Malik et al., 2010) and coronary heart disease (Malik & Hu, 2019).

Findings from online, laboratory- and field-based studies on the effects of HWLs on SSB consumption show promising results (An et al., 2021; Taillie et al., 2020). In Bollard et al.'s (2016) online study, participants viewed an image of an SSB accompanied by either no label, a text-only HWL, or a graphic HWL. The results showed that participants in both HWL conditions reported lower likelihood of purchasing the SSB than those in the control condition, and rated the product as less tasty, attractive, and cool. Billick et al. (2018) found

similar results, and further showed that graphic HWLs were more effective than text-only warnings, sugar content labels, and health star ratings at reducing SSB selection in an online choice task. Studies in more naturalistic settings have shown similar promise for graphic HWLs for SSB products, with results showing that they reduced SSB purchases in a hospital cafeteria from 21.4% to 18.2% of all beverages purchased (Donnelly et al., 2018), and led to a lower number of calories purchased from SSBs in a life-sized convenience store replica (Grummon et al., 2019b).

Overall, the available evidence suggests that graphic HWLs decrease SSB consumption, however, no studies to date have examined the cognitive and neural processes through which these HWLs work. For instance, it is possible that HWLs change the processing of health and taste attributes, as Rosenblatt et al.'s (2018) findings suggested for HWLs on snack foods; however, this has not been tested directly. Further, while some studies show promise for HWLs, others have had less success; for example, Mantzari et al. (2020) found that participants who were offered real drinks with graphic HWLs on their packaging were just as likely to take an SSB as participants who were offered the same drinks with calorie information or no labels displayed. Therefore, more research is still needed on factors that may help HWLs consistently lead to behaviour change.

One factor that may influence the effectiveness of HWLs at reducing SSB consumption is the product-specificity of the warning messages. Of the studies reviewed so far, most investigated HWLs that warned of the health consequences of consuming SSBs specifically, for example, “Beverages with added sugar contribute to tooth decay, diabetes, and obesity” (Billich et al., 2018; Bollard et al., 2016; Donnelly et al., 2018; Grummon et al., 2019b). However, Mantzari et al. (2020) used a more general HWL stating that “Excess sugar consumption causes dental decay” and found no effect on SSB selection. Therefore, it is possible that HWLs that specifically mention sugary drinks are more effective than those

related to the general consequences of an unhealthy diet or high sugar consumption. To a person who is considering SSB consumption, SSB-specific HWLs may carry higher personal relevance, a factor that has been found to increase HWL effectiveness for alcohol (Winstock et al., 2020) and tobacco (Thrasher et al., 2012). Further, some people may be unaware of the negative health consequences of consuming SSBs, particularly frequent consumers (Miller et al., 2019). These people may be less likely to believe that HWL messages apply to them if they refer to a poor diet, compared to if they explicitly mention SSBs. This is in line with literature on tailored versus generic eHealth messages (i.e., delivered directly to the participant via the internet), showing that they promote weight loss more effectively when they are tailored to individual health goals or difficulties (Casado-Aranda et al., 2022; Ryan et al., 2019). For example, a message saying "John, the Pepsi you drink at noon has high levels of fructose, which is bad for your circulation" would be more effective than "Drinking too many sugary beverages or beer may increase the risk of developing type 2 diabetes" (Casado-Aranda et al., 2022).

These findings suggest that, if HWLs can be placed on a spectrum of specificity, messages toward the more specific end (e.g., tailoring HWLs to SSBs, rather than a general poor diet) might be more effective at changing behaviour. Studies on alcohol consumption have found that HWLs were more effective when they warned of specific health consequences (e.g., bowel cancer, depression) compared to more general ones (e.g., cancer, mental illness; Blackwell et al., 2018; Pettigrew et al., 2016). Although these studies focused on consequence-specificity rather than product-specificity, their findings suggest that HWLs with higher specificity are more effective than general ones. However, whether SSB-specific HWLs are more effective than general HWLs remains to be directly tested. This question was therefore a key goal of the second empirical study in this thesis.

1.3 Incidental Emotions and Emotion Regulation

While HWLs primarily elicit *integral emotions* – emotions directly related to the food under consideration in a dietary decision, such as fear about the negative consequences of consumption (Desmet & Schifferstein, 2008) – it is also important to consider emotions that are unrelated to the food, and how these might affect decision-making processes. These have been termed *incidental emotions*: affective responses to a specific stimulus that are unrelated to the object under consideration (Loewenstein & Lerner, 2003). Importantly, incidental emotions can influence decision-making in various domains, including cognitive, social, and health decisions (Achar et al., 2016; Lerner et al., 2015; Västfjäll et al., 2016). Food choices are ultimately influenced by both types of emotions – for instance, integral feelings of pleasantness toward a chocolate bar, as well as incidental anxiety about an upcoming exam could both increase the likelihood of an individual eating the chocolate bar. Further, these emotions can be changed via *emotion regulation* (ER), which refers to processes that a person uses to control which emotions they experience, when they occur, and how strongly they are experienced and expressed (Gross, 2015a; Gross et al., 1998). There is evidence that the regulation of incidental emotions influences subsequent decisions, including dietary choices (Grecucci, 2014; Morawetz et al., 2020b). In this section, I will review the existing literature on the influence of positive and negative incidental emotions on dietary decisions, and the effects of regulating these emotions.

A variety of mechanisms have been suggested for the effect of emotions on eating behaviour (Cameron et al., 2015; Lerner & Keltner, 2000; Macht, 2008). Macht (2008) proposed five principles around emotional influences on eating behaviour. The first is that there are influential food-related emotions (integral emotions). Second, intense emotions, such as high fear and stress, may suppress food intake, as they trigger physiological responses that can interfere with the desire to eat. Third, both negative and positive incidental emotions can impair cognitive eating controls, because the processing of emotional stimuli requires the

allocation of attention and other resources, which are limited in capacity. Fourth, negative emotions may elicit eating as a way of regulating or improving the negative emotional state. Finally, as per Lerner and Keltner's (Lerner & Keltner, 2000) Appraisal Tendency Framework (ATF), emotions may lead foods to be perceived in a way that is congruent with the features of an emotion, for example, some negative emotions are associated with a slowing of cognitive processes (Izard, 2007), which may decrease the tendency to seek out foods (Macht, 2008). While Macht's model explains some reasons behind emotion-related changes in eating behaviour, it does not consistently predict one direction of such changes. Therefore, it is also important to review the experimental evidence regarding the effects of general negative and positive emotions on dietary behaviour.

There is extensive literature on the relationship between negative emotions and eating behaviour, which is typically examined as either quantitative food intake or qualitative dietary decisions (Cardi et al., 2015; Devonport et al., 2019; Evers et al., 2018). Many studies have focused on populations of *restrained eaters* (i.e., people high on the trait tendency to control their diet; Polivy et al., 2020); and people diagnosed with *binge eating disorder* (BED), which is characterised by episodes of excessive food consumption (Brownley et al., 2016). These studies have yielded relatively consistent results, with meta-analyses of laboratory studies showing that induced negative emotions tend to be associated with increased food intake in restrained eaters and binge eaters (Brownley et al., 2016; Cardi et al., 2015).

However, studies within the general population (i.e., those who do not show unusual eating patterns), have found mixed results. On the one hand, there is evidence that some specific negative emotions increase food consumption and unhealthy dietary choices (Aguiar-Bloemer & Diez-Garcia, 2018; Moss et al., 2021). Incidental anxiety has been found to increase visual fixation on unhealthy, hedonic foods, but not healthier foods (e.g., yogurt;

Motoki et al., 2019), which could indicate an emotion-related increase in desire for unhealthy foods. Further, Garg and Lerner (2013) found that when participants underwent emotion induction by listing things that made them sad, they consumed more M&Ms than those in a neutral control condition. In another study, when participants were told that they failed an easy cognitive task, which induced negative emotions, they were more likely to overeat at a subsequent buffet meal than those in a neutral control condition (Chao et al., 2012). Together, these studies suggest that a variety of negative emotions can increase both food intake and unhealthy dietary choices. On the other hand, others have found an opposite effect, whereby negative emotions lead to decreased desire for food (Arend et al., 2022; Cardi et al., 2015; Evers et al., 2018). For instance, Arend et al. (2022) found that when incidental emotions were induced via negative images, participants with BED reported an increase in desire to eat various foods, whereas healthy participants reported a decrease. Others, such as meta-analyses by Cardi et al. (2015) and Evers et al. (2018), found that although negative emotions increased food intake in those with BED and restrained eating, they had no effect in healthy participants. Overall, the relationship between negative emotions and eating behaviour in the general population is unclear.

Compared to the literature on negative emotions, studies on the influence of positive emotions on eating behaviour have produced more consistent results, particularly using food intake as an outcome (Cardi et al., 2015; Collins & Stafford, 2015; Evers et al., 2010). For instance, two separate meta-analyses found that positive emotion induction reliably increased caloric intake across samples of healthy participants, BED patients, and restrained eaters (Cardi et al., 2015; Evers et al., 2018).

Nevertheless, increased caloric intake due to positive emotions does not necessarily correspond to poor dietary choices. On the contrary, there is some evidence that positive emotions can encourage *healthier* choices (Garg et al., 2007; Lyman, 1982; White et al.,

2013). For instance, Garg et al. (2007) found that compared to a neutral condition, participants who read a happy story consumed significantly less of a hedonic food (M&Ms) and more of a healthy food (raisins). Similar effects have been found for other types of induced incidental positive emotions, including hopefulness, which was found to decrease preferences for unhealthy snacks relative to healthy ones (Winterich & Haws, 2011); and awe, which led to greater likelihood of choosing healthy over unhealthy products (Cao et al., 2020). Finally, in a meta-analysis, Cameron et al. (2015) positive emotion induction had no reliable effect on overall amount of caloric or food intake, but did have an effect on food choice, whereby positive emotions led to greater preferences for healthier foods.

However, despite the presented evidence that positive emotions can promote healthy dietary choices, other studies have found an opposite effect (Ashurst et al., 2018; Evers et al., 2013; Reichenberger et al., 2018). Evers et al. (2013) found that participants who watched films inducing positive emotions consumed more calories from unhealthy snacks than those who watched neutral films. Another study examined real-world eating behaviour, with results showing that positive emotions resulted in greater food consumption driven by taste rather than hunger (Reichenberger et al., 2018). Finally, Ashurst et al. (2018) found conflicting findings within their study, with real-world positive emotions increasing participants' likelihood of consuming sweets, but also decreasing likelihood of consuming pizza and fast food. Together, these studies suggest that positive emotions may lead to indulgence; however, their overall effect on the quality of dietary decisions is unclear, due to inconsistencies both between and within existing studies.

As well as yielding conflicting findings, many existing studies on the effects of emotions on eating behaviour did not examine whether these effects differed according to individual perceptions of healthiness and tastiness, instead testing the effects of emotions on overall food intake (Arend et al., 2022; Chao et al., 2012), desire for hedonic foods only

(Evers et al., 2013; Garg & Lerner, 2013), or decisions between pre-classified healthy or unhealthy foods (Cao et al., 2020; Winterich & Haws, 2011). As perceived tastiness and healthiness are key drivers of food choice (Dana et al., 2021), it is important to consider these individual perceptions for a more accurate picture of the effects of emotions on eating behaviour. Therefore, in Study 3 of the present thesis, we examined the effects of both positive and negative emotions, taking into account individual perceptions of the tastiness and healthiness of the food under consideration.

1.3.1 Incidental Emotion Regulation and Dietary Decision-Making

Both negative and positive emotions can be changed by emotion regulation, which may have subsequent effects on decision-making, including those in the dietary domain (Grecucci, 2014). Emotion regulation can be applied with the goal of either *upregulating* (i.e., increasing its intensity) or *downregulating* (i.e., decreasing its intensity) an emotion (Gross, 2001). People can also employ different cognitive strategies to regulate their emotions. Gross (2001, 2015b) illustrated how these strategies occur in the Process Model of Emotion Regulation, which describes emotions as processes that unfold over time in several stages, with different strategies able to intervene at each stage (see Figure 2).

According to the model, a person first selects a situation (e.g., choosing to watch a sad movie) and can modify it (e.g., asking a friend to watch with them). They then deploy their attention toward a particular aspect or aspects of the emotional stimulus. At this stage, people can use a strategy known as *distraction* to intervene, which involves redirecting attention, either visual or cognitive, away from the emotional aspects of the stimulus (McRae, 2016). For instance, rather than focusing on the sad content in the movie, the person may try to focus their attention on something neutral, such as their plans for the rest of the day. Next, in the cognitive change stage of the model, meanings are assigned to the attended aspects of the emotional stimulus. Here, one of the most widely studied strategies can be applied:

reappraisal, which involves reinterpreting the meaning of a stimulus in a way that changes its emotional impact (Gross, 2001, 2015b; McRae, 2016); for example, imagining that the sad situation in the movie might improve over time. In the final stage of the model, experiential (e.g., feeling sad), behavioural (e.g., withdrawing into one's seat), and physiological (e.g., crying) emotion response tendencies are generated, based on the preceding stages in the model. Another ER strategy can be employed at the response modulation stage, *expressive suppression*, which involves restraining these response tendencies using "brute force"; however, this is generally considered a maladaptive strategy, with frequent use carrying negative consequences for psychological and physical wellbeing (Appleton et al., 2013; Gross & John, 2003). Therefore, in this thesis, I focus on distraction and reappraisal, which are antecedent-focused rather than response-focused and have been associated with more positive short- and long-term outcomes (Gross & John, 2003).

Figure 2

The Process Model of Emotion Regulation

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Note. According to this model, emotions unfold based on situations, aspects, and meanings, which lead to the generation of emotional responses. Emotion regulation can be antecedent-focused, occurring at any of the following stages: a) Situation Selection, (b) Situation Modification, (c) Attentional Deployment, (d) Cognitive Change; or response-focused, occurring during (e) Response Modulation. The From "Emotion Regulation in Adulthood: Timing is Everything," by J. J. Gross, 2001, *Current Directions in Psychological Science*, *10*(6), 214-219. Copyright by Academic Press Limited.

There is evidence that the regulation of incidental negative emotions can influence subsequent decision-making (Grecucci, 2014). For instance, previous studies have found that reappraisal of incidental negative emotions reduced risky decisions (Morawetz et al., 2020a) and increase willingness to accept unfair offers in social decision-making tasks (van't Wout et al., 2010). The mechanisms of these effects are not well-understood, but two potential processes have been suggested: changes in emotional experience (e.g., using reappraisal decreases negative emotions, which is the reason for changes in decision-making), and "spillover" cognitive control effects from the ER strategies (Grecucci, 2014). Few experimental studies have been conducted on the effect of incidental emotion regulation on dietary decisions. Several correlational studies have found broad links between emotion regulation tendencies and eating behaviour, with results showing that emotion dysregulation (i.e., general problems with ER) was associated with food addiction (Pivarunas & Conner, 2015) and the tendency to engage in emotional eating (Braden et al., 2018).

Most existing experimental studies on the effect of incidental emotion regulation on eating behaviour have focused on reappraisal and suppression being used to downregulate negative emotions, and have found mixed results (Evers et al., 2010; Morawetz et al., 2020b; Taut et al., 2012). Some studies have shown a beneficial effect of reappraisal on dietary self-control. Taut et al. (2012) gave participants a choice of whether to eat after negative emotion induction during which they either reappraised, suppressed, or experienced their emotional response. Out of participants who chose to eat, the results showed no differences between the three groups in food intake. However, participants who used reappraisal were less likely to begin eating in the first place than those in the other two conditions, which suggests that reappraisal may improve some aspects of dietary self-control. Further, Morawetz et al. (2020b) examined dietary preferences instead of food intake, and found that when participants downregulated incidental negative emotions using reappraisal, they showed a

selective increase in preferences for foods that they considered to be tasty and healthy (Morawetz et al., 2020b). However, another study found no benefits of reappraisal on eating behaviour: when incidental negative emotions were induced, using reappraisal did not change subsequent food intake, whereas suppression had a detrimental effect, leading to increased intake of unhealthy comfort foods (Evers et al., 2010). Therefore, the potential of both reappraisal and other strategies to improve dietary decisions is unclear. In Study 3 of this thesis, we aimed to add to the limited body of existing evidence on how reappraisal influences dietary choices, taking into account taste and health perceptions.

Distraction may be another useful emotion regulation strategy for improving dietary decision-making. This strategy can be employed at the early stages of the emotion generation process (Gross et al., 1998), within the first second of an emotional stimulus appearing (Schubert et al., 2020). Further, there is evidence that although reappraisal leads to greater wellbeing with repeated use, distraction is more effective at decreasing emotion intensity in the short-term, particularly for high-intensity emotions (Shafir et al., 2015). Therefore, distraction as an emotion regulation strategy may be an effective strategy for improving dietary decisions. However, this has not been directly tested. Previous studies around distraction and eating behaviour have examined the effects of performing other activities (e.g., watching television) while eating (i.e., "mindless eating"), and have generally found that distraction *increases* the intake of unhealthy foods (Long et al., 2011; Ogden et al., 2013). However, in these studies, distraction was not used as an emotion regulation strategy, and occurred as a passive process (i.e., participants were given an activity unrelated to eating) rather than active (i.e., intentionally trying to think about something unrelated). Active distraction has been suggested to be more effective at regulating emotions than passive (Webb et al., 2012), as the latter does not involve intentional cognitive control processes. Therefore, the studies showing detrimental effects of distraction on eating behaviour do not

undermine the possibility that distraction as an ER strategy could improve dietary decision-making, which we investigated in Study 3 of this thesis.

Although all the studies on incidental ER and eating behaviour reviewed thus far examined the regulation of negative emotions, positive emotions can also be downregulated by both reappraisal and distraction (Gross et al., 1998; Kalokerinos et al., 2015; Li et al., 2020), and upregulated by reappraisal (Kalokerinos et al., 2015). Given the relationship between positive emotional experience and eating behaviour (Cardi et al., 2015; Evers et al., 2013), it is possible that the up- and down-regulation of positive emotions leads to changes in dietary decisions. However, there are no existing experimental studies that have directly tested this theory. In Study 3 of this thesis, we aimed to fill this gap by testing whether the regulation of positive emotions has subsequent effects on dietary decisions.

1.4 The Present Thesis

The broad aim of this thesis is to investigate the cognitive and neural mechanisms of dietary decision-making and ways in which these mechanisms can be changed. In the literature review above, I have discussed previous findings in three main areas, which correspond to the studies that I will present in Chapters 2, 3, and 4 of this thesis: (1) the neural representation of attributes in dietary decisions; (2) the potential of graphic HWLs to reduce consumption of SSBs; and (3) the impact of incidental emotions and emotion regulation on dietary decisions. In the following sections, I will summarise the main findings from existing studies in each of these areas that are directly relevant, identify the questions left unanswered, and introduce the studies conducted to address these questions.

1.4.1 How and When are Health and Taste Attributes Represented in the Brain?

Chapter 2 (Study 1) focused on neural representations of taste and health attributes during dietary decisions. Previous studies have identified brain regions that may be involved in integrating the taste and health attributes of foods into decisions. Behavioural studies have

also suggested that taste information is processed more quickly than health information studies (Lim et al., 2018; Sullivan et al., 2015). However, an important open question is the timing with which these attributes are processed in the brain and integrated into decisions. To obtain estimates of attribute processing speed, it may be useful to examine neural representations of the attributes. Although some studies have shown that ERP components related to early attention allocation and arousal (e.g., N1, LPP) reflected measures of healthiness (e.g., caloric content; Meule et al., 2013), this may not be as important for food choices as *perceived* healthiness. Further, splitting foods into binary categories of low- and high-calorie does not accurately reflect continuous variation in both perceived and "objective" healthiness. A technique that may do this is multivariate pattern analysis (MVPA), which involves training a classifier to make predictions about a behavioural variable from brain activity (Bode et al., 2019). When applied to EEG data, MVPA allows the entire EEG signal to be utilised rather than only a subset of electrodes, unlike traditional univariate ERP analyses (Bode et al., 2019). Support vector regression (SVR) is a form of MVPA that allows the prediction or "reading out" of continuous values of a variable based on neural activity (Bode et al., 2022). In a given time window, if prediction occurs with above-chance accuracy, neural representations of the attribute are assumed to be present in that time window. Previous studies have used SVR to predict the subjective relevance of objects (Turner et al., 2017), personality traits (Jach et al., 2020), and emotion regulation success (Schubert et al., 2020). SVR may therefore be appropriate for examining the timing of fine-grained neural representations of tastiness and healthiness, with greater nuance than previous studies that treated these attributes as binary (e.g., Meule et al., 2013).

Chapter 2 (Study 1) used two experiments to examine neural representations of perceived fine-grained taste and health attributes, during the first second of processing visual food cues. In Experiment 1, participants viewed images of foods that varied widely in

tastiness and healthiness while EEG was recorded, and rated their perceptions of each image. We then used SVR to predict the taste and health ratings from neural activity in the first second of each food stimulus appearing. In Experiment 2, we aimed to determine whether decoding was possible during dietary decision-making, rather than simply rating attributes. To address this, we re-analysed data from a previous study (Rosenblatt et al., 2018b). The methodology of this study was similar to that of Experiment 1, however, instead of giving health and taste ratings, participants made consumption decisions (i.e., indicated how much they wanted to consume each food) while EEG was recorded. SVR was then used to determine whether previously-given health and taste ratings could be decoded based on neural activity recorded during these consumption decisions. We hypothesised that prediction of taste and health separately would be possible in both experiments. In Experiment 2, we further hypothesised that decoding of both health and taste would be possible at an earlier stage than decoding of the consumption decisions, which could be taken as evidence that both attributes were processed, then integrated into decisions. These experiments will help to determine whether attributes of both taste *and* health are present during the early stages of dietary decision-making, and could form a basis for further studies examining how neural representations of tastiness and healthiness can be changed.

1.4.2 Can Health Warning Labels Change Preferences for Sugar-Sweetened Beverages?

Chapter 3 (Study 2) examined the potential of HWLs to improve dietary decisions. HWLs may be particularly useful for discouraging the consumption of SSBs, due to their high caloric but low nutritional value. The studies reviewed showed mixed results, with some suggesting that HWLs reduce SSB consumption, but others showing no effect. Therefore, more research is needed on the effects of HWLs on SSB consumption, and on factors that may boost such effects. A suggested factor is product specificity, that is, whether HWLs involve warnings that refer specifically to SSBs or to a more general unhealthy diet.

However, whether specific and general labels differ in their ability to prompt behaviour change is an entirely open question. Further, most existing studies examined the ability of HWLs to reduce consumption of SSBs or soft drinks overall. This approach does not consider the fact that SSBs, while mostly high in sugar and low in nutritional value, still vary continuously in healthiness. For example, a drink containing natural fruit may be healthier than Coca Cola, as it has some nutritional value, but less healthy than water, due to its high sugar content. Therefore, the possibility that HWLs could not only decrease absolute SSB consumption but also nudge people toward healthier SSBs is yet to be considered. Finally, little is known about the neural mechanisms that underlie the cognitive processing of SSBs during consumption decisions. One study found evidence that when graphic HWLs were displayed immediately before snack food consumption decisions, neural indices of health and taste attributes changed (Rosenblatt et al., 2018b). However, it is unclear whether HWLs have similar effects on the processing of SSBs.

Chapter 3 (Study 2) therefore had three main aims. The primary aim was to investigate the effectiveness of general and specific HWLs at reducing SSB consumption and promoting healthier choices. Second, we aimed to determine whether SSB-specific HWLs are more effective at reducing unhealthy drink consumption than more general warnings. The final aim was to investigate the neural mechanisms of SSB cue processing, and whether HWLs could change these mechanisms. We did this using a three-stage experimental task with EEG recorded. First, participants rated a set of SSBs on tastiness and healthiness. In the second stage, they were allocated to view HWLs that were either general, SSB-specific, or scrambled (control condition). Finally, they viewed the drinks again and indicated their current willingness to consume (WTC) them. We hypothesised that participants in the two HWL conditions would show lower desire for SSBs considered unhealthy than participants in the control condition. Given the limited existing literature on HWLs involving general versus

product-specific warnings, we did not form specific hypotheses around these types of HWLs. Similarly, we addressed the third aim using an exploratory approach. We first used within-subject analyses to compare the N1, P3, and LPP components for drinks considered to be high and low on healthiness and tastiness, and then used between-subject analyses to test whether these components differed between participants who viewed HWLs and those who did not. The results of this study will contribute toward the limited existing literature on HWLs for decreasing sugary drink consumption, potentially reconciling inconsistencies in the existing literature by furthering current understanding of what kind of labels are most effective.

1.4.3 How do Incidental Emotions and Emotion Regulation Affect Dietary Decisions?

Finally, Chapter 4 (Study 3) focused on the effect of incidental emotions and their regulation on dietary decision-making. Previous studies have found that negative emotions consistently increase food intake in clinical populations and those with maladaptive eating patterns, however, findings from the general population have been mixed. Positive emotions have also been found to increase food intake. However, for both positive and negative emotions, existing studies have primarily focused on food intake, rather than dietary decisions. Therefore, further investigation is needed into how negative and positive emotions affect the quality of dietary intake, not only the quantity. Moreover, although several studies have examined the effects of reappraising incidental negative emotions on food intake and dietary decisions, their results have been inconsistent. Two other relevant, open questions are: (1) whether ER strategies other than reappraisal, such as distraction, can change dietary decisions when used to downregulate incidental emotions, and (2) whether the regulation of positive emotions changes dietary decisions.

Therefore, the broad aim of Chapter 4 (Study 3) was to investigate the effects of emotions and emotion regulation on dietary decisions, in two online experiments. In

Experiment 1, we focused on negative emotions and their downregulation via reappraisal and distraction, in two separate samples. First, participants rated a set of food images on healthiness and tastiness. They were then presented with images that were either neutral or intended to induce negative emotions. Before each image, a cue appeared with instructions to either passively view the upcoming image or downregulate their emotions. Then, a food image appeared and participants indicated their WTC that food. The hypotheses were tested separately for each ER sample. We hypothesised that WTC would be higher after viewing negative images than neutral ones in both samples, with a stronger effect for foods high on perceived tastiness and low on perceived healthiness. We further hypothesised that compared to passive viewing of negative images, emotion regulation would result in decreased WTC. Exploratory analyses were conducted to determine whether these effects differed according to perceived taste and health.

In Experiment 2, we examined the effects of positive emotional experience and regulation, using the same paradigm as in Experiment 1, but with positive instead of negative images. The downregulation of emotions via reappraisal and distraction was again examined in separate samples, with an additional third sample in which participants were instructed to intentionally increase (instead of decreasing) their emotions. For all three samples, we hypothesised that positive emotional experience would increase WTC, compared to neutral. For the reappraisal and distraction samples, we hypothesised that intentionally decreasing positive emotions would decrease overall WTC, compared to passive viewing of images. Finally, in line with this reasoning, we hypothesised that intentionally increasing positive emotions would lead to higher WTC, beyond that reported after passively experiencing them. Due to the limited available literature and mixed findings of previous studies, we did not form specific hypotheses about whether these effects differed according to perceived taste and health. Exploratory analyses were performed to test for these potential interaction effects.

The results of Study 3 will help to fill an important gap in the existing literature around the effects of emotions on dietary decisions by examining both ends of the spectrum of emotional valence, as well as the effects of regulating these emotions.

Chapter 2: Study 1

The following empirical chapter presents the results of two experiments, investigating whether representations of taste and health perceptions can be decoded from neural activity during dietary decisions. This study was published in *Neuropsychologia* and is presented in its published format.

2.1 Aims

The aim of this study was to examine neural representations of two important food attributes, tastiness and healthiness, during the early stages (i.e., first second) of viewing visual food cues and making dietary decisions. In Experiment 1, participants completed a food rating task, giving continuous ratings of how tasty and healthy they perceived various foods to be while EEG was recorded, in separate trials (i.e., only one of taste or health was given per trial). We then applied MVPA for taste and health trials separately. This involved training a classifier to estimate a regression model that predicted the respective rating from distributed patterns of neural activity during the first second after the food cue appeared. We hypothesised that the regression model would be able to predict both attribute ratings above chance level.

In Experiment 2, the analysis approach was very similar. However, instead of neural activity recorded while participants gave the taste and health ratings themselves, we used activity recorded while participants made consumption decisions (i.e., indicated how much they wanted to consume each food). The values being predicted were health and taste ratings that had been given in an earlier experimental stage. Therefore, we aimed to determine whether taste and health representations were still present in the brain when participants were making a dietary decision, but not explicitly considering or processing tastiness and healthiness. We further performed an additional analysis, testing whether the neural activity could be used to predict the consumption ratings (decision strength). As in Experiment 1, we

hypothesised that both taste and health would be decodable during the first second of a consumption decision. To gain further insight into the mechanisms of dietary decisions, we further hypothesised that decision strength would be decodable at a later stage than taste and health, which may reflect both attributes being processed and considered, then integrated into the overall decision.

2.2 Manuscript

Decoding explicit and implicit representations of health and taste attributes of foods in the human brain

Elektra Schubert[1], Daniel Rosenblatt[1], Djamila Eliby[1], Yoshihisa Kashima[1], Hinze Hogendoorn[1], Stefan Bode[1*]

[1] Melbourne School of Psychological Sciences, The University of Melbourne, Australia

* Corresponding author: Stefan Bode, Melbourne School of Psychological Sciences, The University of Melbourne, Parkville, VIC, 3010, Australia; email: sbode@unimelb.edu.au

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Abstract

Obesity has become a significant problem word-wide and is strongly linked to poor food choices. Even in healthy individuals, taste perceptions often drive dietary decisions more strongly than healthiness. This study tested whether health and taste representations can be directly decoded from brain activity, both when explicitly considered, and when implicitly processed for decision-making. We used multivariate support vector regression for event-related potentials (as measured by the electroencephalogram) to estimate a regression model predicting ratings of tastiness and healthiness for each participant, based on their neural activity occurring in the first second of food cue processing. In Experiment 1, 37 healthy participants viewed images of various foods and explicitly rated their tastiness and healthiness. In Experiment 2, 89 healthy participants completed a similar rating task, followed by an additional experimental phase, in which they indicated their desire to consume snack foods with no explicit instruction to consider tastiness or healthiness. In Experiment 1 both attributes could be decoded, with taste information being available earlier than health. In Experiment 2, both dimensions were also decodable, and their significant decoding preceded the decoding of decisions (i.e., desire to consume the food). However, in Experiment 2, health representations were decodable earlier than taste representations. These results suggest that health information is activated in the brain during the early stages of dietary decisions, which is promising for designing obesity interventions aimed at quickly activating health awareness.

Keywords: electroencephalography; dietary decision-making; taste; health; multivariate pattern analysis

Obesity is a global epidemic, and excess body weight is associated with increased risk of chronic diseases, estimated to cause nearly three million annual deaths worldwide (Lauby-Secretan et al., 2016; Stevens et al., 2012). While obesity is a multifaceted issue, there is a strong link to poor food choices leading to a diet high in sugar and fat (Fock & Khoo, 2013). During dietary decisions, although people tend to consider both tastiness and healthiness of foods (Sullivan et al., 2015; Hare et al., 2009), these attributes are often in conflict, and foods considered unhealthy tend to have higher perceived tastiness (Raghunathan et al., 2006; Mai & Hoffmann, 2015). This is problematic because taste attributes tend to drive dietary decisions more strongly (Tepper & Trail, 1998; Pollard et al., 1998; Markovina et al., 2015). To inform the development of effective interventions against obesity, it is therefore important to understand how both perceptions are processed in the brain.

Compared to health, taste is a less abstract, lower-level representation, thought to be processed and integrated into decisions quickly and automatically (Sullivan et al., 2015; Liberman & Trope, 2008; Motoki et al., 2018). Supporting this, several studies have used electroencephalography (EEG) to suggest that the tastiness of foods is reflected by event-related potential (ERP) components occurring during the first second of viewing a food stimulus (Rosenblatt et al., 2018a; Schwab et al., 2017; Sarlo et al., 2013; Schubert et al., 2021). In particular, the late positive potential (LPP), occurring approximately 450-1000 ms after the presentation of a stimulus and previously implicated in emotional responding and arousal (Schupp et al., 2000; Pastor et al., 2008; Gable & Harmon-Jones, 2010), is thought to reflect the caloric or appetitive value of stimuli (Rosenblatt et al., 2018a; Schwab et al., 2017; Schubert et al., 2021). Images of high-calorie foods, including meat dishes and sweets, have been shown to elicit larger LPP amplitudes than vegetable images (Schwab et al., 2017). There is also evidence that the LPP reflects perceived tastiness, with higher amplitudes found in response to images of sugar-sweetened beverages perceived to be tasty compared to non-

tasty (Schubert et al., 2021). This study also found differences between these two categories in the N1 component, which occurs approximately 100 ms after the onset of a stimulus and has been implicated in early attentional processing (Schubert et al., 2021; Carbine et al., 2018).

These studies suggest that when people view food cues, taste perceptions may be activated quickly and automatically, during the first second of processing. However, it is unclear whether this also applies to health perceptions. There is evidence that perceptions of health attributes are activated and represented in the ventromedial prefrontal cortex during dietary decisions (Cosme et al., 2020); however, it is unclear whether this occurs as quickly as the activation of taste attributes. Preliminary evidence from a study using computer mouse trajectory tracking suggests that health attributes are processed and integrated into dietary decisions approximately 195 ms later than taste attributes (Sullivan et al., 2015). It is hence possible that neural representations of healthiness are formed later than taste representations, which may contribute toward people's tendency to choose to eat tasty but unhealthy foods (Tepper & Trail, 1998; Pollard et al., 1998; Markovina et al., 2015). However, no neuroimaging studies to date have used a suitable temporal scale to directly investigate the activation of neural representations of taste and health, and how these representations unfold over time.

The Present Study

Previous ERP studies (Schwab et al., 2017; Schubert et al., 2021) hint at potential processing differences between high- and low-calorie foods in time. Our study, however, went beyond that and investigated whether and when taste and health attributes of foods were neurally represented in brain activity on a trial-by-trial basis. For this, we used a novel multivariate regression approach, which involves training a classifier to predict ratings for healthiness and tastiness based on spatially distributed patterns of neural activity in small

time windows, and then testing its performance on new data. Because it utilises the entire distributed EEG signal (Bode et al., 2019), it becomes possible to "read out" cognitive information, even abstract information such as semantic attributes of objects (Bode et al., 2014) and subtle changes in emotional states (Schubert et al., 2020), which has not been achievable in the past. The present study is the first to apply multivariate regression to directly predict subjective taste and health perceptions from neural activity.

In the present study, we aimed to determine whether taste and health perceptions are decodable in the brain during the early stages of food cue processing. In Experiment 1, we examined representations of these attributes during explicit evaluation of tastiness and healthiness. This involved predicting both tastiness and healthiness ratings based on neural patterns recorded immediately after presenting a food image, but before a response could be prepared. In Experiment 2, we used a similar approach to examine health and taste representations, with the inclusion of an additional experimental phase in which individuals made consumption decisions about food items, but were not explicitly told to consider tastiness and healthiness at the beginning of the phase. For this second experiment, we reanalysed data from a previous study (Rosenblatt et al., 2018a). We hypothesised that health and taste attributes would be decodable from brain activity in both studies. We further hypothesised that evidence for both health and taste decoding would be found in Experiment 2 before the consumption decision outcome was represented, which could be interpreted as evidence that participants integrated both sources of information to inform their decisions.

Experiment 1

2.1 Method

2.1.1 Participants. The sample comprised 39 participants, all right-handed, fluent in written and spoken English, having normal or corrected-to-normal vision, and no dietary

restrictions or eating disorder history. As there is currently no literature on calculating statistical power for multivariate EEG analyses, the sample size was based on previous studies using EEG to examine neural responses to food cues (e.g., Meule et al., 2013; Sarlo et al., 2013). Participants were asked to fast for four hours before the experiment to control for hunger levels. Two participants were excluded because their results fluctuated more than ±3 SD between analysis time windows throughout the entire trial, indicating a failure to fit the regression model (see below). In the final sample, there were 37 participants (age range = 18 to 36 years; *M* = 24.08 years, *SD* = 4.74; 29 females, 8 males). Before the task, participants gave written informed consent, and afterwards they were debriefed and given a voucher payment of AUD$20. The experiment was approved by the Human Research Ethics Committee (ID1955772) of the University of Melbourne and conducted in accordance with the Declaration of Helsinki.

2.1.2 Stimuli. Stimuli were 174 images of foods from the Food-Pics database (450 x 338 pixels), selected based on normative palatability ratings and food categorisations from omnivorous participants (Blechert et al., 2019). The stimuli represented a variety of food types (fruit, vegetables, chocolate, fish, meat, nuts, snacks/meals) and a wide range of subjective palatability.

2.1.3 Questionnaires. Participants completed several questionnaires before the experiment, including demographic information about age, gender, level of education, height, and weight. They then rated their hunger level on a scale of 1 (not at all) to 9 (extremely hungry) and indicated how many hours had passed since their last consumed snack and meal. Finally, they completed several questionnaires about eating behaviour (see Supplementary Material 1).

2.1.4 Procedure. Participants completed the demographic questionnaires before beginning the main task. The main experimental task was presented using Psychtoolbox

(Brainard, 1997) interfacing Matlab R2019b. Each trial began with a fixation cross (1.5 s), followed by a food image (2 s; Figure 1). Then, while the food image remained onscreen, a question appeared underneath – either "How much do you enjoy the taste of this food?" or "How healthy do you consider this food to be?". Participants answered using a continuous sliding scale, ranging from "Not at all" to "Very much". The underlying values of 0 to 100 were not visible to participants. The ends of the scale were randomly reversed on half of the trials to prevent motor preparation in the initial image presentation period (Rosenblatt et al., 2018a). Before starting the experiment, participants were informed that the ends of the scale would switch between trials and told to pay close attention to the scale to prevent selection errors. Participants had 10 seconds to answer by moving the slider to the desired position and clicking the mouse. If no response was given after 10 seconds, the current position of the slider was recorded as a response. Each image was shown twice, once with each question. The experiment consisted of 348 trials, split into twelve experimental blocks. In each block, only one of the questions was asked, alternating between blocks. The question displayed in the first block was randomised across participants. The whole task took approximately one hour, including EEG setup and pack-up.

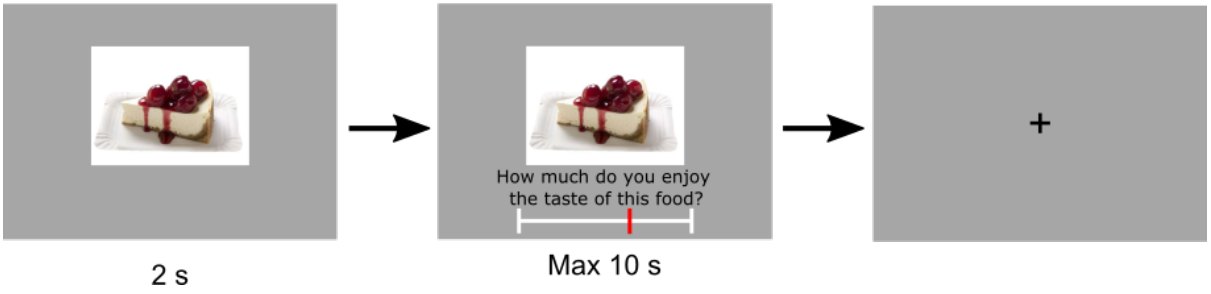

Figure 1. Trial structure for Experiment 1. Participants viewed each image for 2 s before a continuous slider scale appeared, asking them to rate either taste or health, depending on the current block. Health and taste rating blocks were alternated, and all 174 images were rated on each attribute once.

2.1.5 EEG Recording & Preprocessing. Electrophysiological activity was recorded using a 64-channel BioSemi Active II system at a sample rate of 512 Hz, and recording bandwidth of DC-102 Hz. Ag/AgC1 electrodes were attached to a fabric cap according to the International 10-20 system, with additional electrodes beside and below the left eye (horizontal and vertical electrooculogram), and above the left and right mastoids (reference electrodes). Electrode offsets were kept within ±50 μV. Using EEGLab v14.1.2 (Delorme & Makeig, 2004), the data were firstly re-referenced to the average of the mastoids, then high-pass (0.1 Hz) and low-pass (30 Hz) filtered (EEGLab FIR Filter New, default settings). They were segmented into epochs beginning 100 ms before an image was presented (used as the baseline), and ending 1,200 ms after image onset, to capture the first period of visual and semantic processing while avoiding time periods that already contained activity related to motor preparation. Epochs containing muscle and skin potential artefacts were identified via visual inspection and removed. Excessively noisy channels were removed and interpolated using spherical spline interpolation (this occurred for 23 participants; average 2.56 channels interpolated per participant). An independent components analysis (ICA) as implemented in EEGlab was used to identify and remove eye movements, saccades, and blinks. If amplitudes at any channel exceeded ±150 μV, the epochs were excluded from analyses.

2.1.6 Decoding Analysis. For the multivariate pattern analyses (MVPA), linear support vector regression (SVR) as implemented in the Decision Decoding Toolbox v1.0.5 (DDTBOX; Bode et al., 2019) was used to examine the association between brain activity and continuous taste or health ratings for each trial. For each participant, two sets of analyses were performed – one using taste ratings and brain activity recorded after image presentation in taste blocks, and the other using health ratings and brain activity recorded after image presentation in health blocks. A "sliding window" 20 ms wide moved through each epoch of the EEG data in overlapping 10 ms steps. Within each window, all ten data points from the

64 EEG channels were transformed into vectors of spatial brain activity patterns (10 x 64 = 640 features in total) associated with each trial. These vectors were then used to predict the respective ratings (note that this means that data from all channels is always equally represented in the pattern). In this process, a linear SVR model (standard cost parameter C = 0.1, interfacing LIMSVM; Chang & Lin, 2011) was trained on a randomly selected 90% of the data, then tested on the remaining 10%. This process was repeated independently using a 10-fold cross-validation procedure, until all data sets had been used as test data once while training on all other sets (i.e., each time, a new model was trained and tested). The cross-validation process itself was then repeated ten times with newly drawn random data, to obtain a conservative estimate of decoding performance based on average classifier performance from all 10x10 iterations, circumventing drawing biases (for an illustration of the procedure, see Figure 2). In other words, the final output for each analysis time window is an average correlation coefficient calculated across all independent ten iterations of the ten-fold cross-validation and Fisher-Z-transformed (as is common practice in multivariate pattern analysis studies; Bode et al., 2019), which represents the estimate of the decoding accuracy for the respective analysis time window in this participant. Results for each analysis time window are therefore also independently obtained from any other analysis time windows. Note that our SVR approach does not include a feature-selection step (i.e. selecting the most predictive channels only) as the goal is not to maximise the decoding accuracy (i.e. achieve high absolute correlation values), but to provide an unbiased test for whether or not the neural pattern as a whole is predictive of the variable of interest (c.f., Bode et al., 2019).

Each analysis time window produced an average Fisher-Z-transformed correlation coefficient between predicted and true rating scores. To generate an empirical chance distribution for statistical testing, this procedure was repeated for each participant separately with the same data but with the ratings randomly shuffled across trials (c.f., Bode et al., 2019;

Schubert et al., 2020). This means, each participant contributes two time-courses of prediction results (one real decoding, one shuffled-labels decoding), and statistical tests are performed for each analysis time window separately to test for significant differences between the two distributions across participants. Finally, corrections for multiple comparisons were made using cluster-based permutation tests based on the cluster mass statistic, which takes advantage of the statistical non-independence of the adjacent analysis time windows. Note however, that these corrections might be overly conservative given that for each time window, an independent, empirical chance distribution was generated for testing. We therefore report both corrected and uncorrected results.

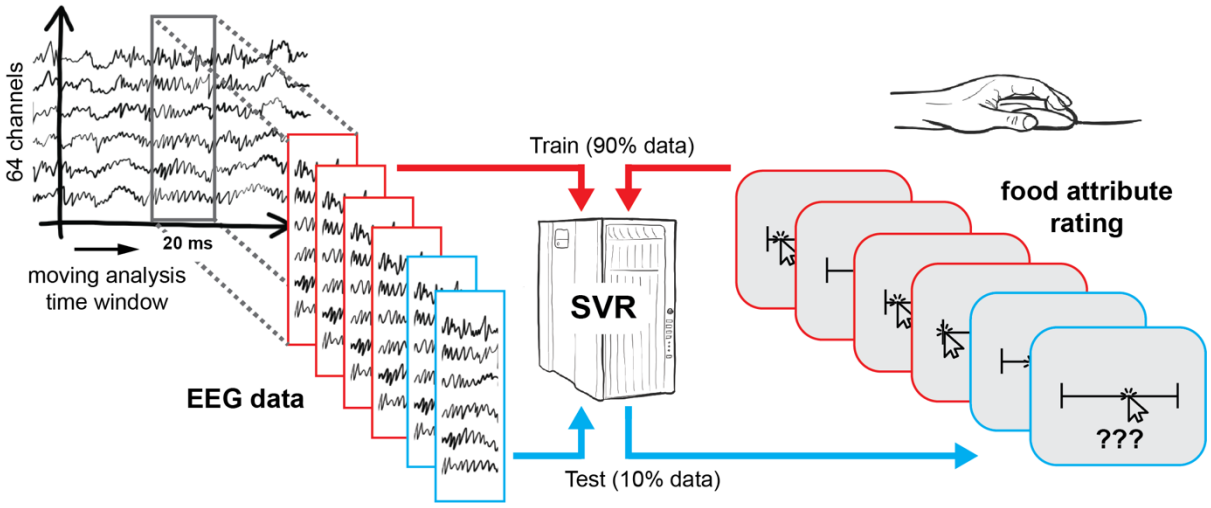

Figure 2. Schematic illustration of the SVR approach. Analyses are conducted in each participant separately. For each analysis time window (20 ms width, moved in non-overlapping steps), patterns of EEG amplitude data from all channels are extracted. A SVR model is trained on a random selection of data from 90% of the trials and used to predict the respective food attribute ratings (i.e., health or taste) from the left-out 10% of test data. This procedure is independently repeated until each 10%-set of data has been used for testing once; and the entire 10-fold cross-validation procedure is repeated again ten times. The

average Fisher-Z-standardised correlation coefficient from all independent 10x10 iterations serves as the estimate for the individual's decoding accuracy.

2.2 Results

Mean responses were 65.27 (*SE* = 4.64) for taste and 47.66 (*SE* = 5.65) for health. As expected, the correlation between taste and health (Pearson's *r*) varied substantially between participants, ranging from -.15 to .87 (*mean r* = .10, *SD* = .33). Overall, there was a significant correlation between average taste and health ratings, $r(35) = .33$, $p = .049$.

Taste ratings could be predicted significantly above chance in several time windows after image onset, starting at 530 ms (see Figure 3A; note that the size of peak correlations between predicted and true labels are due to the normalisation step and comparable to those found in previous studies using an SVR, e.g., Bode et al., 2014; Schubert et al., 2020). Above chance prediction was also possible for health ratings, starting slightly later at 640 ms after image onset (see Figure 3B). Figure 3 further reports all uncorrected significant time windows. For test statistics at each timepoint, see Supplementary Table S3.

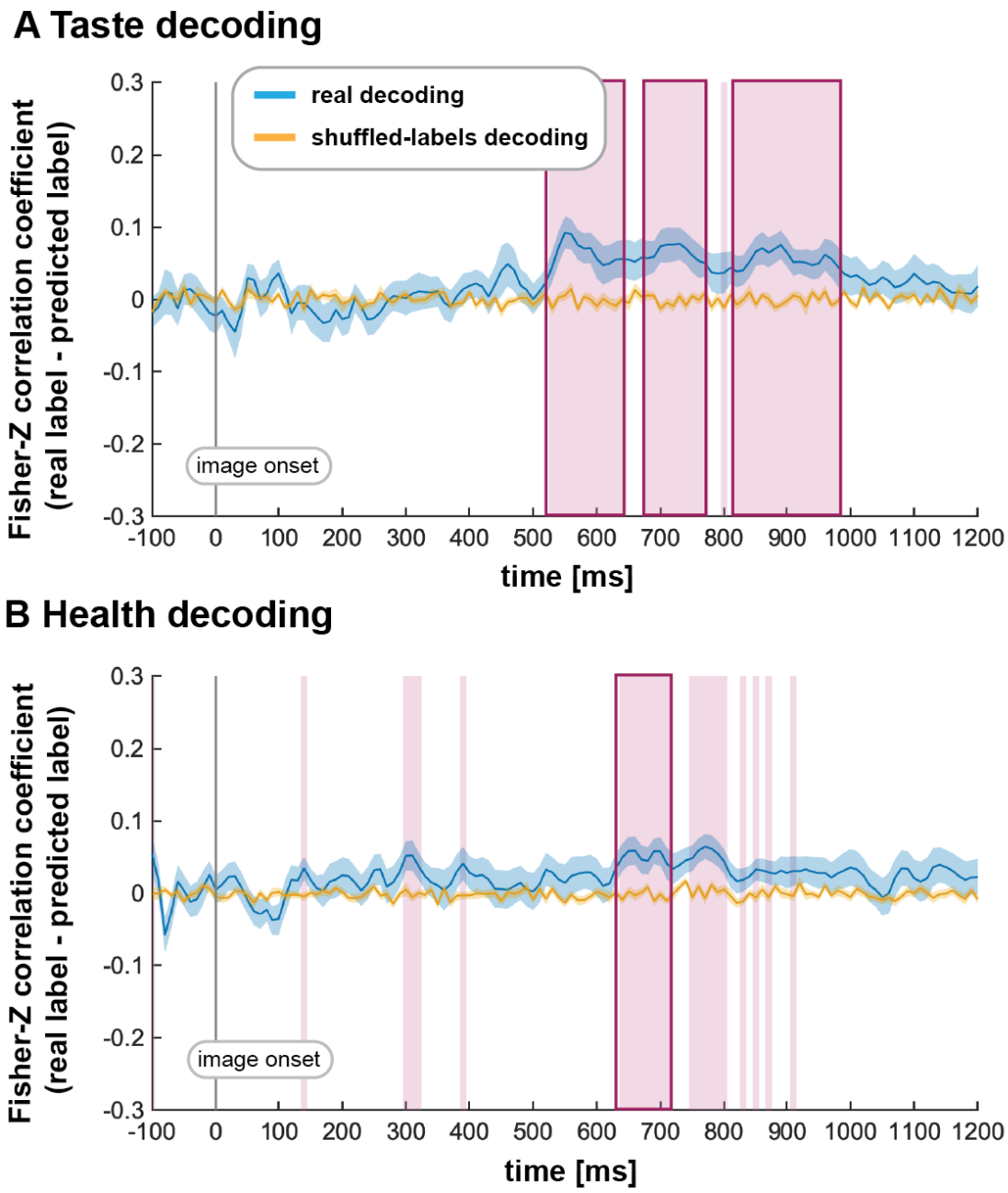

Figure 3. Decoding results for A) taste and B) health ratings. Blue lines represent Fisher-transformed correlation coefficients between predicted and true labels (taste and health ratings), while yellow lines represent decoding results based on shuffled labels (empirical chance distribution). Pink vertical bars highlight time points at which the decoding results significantly differed from the shuffled decoding results ($p < .05$); bolded pink bars represent time windows that remained significant after corrections for multiple comparisons.

Experiment 2

The results from Experiment 1 show that both taste and health attributes could be decoded from brain activity when participants were explicitly instructed to consider them. In Experiment 2, we examined whether such representations were detectable when participants instead made decisions about how much they wanted to consume foods, without being prompted to consider either attribute directly before making these decisions. For this, we reanalysed a large data set recorded during the first stage of a previous study in which participants made exactly these decisions (Rosenblatt et al., 2018a).

3.1 Method

3.1.1 Participants. Ninety-six participants were recruited, all right-handed and fluent in English, and free from any history of eating disorders, or health, religious, or ethical circumstances that prevented them from consuming particular snack foods. Participants were asked to fast for four hours before the experiment to control for hunger levels, and were naïve to the purpose of the study. Three participants were removed due to technical problems with data recording, and a further four were removed post hoc due to excessive artifacts in their EEG data. The final sample comprised 89 participants (62 female, 27 male), aged 18 to 50 years (M = 22.56, SD = 4.78). For the analysis of taste and health, only participants who demonstrated sufficient variability in the relevant outcome variable (taste or health rating SD > 0.7) could be included to achieve a successful regression model fit. As explained below, this experiment assessed ratings on a fixed four-point scale rather than in a continuous fashion as in Experiment 1, which naturally reduced the variability of responses and therefore the number of usable datasets. This selection step resulted in a sample of 55 participants for the taste analysis (39 female, 16 male; M_{age} = 22.55 years, SD = 4.26) and 85 participants for the health analysis (61 female, 24 male; M_{age} = 22.54 years, SD = 4.87). Note that using even stricter variance criteria (e.g., SD > 0.8) further reduced the number of data sets and was

therefore not included here. Participants gave written informed consent before commencing the task, and were debriefed afterwards and compensated with payment of AUD$20. The experiment was approved by the Human Research Ethics Committee (ID 1443258) of the University of Melbourne and conducted in accordance with the Declaration of Helsinki.

3.1.2 Stimuli. Stimuli were 100 colour images (500 x 500 pixels) of snack foods, including nuts, vegetables, fruits, chips, and sweets, selected through another pre-study where a separate sample rated 492 foods on their tastiness, healthiness, and familiarity (see Rosenblatt et al., 2018a). 100 food items were then selected based on the average health and taste ratings for the 492 food images, covering the full spectrum of healthiness and tastiness. Note that this set of snack foods differed from the foods in Experiment 1. The original purpose of the study was to investigate the effect of health warning labels (which were introduced in a second part of this study that was not relevant here) on changes in consumption decisions.

3.1.3 Questionnaires. Participants completed a questionnaire recording demographic information, as well as information on smoking status, dieting status, and food preferences. They also completed a series of questionnaires measuring eating behaviour (see Supplementary Material 2). For further information and full reporting of these questionnaire results, see Rosenblatt et al. (2018a).

3.1.4 Procedure. Before the experiment, participants rated their hunger levels (1 = not at all hungry; 8 = extremely hungry) and recorded the number of hours since their last meal. They then completed a computer-based task during which EEG was recorded, and of which only the first two task stages are relevant here (see Rosenblatt et al., 2018a).

In the first stage, participants rated each item on healthiness and tastiness. Each trial began with a fixation point (2 s to 6 s), followed by a food image (3 s). They then had three seconds to respond to one of two possible questions: “Do you like the taste of this food?” or

"Do you think this food is healthy?". Responses were given on a four point scale (1 = Strong No, 2 = Weak No, 3 = Weak Yes, 4 = Strong Yes) by pressing a button on the computer keyboard, with assignment of keys randomised trial-by-trial (note that this differs from Experiment 1). Each food image appeared twice, such that both health and taste ratings were obtained for each image, resulting in 200 trials in total, distributed over four blocks of 50 trials. These ratings were used to categorise foods into one of five groups, specific to each participant: Healthy-Tasty, Healthy-Not Tasty, Unhealthy-Tasty, Unhealthy-Not Tasty, and Undefined. For more information, including mean number of items in each group per participant, see Rosenblatt et al. (2018a).

Participants then completed the decision stage, which consisted of 50 trials in which half of the food images from each category were presented (the other half was reserved for a second decision stage, after the exposure of health warning messages, that is not relevant here). This ensured that there was a relatively large amount of variability in health and taste ratings for each participant. On each trial, a fixation point was presented (2 s to 6 s), followed by a food image (3 s; see Figure 4). The question "Would you like to eat this food at the end of the experiment?" then appeared. Responses were made on a continuous scale ranging from "Strong No" to "Strong Yes" (midpoint not selectable), using a mouse. The underlying range of -100 to 100 was not visible to participants. The ends of the scale were again randomly reversed trial-by-trial. Participants were informed that their decisions on each trial would directly impact the probability of receiving an item for consumption after the experiment, incentivising realistic choices.

Finally, participants completed the questionnaires collecting demographic and eating-related information. At the end of the experiment, participants received one randomly selected food item that they had responded "Yes" to in the decision stages.

Figure 4. Trial structure for the decision stage in Experiment 2. A fixation point was shown for 2 to 6 s before an image of a food item appeared for 3 s. A continuous slider scale then appeared for 3 s, asking participants how much they would like to eat the food item at the experiment's conclusion.

3.1.5 EEG Recording & Preprocessing. The EEG recording setup mirrored that of Experiment 1 (see Section 2.1.5), with some small differences - the data in Experiment 2 were filtered online with 70 Hz low-pass filter, which however did not make a difference to the following analyses. The data from the decision stage were then separated into epochs time-locked to the presentation of food stimuli. Epochs were 1,300 ms long, including a 100 ms baseline period before stimulus onset, and a post-stimulus window of 1,300 ms. The data were manually screened for artefacts, and an ICA was again conducted to identify and remove components containing eye artefacts. The data were screened once more to eliminate any residual artefacts and signals exceeding ±200 μV.

3.1.6 Decoding Analysis. The decoding parameters and overall approach were the same as those of Experiment 1 (see Section 2.1.6). For Experiment 2, however, three analyses were performed, all using the same EEG epochs from the decision stage – one predicting taste ratings, one predicting health ratings, and one predicting decision strength (ratings reflecting willingness to eat the foods presented in the decision stage). As in Experiment 1, an SVR approach was used for each analysis. The only difference was that health and taste

rating scales in Experiment 2 were discrete (which reduces the variance, but otherwise does not matter for the SVR; Bode et al., 2014). The ratings for decision strength were again a continuous measure.

3.2 Results

Mean ratings for the full sample were 3.02 (*SE* = 0.09) for taste, 2.48 (*SE* = 0.12) for health, and -3.23 (*SD* = 6.55) for decision strength. A linear mixed effects model with participant as a random effect and the attributes health and taste as fixed effects found that decision strength was significantly predicted by health, $\beta = 4.49$, $t(4567) = 7.55$, $p < .001$, and taste, $\beta = 43.99$, $t(4624) = 50.94$, $p < .001$. For each participant, the correlation (Pearson's *r*) between health and taste ratings ranged between -.27 and .56 (*mean r* = .13, *SD* = .19). Overall, there was a significant correlation between taste and health, $r(87) = .28$, $p = .009$.

The decoding of taste began to exceed chance from 740 ms after image onset, with a second cluster starting at 1120 ms (see Figure 5A). Of these, only the second cluster remained significant after correction for multiple comparisons; however, the large and sustained extent of the first cluster strongly suggests that this reflected meaningful information. For health, decoding performance was significantly above chance from 530 ms after image onset (see Figure 5B). Interestingly, even when the first cluster of taste decoding is considered meaningful, health decoding still appeared ~ 200 ms earlier than taste decoding.

In the final analysis, the decoding of decision strength was possible from 830 ms after image onset. This result shows that fine-grained information about decision strength was indeed represented after taste and health representations, suggesting that it is at least possible that both sources of information contributed to computing the decision (see Figure 6). For test statistics from each analysis at each timepoint, see Supplementary Table S8.

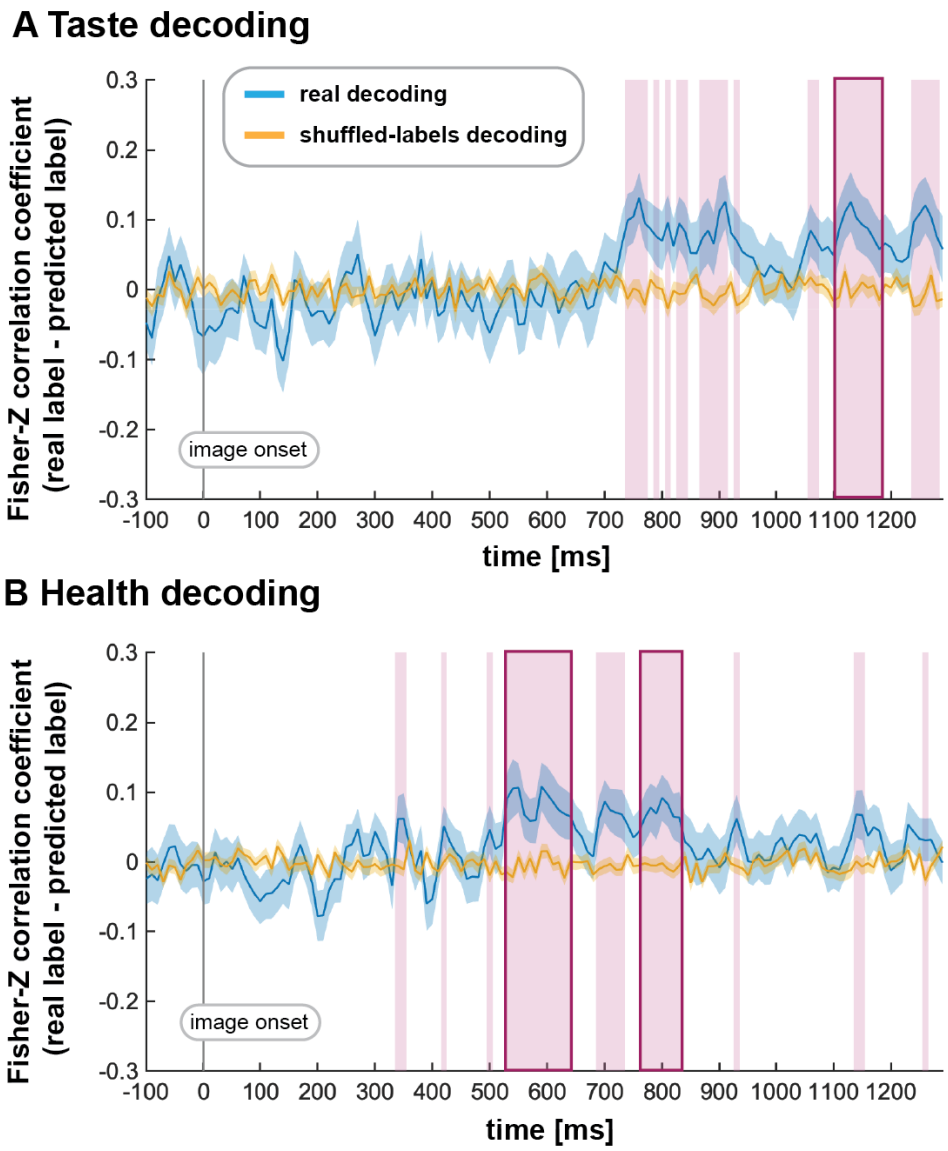

Figure 5. Decoding results from Experiment 2 for A) taste (n = 55) and B) health ratings (n = 85). Blue lines represent Fisher-transformed correlation coefficients between predicted and true labels (taste and health ratings), while yellow lines represent decoding results based on shuffled labels (empirical chance distribution). Pink vertical bars highlight time points at which the decoding results significantly differed from the shuffled decoding results ($p < .05$); bolded pink bars represent time windows that remained significant after corrections for multiple comparisons.

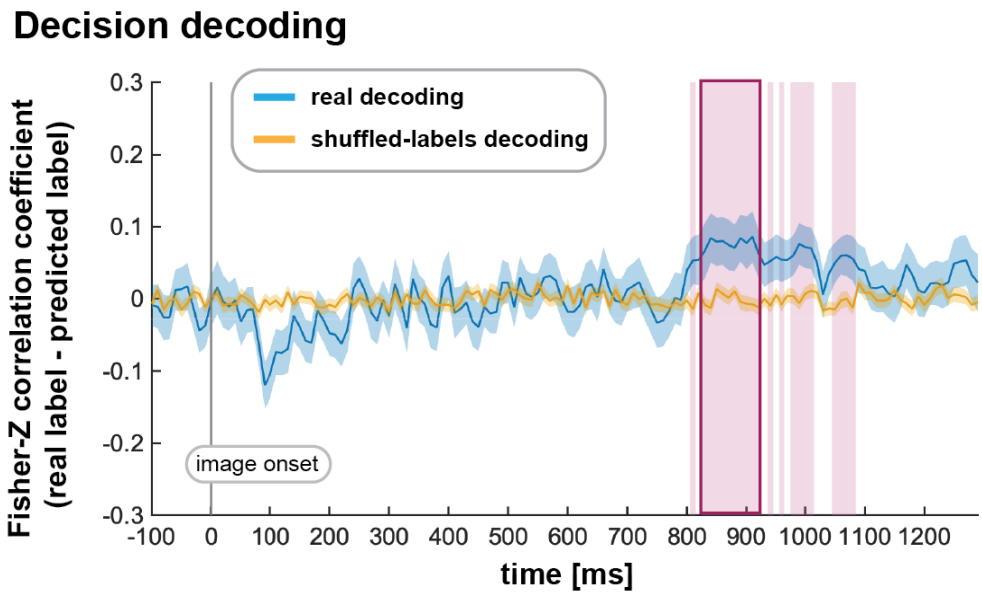

Figure 6. Decoding results from Experiment 2 for decision strength (n = 89). Blue lines represent Fisher-transformed correlation coefficients between predicted and true labels (taste and health ratings), while yellow lines represent decoding results based on shuffled labels (empirical chance distribution). Pink vertical bars highlight time points at which the decoding results significantly differed from the shuffled decoding results ($p < .05$); bolded pink bars represent time windows that remained significant after corrections for multiple comparisons.

Discussion

We conducted two experiments to investigate the neural representations of taste and health attributes. In Experiment 1, we showed that patterns of neural activity in the first 1200 ms after a food image appeared predicted trial-wise ratings of these attributes when participants explicitly considered the tastiness and healthiness of various foods. In Experiment 2, we investigated whether representations of the same attributes could still be decoded from neural activity during a dietary decision, with no direct instruction to consider tastiness or healthiness. We found that it was possible to decode both health and taste ratings, as well as decision strength, from patterns of neural activity occurring in the first second after

a food image appeared, even when participants were not instructed to explicitly consider these aspects.

The results from both experiments show that even subtle differences in the subjective perception of attributes of food stimuli are represented in EEG data, following on from previous ERP studies showing differences in average amplitudes between high- versus low-calorie and tasty versus non-tasty foods and drinks (Schwab et al., 2017; Schubert et al., 2021). For the first time, we also demonstrate that fine differences in health perception could be decoded from early neural activity. While there is evidence that dietary decisions are strongly driven by taste (Tepper & Trail, 1998; Pollard et al., 1998; Markovina et al., 2015; Morawetz et al., 2020), our results directly show that health information is also present in the brain at a similar time, before people make dietary decisions and when they are not explicitly instructed to think about health. Moreover, in our study, both taste and health ratings predicted food decisions, suggesting that both attributes are integrated for making the final choice. This further implies that interventions, such as health warning messages (Rosenblatt et al., 2018a; Cohen & Lesser, 2016), targeted at modifying health attribute processing, could realistically change neural representations at early stages of dietary decisions.

In Experiment 1, in which participants explicitly processed either taste or health in separate trials, our results showed an earlier decoding onset for taste compared to health. This supports previous findings that taste is more salient (Motoki et al., 2018) and is processed more automatically (Liberman & Trope, 2008), and more quickly than health (Sullivan et al., 2015). Interestingly, in Experiment 2, in which participants were not explicitly asked to consider tastiness or healthiness during dietary decision-making, health decoding onset was earlier than that of taste (in fact, health became decodable around the same time as taste in Experiment 1). This is surprising, considering the previous studies point to a general advantage for taste processing (e.g., Sullivan et al., 2015; Lim et al., 2018). One possible

explanation for this reversal is that health processing was given priority because our food stimuli varied substantially in perceived healthiness, whereas most foods were rated as relatively tasty, and hence the variance of taste ratings was smaller than that of health ratings. In consequence, prioritising the quick assessment of health attributes of (mostly) tasty foods might have been a valuable strategy in this study. Future experiments could include more "not tasty" foods to test whether this would change the temporal order of decoding; however, in reality, a large number of "not tasty" options might prove difficult to find. Further, the fact that the stimuli varied substantially in healthiness may have also contributed to the multiple significant decoding windows, as the stimuli that were unambiguously unhealthy (e.g., chocolates) may have been associated with faster processing of their health attributes. Other stimuli (e.g., muesli bars) may have been more difficult to categorise, and may have contributed to the second, later significant decoding window.

Another factor that potentially contributed to the earlier decoding of health relative to taste in Experiment 2 that did not occur in Experiment 1 may be the differences in the scales used. As only four categories were available in Experiment 2, participants may have been forced to make difficult decisions for stimuli that were ambiguous. This may have been particularly applicable to taste decisions, as they are more subjective than health decisions, and may have therefore contributed to the later decoding onset of taste in Experiment 2. Another potential factor is that in Experiment 1, the food images were all of unpackaged foods, whereas many of the snack food images in Experiment 2 were presented in packaging (e.g., branded packets of chips). These packaged food stimuli may have been less likely to prompt the imagination of consumption (Muñoz-Vilches et al., 2020), leading to weaker representations of taste compared to the unpackaged stimuli in Experiment 1. Another explanation for the lack of earlier taste decoding in Experiment 2 might be the lower statistical power relative to health decoding. However, given that the taste decoding analysis

still comprised data from more than 50 participants, and clearly showed significant results later in the trial, this explanation is rather unlikely. However, the absence of significant results should never be interpreted as hard evidence for the absence of a cognitive process because many unknown factors (e.g., more noise in the data, the presence of additional neural processes, etc.) could mask the relevant neural patterns.

Regardless of the exact reason for why health attribute processing seemed to be temporally prioritised over taste processing, the findings of Experiment 2 strongly suggest that although correlated, both attributes were independently important for decision-making. Each attribute individually predicted the final dietary decisions in our regression analysis, and showed a different neural decoding time course. This suggests that the attributes were independent, at least to an extent. Finally, decoding of both attributes preceded the decoding of decision outcomes in time. While this is not direct evidence for causality, it suggests that these neural representations might reflect the process by which participants inform their food decisions.

There are also some limitations which should be noted here. In Experiment 2, although participants were not explicitly instructed to consider tastiness and healthiness in the decision stage, they rated all stimuli on these attributes in an earlier stage of the experiment. This means that these attributes may have been primed to an extent, and may not be processed as strongly or quickly in naturalistic dietary decision-making. Future studies should examine whether these neural representations are still decodable when no attributes have been previously mentioned to participants. However, despite the earlier rating of healthiness and tastiness, participants in Experiment 2 were still not explicitly instructed to consider these attributes “in the moment”, and were free to consider any aspects of the food that they considered relevant to the decision. The fact that they knew they would receive a random food that they had strongly considered for consumption at the end of the experiment

also increased the likelihood of the decision-making process in Experiment 2 resembling the real-life dietary decision-making process. Given this, combined with strong evidence from previous studies that participants do predominantly consider the tastiness and healthiness of foods when making dietary decisions (Lim et al., 2018; Sullivan et al., 2015), it is unlikely that the significant decoding of tastiness and healthiness in Experiment 2 was solely due to priming effects from the earlier rating phase.

Another limitation is that there might be additional factors that influence the processing of health and taste attributes, such as BMI, smoking status, sex, or various personality variables. While our sample sizes were sufficient for the analyses conducted, they nevertheless are too small for meaningful explorations of these factors, and even the larger sample in Experiment 2 was very imbalanced in relation to gender (62 females, 27 males). In addition, the interpretation of individual participants' decoding time-series results is highly problematic, as the amount of noise in the EEG recordings varies substantially between participants. Additionally, potential measures of individual decoding strength, such as the peak value of each participant's decoding results, would vary between time points, which further complicates linking neural decoding strength with potentially relevant personal factors. Future studies could, however, address these questions by deliberately recruiting different samples for direct comparisons (e.g., smokers vs. non-smokers; high BMI vs. low BMI, etc.).

Further, it is possible that both samples were biased to value dietary health more than would be expected in the general population. Recruitment took place via advertisements which specified that the studies related to dietary decision-making, which may have tended to attract participants who were interested in dietary health. No data on individual health valuation was collected for Experiment 1. However, in Experiment 2, the sample mean on the Health factor of the Food Choice Questionnaire (Steptoe et al., 1995) showed no significant

difference from norms (established in a sample from the United Kingdom; Pollard et al., 1998). This suggests that our sample, at least in Experiment 2, did not place unusually high importance on dietary health. A final limitation is that our study can not reveal the underlying neural sources of the predictive signals. While it is possible to run similar decoding models for single channels (e.g., Bode et al., 2012), these analyses still do not allow for a precise localisation of sources and are fundamentally different as the spatially distributed information is lost.

In conclusion, our results show that representations of taste and health attributes of foods can be decoded from brain activity within the first second of cognitive processing, both when participants are explicitly instructed to reflect on them, and when these attributes tacitly inform dietary decision-making. This constitutes a promising finding for public health interventions. Many recently suggested interventions, such as health warning labels at the point-of-sale, rely on their ability to quickly activate an implicit health goal, which can then be experienced as being in conflict with the perceived tastiness of the considered food item (Papies et al., 2016; Rosenblatt et al., 2018a). For this mechanism to be effective, the subjective healthiness of the food has to be perceived quickly and, crucially, before the decision-process has concluded. Our results provide direct neural evidence that this is indeed the case (at least in situations in which a variety of items needs to be considered), suggesting that healthiness perceptions have been formed in the first second of viewing a food cue. Future research must now address whether having engaged with one's own health perception beforehand (as in our Experiment 2) is a necessary condition.

Further, as the present study was the first to use this method to directly decode attributes from neural activity using MVPA, it provides a starting point for future studies to look at how the aspects of decoding may be altered. For example, future research may examine whether public health interventions (such as nutrition labelling; Lim et al., 2018, or

general and specific health warning messages; Rosenblatt et al., 2018a, b; Schubert et al., 2020) can alter the strength or time course of health and taste decoding. The present study's results could also be used by market researchers, to determine which product attributes are rapidly processed. Finally, future studies may build upon the present results by examining whether the strength or time course of decoding is different for decisions involving dietary self-control versus those that do not (see Van Der Laan, 2014; Rosenblatt et al., 2018a), which would help to further deepen our understanding of dietary decision-making. However, such a study would require a high number of items in each category that still have sufficient variance in both health and taste ratings for multivariate decoding analyses to be applied.

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2.3 Supplementary Materials

Supplementary Material 1 - Experiment 1

Questionnaires

Participants completed the Dutch Eating Behaviour Questionnaire (DEBQ; Van Strien et al., 1986), which consists of three scales measuring restrained eating (i.e., the tendency to restrict food intake), emotional eating (i.e., the tendency to eat in response to emotional changes), and external eating (i.e., the tendency to eat in response to external food cues). They also completed the Yale Food Addiction Scale (YFAS; Gearhardt et al., 2009), which measures clinically significant addiction to food.

Results. The sample had an average BMI of 23.75 (*SD* = 4.66; range 18.26 to 36.63), which falls within the normal range (Nuttall, 2015). Average self-reported hunger levels were 5.19 (scale from 1 "not hungry at all" to 9 "very hungry"; *SD* = 1.85), indicating that participants were slightly hungry. On average, participants reported that 8.92 hours (*SD* = 5.32) had passed since their last meal, and 7.27 hours (*SD* = 6.05) since their last snack. This suggests that most participants adhered to the condition of not eating for four hours before the experiment. The questionnaire showed that our sample significantly exceeded norms of all three scales of the DEBQ (Table S1). Note, however, that the questionnaire is normed for a German sample, and no Australian norms currently exist (Nagl et al., 2016). On the YFAS (Table S2), our sample did not appear to differ greatly from norms taken from North American undergraduates (Gearhardt et al., 2009), except on the "Tolerance" and "Continued use despite problems" scales. Three participants met the criteria for clinically significant food addiction but were still included in the sample.

Supplementary Table S1.

Sample means from Experiment 1 for the Dutch Eating Behavior (DEBQ) questionnaire, along with norms and statistical tests for comparison.

	M	SD	M_{Norm}	SD_{Norm}	*t*	*p*
DEBQ-Restraint	2.81	0.75	2.23	0.87	4.42	< .001
DEBQ-Emotional	2.65	0.84	1.70	0.76	6.82	< .001
DEBQ-External	3.19	0.58	2.57	0.74	7.04	< .001

Note: Norms are taken from Nagl et al. (2016) for a German sample. Ratings were given on a scale from 1 to 5. The DEBQ measures restrained eating, emotional eating, and external eating.

Supplementary Table S2.

Results for the Yale Food Addiction Scale (YFAS) questionnaire, including sample percentages on each component, and norm percentages for comparison.

	Percentage	Norm Percentage
Diagnosis of Food Dependence	8.1%	11.6%
Withdrawal	13.5%	16.3%
Tolerance	89.2%	13.5%
Continued Use Despite Problems	73.0%	28.3%
Important Activities Given Up	24.3%	10.3%
Large Amounts of Time Spent	10.81%	24.0%
Loss of Control	13.51%	21.7%
Have Tried Unsuccessfully to Cut Down or Worried About Cutting Down	86.5%	71.3%
Clinically Significant Impairment	8.1%	14.0%

Supplementary Table S3.

Test statistics for each taste and health multivariate pattern analysis in Experiment 1, including p- and t-values, and Cohen's d. Results have not been corrected for multiple comparisons.

	Taste			Health		
Time Step	*t*	*p*	*d*	*t*	*p*	*d*
1	2.21	0.02**	4.03	-0.10	0.54*	-0.11
2	0.62	0.27	1.24	-0.43	0.66	-0.49
3	-2.52	0.99	-4.74	-0.02	0.51	-0.03
4	-0.96	0.83	-1.81	0.11	0.46	0.17
5	0.50	0.31	1.04	-0.45	0.67	-0.64
6	0.66	0.26	1.10	-0.16	0.56	-0.22
7	-0.43	0.67	-0.71	0.75	0.23	1.06
8	-0.35	0.64	-0.66	-0.07	0.53	-0.08
9	-0.13	0.55	-0.22	-0.51	0.69	-0.64
10	0.93	0.18	1.44	-0.76	0.77	-1.06
11	0.49	0.31	0.70	-0.71	0.76	-0.97
12	0.93	0.18	1.43	-1.50	0.93	-1.45
13	1.36	0.09*	2.13	-1.24	0.89	-1.58
14	0.89	0.19	1.53	-0.93	0.82	-1.64
15	0.24	0.40	0.41	-0.31	0.62	-0.45
16	-0.31	0.62	-0.53	0.60	0.28	0.77
17	-0.52	0.70	-0.89	0.87	0.19	1.02
18	-1.34	0.91	-2.18	-0.05	0.52	-0.06
19	-0.75	0.77	-0.98	0.18	0.43	0.24
20	-1.77	0.96	-2.85	1.23	0.11	1.51
21	-1.69	0.95	-2.87	1.35	0.09*	1.48
22	-0.10	0.54	-0.18	1.31	0.10	1.21
23	0.94	0.18	1.52	-0.38	0.65	-0.64
24	0.97	0.17	1.43	-0.62	0.73	-0.77
25	2.21	0.02**	2.90	0.36	0.36	0.49

26	0.98	0.17	1.36	-0.71	0.76	-1.39
27	0.48	0.32	0.67	-0.88	0.81	-1.24
28	-0.02	0.51	-0.03	-1.45	0.92	-2.07
29	0.60	0.27	1.19	-1.10	0.86	-1.83
30	0.45	0.33	0.87	-0.78	0.78	-1.06
31	0.84	0.20	1.71	-0.84	0.80	-1.05
32	1.19	0.12	2.23	-1.01	0.84	-1.15
33	0.92	0.18	1.62	-0.12	0.55	-0.12
34	0.39	0.35	0.65	0.05	0.48	0.06
35	0.47	0.32	0.91	-0.91	0.81	-1.13
36	1.13	0.13	1.67	-0.97	0.83	-1.09
37	1.48	0.07*	2.69	-1.01	0.84	-1.40
38	0.41	0.34	0.77	-0.18	0.57	-0.20
39	1.15	0.13	2.22	0.47	0.32	0.47
40	1.36	0.09*	2.24	0.01	0.50	0.01
41	2.04	0.02**	3.42	-0.24	0.60	-0.31
42	2.51	0.01**	4.28	0.42	0.34	0.52
43	1.90	0.03**	2.74	0.48	0.32	0.62
44	1.26	0.11	1.92	0.41	0.34	0.56
45	0.47	0.32	0.74	0.14	0.44	0.17
46	1.06	0.15	1.96	0.12	0.45	0.13
47	-0.08	0.53	-0.19	-0.57	0.71	-0.73
48	0.86	0.20	1.87	-0.04	0.51	-0.05
49	1.35	0.09*	2.48	0.50	0.31	0.52
50	2.01	0.03**	3.27	0.81	0.21	0.96
51	1.31	0.10	2.32	0.48	0.32	0.43
52	0.97	0.17	1.79	1.28	0.10	1.53
53	1.02	0.16	1.95	0.80	0.22	0.87
54	0.70	0.24	1.47	0.53	0.30	0.68
55	0.20	0.42	0.43	0.71	0.24	0.94

56	0.64	0.26	1.21	1.35	0.09*	2.87
57	0.14	0.44	0.26	1.49	0.07*	2.70
58	0.40	0.34	0.80	1.34	0.09*	2.17
59	0.58	0.28	0.92	0.78	0.22	0.88
60	-0.10	0.54	-0.20	0.43	0.34	0.56
61	0.45	0.33	0.85	0.35	0.36	0.40
62	0.26	0.40	0.48	0.50	0.31	0.57
63	1.53	0.07*	3.01	0.65	0.26	0.76
64	1.04	0.15	1.66	2.35	0.01**	2.97
65	1.04	0.15	1.83	3.19	0.00***	3.54
66	0.99	0.17	2.05	4.27	0.00***	4.46
67	0.91	0.18	1.92	4.03	0.00***	3.87
68	1.45	0.08*	2.70	3.81	0.00***	4.55
69	1.58	0.06*	2.84	3.11	0.00***	3.40
70	1.23	0.11	2.47	2.70	0.01**	3.64
71	0.77	0.22	1.48	1.97	0.03**	3.36
72	0.45	0.33	0.86	1.94	0.03**	2.37
73	0.74	0.23	1.47	1.83	0.04**	2.83
74	1.61	0.06*	2.49	2.09	0.02**	3.27
75	2.66	0.01**	4.34	2.14	0.02**	2.86
76	2.38	0.01**	4.13	1.67	0.05*	3.08
77	3.02	0.00***	4.59	1.53	0.07*	2.01
78	2.29	0.01**	3.40	1.62	0.06*	2.75
79	1.95	0.03**	2.66	2.34	0.01**	2.63
80	3.56	0.00***	5.07	2.20	0.02**	2.77
81	2.55	0.01**	4.37	3.39	0.00***	4.44
82	2.18	0.02**	3.81	2.98	0.00***	4.09
83	1.42	0.08*	2.57	3.04	0.00***	4.35
84	1.53	0.07*	2.26	3.44	0.00***	3.71
85	1.51	0.07*	2.10	3.50	0.00***	4.05

86	3.10	0.00***	3.99	2.49	0.01**	2.85
87	2.81	0.00***	3.67	2.06	0.02**	2.78
88	3.59	0.00***	5.31	2.16	0.02**	2.11
89	2.48	0.01**	3.69	1.50	0.07*	2.44
90	2.58	0.01**	3.94	1.32	0.10	1.75
91	2.14	0.02**	2.85	1.77	0.04**	2.48
92	1.50	0.07*	2.14	1.34	0.09*	1.91
93	1.62	0.06*	2.24	2.22	0.02**	2.36
94	1.70	0.05*	2.16	1.86	0.04**	2.09
95	1.52	0.07*	1.73	1.99	0.03**	2.13
96	2.31	0.01**	2.85	2.97	0.00***	3.77
97	1.34	0.09*	1.96	2.83	0.00***	3.33
98	1.91	0.03**	2.59	2.71	0.01***	3.28
99	1.03	0.15	1.29	3.61	0.00***	4.16
100	1.36	0.09*	2.28	3.98	0.00***	4.27
101	1.24	0.11	2.18	3.11	0.00***	3.47
102	1.78	0.04**	2.57	2.36	0.01**	2.35
103	0.95	0.18	1.26	2.53	0.01**	2.49
104	1.52	0.07*	2.55	3.39	0.00***	3.12
105	1.55	0.07*	2.26	1.75	0.04**	1.89
106	1.67	0.05*	2.46	2.60	0.01**	2.59
107	0.81	0.21	1.30	2.27	0.01**	2.59
108	1.07	0.14	1.84	2.45	0.01**	3.28
109	1.09	0.14	1.76	1.69	0.05*	2.46
110	1.12	0.13	2.33	0.95	0.17	1.28
111	1.43	0.08*	3.04	1.20	0.12	1.76
112	1.09	0.14	1.99	1.67	0.05*	2.20
113	0.97	0.17	1.76	0.49	0.31	0.53
114	0.67	0.25	1.20	1.02	0.16	1.19
115	0.40	0.34	0.80	0.59	0.28	0.70

116	0.16	0.44	0.31	1.35	0.09*	1.57
117	0.22	0.41	0.44	1.55	0.07*	1.95
118	1.14	0.13	2.40	0.65	0.26	0.76
119	1.60	0.06*	2.91	0.64	0.26	0.71
120	1.30	0.10	2.29	1.01	0.16	1.25
121	0.74	0.23	1.55	1.00	0.16	1.49
122	0.28	0.39	0.66	1.27	0.11	1.79
123	0.66	0.26	1.48	0.54	0.30	0.75
124	1.40	0.08*	3.14	1.03	0.16	1.40
125	1.49	0.07*	3.02	0.41	0.34	0.44
126	1.48	0.07*	2.72	0.59	0.28	0.67
127	1.16	0.13	2.02	0.89	0.19	1.15
128	1.05	0.15	1.98	-0.10	0.54	-0.12
129	0.87	0.20	1.98	0.09	0.46	0.12
130	0.69	0.25	1.28	0.41	0.34	0.62
131	1.14	0.13	2.29	0.50	0.31	0.64

Note: * $p < .10$, ** $p < .05$, *** $p < .001$

Supplementary Material 2 – Experiment 2

Participants completed the DEBQ (Van Strien et al., 1986; see Section 2.1.3) and the Food Choice Questionnaire (FCQ; Pollard et al., 1998), which measures the importance of nine factors underlying an individual's food choice, such as convenience, health, and ethical concern, on a four-point scale (1 = not at all important; 4 = very important).

Results

The average BMI of the sample was 21.02 (*SD* = 2.24; range 16.65 to 27.77; note that 12 participants chose not to report their height/weight and are therefore excluded from this average), which falls within the "normal" range (Nuttall, 2015). On average, participants had fasted for 6.95 hours (*SD* = 4.66) and gave hunger ratings of 4.63 (scale from 1 = not at all hungry to 8 = extremely hungry; *SD* = 1.70). As in Experiment 1, the sample significantly exceeded the norms (Nagl et al., 2016) on all three dimensions of the DEBQ (see Table S4). As mentioned above, the norms from Nagl et al. (2016) are taken from a German sample – as the Australian samples in Experiments 1 and 2 both exceeded the norms, this can likely be attributed to cultural differences. On the FCQ, our sample significantly exceeded the norms (Pollard et al., 1998) for mood, convenience, price, familiarity, and ethical concern (see Table S5).

Supplementary Table S4.

Sample means from Experiment 2 for the Dutch Eating Behavior (DEBQ) questionnaire, along with norms and statistical tests for comparison.

	M	SD	M_{Norm}	SD_{Norm}	*t*	*p*
DEBQ-Restraint	2.77	1.35	2.23	0.87	3.78	< .001
DEBQ-Emotional	2.60	1.18	1.70	0.76	7.25	< .001

DEBQ-External	3.17	0.87	2.57	0.74	6.55	< .001

Note: Norms are taken from Nagl et al. (2016) for a German sample. Ratings were given on a scale from 1 to 5. The DEBQ measures restrained eating, emotional eating, and external eating.

Supplementary Table S5.

Sample means from Experiment 2 for the Food Choice Questionnaire (FCQ), along with norms and statistical tests for comparison.

	M	SD	M_{Norm}	SD_{Norm}	*t*	*p*
Health	2.95	0.78	2.82	0.72	1.60	.114
Mood	2.67	0.80	2.10	0.73	6.73	< .001
Convenience	2.99	0.67	2.75	0.80	3.29	.001
Sensory Appeal	2.88	0.55	2.99	0.63	-1.80	.075
Natural Content	2.81	0.69	2.45	0.86	-0.01	.999
Price	2.97	0.69	2.83	0.80	2.03	.045
Weight Control	2.48	0.90	2.38	0.87	0.95	.345
Familiarity	2.41	0.73	1.76	0.68	8.43	< .001
Ethical Concern	2.07	0.82	1.86	0.78	2.34	.021

Note: Norms are taken from Pollard et al. (1998) for a sample from the UK. Ratings were given on a scale from 1 to 4.

Supplementary Table S6.

Test statistics for the taste, health, and decision strength multivariate pattern analysis results in Experiment 2, including p- and t-values, and Cohen's d. Results have not been corrected for multiple comparisons.

	Taste			Health			Decision Strength		
Time Step	*t*	*p*	*d*	*t*	*p*	*d*	*t*	*p*	*d*
1	-0.87	0.805	-1.09	-0.61	0.727	-0.90	-0.07	0.528	-0.09
2	-1.05	0.852	-1.40	-0.15	0.560	-0.25	-0.72	0.764	-0.92
3	-0.13	0.552	-0.20	-0.58	0.717	-0.87	-0.33	0.628	-0.45
4	0.44	0.329	0.65	0.72	0.237	1.02	-0.75	0.771	-0.91
5	0.52	0.304	0.68	0.74	0.230	0.97	0.37	0.357	0.46
6	0.16	0.437	0.22	0.93	0.177	1.18	0.88	0.190	1.14
7	0.88	0.191	1.13	0.61	0.271	0.87	0.71	0.240	0.94
8	0.74	0.232	1.14	-0.22	0.585	-0.31	-0.73	0.767	-0.90
9	-0.34	0.633	-0.43	-0.21	0.585	-0.29	-1.62	0.945	-2.03
10	-1.30	0.900	-2.33	-0.65	0.740	-0.83	-0.82	0.794	-1.02
11	-1.31	0.902	-2.01	-0.83	0.796	-1.17	-0.13	0.552	-0.20
12	-1.16	0.875	-1.87	-0.66	0.744	-1.00	0.22	0.414	0.35
13	-1.09	0.860	-1.84	0.19	0.427	0.26	0.16	0.436	0.25
14	-0.73	0.766	-0.87	-0.09	0.537	-0.14	-0.12	0.547	-0.18
15	-0.43	0.667	-0.58	0.20	0.421	0.29	0.20	0.421	0.26
16	-0.54	0.705	-0.80	-0.29	0.614	-0.41	-1.00	0.840	-1.48
17	-0.56	0.712	-0.76	-0.40	0.656	-0.54	-0.49	0.686	-0.62
18	1.15	0.128	1.23	-0.84	0.800	-1.09	-0.22	0.587	-0.28
19	-0.56	0.710	-0.74	-1.16	0.876	-1.61	-1.50	0.931	-1.81
20	-1.36	0.910	-1.81	-1.29	0.899	-1.72	-3.72	1.000	-4.72
21	-1.19	0.881	-1.33	-1.72	0.955	-2.31	-2.86	0.997	-3.87
22	-1.33	0.905	-1.61	-1.48	0.928	-2.17	-2.19	0.984	-2.86
23	-0.79	0.783	-1.06	-0.92	0.821	-1.40	-1.95	0.973	-2.56
24	-1.84	0.964	-2.61	-1.62	0.945	-2.33	-2.23	0.986	-3.14

25	-1.81	0.962	-2.46	-0.94	0.825	-1.36	-0.45	0.674	-0.61
26	-1.28	0.897	-1.84	-0.56	0.710	-0.83	-1.34	0.908	-1.68
27	0.38	0.352	0.50	0.21	0.415	0.29	-1.93	0.971	-2.39
28	-0.22	0.587	-0.28	0.74	0.232	1.07	-1.95	0.973	-2.47
29	-0.12	0.546	-0.16	0.04	0.485	0.05	-0.15	0.560	-0.18
30	-0.93	0.822	-1.36	-0.28	0.610	-0.42	-0.56	0.711	-0.69
31	-0.49	0.686	-0.64	-2.33	0.989	-3.47	-1.21	0.886	-1.57
32	-0.75	0.771	-1.09	-1.86	0.967	-2.79	-1.10	0.863	-1.54
33	-1.76	0.958	-2.05	-0.53	0.703	-0.78	-1.79	0.962	-2.51
34	-0.05	0.518	-0.06	-1.08	0.858	-1.49	-1.51	0.932	-1.99
35	0.11	0.457	0.14	-0.66	0.744	-0.94	0.64	0.261	0.92
36	0.38	0.353	0.54	0.87	0.195	1.14	0.85	0.199	1.08
37	0.73	0.234	1.07	1.30	0.098*	1.52	0.36	0.361	0.49
38	1.21	0.116	1.89	1.45	0.076*	1.73	-0.26	0.601	-0.36
39	0.13	0.449	0.20	0.44	0.330	0.60	-0.96	0.830	-1.28
40	-1.08	0.858	-1.54	0.56	0.288	0.71	0.09	0.464	0.11
41	-1.11	0.865	-1.68	1.56	0.062*	1.83	-0.16	0.564	-0.21
42	-0.73	0.764	-1.04	1.09	0.139	1.41	0.29	0.386	0.44
43	0.00	0.500	0.00	0.50	0.308	0.66	0.18	0.428	0.25
44	-0.22	0.588	-0.30	-0.94	0.826	-1.23	-1.38	0.915	-1.88
45	-0.46	0.677	-0.64	1.87	0.032**	2.61	1.15	0.126	1.38
46	-0.11	0.545	-0.15	1.89	0.031**	2.82	0.23	0.409	0.32
47	0.22	0.413	0.30	-0.21	0.582	-0.30	-0.58	0.718	-0.77
48	-0.65	0.740	-0.95	0.07	0.470	0.10	-1.03	0.848	-1.41
49	1.22	0.114	1.72	0.85	0.198	1.34	-0.86	0.805	-1.20
50	-0.42	0.663	-0.66	-1.90	0.970	-2.91	0.74	0.230	0.97
51	-0.08	0.532	-0.12	-1.15	0.873	-1.80	1.13	0.130	1.63
52	-0.56	0.711	-0.77	0.18	0.429	0.24	-0.18	0.573	-0.26
53	-0.75	0.771	-0.87	1.67	0.049**	1.99	-0.30	0.617	-0.37
54	-0.31	0.620	-0.38	0.54	0.295	0.72	-0.53	0.701	-0.66

55	0.11	0.455	0.16	0.26	0.396	0.37	-0.97	0.834	-1.49
56	-0.36	0.642	-0.56	0.47	0.318	0.76	-1.46	0.926	-2.01
57	-0.38	0.646	-0.53	-0.65	0.741	-0.97	-0.06	0.525	-0.07
58	-0.80	0.786	-1.13	-0.61	0.727	-0.95	-1.11	0.865	-1.29
59	-0.32	0.625	-0.40	-0.42	0.663	-0.65	-0.79	0.785	-1.04
60	-0.96	0.828	-1.39	0.46	0.324	0.63	0.76	0.226	0.98
61	-1.74	0.956	-2.66	1.86	0.033**	2.54	0.35	0.362	0.45
62	-0.87	0.806	-1.30	0.45	0.326	0.68	-0.85	0.800	-1.01
63	-0.13	0.553	-0.20	1.10	0.138	1.62	0.78	0.218	1.01
64	0.11	0.456	0.17	2.85	0.003**	4.10	0.20	0.421	0.29
65	-0.16	0.565	-0.26	2.93	0.002**	4.93	0.11	0.454	0.16
66	-1.17	0.877	-1.74	2.73	0.004**	3.85	-0.48	0.682	-0.55
67	-0.84	0.797	-1.18	2.10	0.020**	3.18	0.76	0.226	0.95
68	-0.27	0.605	-0.43	1.82	0.036**	2.08	1.03	0.153	1.39
69	-0.64	0.737	-1.22	2.07	0.021**	2.92	0.70	0.242	0.94
70	-1.08	0.857	-1.78	2.47	0.008**	3.59	0.05	0.482	0.06
71	-0.03	0.511	-0.05	1.99	0.025**	3.17	-1.06	0.853	-1.46
72	-0.01	0.503	-0.01	2.34	0.011**	3.46	-0.29	0.615	-0.46
73	-0.37	0.642	-0.71	2.02	0.023**	2.90	-0.71	0.760	-0.95
74	-0.05	0.518	-0.10	2.54	0.006**	3.57	0.82	0.207	1.15
75	0.53	0.297	1.04	1.88	0.032**	2.51	0.31	0.379	0.47
76	0.39	0.351	0.73	1.28	0.102	1.82	-0.06	0.525	-0.09
77	-0.14	0.557	-0.28	0.98	0.165	1.44	0.95	0.172	1.20
78	-0.44	0.668	-1.03	0.42	0.339	0.51	0.68	0.249	0.91
79	-0.77	0.778	-1.58	0.77	0.222	0.99	-0.49	0.686	-0.61
80	0.15	0.440	0.30	2.18	0.016**	2.80	-0.01	0.502	-0.01
81	0.54	0.296	1.08	2.89	0.002**	3.58	0.68	0.249	0.84
82	0.60	0.277	1.23	2.37	0.010**	3.00	0.28	0.391	0.39
83	0.07	0.472	0.16	2.35	0.010**	3.17	0.66	0.257	0.95
84	1.14	0.130	2.40	2.15	0.017**	3.05	-0.05	0.519	-0.07

85	2.68	0.005**	5.03	1.18	0.121	1.64	-0.21	0.582	-0.30
86	2.76	0.004**	4.58	1.32	0.095*	1.59	-0.71	0.761	-1.05
87	3.68	0.000***	5.93	1.44	0.076*	1.85	-0.54	0.706	-0.81
88	3.25	0.001**	5.31	1.71	0.045**	2.53	-0.12	0.549	-0.19
89	1.64	0.053*	3.27	2.21	0.015**	3.22	0.18	0.429	0.26
90	1.78	0.040**	3.29	1.86	0.033**	2.87	0.19	0.424	0.29
91	1.50	0.070*	3.10	2.65	0.005**	3.63	1.20	0.117	1.69
92	2.85	0.003**	5.47	3.00	0.002**	3.59	1.97	0.026**	2.70
93	1.48	0.072*	2.85	2.29	0.012**	3.05	1.17	0.123	1.82
94	2.58	0.006**	4.50	1.85	0.034**	2.66	1.79	0.038**	3.00
95	2.06	0.022**	3.89	0.51	0.304	0.80	2.72	0.004**	3.88
96	0.92	0.181	1.80	1.22	0.112	2.01	1.92	0.029**	2.63
97	0.63	0.265	1.31	0.13	0.448	0.21	2.11	0.019**	2.92
98	1.69	0.048**	3.66	0.87	0.192	1.31	1.94	0.028**	2.93
99	2.02	0.024**	4.29	0.67	0.253	1.00	1.88	0.032**	2.41
100	1.84	0.036**	3.76	0.28	0.389	0.43	2.82	0.003**	3.54
101	2.49	0.008**	5.22	-0.09	0.537	-0.16	2.21	0.015**	3.37
102	3.20	0.001**	5.65	-0.29	0.614	-0.46	2.54	0.006**	3.74
103	1.63	0.055*	3.06	1.17	0.122	1.60	2.03	0.023**	2.98
104	1.95	0.028**	4.04	1.88	0.032**	2.64	1.40	0.083*	1.88
105	1.53	0.066*	3.10	1.34	0.092*	1.70	1.87	0.032**	2.48
106	1.09	0.141	2.39	0.56	0.288	0.77	1.61	0.055*	2.09
107	0.71	0.239	1.31	-0.06	0.525	-0.09	1.97	0.026**	2.49
108	-0.03	0.512	-0.05	0.16	0.438	0.23	1.60	0.056*	1.97
109	0.58	0.284	1.13	0.23	0.408	0.34	1.85	0.034**	2.24
110	0.77	0.222	1.69	0.14	0.446	0.20	2.70	0.004**	3.28
111	0.57	0.287	1.11	0.74	0.230	0.96	2.27	0.013**	2.59
112	0.04	0.485	0.08	0.71	0.240	1.03	1.95	0.027**	2.35
113	0.33	0.372	0.60	-0.08	0.531	-0.11	1.38	0.086*	1.62
114	-0.05	0.520	-0.10	0.91	0.181	1.38	0.68	0.249	0.90

115	0.17	0.434	0.42	0.65	0.258	0.89	1.43	0.079*	1.94
116	1.27	0.106	2.60	0.49	0.313	0.73	2.18	0.016**	2.58
117	1.75	0.043**	3.41	0.85	0.200	1.12	2.30	0.012**	2.48
118	1.90	0.031**	3.27	0.87	0.193	1.07	1.89	0.031**	2.41
119	1.12	0.134	2.36	0.67	0.252	0.83	2.03	0.023**	2.73
120	1.25	0.108	2.97	-0.05	0.518	-0.06	0.55	0.292	0.78
121	1.37	0.089*	3.14	0.17	0.434	0.21	0.89	0.187	1.21
122	2.25	0.014**	4.70	0.18	0.428	0.24	0.22	0.415	0.28
123	1.88	0.032**	4.04	0.69	0.245	0.96	0.49	0.314	0.67
124	2.96	0.002**	6.75	1.25	0.108	1.74	0.53	0.300	0.82
125	2.25	0.014**	5.32	1.85	0.034**	2.61	0.24	0.407	0.33
126	1.82	0.037**	4.15	1.99	0.025**	2.87	-0.21	0.583	-0.33
127	1.77	0.041**	4.21	0.97	0.168	1.52	0.55	0.291	0.83
128	1.77	0.041**	3.22	1.59	0.057*	2.24	1.60	0.057*	2.14
129	1.68	0.049**	3.37	0.82	0.207	1.14	1.36	0.089*	1.89
130	1.37	0.089*	2.65	0.47	0.318	0.66	0.23	0.409	0.36
131	1.30	0.099*	2.49	-0.32	0.625	-0.50	0.49	0.311	0.67
132	0.67	0.254	0.99	-0.14	0.556	-0.22	0.66	0.257	0.80
133	0.78	0.220	1.53	-0.18	0.570	-0.23	0.25	0.402	0.31
134	0.84	0.203	1.68	1.01	0.158	1.40	0.01	0.496	0.01
135	2.78	0.004**	6.12	1.65	0.051*	2.11	0.62	0.267	0.86
136	2.58	0.006**	6.10	0.64	0.263	0.82	1.21	0.115	1.71
137	3.02	0.002**	5.58	1.75	0.042**	2.24	1.29	0.101	1.86
138	1.95	0.028**	3.76	1.09	0.138	1.46	1.34	0.091	2.05
139	1.94	0.029**	4.63	0.22	0.412	0.27	1.08	0.142	1.65
140	1.40	0.084*	3.58	-0.68	0.750	-0.89	0.64	0.262	1.09

Note: * $p < .10$, ** $p < .05$, *** $p < .001$

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2.4 Summary

In this chapter, two experiments were presented with the overarching aim of examining neural representations of taste and health attributes during the early stages of dietary decision-making. Across both experiments, tastiness and healthiness perceptions could be decoded significantly above chance from neural activity, which suggests that these representations were present in the brain during both rating and decision-making. Further, in Experiment 2, both taste and health attributes became decodable at an earlier stage than did decision strength.

These findings highlight the importance of perceived taste and health for dietary decisions, consistent with previous studies (Lim et al., 2018; Sullivan et al., 2015; Tusche & Hutcherson, 2018). Further, our results suggest that both of these attributes are processed quickly and automatically, within one second of a visual food cue appearing. The finding that it was only possible to decode decision strength after taste and health attributes were already decodable may suggest a dietary decision-making model whereby attributes are sequentially processed before being integrated into a final decision. This is consistent with existing models of food choice that emphasise processes of valuation, that is, assigning value to attributes which determines a decision (e.g., Furst et al., 1996).

In the two studies that follow, I will shift the focus from the process of dietary decisions to factors that may change and influence these decisions. Due to the important role of tastiness and healthiness in dietary decisions, supported by both previous literature (Furst et al., 1996; Lim et al., 2018; Sullivan et al., 2015; Tusche & Hutcherson, 2018) and our findings from Study 1, we took both attributes into account in the two studies presented in Chapters 3 and 4, testing for interactions between each attribute and the effects of HWLs (Study 2) or emotional processes (Study 3). This approach also allowed us to look beyond examining changes in broad food or

drink consumption or calorie intake (which has often been used as an outcome variable in previous studies; e.g., Billich et al., 2018; Bollard et al., 2016; Meule et al., 2013), to also consider changes to preferences regarding tastiness and healthiness.

Chapter 3: Study 2

The following empirical chapter presents a laboratory-based study on the effectiveness of general and specific graphic HWLs at changing consumption decisions regarding sugary drinks, incorporating EEG. This study was published in *Appetite* and is presented in its published format.

3.1 Aims

The overarching aim of Study 2 was to examine the effects of general and product-specific HWLs on willingness to consume (WTC) sugary drinks. Further, there were three more specific aims. First, we aimed to determine whether either type of graphic HWL could promote healthier SSB consumption, given that existing studies have produced inconsistent findings (cf. Bollard et al., 2016; Mantzari et al., 2020). The second aim was to compare the effectiveness of HWLs that referred to the health consequences of an unhealthy diet (general HWLs) with those that explicitly mentioned sugary drinks (specific HWLs). The third and final aim was to examine the neural processing of visual SSB cues, which included testing whether this processing changed after people were presented with HWLs.

To address these aims, participants completed a hypothetical SSB decision-making task while EEG was recorded. They were allocated to one of three conditions: specific HWL, general HWL, or control. The task involved rating a set of drink images on healthiness and tastiness, viewing a set of HWLs which differed according to their allocated condition, then viewing the SSBs again and indicating their WTC each one. To address the first aim, we hypothesised that participants who had viewed a HWL (either general or specific) would report lower WTC than those in the control condition. We addressed the second and third aims using an exploratory approach with no specific hypotheses. To examine whether general and specific HWLs differed in their effectiveness, we performed linear mixed effects model analyses to test whether participants from each condition reported different levels of WTC.

Further, we tested for interaction effects with tastiness and healthiness ratings, to determine whether the effectiveness of the HWLs depended on perceptions of these attributes. To address the final aim regarding the neural processing of visual SSB cues, we examined three ERP components commonly implicated in the processing of food and beverage cues (Carbine et al., 2018; Rosenblatt et al., 2018b), the N1, P3, and LPP. Specifically, we compared the amplitude of each component between different types of SSBs (e.g., healthy vs. unhealthy) and between the different HWL conditions.

3.2 Manuscript

General and specific graphic health warning labels reduce willingness to consume sugar-sweetened beverages

Elektra Schubert[1], Emma Smith[1], Maja Brydevall[1], Carmen Lynch[1], Elysha Ringin[1], Helen Dixon[2], Yoshihisa Kashima[1], Melanie Wakefield[2], Stefan Bode[1*]

[1] Melbourne School of Psychological Sciences, The University of Melbourne, Australia

[2] Centre for Behavioural Research in Cancer, Cancer Council Victoria, Australia

* Corresponding author: Stefan Bode, Melbourne School of Psychological Sciences, The University of Melbourne, Parkville, VIC, 3010, Australia; email: sbode@unimelb.edu.au; phone: +61(0)390353849

Abstract

Sugar-sweetened beverage (SSBs) consumption is associated with obesity and other severe negative health consequences. The present study examined the effectiveness of two types of health warning labels (HWLs) in modulating dietary choices for SSBs: specific HWLs, presenting health consequences associated with consuming SSBs, and general HWLs, presenting health consequences of an unhealthy diet and obesity. While electroencephalography (EEG) was recorded, 63 participants completed a computer-based task in which they were first randomly allocated to view either SBB-specific, general, or non-warning control HWLs. They then viewed images of a range of SSB products, varying on perceived healthiness and tastiness, and rated their willingness to consume (WTC) each one. Linear mixed-effect model analyses revealed that general and specific HWLs both decreased WTC SSBs perceived as tasty, compared to the control condition. For general HWLs, this effect was reduced for SSBs perceived to be healthy, suggesting that specific HWLs may be more effective at reducing SSB consumption. The EEG data showed that SSBs considered unhealthy elicited greater N1 amplitudes, and tasty SSBs elicited greater late positive potential (LPP) amplitudes, possibly reflecting attentional allocation and craving responses, respectively. However, no strong differences between HWL types were found. Taken together, the results suggest that graphic HWLs, both general and specific, have the potential to reduce SSB consumption, but they do not strongly modulate craving-related neural responses to SSBs.

Keywords

Sugar-sweetened beverages (SSBs); health warning labels (HWLs); electroencephalography (EEG); craving; health; sugary drinks

Background

Excess body weight is estimated to cause nearly three million deaths annually worldwide (Stevens et al., 2012), and is associated with increased risk of serious chronic diseases (Lauby-Secretan et al., 2016). By 2025, it is estimated that one in five adults will be obese (NCD Risk Factor Collaboration, 2016). A leading contributor toward excess weight and obesity is poor a diet, particularly high intake of added sugar (Te Morenga et al., 2012). Sugar-sweetened beverages (SSBs) are nutrient poor while being a substantial source of added sugar in the Australian diet (Lei et el. 2016; Australian Bureau of Statistics, 2014). SSB consumption is prevalent in Australia, especially among young adults and males (Miller et al., 2020). High SSB consumption is linked to weight gain and a range of health problems, including type 2 diabetes (Malik et al., 2010), cardiovascular disease (Fung et al., 2009), and increased risk of dental cavities and erosion (Mishra & Mishra, 2011). A number of interventions have been implemented in Australia that may help reduce SSB consumption, including mandatory nutrition labelling (Australia New Zealand Food Standards Code, 2019; MacKay, 2011), and obesity prevention public health campaigns (Morley et al., 2018; Morley et al., 2019). Another suggested intervention is mandatory health warning labels (HWLs) on packages and at point-of-sale to warn consumers about health risks associated with unhealthy products, with some jurisdictions already mandating HWLs for SSBs (Grummon & Hall, 2020).

1.1 Efficacy of HWLs for Food and Beverage Consumption

Numerous studies support the effectiveness of HWLs – especially graphic (pictorial) HWLs – on cigarette packaging, finding that they can discourage smoking initiation and encourage smoking cessation (Noar, Hall, et al., 2016). Recent meta-analyses suggest that HWLs may have similar effects on unhealthy food (Clarke et al., 2020) and beverage (Grummon & Hall, 2020; Gupta et al., 2020) consumption, finding that they can enhance

consumer awareness and correct misconceptions of the healthiness of products, increase knowledge about health risks associated with product consumption, reduce visual attention to the marketing elements on drink packaging, and prompt healthier decision-making for both hypothetical consumption tasks and actual consumption. Negatively framed graphic labels have been found to be most effective in decreasing participants' willingness to consume (WTC) unhealthy snack foods, compared to text-only or positively framed messages (Rosenblatt et al., 2018a; Rosenblatt et al., 2018b). This finding may extend to SSBs – in experimental laboratory-based studies, graphic HWLs (e.g., "Drinking drinks with added sugar contributes to obesity, type 2 diabetes, and tooth decay", accompanied by an image of decayed teeth) have been found to promote healthier SSB choices than text-only HWLs, sugar information, or health star rating labels (Billich et al., 2018; Scully et al., 2020). However, Mantzari et al. (2020) found no differences in SSB choice between participants who were offered real SSBs displaying graphic HWLs, calorie information, or no label. Therefore, although there is evidence that HWLs can be effective at reducing SSB consumption, further research is needed to investigate the types of labels that can consistently produce behaviour change.

Negatively framed graphic HWLs seem to influence dietary change through a mediator effect of negative emotionality. In studies investigating tobacco control, graphic HWLs have been found to elicit negative emotions, which in turn influence behaviour change (Brewer et al., 2016; Cho et al., 2018; Emery et al., 2014; Evans et al., 2018). Similarly, it has been found that stronger negative emotional responses are elicited by negatively framed HWLs for snack foods, compared to positively framed HWLs (Rosenblatt et al., 2019). For SSBs, negatively framed graphic HWLs similarly elicit more negative emotion than text-only HWLs, sugar content signs, and Health Star Ratings (Scully et al., 2020). Donnelly et al. (2018) found that the effect of HWLs on SSB choices occurs via a two-stage mediation

process, whereby HWLs increase negative affect, which leads to consideration of health risks and subsequently increases dietary self-control. Supporting this, Mantzari et al. (2018) found that negative emotional arousal mediated the effect of graphic HWLs on SSB selection, such that when the HWL elicited a greater negative emotional reaction, participants were less likely to select an SSB from a vending machine.

Early field-based studies also demonstrated promise for the success of food and beverage HWLs in promoting healthier dietary choices in the real world (Bleich et al., 2014; Donnelly et al., 2018). Donnelly et al. (2018) found that displaying graphic HWLs in a hospital cafeteria for two weeks led to a reduction in SSB purchases, whereas displaying calorie information or text HWLs did not. Furthermore, Grummon, Smith, et al. (2019) used a simulation model on US Health and Nutrition Examination Surveys to show that a national SSB HWL policy would reduce average SSB intake, total energy intake, BMI, and obesity prevalence, supporting the wide-scale efficacy of HWL policies. Together, these studies provide evidence for the effectiveness of negatively framed graphic HWLs over positively framed or text-only messages. However, there might be the potential to further increase the efficacy of such HWLs by making them more product specific.

1.2 General versus Specific HWLs

In recent food and beverage HWL efficacy research, laboratory-based studies have found evidence for the effectiveness of both HWLs that specifically warn consumers about health risks associated with SSB consumption (Billich et al., 2018; Donnelly et al., 2018; Roberto et al., 2016; VanEpps & Roberto, 2016), and those that warn of more general health risks associated with being overweight or having an unhealthy diet (Rosenblatt et al., 2018a). Previous studies have suggested that HWLs related to the health risks of alcohol consumption are more believable and more effective at reducing intended alcohol consumption when they display specific consequences (e.g., bowel cancer, depression), compared to more general

consequences (e.g., cancer, mental illness; Pettigrew et al., Miller et al., 2016; Blackwell et al., 2018). This suggests that HWLs are more believable and effective when they highlight specific rather than general health threats.

However, for SSBs, it is also useful to determine whether there is an advantage for product-specific (rather than consequence-specific) HWLs. Australians, particularly those who regularly consume SSBs, have been found to have low awareness of the health risks of SSBs (Miller et al., 2019). HWLs that state the consequences of SSBs specifically, rather than the consequences of an unhealthy diet in general, may raise awareness of the negative health effects of SSBs and subsequently decrease consumption more effectively. However, general labels that could also be used on other unhealthy food or beverage items would have a favourable advantage in terms of widescale applicability and cost-effectiveness. Therefore, it is important for policy-makers to understand whether SSB-specific HWLs have an advantage over general HWLs.

1.3 Using EEG to examine processing of SSBs and efficacy of HWLs

To date, most research testing responses to HWLs on foods and beverages has relied on self-reported (conscious) emotions, cognitions, and preferences, as well as overt behaviour (Grummon et al., 2019; Clarke et al., 2020), while relatively little is known about neural processes that mediate the effect of HWLs on dietary choices (cf. Rosenblatt et al., 2018b). Nonetheless, the cognitive and neural processing of food and beverage cues is likely to be important for understanding food-related cognition. This is because encountering visual food cues in the environment may trigger cravings and overeating (Meule & Vogele, 2013), and food image viewing can be seen as a preparatory stage for food intake (Blechert et al., 2019). Several event-related potential (ERP) components thought to be related to the processing of food cues have been identified. In particular, Carbine et al. (2018) found in a systematic review that ERP component amplitudes reflecting early or late attention allocation tended to

be greater in response to palatable food cues, compared to less palatable foods or neutral cues (e.g., office items). These components include the N1, thought to index early attention allocation, and the P3 and late positive potential (LPP), thought to relate to later attention allocation (Gable & Harmon-Jones, 2010; Toepel et al., 2009; Harris et al., 2013; Littel et al., 2012).

ERP components have also been used to examine the effectiveness of HWLs on processes involving early attentional allocation and craving responses. Rosenblatt et al. (2018b) compared N1, P3, and LPP components during exposure to snack foods before and after participants viewed either graphic HWLs, or scrambled control labels. The HWL group displayed attenuated P3 and LPP amplitudes after HWL exposure compared to the control group, dependent on taste ratings. This demonstrates the utility of ERPs for investigating the effectiveness of HWLs. However, it is unclear whether ERP components also reflect craving responses when SSB cues are viewed, and whether these neural responses are altered by HWL interventions.

1.4 Aims of the Present Study

The primary aim of the present study was to determine the efficacy of specific and general HWLs in promoting healthier drink choices. It was hypothesised that participants who viewed HWLs would show lower preferences for SSBs considered unhealthy, compared to those who did not view HWLs. The second aim was to explore whether HWLs specific to SSBs (warning of health consequences associated with consuming SSBs) differed in their effectiveness in reducing unhealthy drink choices, compared with general HWLs (warning of health consequences of an unhealthy diet and obesity). Finally, we aimed to investigate the neural mechanisms of the cognitive processing of SSB-related cues, and the ability of HWLs to impact these mechanisms. This was addressed with an exploratory approach, comparing the N1, P3, and LPP components both between different types of SSBs (e.g., those

considered unhealthy vs. healthy), and between participants who viewed HWLs and those who did not.

Method

2.1 Participants

Seventy-two participants were recruited via online advertisements at the University of Melbourne, all between 18 and 40 years of age, right-handed, fluent in written and spoken English, not currently pregnant or on a diet, having no history of an eating disorder, and reporting that they consume at least some SSBs regularly, however, we did not specify a hard criterion for what exactly defines regular consumption. This was done to filter out potential participants who might already dislike SSBs altogether. The sample size was similar to other studies also using EEG to evaluate the effectiveness of interventions to improve dietary decisions (e.g., Meule et al., 2013; Sarlo et al., 2013; Rosenblatt et al., 2018b). Nine participants were excluded from all analyses: eight for having an insufficient number of trials with familiar drinks (fewer than 50%; see below for assessment of familiarity), and one for having excessively noisy EEG data. Excluding them from all analyses ensured that the results from both the behavioural and EEG analyses were based on the same consistent sample. The final sample comprised 63 participants, aged 18 to 40 years (M = 24 years, SD = 5.47; 40 females, 23 males). Participants gave written informed consent, were debriefed after completing the task, and were compensated AUD$20 and a beverage of their choice after the experiment. The experiment was approved by the Human Research Ethics Committee (ID 1851182.1) of the University of Melbourne and conducted in accordance with the Declaration of Helsinki.

2.2 Stimuli

To mimic a selection of products in a standard Australian supermarket, 54 images of cold, non-alcoholic beverages (selected from an online supermarket catalogue) were

presented (see Figure 1A for examples). The stimulus set comprised a range of beverage items, including milk, flavoured milk, milk alternatives, energy drinks, water, flavoured water, fruit juice, soft drink, iced tea, and iced coffee. The majority of items met definition criteria for an SSB (see ABS, 2014), with the exception of non-flavoured water and milk products.

HWL stimuli comprised negatively framed messages accompanied by graphic images, in line with past studies demonstrating the effectiveness of these label formats at improving intended and actual dietary choices (Billich et al., 2018; Donnelly et al., 2018; Mantzari et al., 2018; Rosenblatt et al., 2018a; Scully et al., 2020). These stimuli were adapted from negatively framed graphic HWLs used in Rosenblatt et al. (2018a). These contained general warning messages relating to having a poor diet, being overweight, and the subsequent increased risk of developing health conditions. The HWLs were split into two categories – General HWLs (Figure 1B) and Specific HWLs (Figure 1C) – with six different messages used in each. Four of the accompanying images were unique for each condition, and two images were used in both conditions because they could be combined well with each message type.

The General HWLs focused on health risks of poor diet such as arthritis, heart disease, type 2 diabetes, weight gain, thyroid cancer, and decreased life expectancy, whereas the Specific HWLs contained messages relating specifically to the health risks of consuming SSBs. Three of the Specific HWLs were matched with the General HWLs on message content (type 2 diabetes, weight gain, cancers), two contained messages relating to health conditions linked to SSB consumption (increased risk of tooth decay and toxic fat around organs; Mishra & Mishra, 2011), and one depicted the number of teaspoons of sugar in an SSB, similar to sugar content labels used in previous studies (Billich et al., 2018; Mantzari et al., 2018; Scully et al., 2020). For a third control condition, six stimuli were created using the

same layout and font as the general and specific labels, but with randomly sorted pixels of the graphic images so that the image was unrecognisable, accompanied by nonsense words of similar length to their counterparts (Figure 1D). For all 18 HWL stimuli used, see Supplementary Figure S1.

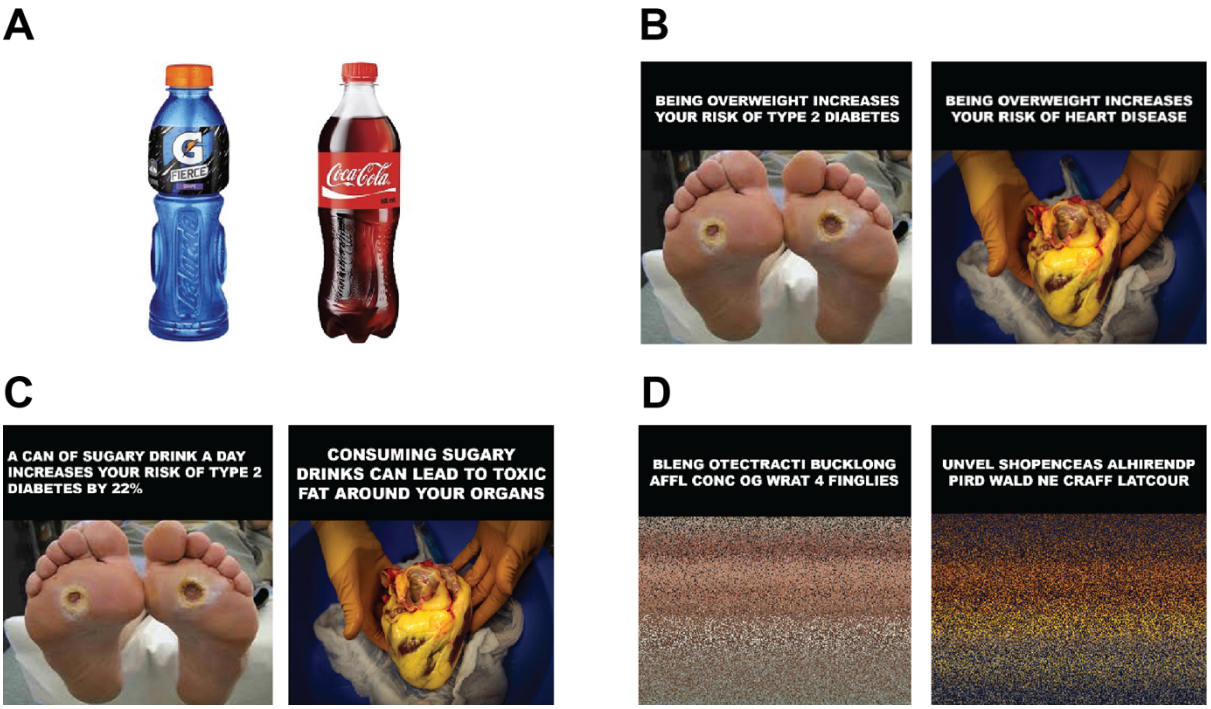

Figure 1. Examples of (A) SSB stimuli; (B) general HWLs; (C) specific HWLs; and (D) control HWLs.

2.3 Questionnaires

To explore the influence of consumer heterogeneity on HWL efficacy, participants completed five questionnaires. The first assessed demographic information, including gender, body mass index (BMI), perceived healthiness of current diet and exercise levels, and two forms of socioeconomic status (SES) – perceived SES during childhood, and current perceived SES.

The Behavioural Inhibition/Avoidance Scales (Carver & White, 1994) assessed two motivational systems: the Behavioural Inhibition System (BIS), suggested to be related to

signals of possible threat, punishment, or non-reward, and the Behavioural Activation System (BAS), thought to be activated by cues of reward and non-punishment (Poythress et al., 2008; Carver & White, 1994). This scale has four subscales, all including 6 items assessed on a 4-point Likert Scale (*1 = very true for me; 4 = very false for me*): one BIS scale, BAS Drive, BAS Fun Seeking, and BAS Reward Responsiveness.

The 40-item State-Trait Anxiety Inventory (Form Y; STAI; Spielberger et al., 1983) was used to assess state and trait anxiety, with two subscales, both measured on a 4-point scale: State Anxiety (*1 = not at all; 4 = very much* so), and Trait Anxiety (*1 = almost never; 4 = almost always*).

A short form of the Lovibond and Lovibond's (1995) Depression Anxiety Stress Scale (DASS-21; Alfonsson et al., 2017) was administered to assess depression, anxiety, and stress symptoms, as well as overall psychological distress, within the past week. This questionnaire involves three subscales: DASS21-D (Depression), DASS12-A (Anxiety), and DASS21-S (Stress), all measured on a 4-point scale (*0 = never; 3 = almost always*).

Finally, an 8-item version of Cooper et al.'s (1987) Body Shape Questionnaire (BSQ-8d) was used to assess body shape concerns and dissatisfaction, in the domains of general body dissatisfaction, body dissatisfaction relating to an eating disorder, and body dissatisfaction related to others (Evans & Dolan, 1993). This questionnaire used a 6-point scale ranging from 1 (never) to 6 (always).

For analysis of these questionnaires, see Supplementary Material 1. This involves the exploration of potential effects of demographic variables (Australian Bureau of Statistics, 2014; Han & Powell, 2013; Mannocci et al., 2014; Mazarello Paes et al., 2015; Nonnemaker et al., 2014), sensitivity to rewards and punishment (Franken, 2002; Franken & Muris, 2006), impulsivity (Jasinska et al., 2012), body image (Kim et al., 2008), and mental health states (Roberts et al., 2014; Wahl et al., 2017) on HWL efficacy. Note, however, that given the

relatively small sample size of our study for such analyses, the results should be interpreted with caution.

2.4 Procedure

Participants completed a computer-based task modified from Rosenblatt et al. (2018a) on a 1680 x 1050 pixel LCD monitor, using a chin rest with their eyes 60 cm from the monitor. Stimuli were presented using Psychtoolbox v3 (Kleiner et al., 2007) and Matlab R2017a. In a between-subjects design, participants were randomly allocated to the Control HWL, General HWL, or Specific HWL group. The task involved three stages: the Rating Stage, Priming Stage, and Primed Decision Stage. Before the experiment, participants viewed instructions presented on the computer screen, and also received verbal instructions before each stage.

The Rating Stage comprised 54 trials, each involving the presentation of a different beverage image (Figure 2A). Each trial began with a fixation cross presented for 1.5 s, followed by a randomly selected beverage image. The image was displayed by itself for 2 s, then the first of four questions appeared sequentially underneath it. Firstly, participants indicated whether they were familiar with the beverage (YES or NO; no time limit). They were told that Familiarity was not brand-specific but corresponded to their familiarity with that type of product generally. If they answered NO, they were automatically directed to the next trial; if YES, they then rated how frequently they consume the beverage on an ordinal scale (1 = Daily, 2 = A few times per week, 3 = A few times per month, 4 = A few times per year, 5 = Never). Finally, participants rated how healthy they considered the drink to be, and how much they enjoyed the taste of the drink, both on a continuous rating scale with an underlying range of 0 to 100. They gave these ratings by using a computer mouse to move a bar on the scale to the position they considered appropriate, between “Not at all” on one end to “Very much” at the other. To ensure participants were paying attention, the end points of

the scale were randomised across trials (participants were also informed of this at the beginning of the stage). If no response was given after 10 s, the current position of the bar was recorded as the response.

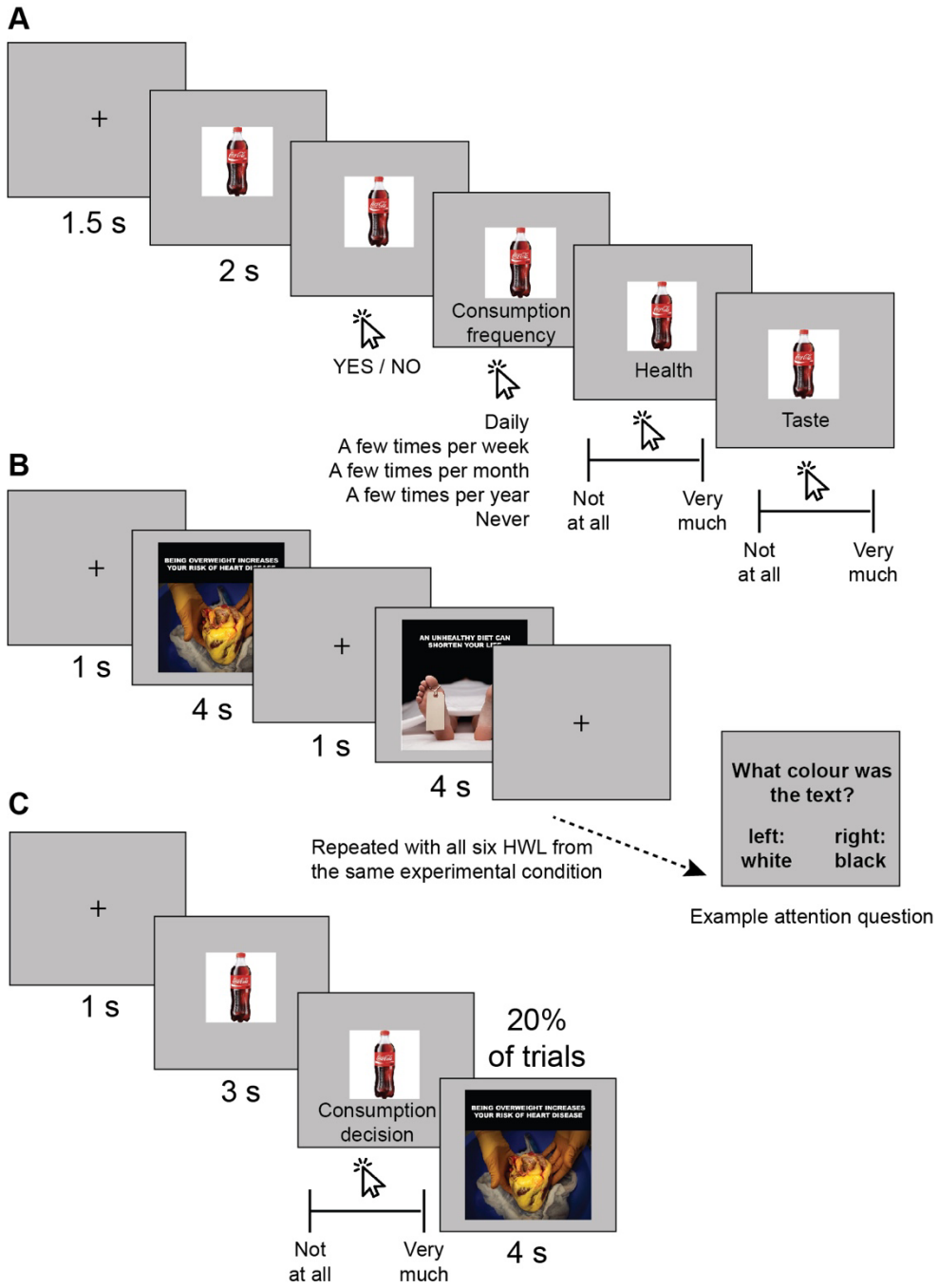

Figure 2. Experimental paradigm. A) Rating Stage: Participants were asked to rate each beverage on four dimensions: Familiarity, Consumption, Health, and Taste. Responses were

given via mouse click (10 s time limit). Questions were shown under each image. Familiarity: "Are you familiar with this drink?"; Consumption frequency: "How often do you consume this drink?"; Taste: "How much do you enjoy the taste of this drink?", Health: "How healthy do you consider this drink to be?" Response options are shown in the figure. B) Priming Stage: All six HWL or control images for the same allocated HWL condition were shown in direct succession. Once all HWLs had been shown, participants responded to an attention check. C) Decision Stage: Participants rated their willingness to consume the item. Responses were given via mouse click (10 s time limit). HWLs were presented in 20% of all trials, and the type of HWL presented was dependent on HWL condition allocation.

In the Priming Stage (Figure 2B), participants were presented with six HWL stimuli, reflecting their assigned experimental condition (General, Specific, or Control). To ensure participants were paying attention, they were told at the beginning of the stage that they would be required to answer questions about the images that would appear. Before each HWL, a fixation cross was shown for 1 s. Each HWL image was then displayed for 4 s. Participants then answered basic questions about the visual properties of the images ("What colour was the text?" and "How many images did you see?").

In the Decision Stage (Figure 2C), participants were told that for each trial, they would need to indicate how much they would currently like to consume each beverage (henceforth referred to as "willingness to consume": WTC), and that one of the beverages they indicated they would like to consume would be given to them at the end of the experiment. Only the beverages indicated as familiar in the Rating Stage were presented in the Decision Stage – therefore, each participant completed as many trials as they had familiar drinks. The images were presented in the same order as in the Rating Stage. Each trial began with a fixation cross presented for 1.2 s, followed by a drink image alone for 2 s. A continuous rating scale then appeared underneath the image, similar to those in the Rating

Stage, and participants gave a response from “Very Much” to “Not at All”. The end points of the scale randomly reversed across trials, and participants were told at the beginning of the stage to check this before making a response. As in the Priming Stage, if no response was given after 10 s, the position of the slider was recorded as a response. Throughout this stage, HWLs (dependent on the allocated HWL condition) randomly appeared again between 20% of trials, in order to simulate real-life viewing of HWLs and to reinforce their effectiveness while engaged in dietary decision-making.

After completing the computer task, participants completed the questionnaires, and were then debriefed. For ethical reasons, participants could opt out of completing the questionnaires relating to depression, anxiety, and body image, and not all participants decided to complete every questionnaire. On average, participants took approximately one hour to complete the experiment, including EEG setup.

2.5 Behavioural Data Analysis

The hypothesis that participants who viewed HWLs would show lower preferences for SSBs considered unhealthy, compared to those who did not view HWLs, was specified prior to data collection. To address this, linear mixed-effects model analyses were performed using the lme4 package (Bates et al., 2015) in R 3.5.3 (R Core Team, 2016). HWL condition, health ratings, and taste ratings were modelled as fixed effects. Participants and beverage stimuli were modelled as random effects to control for heterogeneity and variation across participants (Bell et al., 2019), in turn reducing opportunities for type 1 errors (Aarts et al., 2014). Mixed effects modelling was also selected for the investigation of dietary decision making due to its ability to handle relatively small sample sizes and accommodate missing data and different numbers of trials between participants (Edwards, 2000; Quené & Van den Bergh, 2004). This analytic plan was specified prior to data collection and analysis, but was not formally preregistered.

Likelihood ratio tests were used to assess model fit through a backward elimination approach. Models containing all possible predictors along with the theoretically plausible interaction terms were compared to models lacking predictors and combinations of predictors. Satterthwaite's (1946) Approximation for Degrees of Freedom was used to obtain *p* values. Follow-up analyses were conducted to further explore significant interactions from the most successful model in relation to subjective item groupings. For this, the average effects of the General and Specific HWL conditions were each expressed in relation to the Control condition (i.e. the percentage of increased or decreased consumption decisions relative to control). One sample *t* tests were then used to investigate these effects separately for drink items classified (see Section 3.3) as "low health, low taste" (LHLT), "high health, high taste" (HHHT), "low health, high taste" (LHHT) and "high health, low taste" (HHLT) . The latter two constituted the main item categories of interest in which taste and health were in conflict, and for which behavioural change has been found for snack foods (Rosenblatt et al., 2018a). These classifications were made using a median split – for each participant, items with health or taste ratings above that participant's median were classified as relatively high health or taste, and ratings below the median were classified as relatively low health or taste.

To explore the relationship between consumer characteristics and WTC subsequent to HWL exposure, a series of correlational analyses was conducted. For this, participants' responsiveness to HWLs (expressed as the difference in WTC relative to the Control condition) was correlated with their questionnaire data using Pearson's correlations for continuous variables, and Point-biserial correlations for categorical variables. This analysis was exploratory and no hypotheses were specified in advance.

2.6 EEG Data Recording, Pre-processing, and Analysis

During the main, computer-based task, electrophysiological activity was recorded by a 64-channel BioSemi Active II system, with a sample rate of 512 Hz and recording

bandwidth DC-102 Hz. The International 10-20 system was used, with 64 Ag/AgC1 electrodes attached to a fabric cap. There were four additional electrodes next to and below the left eye (to record the horizontal and vertical electrooculogram), and above the left and right mastoids. Electrode offsets remained within ±50 μV.

EEG data from the Primed Decision Stage was analysed, and EEGLab v14.1.2 (Delorme & Makeig, 2004) was used for pre-processing. First, the data were re-referenced to the average of left and right mastoids. The data were then high-pass (0.1 Hz) and low-pass (30 Hz) filtered (EEGLab FIR Filter New, default settings), and segmented into epochs beginning 100 ms before the presentation of a beverage image (used to baseline-correct each epoch), and ending 1,100 ms after image presentation. Via visual inspection, muscle and skin potential artefacts were identified and epochs containing these were removed. Excessively noisy channels were removed and interpolated using spherical spline interpolation (average number of channels interpolated = 0.62, range 0-3). Eye movements, saccades, and blinks were then identified and removed using an independent components analysis (ICA) in EEGLab. Epochs were not included in analyses if amplitudes at any channel exceeded ±150 μV.

Due to the limited literature on the neural processing of SSB-related cues, no hypotheses were pre-specified for the EEG data, and the analysis, though planned prior to data collection, was exploratory. In order to quantify the ERP components of interest (N1, P3, and LPP), a similar approach was used to that of Rosenblatt et al. (2018b), and the same regions of interest (based on electrode sites typically featured in image viewing literature) and time windows were selected (see also Olofsson et al., 2008). We quantified the N1 as the mean amplitude of four occipital electrodes at and adjacent to the midline (Oz, O2, O1, and Iz), in the time window of 125 to 200 ms after image presentation. Midline parietal electrodes

(CPz, Pz, and Oz) were used to measure the P3 (250-450 ms) and LPP (450-750 ms) components.

In order to examine the neural processing of SSB-related visual cues and the impact of HWLs on this, a series of two-way mixed ANOVAs were performed, with health or taste category as within-subjects factors, HWL condition (Specific, General, or Control) as a between-subjects factor, and ERP component (N1, P3, or LPP) as the outcome variable. Where significant effects for HWL condition were detected, post hoc, Bonferroni-corrected *t* tests were performed to examine pairwise differences.

Results

3.1 Participant Characteristics

The demographic, personality, and mental health-related participant characteristics are displayed in Table 1. Nineteen percent of the sample had a BMI within the overweight range, and almost four percent fell within the obese range. On average, the mean frequency of consumption rating reported in the rating stage was 3.69 (SD = 0.45), which means that on average, participants reported consuming these drinks at least a few times per month to a few times per year. Between the HWL conditions, there were no significant differences in any of the demographic characteristics or questionnaire results (see Table 1). There were also no significant differences between the HWL conditions in frequency of consumption of SSBs in the study, $\chi^2(2) = 0.71$, $p = .700$, nor on perceived healthiness, $F(2, 60) = 2.75$, $p = .072$; or tastiness, $F(2, 60) = 0.84$, $p = .435$ of SSBs. Overall, there was no evidence for any meaningful *a priori* differences between the groups, therefore none of the variables were included as a covariate for the main analysis, and the Control HWL condition was concluded to be a valid control group.

Table 1.

Demographic, personality, and mental health characteristics by HWL condition (N = 63), including tests for differences between the conditions.

Characteristic	General (n = 21)	Specific (n = 21)	Control (n = 21)	Test Statistic (χ^2/F)	p
Gender, n (%)				9.51(χ^2)	.050
Female	9 (42.9%)	13 (61.9%)	18 (85.7%)	n/a	n/a
Male	11 (52.4%)	8 (38.1%)	3 (14.3%)	n/a	n/a
Other	1 (4.8%)	0 (0%)	0 (0%)	n/a	n/a
Age, M (SD)	24.86 (6.05)	22.10 (4.52)	25.05 (5.49)	1.97 (F)	.148
BMI, M (SD)	23.20 (4.77)	21.77 (2.97)	21.45 (3.02)	1.35 (F)	.267
Underweight (BMI < 18.5), n (%)	3 (14.5%)	2 (9.5%)	0 (0%)	n/a	n/a
Healthy (BMI 18.5-24.9), n (%)	15 (71.4%)	14 (66.7%)	14 (66.7%)	n/a	n/a
Overweight (BMI 25-29.9), n (%)	2 (9.5%)	5 (23.8%)	5 (23.8%)	n/a	n/a
Obese (BMI ≥ 30), n (%)	1 (4.8%)	0 (0%)	2 (9.5%)	n/a	n/a
Perceived Healthiness of Diet, M (SD)	52.81 (20.63)	59.10 (16.46)	63.15 (18.16)	1.63 (F)	.204
Perceived Healthiness of Exercise, M (SD)	45.00 (24.79)	53.20[a] (26.11)	50.30[a] (25.67)	0.55 (F)	.582

Upbringing SES, M (SD)	59.81 (17.93)	60.38 (16.96)	64.38 (18.78)	0.41 (*F*)	.668
Current SES, M (SD)	41.76 (21.06)	43.70[a] (18.42)	52.05 (18.88)	1.64 (*F*)	.202
BAS Drive, M (SD)	10.75[a] (2.55)	11.45[a] (2.19)	11.26[b] (1.70)	0.55 (*F*)	.579
BAS Fun Seeking, M (SD)	11.70[a] (2.49)	11.60[a] (1.96)	12.37[b] (1.71)	0.78 (*F*)	.465
BAS Reward Responsiveness, M (SD)	17.15[a] (2.60)	17.50[a] (1.93)	17.32[b] (2.52)	0.11 (*F*)	.897
BIS, M (SD)	21.55[a] (3.02)	21.30[a] (2.68)	21.05[b] (3.60)	0.13 (*F*)	.883
STAI-State	39.47[b] (13.65)	36.55[a] (9.46)	38.26[b] (7.69)	0.38 (*F*)	.686
STAI-Trait	47.00[c] (12)	44.30[a] (8.98)	44.40[a] (8.52)	0.45 (*F*)	.638
BSQ-8d	20.84[b] (8.64)	19.90[a] (7.09)	20.29[a] (7.96)	0.07 (*F*)	.933
DASS21-D, M (SD)	4.30[a] (3.91)	4.10[a] (4.12)	4.52 (4.04)	0.11 (*F*)	.900
DASS21-A, M (SD)	4.70[a] (3.70)	4.40[a] (2.58)	3.33 (2.73)	0.82 (*F*)	.455
DASS21-S, M (SD)	6.20 (3.91)	6.25 (3.29)	4.33 (3.35)	1.42 (*F*)	.254

Note. M = Mean. SD = Standard Deviation. BMI = Body Max Index. SES = Socioeconomic Status. BAS = Behavioural Avoidance Scale. BIS = Behavioural Inhibition Scale. STAI = State Trait Anxiety Inventory. BSQ-8d = Body Shape Questionnaire. DASS21 = Depression Anxiety Stress Scales). Perceived healthiness of diet and exercise level range from 0 (Not at all Healthy) to 100 (Extremely Healthy) on a slider response scale. Upbringing and Current SES range from 0 (Extremely Poor) to 100 (Extremely Wealthy). BAS Drive, BAS Fun Seeking, BAS Reward

Responsiveness, BIS correspond to the four subscales of the Behavioural avoidance/inhibition scales (BIS/BAS). DASS21-D, DASS21-A, and DASS21-S correspond to depression, anxiety and stress scales of the DASS21 respectively.

[a] 1 missing value of score for label condition

[b] 2 missing values or scores for label condition

[c] 3 missing values or scores for label condition

3.2 Impact of HWLs on Willingness to Consume SSBs

A linear mixed-effects model was constructed with WTC as the dependent variable. HWL condition (with levels Control, General HWL, and Specific HWL), health and taste ratings (as continuous variables) were included as fixed factors, and participants and beverage stimuli were modelled as random factors. Given that HWL conditions were expected to potentially interact with health and taste ratings (as per Rosenblatt et al., 2018a), the two-way interactions HWL condition x health ratings, and HWL condition x taste ratings, as well as three-way interaction HWL condition x taste ratings x health ratings, were also included. The full model was then compared to a set of theoretically plausible but simpler models in which interaction terms and main effects were systematically removed, using a backward elimination approach (for the model structure and fit of all models investigated, see Supplementary Table S1). The removal of the three-way interaction significantly reduced the goodness of fit, $\chi^2(2) = 8.15$, $p = .017$.

Given that the full model was the best fitting, in the next step the beta values for each factor were analysed (see Table 2). The main effects of health and taste were significant. A significant two-way interaction effect was found between the General HWL condition and taste ratings, and between the Specific HWL condition and taste ratings. Finally, a small but significant three-way interaction effect was found between the General HWL condition, health ratings, and taste ratings. This suggests that the effect of General HWL at reducing WTC is greater for high-taste drinks, but if the drink is perceived to be healthy, this effect is reduced. The three-way interaction nevertheless provides evidence that while the interaction of HWL condition and taste was important in its own right, to fully understand the effect of HWLs on WTC, the interplay of all three factors had to be taken into account. However, it should be noted that the next best model, in which the three-way interaction was removed,

still provided a good fit, and also showed more substantial two-way interaction effects for HWL Condition with Taste and Health, respectively (see Supplementary Table S1).

Table 2.

Mixed effects model results for the most successful model, which explains willingness to consume SSBs by including raw taste ratings, health ratings, and HWL condition as fixed factors, along with interaction terms. Participants and stimuli were included as random effects.

Predictors	B (SE)	*p*
Intercept	1.99 (4.52)	.659
Health	0.15 (0.07)	.021*
Taste	0.57 (0.05)	< .001**
HWL Condition		
General	7.73 (5.86)	.188
Specific	2.26 (6.58)	.731
Health x Taste	-0.01 (0.01)	.908
HWL Condition x Health		
General HWL	-0.06 (0.09)	.542
Specific HWL	0.04 (0.11)	.718
HWL Condition x Taste		
General HWL	-0.35 (0.07)	< .001**
Specific HWL	-0.27 (0.08)	< .001**
HWL Condition x Health x Taste		
General HWL	0.01 (0.01)	.004**
Specific HWL	0.01 (0.01)	.139

* $p < .05$, ** $p < .001$

3.3 Condition-specific effects of HWLs on Willingness to Consume SSBs

The interactions between the HWL conditions, health, and taste ratings were further explored using a different, slightly simplified approach by looking into the health-taste categories of SSBs described in Section 2.5. For each participant, average willingness-o-consume (WTC) was calculated for each category (LHLT, HHHT, LHHT, HHLT) and averaged across all participants in each of the two meaningful HWL conditions. Next, WTC in the General and Specific HWL conditions was expressed as a percentage difference from the Control HWL condition - within each participant in the General and Specific HWL conditions, average WTC was calculated for each health-taste category and compared against the group average of the Control condition. These percentage scores indicated how much less (or more) WTC was expressed in each of the meaningful HWL conditions, compared to the Control HWL condition (Figure 3). A series of one sample *t* tests were conducted on this measure for both HWL conditions.

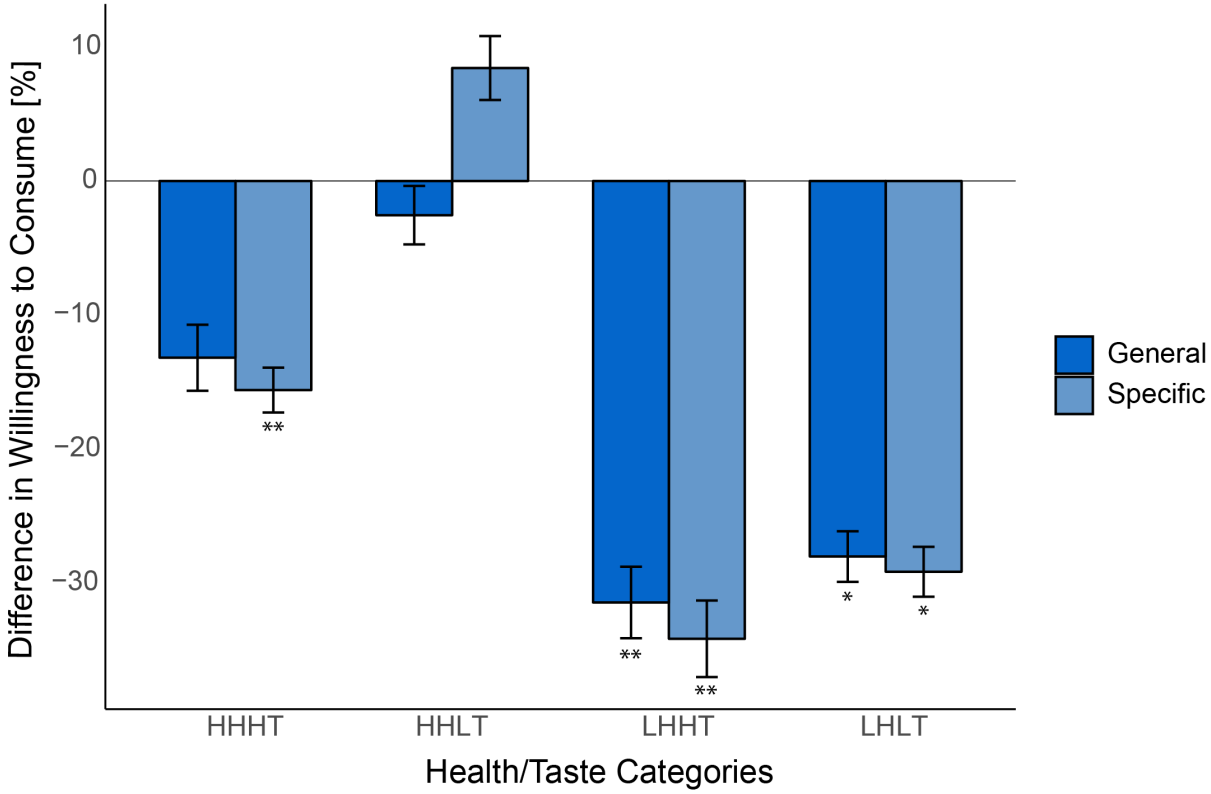

Figure 3. Proportion of difference from Control HWL condition in willingness to consume SSBs by perceived taste-health categories (High Health/High Taste, High Health/Low Taste, Low Health/High Taste, Low Health/Low Taste) for General and Specific HWL conditions. Error bars represent standard error of the mean. * $p < .05$, ** $p < .01$.

Firstly, the percentage scores for LHHT beverages in both the General and Specific HWL conditions were significantly lower than zero, $t(19) = -3.39$, $p = .003$, $d = .76$, and $t(20) = -3.55$, $p = .002$, $d = 0.77$, respectively. Both these effect sizes can be considered medium (Cohen, 1988). Secondly, for LHLT items, the average percentage scores in the General and Specific HWL conditions were also significantly lower than zero, $t(19) = -2.14$, $p = .046$, $d = 0.48$ and $t(20) = -2.32$, $p = .031$, $d = 0.51$, respectively. These effect sizes can be considered small (General HWL condition) and medium (Specific HWL condition; Cohen, 1988) respectively. For HHHT items, percentage scores were significantly lower than zero for the Specific HWL condition, $t(20) = -3.32$, $p = .003$, $d = .72$, but not the General HWL condition,

$t(20) = -1.74$, $p = .097$ For HHLT items, there were no significant differences from zero for the General, $t(20) = 0.51$, $p = .615$, or Specific HWL conditions, $t(20) = 1.53$, $p = .142$. There were no significant differences between the General and Specific HWL conditions for any of the four health-taste categories: HHHT, $t(40) = 0.29$, $p = .771$; LHHT, $t(39) = 0.22$, $p = .828$; HHLT, $t(40) = -0.72$, $p = .476$; LHLT, $t(39) = 0.07$, $p = .945$.

3.4 Relationship Between Participant Characteristics and Willingness to Consume SSBs after HWL Exposure

Explorative correlational analyses were conducted to investigate whether the effects of HWLs, as calculated in Section 3.3, were associated with sociodemographic (age, BMI, diet, exercise, and SES), personality and mental health characteristics (the BIS/BAS subscales, STAI subscales, BSQ-8d, and DASS21 subscales). Note that for this analysis, participants in the Control condition were necessarily excluded, as they were not exposed to real HWLs and the effect of HWL was calculated relative to the average of this group. To maximise statistical power, and because effects for general and specific HWLs were very similar, results were averaged across both HWL conditions here. A positive correlation was found between the effect of HWLs for HHLT beverages and BAS-RR subscale scores, $r = .33$, $p = .043$. There was also a negative correlation between age and the effect of HWLs for HHLT beverages, $r = -.34$, $p = .031$. No other significant correlations were found between the effect of HWLs and any other demographic or mental health-related variables (see Supplementary 3 for correlation tables and statistical tests).

3.5 EEG Results

A series of ANOVAs were conducted to examine both within- and between-subjects effects on the three ERP components of interest (N1, P3, and LPP).

For the first set of analyses, we pooled items into high vs low Health irrespective of Taste, and high vs low Taste irrespective of Health, respectively. A two-way mixed ANOVA

with Health (High Health; HH, Low Health; LH) as a within-subjects factor and HWL condition (General, Specific, Control) as a between-subjects factor showed a significant main effect of Health on the N1 component, $F(1, 60) = 6.93$, $p = .011$, whereby amplitudes were more negative-going for HH compared to LH items (illustrated in Figure 4A). There was no significant main effect of HWL Condition, $F(2, 60) = 1.08$, $p = .348$, nor was there a Health x HWL Condition interaction effect, $F(2, 60) = 0.65$, $p = .528$. A separate ANOVA for high vs low Taste showed no main effect of Taste, $F(1, 60) = 0.57$, $p = .455$, nor a Taste x HWL Condition interaction effect, $F(2, 60) = 0.19$, $p = .825$.

For the P3 component, an ANOVA (structured as above) for Health showed a trend toward a difference between the HWL conditions, $F(2, 60) = 3.05$, $p = .055$. Post-hoc, Bonferroni-corrected pairwise comparisons showed no significant differences, but a trend toward significance when comparing the General and Specific HWL groups, $t(19) = -0.54$, $p = .094$. There was no main effect of Health, $F(1, 60) = 0.28$, $p = .597$, nor a Health x HWL Condition interaction effect, $F(2, 60) = 0.53$, $p = .591$. A separate ANOVA for Taste found no main effect of Taste, $F(1, 60) = 0.89$, $p = .348$, nor a Taste x HWL Group interaction effect, $F(2, 60) = 0.02$, $p = .978$.

For LPP amplitudes, the ANOVA for Health found that there was no main effect of Health, $F(1, 60) = 2.34$, $p = .131$, nor an interaction effect between Health x HWL Condition, $F(2, 60) = 0.22$, $p = .806$, and a trend toward a main effect of HWL Condition, $F(2, 60) = 2.76$, $p = .071$, although pairwise Bonferroni-corrected post hoc tests found no significant differences between the groups. The respective ANOVA for Taste found a main effect of Taste, $F(1, 60) = 8.96$, $p = .004$ (illustrated in Figure 4B), but no Taste x HWL Condition, $F(2, 60) = 0.32$, $p = .944$.

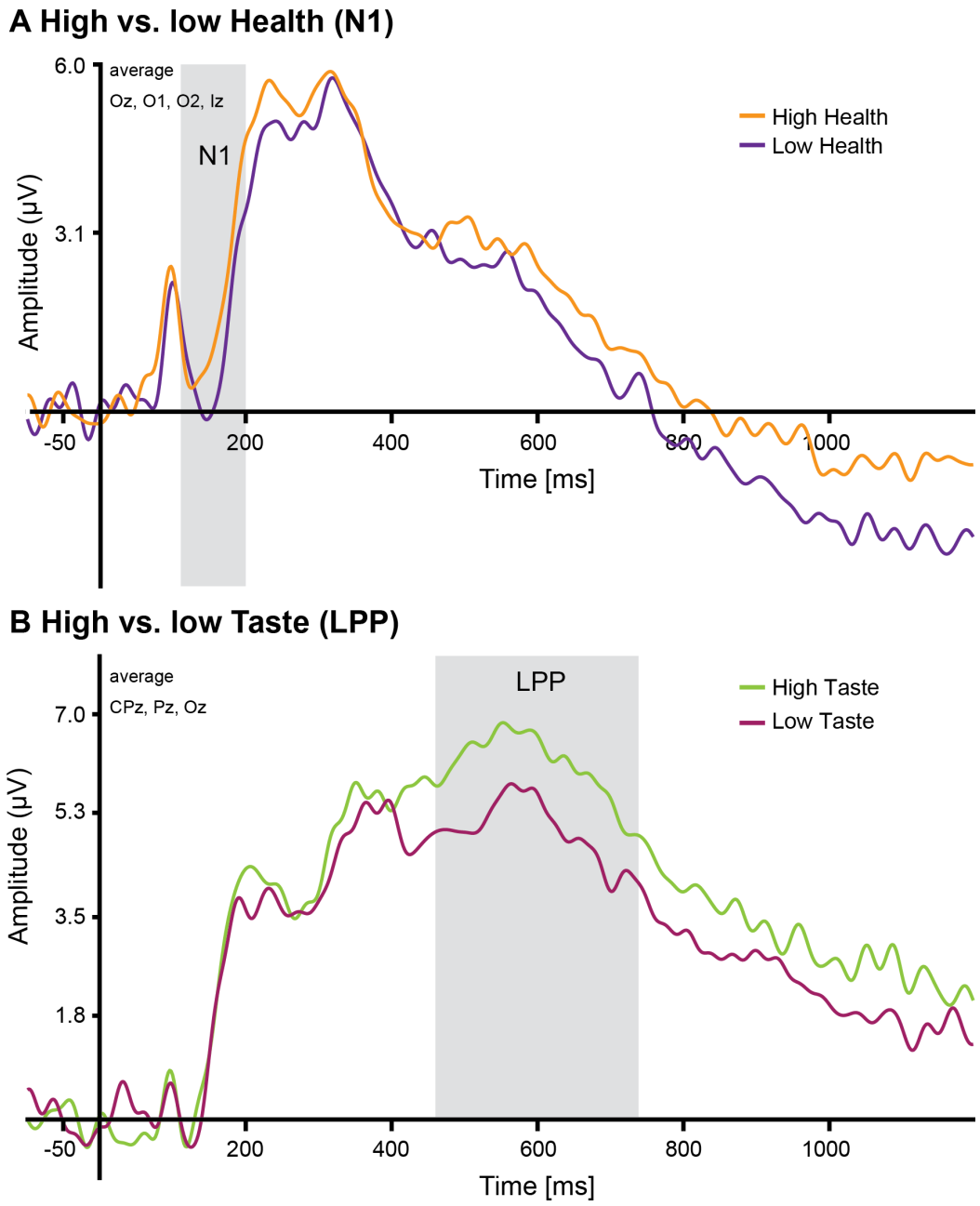

Figure 4. Displayed are: A) Significant differences in the N1 amplitudes for the comparison low vs. high Health (illustrated here for the average of all HWL conditions; results were similar for all three conditions). B) Significant differences in the LPP amplitudes for the comparison low vs. high Taste (illustrated here for the average of all HWL conditions; results were similar for all three conditions).

We further conducted more detailed ANOVAs using the separate item groups (HHHT, HHLT, LHHT, LHLT) as the within-subjects factor and, as before, HWL condition (General, Specific, Control) as a between-subjects factor to investigate whether there were more specific effects of HWL condition on the ERP components of interest. Given that most of these tests were negative, the detailed results are not reported here. Most importantly, again no significant differences between HWL Conditions emerged for any of the ERP components. The only relevant effect was a main effect for health-taste category for LPP amplitude, $F(1, 60) = 7.05$, $p = .010$. Follow-up analyses revealed lower amplitudes for HHLT compared to the problematic item group of highly craved but unhealthy LHHT items in each HWL condition (Figure 5).

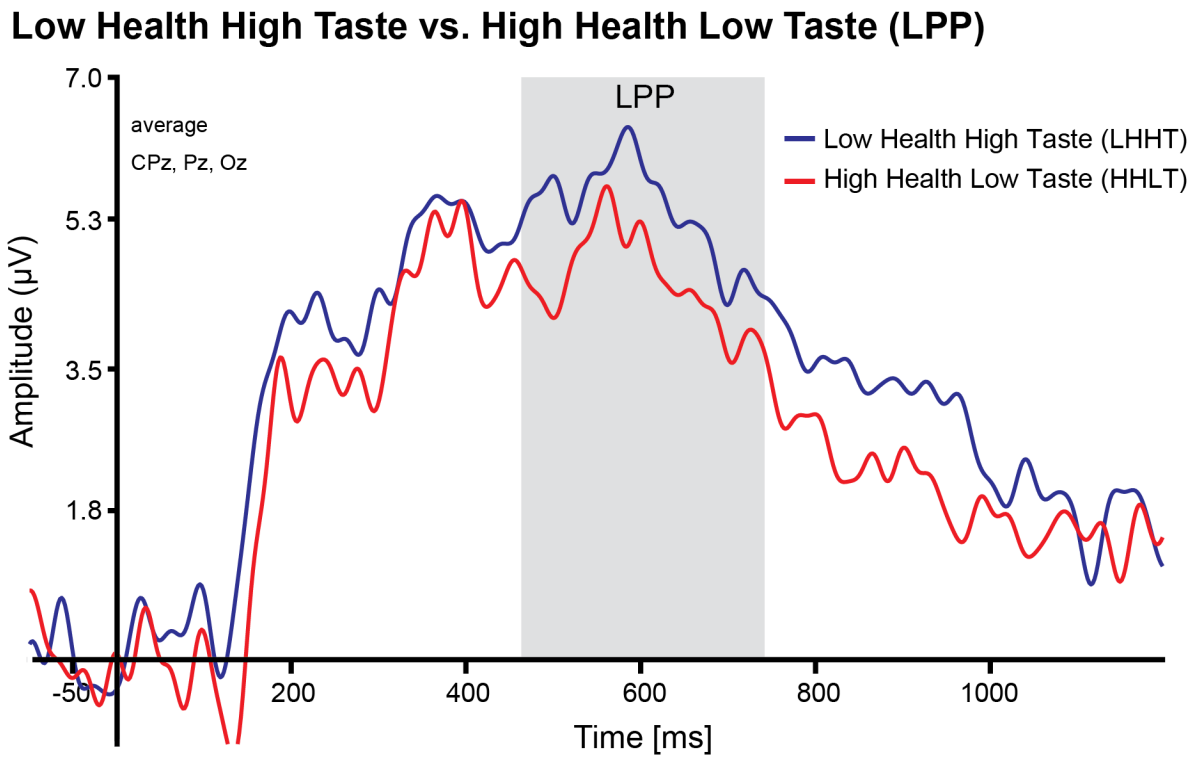

Figure 5. Displayed are the LPP amplitudes for low health, high taste (LHHT) and high health, low taste (HHLT) beverages, averaged across HWL conditions (each condition had a very similar profile).

Discussion

The present study provides evidence that graphic HWLs can effectively modulate dietary choices for SSBs and sheds light on the neural processing of SSB-related cues. We found that participants who viewed graphic HWLs were less willing to consume beverages, in particular those that they considered to be tasty, compared to participants in the control condition. Further, we found that the effectiveness of general HWLs was reduced for SSBs considered to be healthy, while specific HWLs were effective at decreasing WTC for tasty SSBs, regardless of perceived healthiness. We also found evidence for enhanced neural processing of health reflected by the N1 component, and for taste reflected by the LPP component. We did not find strong evidence for a modulation of neural signals due to HWLs, and only a trend towards stronger P3 components for general compared to specific HWL. This suggests that although behaviour showed effects for HWLs, the neural processing was clearly dominated by the features of the SSBs.

Our linear mixed effects model suggested that both specific and general HWLs effectively reduced willingness to consume SSBs, and that this reduction was greater for SSBs perceived as tasty, compared to less tasty. The follow-up analyses, which operationalised the effects of HWLs relative to the control group, also showed that both types of HWLs reduced willingness to consume SSBs perceived as unhealthy, compared to the control group. Both HWL groups differed from the control group in WTC most strongly for SSBs rated as unhealthy and tasty. This result is consistent with previous laboratory-based findings indicating that aversive images and negatively framed graphic HWLs can discourage consumption of unhealthy food and beverage items, reflected by lower self-reported desire to consume them (Rosenblatt et al., 2018a; Bollard et al., 2016; Grummon & Hall, 2020; Scully et al., 2020), and lower likelihood of choosing them in vending machine simulations (Hollands & Marteau, 2016; Billich et al., 2018; Grummon & Hall, 2020; VanEpps &

Roberto, 2016). The success of negatively framed HWLs in promoting food and beverage-related behavioural change is likely due to their ability to elicit strong negative emotions (e.g., fear) and, in turn, lead to greater consideration of health risks (Donnelly et al., 2018; Rosenblatt, et al., 2019). HWLs may also modulate dietary choices through undermining positive perceptions of the product – for example, Bollard et al. (2016) found that graphic HWLs reduced perceptions of SSBs as "cool" and "fashionable". Finally, HWLs may act as a priming tool, activating health goals by making the health information surrounding food and beverage cues more salient (Papies, 2016). In the present study, the HWLs may have drawn attention to the health aspects of the SSBs, leading to greater consideration of health over tastiness.

Although we found that exposure to HWLs was related to reduced preference for tasty items, for the general HWL condition there was a three-way interaction between HWL condition, health, and taste, which suggests that the positive impact of general HWLs is lessened when drinks are perceived as healthy. The lack of a similar three-way interaction for specific HWLs might suggest that they are more effective than general HWLs at reducing desire to consume SSBs, as they reduced desire for tasty SSBs, regardless of the drink's perceived health. This was supported by the follow-up analyses – the general HWL condition did not differ from the control group in their desire for SSBs perceived as healthy and tasty, suggesting that general HWLs had no effect on these types of SSBs. Conversely, participants who viewed specific HWLs were less willing than the control group to consume SSBs perceived as healthy and tasty, suggesting that specific HWLs may have decreased willingness to consume all SSBs in the study, not just those considered unhealthy. The apparent success of specific HWLs supports research on cancer-related HWLs on alcohol packaging (Pettigrew et al., 2016; Miller et al., 2016; Blackwell et al., 2018; Wilkinson & Room, 2009), which found that specific HWLs reduced intended alcohol consumption more

effectively than general HWLs. However, while these studies focused on the advantages of HWLs stating specific health consequences, the present study suggests an additional advantage for product-specific HWLs, warning of the consequences of consuming SSBs over an unhealthy diet in general. This may be because specific HWLs could simultaneously increase awareness about the health consequences of SSBs, which is generally low (Miller et al., 2019), and elicit negative emotions. Conversely, general HWLs may elicit negative emotions, but if individuals still do not believe that SSBs are unhealthy, their willingness to consume them is unlikely to be changed. It should be noted, however, that albeit significant, these interaction effects were rather small, most likely due to the relatively small sample size and the substantial variation in perceived taste and health characteristics for individual items.

Although we found some evidence that the effect of specific HWLs depended less on the characteristics of the SSB items, compared to general HWLs, there was no strong advantage of either type of HWL for drinks perceived to be unhealthy. This result may have arisen because although the specific HWLs may have reduced perceived healthiness of SSBs overall, both types of HWLs were likely to have elicited a similar level of negative emotion. Firstly, as the relationship between an unhealthy diet and adverse health conditions is well-established, the general HWLs may have conveyed a similar sense of threat to the specific HWLs. Secondly, two of the six images in the specific HWL condition contained sugar content warnings and images, which are less likely to have increased negative emotional arousal than the graphic HWL images (Mantzari et al., 2018) and may have weakened the effect of the specific HWLs. A recent meta-analysis (Grummon & Hall, 2020) and systematic review (Gupta et al., 2020) both found that SSB warnings about diet-related health consequences tend to be more effective than those highlighting sugar content or other nutritional attributes. Future studies could systematically test whether graphic images illustrating health consequences versus sugar content produce stronger effects when

accompanied by SSB-specific versus general HWL text captions. Finally, the images used here were always of a general nature – only the text differed between general and specific labels. This may suggest that the most persuasive element of each HWL was the image itself, with the text being less important. This is in line with a recent study which found that image-only HWLs were more effective at reducing alcoholic drink choice than image-and-text HWLs (Clarke et al., 2020). However, it seems impossible to create SSB-specific images (without depicting general health consequences) that could elicit comparably strong negative affect. Hence, in reality graphic HWLs relating purely to the consequences of consuming SSBs specifically might be difficult to create, and HWLs with a "health general" core message may be just as effective. Future studies should, however, directly assess consumer perceptions associated with each label type, to gain insight into the psychological mechanisms underlying their effects.

The EEG results showed that on average, N1 amplitudes were higher in response to beverages considered relatively unhealthy compared to those considered relatively healthy. This finding has implications for the neural processing of SSB-related cues, suggesting that early cognitive processes may already reflect differences in perceived health (Rosenblatt et al., 2018b). Considering that all drinks were perceived as relatively tasty (and the division into high and low taste was only relative), the difference in N1 amplitudes may reflect enhanced allocation of attention toward unhealthy but desirable beverages (Carbine et al., 2018), highlighting the pervasiveness of learned craving responses. This further highlights the strong early automatic processing that any effect of HWLs must overcome to trigger behavioural change. The LPP result for taste may be related to differences in conscious allocation of attention to tasty beverages, or motivation-related arousal (Carbine et al., 2018; Hajcak, MacNamara, & Olvet, 2010), which provides some evidence that cues for different types of SSBs are processed differently in the brain. Taken together, these two findings also

suggest that previous research showing differences in N1 and LPP components between the viewing of highly palatable versus less palatable food items (see Carbine et al., 2018) can be extended to apply to SSBs. This could be useful for future studies in investigating the effectiveness of interventions designed to reduce consumption of SSBs.

Interestingly, unlike the N1 and LPP, the P3 component did not show any differences between SSB categories. As an increased P3 component in response to palatable food cues has been shown fairly consistently in previous studies (see Carbine et al., 2018), not finding health- or taste-related effects was unexpected. This discrepancy may be explained by the fact that packaged drink stimuli are by nature more complex than commonly used food stimuli (e.g., Food-Pics database; Blechert, Meule, Busch, & Ohla, 2014). The P3, like the LPP, is thought to reflect conscious attentional allocation processes (Carbine et al., 2018). However, given that the following component (the LPP) showed taste-related differences at the same channels, and visual inspection of the waveforms show the same trend in the data for the P3, the absence of effects should be interpreted with caution. As discussed below, while using a relatively large sample for typical EEG studies, our study was nevertheless limited by the sample size for these analyses. Future studies should examine this in more detail by directly comparing ERP amplitudes between food versus beverage stimuli or branded versus non-branded stimuli.

The second goal of our EEG analysis was to use the N1, P3, and LPP to examine the effectiveness of the HWLs at reducing neural responses to unhealthy, desirable SSBs. While the qualitative pattern of results for the P3 and LPP indeed pointed in this direction (comparable to Rosenblatt et al., 2018a), these results were not significant, and only trends toward significance were found between the General HWL and Control conditions. As the LPP component often reflects arousal (Hajcak et al., 2010), and within participants was larger for tasty compared to less tasty drinks, and amplitudes were also increased for “craved” low

health, high taste beverages compared to high health, low taste beverages, it is likely that an increased LPP reflected increased craving. In turn, a reduction of the LPP, as observed by trend for General HWLs, may indicate a reduced craving response for those who viewed General HWLs, compared to controls. This trend, however, should not be over-interpreted and is more indicative that despite their effectiveness, HWLs did not seem to have strong effects on the neural signature of SSB processing. As mentioned above, this may have been due to the relatively small sample size and between-subjects design that made it difficult to detect a potentially small effect that was additionally masked by stronger effects of the SSB/craving responses, which were processed in the same time window. Note that the SSBs in this study were all high on sugar content, and objectively very few drinks were truly "healthy" (i.e. only the non-flavoured water and some milk-based drinks), while the snack foods used in Rosenblatt et al. (2018b) included relatively more healthy and potentially fewer craved options (e.g., some vegetables and fruits). Hence, it is possible that differences in ERPs to HWLs between these studies were due to differences in the strength of craving responses to the food and beverage cues and their ability to mask the HWL effects on the same components. Therefore, these findings therefore also suggest that while being successful in altering behaviour, HWLs for SSBs may not easily change the strong, craving-related neural processes that are observed during exposure to products. However, if HWLs on SSBs were implemented as a policy, the repeated pairing of SSBs with images depicting their negative health consequences may result in an eventual breakdown of these processes (Hollands & Marteau, 2016). Future research may examine this by examining the neural effects of HWLs in longitudinal studies.

The present study has several strengths. Firstly, the between-subjects design made it difficult for participants to intentionally manipulate their responses, as they were unaware that other participants were exposed to different HWL conditions. Secondly, the

incorporation of EEG allowed the examination of early, automatic cognitive processes, which is not possible in a purely behavioural task. Finally, participants were told that they would receive an SSB at the end of the task, selected based on their responses. This may have encouraged participants to give accurate WTC ratings that would correspond to their real-life decisions. However, this is not guaranteed, and this study therefore cannot directly reveal the impact of HWLs on real SSB consumption. Another limitation is that our sample (of mostly young university students) showed lower rates of overweight/obesity than the Australian adult population (35.6% overweight and 31.3% obese, 40-50% for young adults; Australian Bureau of Statistics, 2018). This means that it remains to be tested whether these results would generalise to obese participants, or those with less education. Graphic HWLs may be perceived as stigmatising by people with obesity, and may also increase weight-related stigma in healthy participants (Hayward & Vartanian, 2019). This might undermine their effectiveness in obese participants, which the present study did not examine. Future studies and policy-makers should carefully consider the effects of implementing graphic HWLs on food and beverage packaging, to ensure that the costs do not outweigh the benefits.

In conclusion, the present experimental study contributes to our understanding of the efficacy of graphic HWLs as a population-based strategy in tackling growing overweight and obesity rates, which in turn are linked to a range of physical and mental health problems. This is the first study to examine the difference between SSB-specific HWLs compared to more general, diet and weight-based HWLs in modulating consumers' willingness to consume SSBs. We found that both HWL types effectively decreased willingness to consume SSBs subjectively perceived as being tasty, but this effect was reduced for general HWLs when the SSBs were perceived as healthy. This provides evidence for a small advantage of SSB-specific HWLs, but further research is required to determine whether different specific HWLs, more likely to elicit negative emotions, may be more effective. Our EEG results

further shed light on the neural processing of SSBs, and they show no strong modulations of craving-related neural signals by HWLs. Further studies, in particular in a real-world context, are now required to examine the effectiveness of different HWLs in purchasing scenarios, in order to inform which types will be superior for obesity prevention interventions.

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Author Contributions

S.B., H.D., Y.K., M.W. conceptualised the research. S.B., M.B. designed the research. M.B. programmed the task. M.B., C.L., E.R., E. Schubert collected the data. E. Schubert, E. Smith, M.B. analysed the data. E. Schubert, E. Smith, S.B. wrote the paper. All authors contributed to revisions of the manuscript, discussed the results, and have approved the final article.

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3.3 Supplementary Materials

Supplementary Material

General and specific graphic health warning labels reduce willingness to consume sugar-sweetened beverages

Elektra Schubert[1], Emma Smith[1], Maja Brydevall[1], Carmen Lynch[1], Elysha Ringin[1], Helen Dixon[2], Yoshihisa Kashima[1], Brian Oldenburg[3], Melanie Wakefield[2], Stefan Bode[1,4,*]

[1] Melbourne School of Psychological Sciences (MDHS), The University of Melbourne, Australia

[2] Centre for Behavioural Research in Cancer, Cancer Council Victoria, Australia

[3] Melbourne School of Population and Global Health (MSPGH), The University of Melbourne, Australia

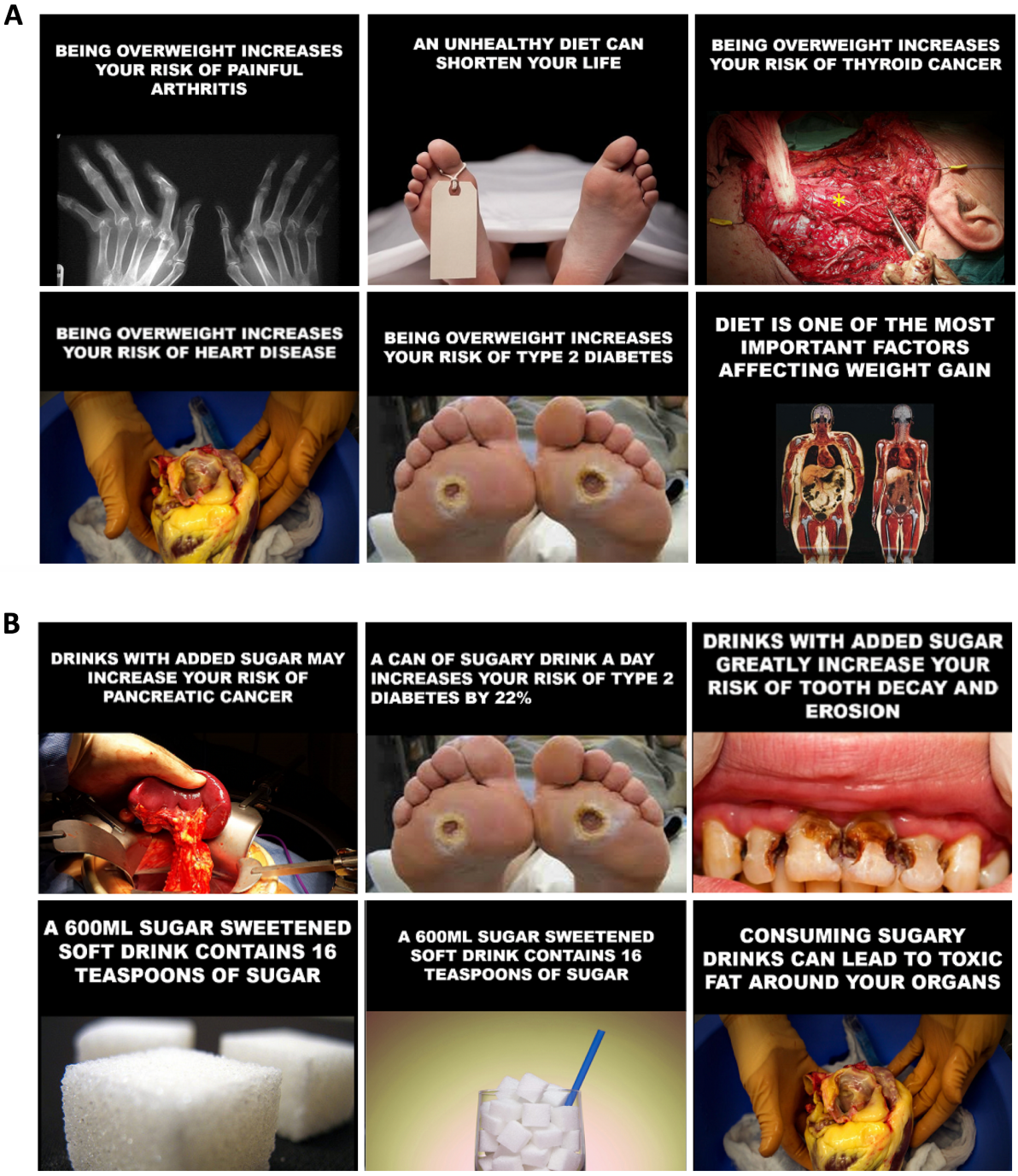
[4] Department of Psychology, The University of Cologne, Germany

* Corresponding author: A/Prof Stefan Bode, Melbourne School of Psychological Sciences, The University of Melbourne, Parkville, VIC, 3010, Australia; email: sbode@unimelb.edu.au; phone: +61(0)390353849

Supplementary Material 1

Relationship Between Participant Characteristics and Willingness to Consume SSBs after HWL Exposure

Explorative correlational analyses were conducted to investigate whether the effects of HWLs, as calculated in Section 3.3, were associated with sociodemographic (age, BMI, diet, exercise, and SES), personality and mental health characteristics (the BIS/BAS subscales, STAI subscales, BSQ-8d, and DASS21 subscales). Note that for this analysis, participants in the Control condition were necessarily excluded, as they were not exposed to real HWLs and the effect of HWL was calculated relative to the average of this group. To maximise statistical power, and because effects for General and Specific HWLs were very similar, results were averaged across both HWL conditions here. A positive correlation was found between the effect of HWLs for HHLT beverages and BAS-RR subscale scores, $r = .33$, $p = .043$. There was also a negative correlation between age and the effect of HWLs for HHLT beverages, $r = -.34$, $p = .031$. No other significant correlations were found between the effect of HWLs and any other demographic or mental health-related variables (see Supplementary 3 for correlation tables and statistical tests). Due to the exploratory nature of these analyses, and the small sample size for this purpose, future studies should attempt to replicate these findings with a larger sample.



Supplementary Figure S1. Full set of health warning label (HWL) stimuli used, for the (A) General and (B) Specific HWL conditions.

***Supplementary Table S1*:** Null model with willingness to consume (WTC) as an outcome variable, with Participant ID and Drink as random effects.

Predictors	β (SE)	p
Intercept	40.53 (2.44)	< .001***

***Supplementary Table S2*:** Mixed effects model with willingness to consume (WTC) as an outcome variable, with Participant ID and Drink as random effects, and Group as a fixed effect.

Predictors	β (SE)	p
Intercept	45.88 (3.45)	< .001***
HWL Condition		
General	-8.57 (4.30)	.051
Specific	-7.49 (4.31)	.089

***Supplementary Table S3*:** Mixed effects model with willingness to consume (WTC) as an outcome variable, with Participant ID and Drink as random effects, and Health and Group as fixed effects.

Predictors	β (SE)	p
Intercept	29.82 (3.15)	< .001***
Health	0.32 (0.02)	< .001***
HWL Condition		
General	-6.62 (3.89)	.094
Specific	-6.61 (3.90)	.095

***Supplementary Table S4*:** Mixed effects model with willingness to consume (WTC) as an outcome variable, with Participant ID and Drink as random effects, and Taste and Group as fixed effects.

Predictors	β (SE)	p
Intercept	16.53 (3.42)	< .001***
Taste	0.46 (0.02)	< .001***
HWL Condition		
General	-7.19 (4.04)	.080
Specific	-7.32 (4.05)	.075

***Supplementary Table S5*:** Mixed effects model with willingness to consume (WTC) as an outcome variable, with Participant ID and Drink as random effects, Taste, Health, and Group as fixed main effects, and interaction effects between Group x Health and Group x Taste.

Predictors	β (SE)	p
Intercept	2.30 (3.67)	.532
Taste	0.56 (0.03)	< .001***
Health	0.15 (0.03)	< .001***
HWL Condition		
General	-0.16 (4.89)	.975
Specific	-3.67 (5.17)	.478
HWL Condition x Taste		
General	-0.22 (0.05)	< .001***
Specific	-0.18 (0.05)	< .001***
HWL Condition x Health		
General	0.18 (0.04)	< .001***

Specific	0.18 (0.04)	< .001***

***Supplementary Table S6*:** Mixed effects model with willingness to consume (WTC) as an outcome variable, with Participant ID and Drink as random effects, Taste, Health, and Group as fixed main effects, and interaction effects between Group x Health, Group x Taste, and Health x Taste.

Predictors	β (SE)	p
Intercept	7.55 (4.02)	.061
Taste	0.48 (0.04)	< .001***
Health	0.03 (0.05)	.544
HWL Condition		
General	-1.41 (4.91)	.774
Specific	-3.97 (5.17)	.443
Health x Taste	0.01 (0.01)	.001**
HWL Condition x Taste		
General	-0.20 (0.05)	< .001***
Specific	-0.17 (0.05)	< .001***
HWL Condition x Health		
General	0.18 (0.04)	< .001***
Specific	0.18 (0.04)	< .001***

***Supplementary Table S7*:** Backward elimination approach, comparing the full model (with all main and interaction effects included) to a series of theoretically plausible but simpler models.

Model	χ^2	*p*

HWL Condition + Taste + Health + Condition*Health + Condition*Taste + Health*Taste	8.15	.017**
HWL Condition + Taste + Health + Condition*Taste + Condition*Health	18.52	< .001***
HWL Condition + Taste + Health	62.00	< .001***
HWL Condition + Health	461.48	< .001***
HWL Condition + Taste	191.55	< .001***
HWL Condition	630.29	< .001***
Null Model	634.83	< .001***

Supplementary Table S8: Pearson product-moment correlations of percentage difference scores for each health-taste category with sociodemographic characteristics.

Category	Age	BMI	Diet	Exercise	Upbringing SES	Current SES
HHHT	-.25	-.24	.13	.07	.08	.02
LHHT	-.34*	-.19	.18	.09	-.13	.12
HHLT	.10	-.21	.27	.17	-.12	.22
LHLT	-.24	-.08	.11	.15	-.13	.07

Note. * $p < .05$. BMI = Body Mass Index. SES = Socioeconomic Status. Gender was excluded from analysis due to inability to correlate percentage change scores with a nominal variable with three categories (male, female, other) and large proportion of females in the sample.

Supplementary Table S9: Pearson product-moment correlations between percentage difference scores for each health-taste category and personality and mental health characteristics.

Category	BAS-D	BAS-FS	BAS-RR	BIS	STAI-S	STAI-T	BSQ-8d	DASS21-D	DASS21-A	DASS21-S
HHHT	.16	.29	.26	.08	.08	.07	.05	-.07	.23	-.04
LHHT	-.02	.14	.15	-.03	.21	.17	-.17	.03	.12	-.21
HHLT	.28	.29	.33*	-.20	.07	-.07	-.02	-.08	.14	-.17
LHLT	.12	.07	.13	-.13	.19	.11	-.10	-.08	.15	-.23

Note. * $p < .05$. BAS = Behavioural Avoidance Scale. BIS = Behavioural Inhibition. STAI = State-Trait Anxiety Inventory. BSQ-8d = Body Shape Questionnaire. BAS-D, BAS-FS, BAS-RR, and BIS correspond to the four subscales of the Behavioural Avoidance/Inhibition Scales (BAS/BIS). DASS21-D, DASS21-A, and DASS21-S correspond to the Depression, Anxiety, and Stress scales of the DASS21 respectively.

3.4 Summary

In this study, we examined the effects of graphic HWLs on consumption decisions for sugary drinks. This was done using an EEG task in which participants viewed general HWLs, SSB- In this study, we examined the effects of graphic HWLs on consumption decisions for sugary drinks. This was done using an EEG task in which participants viewed general HWLs, SSB-specific HWLs, or control images, before making decisions on how much they wanted to consume a variety of beverage products.

In our behavioural analyses, we addressed the first two aims of the study, which were to (a) examine the effects of HWLs on WTC drinks, and (b) compare the effectiveness of general versus product-specific HWLs at changing consumption decisions. Regarding the first aim, our results supported the hypothesis that overall WTC would be lower for participants who viewed a HWL (either general or specific), compared to those in the control condition. This suggests that graphic HWLs may discourage the consumption of sugary drinks, which is in line with previous studies that used similar hypothetical paradigms (Billich et al., 2018; Bollard et al., 2016), as well as those conducted in more naturalistic settings such as a hospital cafeteria (Donnelly et al., 2018) and convenience store replica (Grummon et al., 2019b). In relation to the second aim, we found no direct differences in WTC between general and specific HWLs. However, we did find a three-way interaction between taste, health, and HWL condition for the general but not specific HWL group. This interaction showed that the effectiveness of general HWLs decreased as perceived healthiness of the drink increased, or in other words, general HWLs were less effective at changing consumption decisions for “healthy” SSBs. Specific HWLs, however, remained constant in their effectiveness regardless of perceived healthiness. This suggests that HWLs may be more effective when they are SSB-specific, as they could overcome the potential issue of consumers being unaware of the health risks of SSBs (Miller et al., 2019).

The third aim of Study 2 was to explore the neural mechanisms of SSB processing during decision-making. Using an exploratory approach, we first tested whether three ERP components, the N1, P3, and LPP, differed when participants made decisions regarding drinks of different tastiness and healthiness levels. The P3 did not seem to reflect either attribute, as it did not significantly differ between drinks that were high versus low on tastiness or healthiness. The N1, however, was more negative for foods that were considered unhealthy compared to healthy. As the N1 has previously been associated with early and automatic attentional allocation (Vogel & Luck, 2000), this result may suggest that people automatically orient their attention toward unhealthy drinks, consistent with previous EEG studies on food cue processing (Carbine et al., 2018; Rosenblatt et al., 2018b). Further, the LPP was more positive in amplitude for foods considered to be tasty compared to those lower in tastiness. Consistent with previous studies, this suggests that the LPP may reflect early craving and arousal responses that occur in the first second of a dietary decision (Carbine et al., 2018). Finally, we compared the same ERP components between the three conditions (general HWL, specific HWL, and control), but found no significant differences. Although this result may have occurred due to the between-subjects design which makes it difficult to detect small differences between ERP components, it could also suggest that although HWLs can change intended behaviour, they do not result in changes to strong, early, craving-related responses to SSB cues.

Although HWLs have potential as a powerful public health intervention, dietary decisions are also influenced by other factors. One such factor may be incidental emotions, which can be triggered by internal and external stimuli. It is possible that in Study 2, the changes seen in the HWL groups were at least partially a result of emotional changes, as previous studies have found the effects of HWLs on SSB decision-making to be mediated by negative emotionality (Donnelly et al., 2018). In the following chapter, however, we moved

our focus away from HWLs and focused purely on the effects of both positive and negative emotions on dietary decisions. Given the importance of perceived tastiness and healthiness in the linear mixed effect models of Study 2, we continued to measure participant perceptions of these attributes and include them in our analyses.

Chapter 4: Study 3

The following chapter presents a final empirical study with two experiments, investigating the effects of incidental positive and negative emotions and emotion regulation on dietary decisions. This study was submitted for publication to *Appetite*, and is presented in its submitted form, formatted according to American Psychological Association (APA) guidelines (7th edition).

4.1 Aims

The broad aims of Study 3 were to examine the effects of incidental emotions and the regulation of these emotions on dietary decisions. Experiment 1 was focused on negative emotions, and the down-regulation (i.e., decreasing the intensity) of these emotions using two strategies, reappraisal and distraction. In Experiment 2, we shifted our focus to positive emotions, and explored the effects of the down-regulation, via the same two strategies, and up-regulation (i.e., increasing the intensity) of these emotions. In each experiment, we investigated the different strategies within separate samples, to simplify the process of instructing participants to regulate their emotions.

Both experiments involved a similar task setup and paradigm. First, participants rated a set of food images on both tastiness and healthiness. Second, they viewed instructions and an example for their allocated emotion regulation strategy, and were told to apply these instructions when they saw the word “Regulate” during the next part of the task. The next part was the main experiment, which comprised a series of trials, each beginning with an instructional cue or either “Regulate” or “Look” (which would involve the participant passively allowing any emotions to unfold). An image then appeared, selected to be either neutral or emotional (i.e., negative for Experiment 1, positive for Experiment 2) in valence. Participants responded to the image based on the cued instruction. Finally, a food image appeared, and participants rated their current WTC.

In both experiments, we addressed the aim of the study by comparing WTC ratings between different trial types. In Experiment 1, we expected that negative emotional experience would lead to increased WTC, hypothesising that ratings would be higher after passively viewing negative images compared to neutral. We expected that regulating these emotions via both strategies would mitigate the effect of negative emotional experience, such that WTC ratings would be lower when regulating in response to negative images, compared to passively viewing them. In Experiment 2, we expected that experiencing positive emotions would also increase desire for food, and hypothesised that WTC ratings would be higher after passively viewing positive versus neutral images. Finally, as the effects of regulating positive emotions have scarcely been studied, we did not form specific hypotheses regarding emotion regulation in Experiment 2; however, we explored the effects of emotion regulation on dietary choice by comparing trials in which participants passively viewed positive images (i.e., experienced positive emotions), compared to those where they were instructed to regulate their emotional response.

4.2 Manuscript

Positive Emotions and their Upregulation Increase Willingness to Consume Healthy Foods

Elektra Schubert[1], Stefan Bode[1*]

[1] Melbourne School of Psychological Sciences, The University of Melbourne, Australia

* Corresponding author: Stefan Bode, Melbourne School of Psychological Sciences, The University of Melbourne, Parkville, VIC, 3010, Australia; email: sbode@unimelb.edu.au

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Abstract

While highly relevant for everyday life, it is unclear whether experiencing incidental positive or negative emotional states, and active emotion regulation, influence the weighting of perceived taste and health in food choices. In Experiment 1, we examined two emotion regulation strategies, reappraisal and distraction, used to decrease negative emotions. Participants were cued to experience or decrease their emotional response for either neutral or negative incidental emotion-inducing images. They subsequently rated their willingness to consume foods, which varied in their taste and health attributes. Mixed-effects model analysis showed that compared to neutral, negative emotions decreased willingness to consume, regardless of perceived taste and health, but neither emotion regulation strategy had a significant effect. Experiment 2 used images inducing incidental positive emotions in combination with three emotion regulation strategies: reappraisal, distraction, and increasing positive emotions. Experiencing positive emotions generally increased willingness to consume, with stronger effects for tasty and healthy foods. Decreasing positive emotions via reappraisal decreased willingness to consume, particularly for healthy foods. Increasing positive emotion intensity further increased willingness to consume, with stronger effects for healthy foods. The results suggest that experiencing positive emotions increases desire particularly strongly for healthy foods, which can additionally be modulated via emotion regulation. This has important implications for designing health-related interventions targeting mood improvement.

1 Introduction

Emotions play an important role in shaping human decision-making (LeBlanc et al., 2014; Lerner et al., 2015). The object of a decision may elicit direct affective responses, which have been termed integral emotions (Loewenstein & Lerner, 2003). However, decision-makers often also experience *incidental emotions*, which are affective responses that are elicited by specific stimuli, but unrelated to the object of a decision (Loewenstein & Lerner, 2003). For example, when deciding to eat a chocolate bar, a person may experience feelings of desire elicited by the food (integral emotions), but also anxiety about an upcoming exam (incidental emotion). Incidental emotions can influence decision-making in various domains, including cognitive, social, consumer, and health decisions (Achar et al., 2016; Lerner et al., 2015; Västfjäll et al., 2016). Incidental emotions are particularly important in dietary decision-making, as strong negative emotions can lead to emotional eating (Macht & Simons, 2011), which is defined as excess consumption of food as a coping mechanism. For example, students are more likely to overindulge on fast food and sweets when experiencing exam-related stress (Macht et al., 2005). Emotional eating has been linked to negative clinical outcomes such as binge eating disorder (BED) and obesity (Turton et al., 2017; Zeeck et al., 2011), which are further associated with serious comorbid health issues, including type II diabetes, cardiovascular diseases, and most types of cancer (Guh et al., 2009; Lauby-Secretan et al., 2016). Therefore, it is important to investigate how incidental emotions influence dietary decisions, and how to reduce these effects. One way to modulate an emotional experience is emotion via regulation (ER) – a set of processes that people use to influence which emotions they have, when they occur, and how strongly they experience and express these emotions (Gross, 1998; Gross, 2008). When applied to incidental emotions, ER can affect decision-making either by altering the emotional state, or through “spillover” effects of using a cognitive control strategy (Grecucci & Sanfey, 2014; Morawetz et al., 2019). To

inform the development of interventions for emotional eating, it is therefore crucial to understand how the effects of both emotion experience and ER impact dietary decision-making.

1.1 Experiencing Emotions

Several studies have shown links between incidental negative emotions and eating behaviour (Cardi et al., 2015; Evers et al., 2018; Ferrer et al., 2020). It is suggested that in these situations, food consumption acts as a form of ER itself, with its hedonic value helping to improve the person's emotional state (Macht & Simons, 2011). Meta-analyses of laboratory studies have shown that induced negative emotions tend to be associated with increased food intake in restrained eaters and binge eaters (Brownley et al., 2016; Cardi et al., 2015). However, studies within the general population (i.e., those who do not show unusual eating patterns) are limited and have found mixed results. Some studies have shown that different types of induced negative emotions such as sadness (Garg & Lerner, 2013) and frustration (Chao et al., 2012) led to increased food consumption. However, others showed an opposite effect, whereby healthy participants reported a *decreased* desire to eat after negative emotion induction (Arend et al., 2021; Ventsel et al., 2022). Other studies have found no effect of experimentally induced negative emotions on food intake in the general population (Cardi et al., 2015; Evers et al., 2018; Jampour et al., 2019). Overall, due to the inconsistent findings of existing studies, the effect of negative emotional state on food intake is unclear.

Further, there is evidence that negative emotions influence not only food intake, but also the type of food consumed (Ferrer et al., 2020; Garg et al., 2007; Motoki et al., 2019). In an eye-tracking study, Motoki et al. (2019) found that when participants listed things that made them anxious, inducing incidental anxiety, they fixated more on unhealthy, hedonic foods (e.g., chips) than healthier foods (e.g., yogurt). There is also evidence that this fixation

extends to consumption, as Garg et al. (2007) showed that participants who read sad stories consumed more sugary snacks (M&Ms) than raisins, whereas those who read happy stories showed the opposite pattern. Further, in a meta-analysis, Ferrer et al. (2020) found that negative incidental emotions reliably increased various appetitive risk behaviours, including the consumption of nutrient-poor, calorie-dense foods.

Overall, there is evidence that a negative emotional state increases food consumption, particularly for unhealthy, tasty foods. However, previous experimental studies (Garg et al., 2007; Motoki et al., 2019) primarily defined healthiness based on caloric content, whereas in reality, food choices are driven strongly by individual beliefs about health, which may not be accurate (Dana et al., 2021). Our study therefore examined how incidental emotions influence dietary decisions, taking into account perceived healthiness of the food under consideration.

People also frequently experience positive incidental emotions. According to Lerner and Keltner's (2000) Appraisal-Tendency Framework (ATF), emotions can prompt a cognitive predisposition to appraise stimuli consistently with the emotion. This theory suggests that when people experience positive emotions, they may perceive foods as more appealing, leading to greater consumption. Supporting this, previous studies have found that positive emotions result in increased food intake (Cardi et al., 2015; Evers et al., 2018). Further, there is some evidence that positive emotions promote healthier dietary choices by increasing preference for healthy foods (Lyman, 1982) and decreasing desire for unhealthy snacks (Winterich & Haws, 2011). Cameron et al. (2015) found further support for this notion in a meta-analysis, showing that induced positive affect led participants to choose healthier foods for consumption. However, other studies suggest that positive emotions lead to unhealthier dietary choices (Ashurst et al., 2018; Evers et al., 2013; Macht, 1999). One study found that hedonic eating (i.e., consuming tasty, unhealthy foods) was more common after experiencing joy, compared to neutral and negative emotions (Macht, 1999). More

recently, Evers et al. (2013) found that positive emotion induction resulted in greater intake of unhealthy snacks compared to a neutral control group, and that the everyday experience of positive emotions was associated with real-life snack intake. Finally, another study found that induced positive emotions resulted in a greater tendency to choose some high-calorie foods, including meats and sweets, but also decreased the likelihood of eating others, including fast food and pizza (Ashurst et al., 2018). Therefore, the overall evidence on whether positive emotions are detrimental or helpful for dietary self-control is mixed.

1.2 Emotion Regulation

ER alters a person's emotional state by decreasing (*downregulating*) or increasing (*upregulating*) the intensity of an experienced emotion. People can regulate emotions using different strategies, one of which is *cognitive reappraisal* (henceforth referred to as *reappraisal*). This involves reinterpreting the meaning of an emotional situation or stimulus in a way that changes its emotional impact (Gross, 2008). Several studies have shown that downregulating incidental negative emotions using reappraisal leads to decreased food intake, compared to passively allowing them to unfold (Evers et al., 2010; Taut et al., 2012). However, there is limited evidence on how ER influences the type of food chosen for consumption. Morawetz et al. (2020) found that when participants downregulated induced incidental negative emotions using reappraisal, they showed a greater preference for healthy foods, compared to when they allowed their emotions to unfold. However, another study found no effect of reappraisal on food intake, for neither "comfort" nor healthy foods (Evers et al., 2010). In fact, contrary to the idea that ER reduces emotional eating, Evers et al. (2010) found that after using *expressive suppression* to regulate negative emotions, participants consumed more chocolate and crisps than those given no instruction to regulate. However, expressive suppression, which involves attempting to intentionally reduce an emotional

response using “brute force”, is generally considered less adaptive than reappraisal (Gross, 1998; Goldin et al., 2008), and is less relevant in this context.

More useful for the regulation of everyday emotions is *distraction*, an ER strategy that involves redirecting one’s thoughts to something unrelated to the emotional stimulus or situation (Gross, 1998; Gross, 2015). Distraction can be successfully applied within the first second of experiencing a negative emotion (Schubert et al., 2020), and there is evidence that it is particularly effective for regulating high-intensity emotions (Shafir et al., 2015). It may also be superior to reappraisal in the short-term (Shafir et al., 2015). Therefore, distraction may be appropriate for avoiding emotion-related increases in food intake, which are suggested to result from the immediate consequences of negative emotions (Cardi et al., 2015; Evers et al., 2018). However, whether the regulation of negative emotions impacts dietary decisions is an entirely open question. We therefore used both ER strategies, reappraisal and distraction, for negative emotions in this study.

Although it is well-established that positive emotions can also be regulated (Gross, 1998), this has received less attention in existing literature than negative emotions. There is evidence that positive emotional states can be both decreased and increased by reappraisal (Kalokerinos et al., 2015), and decreased by distraction (Li et al., 2020). However, it is unclear whether these shifts in positive incidental emotional states lead to changes in subsequent dietary decisions. There is some evidence for a link between the downregulation of incidental positive emotions and risk-taking behaviour, with one study showing that participants with a poorer ability to downregulate positive emotions had spent a greater number of days in hospital due to injury (Zou et al., 2017). This suggests a link between difficulty regulating positive emotions and impulsive behaviours, which might include unhealthy dietary decisions. However, as Zou et al. (2017) only examined correlational, individual differences, it is unclear whether regulating positive emotions has a causal effect

on impulsive behaviour, and whether this impulsivity extends to dietary decision-making. Further, little research exists on the impact of the *upregulation* (i.e., increasing the intensity) of positive emotions on decision-making. Therefore, in the present study we examined the effects of both increasing and decreasing positive emotions on dietary decisions.

1.3 The Present Study

The aim of the present study was to investigate the effects of incidental emotions and regulation of these emotions on dietary decisions, particularly in relation to taste and healthiness of food items under consideration. Given the importance of how people subjectively judge these qualities, and the discrepancies in previous research, we focussed on perceived taste and perceived healthiness. We further conducted separate studies to investigate both negative and positive emotions (and the regulation of such), using the same experimental framework. In both experiments, we included a neutral condition with no emotion induction, allowing us to examine the effects of incidental emotional state and regulation in the same experiment.

In Experiment 1, we examined the effects of negative incidental emotions and their downregulation (i.e., decreasing the intensity) via distraction and reappraisal on dietary choice using an online study. Participants were randomly allocated to either a reappraisal or distraction sample, and instructed and trained to use their respective strategy. By separating the samples, we avoided unwanted confusion between strategies and carry-over effects between trials, which can occur when participants are required to repeatedly switch between different ER strategies (Shafir & Sheppes, 2020). On each trial, participants viewed negative emotionally charged images and responded by either passively viewing, or regulating their emotional response. Next, they immediately indicated their willingness to consume (WTC) a subsequently displayed food item. Throughout the task, participants also viewed neutral

instead of emotional images, again followed by food items, allowing for the comparison of WTC between neutral and negative emotional states. Before the main task, participants rated all food images on health and taste, allowing us to determine whether the effects of emotions and ER differed according to perceived health and taste. For both ER strategies, we hypothesised that WTC would be higher after viewing negative images, compared to neutral (Cardi et al., 2015; Evers et al., 2018; Ferrer et al., 2020). For ER, we hypothesised that WTC would be lower after ER was used in response to negative images, compared to when the images were passively viewed (Morawetz et al., 2020). Further, we hypothesised that this effect would be stronger for foods rated low on health and high on taste (Garg et al., 2007; Motoki et al., 2019). We did not test for differences between the two ER strategies, which both have been demonstrated to be effective in many situations (Gross, 1998; Gross, 2015). There was no reason to hypothesise that they would differently impact dietary choices, and we were more interested in whether they both had independently similar effects. A comparison between studies was beyond the scope of our study.

In Experiment 2, we investigated the effect of incidental positive emotions and ER on desire for food. We again used reappraisal and distraction to determine their effects of both on WTC, again in different samples. Given that both increasing and decreasing positive emotions may be useful for different life situations (Gross, 2013) in which food decisions can be made, we added an additional strategy (assigned to a third sample), which required participants to increase their positive emotional response. We hypothesised that positive emotion induction would result in increased WTC, compared to neutral (Cameron et al., 2015; Evers et al., 2013; Winterich & Haws, 2011). Regarding ER, we hypothesised that decreasing positive emotions, both via reappraisal and distraction, would decrease WTC overall. In line with this reasoning, we further hypothesised that intentionally increasing positive emotions would lead to even higher WTC. Due to the mixed findings in the

literature, we performed exploratory analyses to examine whether these effects differed according to individual perceptions of tastiness and healthiness.

2 Experiment 1

2.1 Method

2.1.1 Participants

A total of 482 participants were recruited, 193 via Prolific (www.prolific.co) and 289 via an online system for first year psychology students' research participation credits at the University of Melbourne. No significant differences in the key variables of interest were found between participants from the two recruitment sources (see Supplementary Table S1), so we pooled them. All participants were required to be fluent in written and spoken English and either live in Australia (Prolific participants) or be enrolled in an undergraduate psychology course at the University of Melbourne. As the focus of this study was on the general, non-clinical population, participants with a history of an eating disorder were excluded. As some images in the task included meat and common allergens, participants were also required to have no special dietary requirements. Although these exclusion criteria were specified in the recruitment materials, 48 participants were excluded post-hoc for reporting that they had dietary requirements or history of an eating disorder. A further 30 participants were excluded for showing little desire to consume any foods in the study (mean or median willingness to consume rating < 10 out of 100). The final sample comprised 404 participants in total, aged between 18 and 60 years (M_{age} = 24.02, SD = 8.35; 232 females, 170 males, 2 non-binary). At the beginning of the experiment, participants were allocated to either the distraction or reappraisal sample. Descriptive statistics and baseline ratings for each sample are displayed in Table 1. Ethics approval was obtained from the Human Research Ethics

Committee (ID 1955772.1) of the University of Melbourne, and the study was conducted in accordance with the Declaration of Helsinki.

Table 1

Experiment 1 Demographics and Baseline Negative Emotionality Ratings for Each Sample

	Reappraisal Sample (N = 215)	**Distraction Sample (N = 189)**
	***M* (*SD*)**	***M* (*SD*)**
Age	22.35 (5.80)	25.48 (9.83)
Hours Since Last Meal	4.03 (4.65)	3.9 (4.01)
Hours Since Last Snack	6.14 (7.31)	6.19 (6.74)
Negative Emotional Rating[a]	21.11 (23.91)	21.30 (22.29)
PANAS-X Negative Affect[b]	18.52 (7.16)	18.65 (7.25)
	***N* (%)**	***N* (%)**
Gender		
Male	98 (45.58)	72 (38.10)
Female	116 (53.95)	116 (61.38)
Non-Binary	1 (0.47)	1 (0.53)
Highest Level of Education		
Incomplete Secondary	1 (0.47)	1 (0.53)
Secondary School	104 (48.37)	114 (60.32)
Bachelor/Undergraduate	53 (24.65)	59 (31.21)
Bachelor with Honours	17 (7.91)	18 (9.52)
Masters	11 (5.12)	16 (8.47)
Postgraduate	3 (1.40)	7 (3.70)

[a] Ratings were given at baseline (before emotion induction) on a scale from 0 to 100.

[b] Possible scores range from 10 to 50, with higher scores indicating greater negative affect.

2.1.2 Stimuli

In the first part of the task, the rating stage, a set of food stimuli was used, comprising 60 food images from the Food-Pics database (Blechert et al., 2019), resized to 450 x 348 pixels. These images were selected based on normative ratings and categorisations from omnivorous participants (Blechert et al., 2019), to represent a wide variety of food types (fruit, vegetables, chocolate, fish, meat, nuts, snacks/meals) varying in healthiness and subjective palatability.

In the second part of the task, the experimental stage, the same set of food stimuli was used, along with a total of 50 negative stimuli and 20 neutral stimuli. The negative stimuli comprised 25 images from the Nencki Affective Picture System (NAPS; Marchewka et al., 2014) and 25 from the Socio-Moral Image Database (SMID; Crone et al., 2018). These stimuli were drawn from two different databases to allow for a wide selection of the most appropriate images for our purposes with the highest negative valence. Based on normative ratings for each database (Crone et al., 2018; Marchewka et al., 2014), all images selected were rated as negative in valence (< median) while excluding overly distressing or inappropriate images. The neutral stimuli consisted of 20 images from the NAPS of everyday objects, with normative valence ratings that were neither positive nor negative (Marchewka et al., 2014). For the full set of food and emotion-inducing images used in Experiment 1, as well as mean normative ratings, see Supplementary 2.

2.1.3 Experimental Paradigm

The main task contained two stages: the rating stage and the experimental stage. The purpose of the rating stage was to determine participants' perceptions of the taste and health properties of the food stimuli set, so that they could be accounted for in the main analysis. In this stage, participants viewed each of the 60 food stimuli and responded to the question "How much do you enjoy the taste of this food?", using a continuous slider scale (with a range of 0 to 100 that was not visible to participants). There was no time limit for responses.

After answering this question for all food stimuli, this process was repeated, but with the question “How healthy do you consider this food to be?”.

The purpose of the experimental phase was to examine the effects of negative emotions and the regulation of these emotions on WTC. Before this phase began, participants viewed descriptions of the two types of instructions: “Look” and “Decrease”. Look trials were the same for all participants, regardless of their allocated sample. For these trials, participants were instructed to keep their attention focused on the image, and let any thoughts or emotions naturally unfold (Ochsner et al., 2004). For Decrease trials, the instruction depended on the participant’s allocated sample. Those in the reappraisal sample were instructed to reinterpret the meaning of the image in a way that lessened its emotional impact (McRae et al., 2010). Those in the distraction sample were told to look at the image, but to think about something neutral and unrelated to the image, such as their plans for the rest of the day (Sheppes & Meiran, 2007). Each set of instructions included an example image and a description of how the relevant strategy could potentially be applied. The instructions and example for each cue and strategy are displayed in Supplementary Table S5.

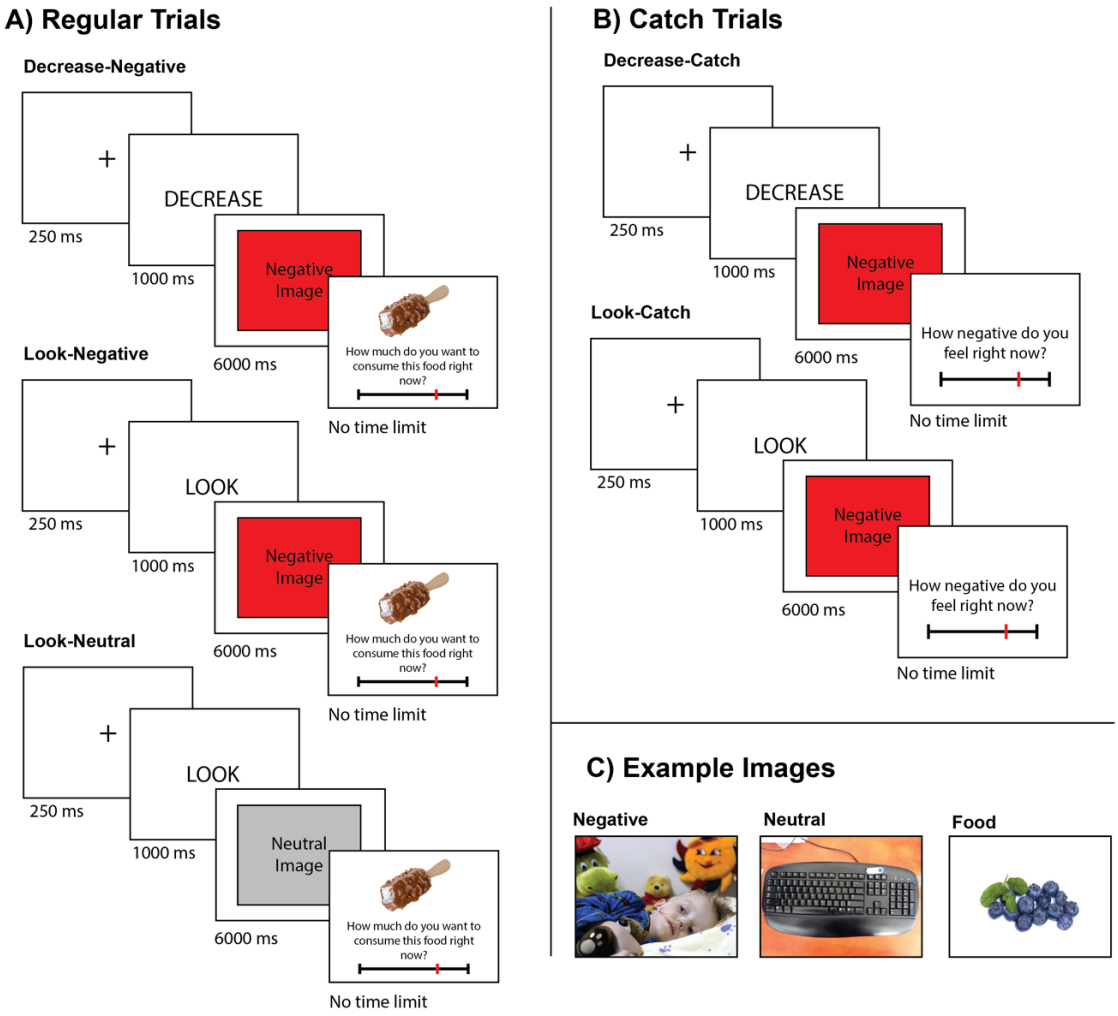
Each trial began with a fixation cross, presented for 250 ms, followed by an instruction (either “Look” or “Decrease”) for 1000 ms. A negative or neutral image would then appear for 6000 ms, during which time the participant either passively viewed the image, or applied the relevant strategy to regulate their emotions. Neutral images were only used in combination with the Look instruction (as downregulating a neural emotion is not possible), whereas negative images could follow both types of instructions. Immediately after, a food image appeared with a slider response scale underneath it (with a range of 0 to 100, which was not visible to participants), and participants were instructed to rate how much they wanted to consume the food in that moment from “Not at all” to “Very much”. No time limit was given for these responses, but participants were encouraged to make an immediate

decision, and they needed to move the slider from its starting position for the experiment to proceed further. For a visual representation of trial structure, see Figure 1A. In total, there were 20 regulation trials with negative images (Decrease-Negative), 20 look trials with negative images (Look-Negative), and 20 look trials with neutral images (Look-Neutral).

In addition to the 60 regular trials, there were 10 randomly interspersed catch trials (see Figure 1B), all with negative images. The purpose of these trials was to obtain negative emotional ratings for both Look and Decrease instructions, allowing a manipulation check to determine whether participants effectively engaged with the regulation task. Each catch trial began identically to the main trials, with a cue to either Look (Look-Catch) or Decrease (Decrease-Catch), followed by a negative image (6000 ms). Then, instead of viewing a food image, participants responded to the question “How negative do you feel right now?” on a slider from “Not at all negative” to “Very negative”. Allocation of the negative images to Decrease-Negative, Look-Negative, or catch trial was randomised for each participant.

Figure 1

Structure and Timing of Regular and Catch Trials



Note. A) Regular trials. Participants were cued to either decrease their emotional response or passively view the upcoming image. The strategy used during Decrease-Negative trials was either reappraisal or distraction, depending on the participant's allocated sample. They then viewed a negative or neutral image and responded accordingly, followed by a food image. They rated how much they wanted to consume the food using a mouse click. B) Catch trials. Participants were cued to either decrease their emotional response, using their allocated strategy, or passively view the upcoming image. They then viewed a negative image and

rated their current emotional state. C) Example images for each category (Negative, Neutral, and Food). For the full set of images used, see Supplementary 2.

2.1.4 Procedure

Before beginning the main task, participants completed a demographics questionnaire, in which they reported their age, gender, level of education, and profession. They also specified any dietary requirements. Next, they rated their hunger on a scale of 0 (not hungry at all) to 7 (very hungry), which was similar to scales used to measure hunger in existing studies on emotions and food choice (e.g., Evers et al., 2013; Macht et al., 2002; Macht et al., 2005), and reported how many hours had passed (range of 0 to 24 hours) since their last meal and snack. They then rated their current level of overall negative emotion on a continuous scale (range of 0 to 100, numbers were not visible to participants) that aligned with the scale used in the experimental stage. Finally, they completed the general negative affect subset of the Positive and Negative Affect Scale – Expanded Form (PANAS-X; Watson & Clark, 1994), in which they rated the extent to which they had experienced various emotions (e.g., afraid, upset) during the past week, on a scale of 1 (very slightly or not at all) to 5 (extremely). These variables were mainly used to make sure there were no major imbalances in pre-existing negative affect or hunger between samples. They were then allocated to an ER strategy sample (either distraction or reappraisal) and proceeded to the next part of the task.

The experimental task was coded using jsPsych (de Leeuw, 2015) and hosted online via cognition.run. Participants completed the rating phase, then the experimental phase. In total, the whole experiment took approximately 30 minutes. At the end of the experiment, participants were reimbursed with GBP£3.60 if recruited via Prolific, and with course participation credits if recruited via the University of Melbourne.

2.1.5 Data Analysis

To determine whether incidental ER strategies influenced dietary decisions, linear mixed effects model analyses were performed using the lme4 package (Bates et al., 2015) in RStudio 1.1.463 (RStudio Team, 2020). This analysis was chosen due to its ability to account for the hierarchical nature of the data, with trials grouped within each participant (Meteyard & Davies, 2020). A separate model analysis was performed for each sample (distraction and reappraisal). Examining differences between strategies was beyond the scope of the present study. Participant, negative image, and food image were tested as random effects to account for correlations between data from the same participant or stimulus. Fixed effects included trial type (Look-Negative, Decrease-Negative, or Look-Neutral), taste ratings, health ratings, and hunger ratings.

In each model, the ICC of each potential random effect was examined, and if the effect explained an insufficient amount of variance (< 5%), it was not included in subsequent models. Model fit was assessed using a simple to complex approach (Meteyard & Davies, 2020), whereby the simplest model (null model) was first specified, then fixed effects and theoretically plausible interaction effects were added, and pairwise likelihood ratio tests were conducted to determine whether adding each effect significantly improved model fit. Satterthwaite's (1946) Approximation for Degrees of Freedom was used to obtain *p* values for the fixed and interaction effects. For the trial type variable, beta and *p* values were first generated using Look-Negative as a reference condition, to test whether negative emotions influenced WTC (by comparing with Look-Neutral) and whether regulating these emotions had an effect (by comparing with Decrease-Negative). As the variable had three levels, the "relevel" function was then used to change the reference condition to Look-Neutral (Degno et al., 2019), and beta values were regenerated for the comparison of Look-Neutral and Decrease-Negative. This approach allowed for pairwise comparison of all conditions, for both main and interaction effects. The MuMIn package in R (Barton, 2020) was used to

calculate R^2 values for the best fitting model. When significant interaction effects were found, plots were created using the visreg package in R (Breheny & Burchett, 2017). The bootMer function of the lme4 package (Bates et al., 2015) was then used to create 95% confidence intervals, using 5000 bootstrapped samples.

2.2 Results

2.2.1 Descriptive Statistics

Descriptive statistics for participants in each sample are displayed in Table 3, including means, standard deviations, and correlation coefficients between taste, health, and hunger ratings. Both samples showed a positive correlation between taste and health, suggesting that the participants tended to consider healthy foods to be tasty. Significant positive correlations were also found between hunger and health (distraction sample) and hunger and taste (reappraisal sample). Although some significant correlations were found between the predictors in the linear mixed effects model analyses (health, taste, and hunger), such correlations are usually only considered problematic if they are strong (Schielzeth et al., 2020). Weak to moderate correlations, as seen here, are unlikely to impact the analysis.

Table 3

Descriptive Statistics for Each Predictor, Grouped by Sample

Strategy	Rating	M	SD	R_{Taste}	R_{Health}	R_{Hunger}
Distraction	Taste	66.12	24.81	1	-	-
	Health	46.85	32.38	.14*	1	-
	Hunger	1.80	1.75	.08	.16*	1
Reappraisal	Taste	64.46	25.82	1	-	-
	Health	46.75	31.25	.21**	1	-

Hunger	1.86	1.75	.18*	-.04	1

* $p < .05$; ** $p < .01$

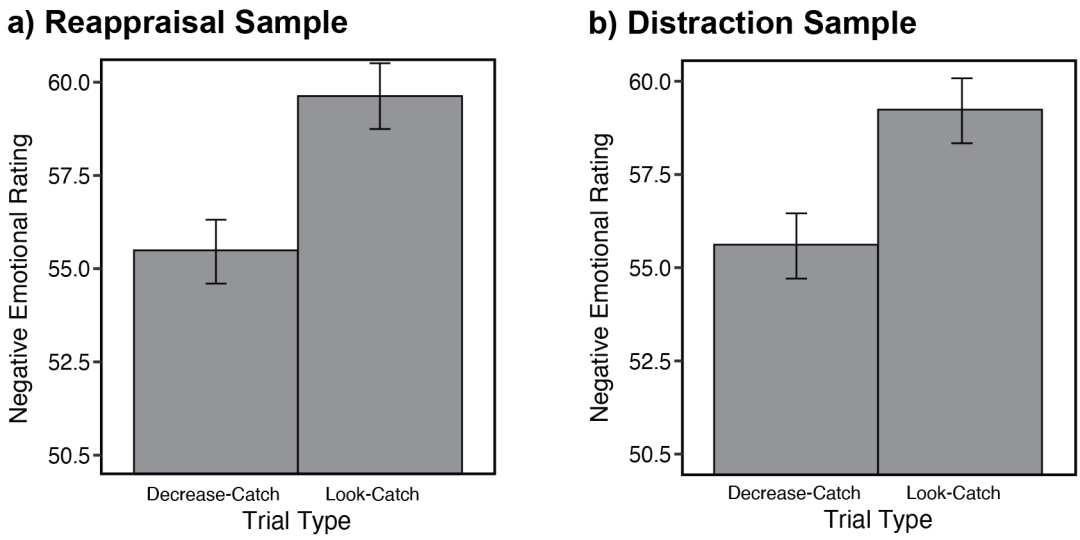
Note. Taste and health ratings were given on a continuous sliding scale, ranging from 0 to 100. Hunger ratings were given on a Likert-type scale from 1 (not at all hungry) to 7 (extremely hungry).

2.2.2 Preliminary Analyses

To check that participants were implementing ER as instructed, the data from the catch trials were aggregated such that a mean negative emotional rating for Look-Catch and Decrease-Catch trials was computed for each participant (see Figure 2). A repeated measures *t*-test was performed within the distraction and reappraisal samples separately. This showed that on average, participants reported feeling significantly less negative in Decrease-Catch trials than in Look-Catch trials, in both the distraction, $t(215) = 3.43$, $p < .001$, 95%CI[1.53, 5.65], and Reappraisal sample, $t(219) = 4.16$, $p < .001$, 95%CI[1.94, 5.44]. This suggests that participants in both samples were successfully performing ER as instructed.

Figure 2

Mean Negative Emotionality Ratings for each Sample in the Catch Trial Analysis



Note. Error bars represent standard error of the mean. Ratings were given on a scale of 0 to 100, with higher scores indicating more negative emotion.

2.2.3 Linear Mixed Effects Model Results

Separate linear mixed effects model analyses were performed for the two samples predicting WTC ratings. Catch trials were excluded and were only used for the manipulation check (see above). For comparisons of all models tested, see Supplementary 4.

2.2.3.1 Reappraisal

First, the null model was specified, which showed that participant (ICC = .23) and negative image (ICC = .07) explained a substantial amount of variance, but food image did not (ICC = .02) and was therefore not included in subsequent models. Adding hunger, taste, and health ratings as predictors each individually improved model fit. Adding trial type (Look-Negative, Look-Neutral, or Decrease-Negative) improved model fit, as did the trial type * taste interaction. Adding other two-way (trial type * health) and three-way (trial type * taste * health) interactions had no effect on model fit. For the best fitting model, the R^2 values showed that fixed effects explained 22.20% of the variance in WTC, and fixed and random

effects combined explained 43.86% of the variance. The beta values for each predictor are displayed in Table 4. Taste, health, and hunger all positively predicted WTC.

Negative Emotional State. There was a significant main effect of trial type (Look-Neutral), suggesting that negative emotions resulted in significantly lower WTC scores, compared to neutral emotions. The trial type (Look-Neutral) * taste interaction effect (see Figure 3A) suggests that for foods rated low in taste, the difference between Look-Negative and Look-Neutral was minimal. However, as perceived tastiness increased, the difference in WTC between these trial types also increased, meaning that experiencing negative emotions had a greater effect on WTC for tasty foods than non-tasty foods.

Emotion Regulation. While there was no significant effect of trial type (Decrease-Negative), WTC ratings trended higher for Decrease-Negative than Look-Negative trials. The relevelled analysis showed that when Look-Neutral was used as a reference condition, there was a significant main effect of trial type (Decrease-Negative), b = -1.27, SE = 1.32, t(11166) = -0.96, p = .005, and a significant trial type (Decrease-Negative) * taste interaction, b = -0.15, SE = 0.02, t(11168) = -7.91, p < .001, 95%CI[-0.19, -0.11]. Together, these effects suggest that WTC was lower in Decrease-Negative than Look-Neutral trials, and that this difference increased as perceived tastiness increased. In other words, this analysis did not provide evidence that reappraisal significantly affected WTC.

Table 4

Beta Estimates for the Best Fitting Model for Participants in the Reappraisal Sample

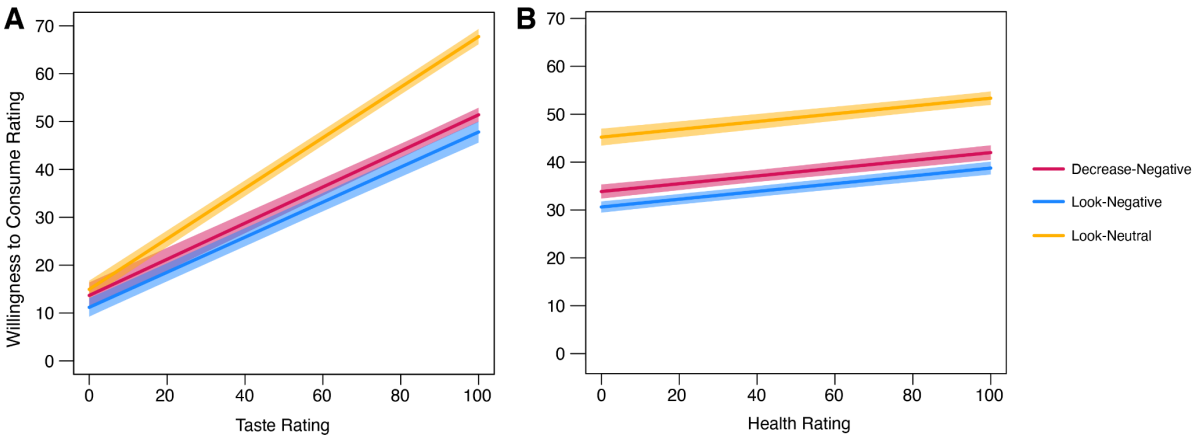
Predictor	Estimate	*SE*	*t*	*p*	95%CI
Intercept	6.43	1.64	3.91	< .001***	[3.20, 9.65]
Taste	0.37	0.01	26.12	< .001***	[0.34, 0.39]
Health	0.08	0.01	12.50	< .001***	[0.07, 0.09]

Hunger	1.04	0.52	2.00	.046*	[0.02, 2.06]
Trial Type (Look-Neutral)	3.75	1.33	2.83	.005**	[1.15, 6.36]
Trial Type (Decrease-Negative)	2.49	1.31	1.91	.056	[0.07, 5.05]
Trial Type (Look-Neutral) x Taste Rating	0.16	0.02	8.46	< .001***	[0.12, 0.20]
Trial Type (Decrease-Negative) x Taste Rating	0.01	0.02	0.59	.556	[-0.03, 0.05]

Note: * $p < .05$; *** $p < .001$; For trial type, Look-Negative was used as a reference condition.

Figure 3

Regression Plots for Main and Interaction Effects of Trial Type in the Reappraisal Sample



Note. Shaded areas represent bootstrapped 95% confidence intervals. Ratings were given on a scale of 0 to 100.

2.2.3.2 Distraction

Again, the null model was specified, which included participant, food image, and negative image as random effects. Only participant (ICC = .20) and negative image (ICC = .05) explained a substantial amount of variance, therefore food image (ICC = .02) was not

included in subsequent models. When hunger, taste, and health ratings were individually added to the model, each significantly improved the fit. Adding trial type (Look-Negative, Look-Neutral, or Decrease-Negative) also significantly improved model fit, as did the trial type * taste interaction. The trial type * health interaction, nor a three-way trial type * taste * health interaction improved model fit. The R^2 values for the best fitting model showed that the fixed effects explained 23.36% of the variance in WTC, and fixed and random effects combined explained 44.74%. Beta values for each predictor were calculated and analysed (see Table 5). The main effects of taste, health, and hunger ratings showed that participants who reported higher hunger reported higher WTC, and participants showed greater WTC for foods that they considered to be tasty and healthy.

Negative Emotional State. The main effect of trial type showed that WTC ratings were lower for Look-Negative compared to Look-Neutral trials (see Figure 4), suggesting that induced negative emotions decreased WTC. Regression plots of the trial type * taste interaction (see Figure 4B) showed that the higher the perceived taste, the greater the difference in WTC between Look-Negative and Look-Neutral trials, suggesting that experiencing negative emotions affected WTC foods considered tasty more than those low on perceived taste.

Emotion Regulation. There was no difference in WTC between Look-Negative and Decrease-Negative trials, suggesting no effect of distraction on WTC. The relevelled analysis, with Look-Neutral as reference condition, showed that relative to Look-Neutral, there was a main effect of Decrease-Negative, b = -3.62, SE = 1.68, $t(363)$ = -2.16, p = .032, 95%CI[-6.91, -0.32], whereby WTC was higher in Look-Neutral trials than Decrease-Negative. There was also a significant trial type (Decrease-Negative) * taste interaction, b = -0.12, SE = 0.02, $t(12643)$ = -5.68, $p < .001$, 95%CI[-0.14, -0.07], suggesting that the difference in WTC between Decrease-Negative and Look-Neutral became greater as

perceived taste increased. Overall, this was a similar pattern to that seen when comparing Look-Neutral and Look-Negative, and there was no evidence for a significant change of WTC when regulating emotions via distraction.

Table 5

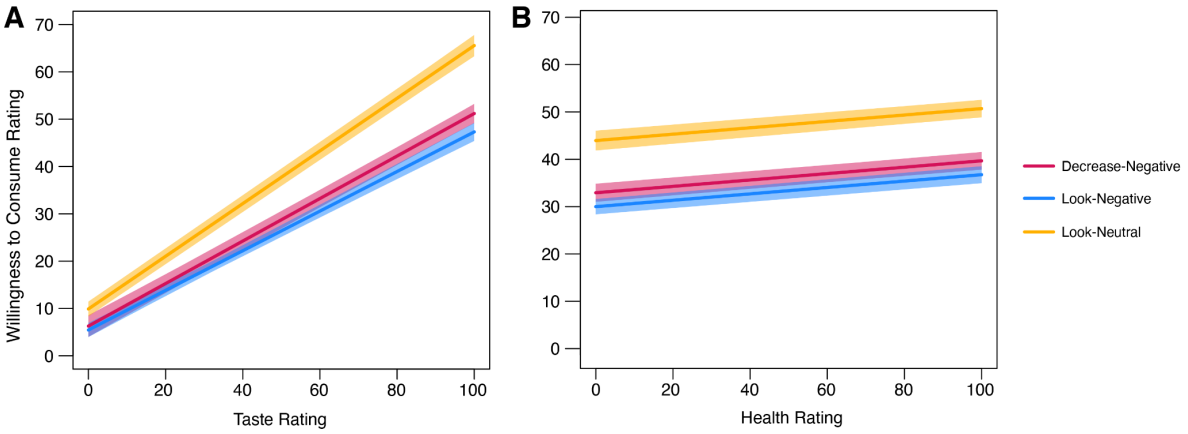
Beta Estimates for the Best Fitting Model for Participants in the Distraction Sample

Predictor	Estimate	*t*	*SE*	*p*	95%CI
Intercept	0.62	0.37	1.70	.714	[-2.72, 3.96]
Taste	0.42	30.50	0.01	< .001***	[0.39, 0.45]
Health	0.07	11.30	0.01	< .001***	[0.06, 0.08]
Hunger	1.87	3.66	0.51	< .001 ***	[0.86, 2.87]
Trial Type (Look-Neutral)	4.44	2.65	1.33	.008**	[1.15, 7.73]
Trial Type (Decrease-Negative)	0.82	0.62	1.67	.533	[-1.77, 3.42]
Trial Type (Look-Neutral) x Taste	0.14	7.35	0.02	< .001***	[0.10, 0.18]
Trial Type (Decrease-Negative) x Taste	0.03	1.63	0.02	.103	[-0.01, 0.07]

Note: * $p < .05$; *** $p < .001$; For Trial Type, Look-Negative was used as a reference condition.

Figure 4

Regression Plots for Main and Interaction Effects of Trial Type in the Distraction Sample



Note. Shaded areas represent bootstrapped 95% confidence intervals. Ratings were given on a scale of 0 to 100.

2.2.4 Preliminary Summary

In summary, we found similar results for distraction and reappraisal. Both samples showed differences in WTC between neutral emotions and initially experiencing negative emotions, however, contrary to the hypothesised direction, negative emotions decreased WTC. Neither group showed a change in WTC after engaging in reappraisal or distraction.

3 Experiment 2

3.1 Method

3.1.1 Participants

In total, 402 participants were recruited via an online system for first year psychology students' research participation credits at the University of Melbourne. All inclusion and exclusion criteria were the same as in Experiment 1. Students who had participated in Experiment 1 were not explicitly excluded from Experiment 2, however, as data collection took place in a new semester and academic year, it is unlikely that there were participants who took part in both experiments. Thirty-five participants were excluded for reporting that they had dietary requirements or history of an eating disorder. A further 17 were excluded for

showing little desire to consume any foods in the study (mean or median WTC rating < 10 out of 100). The final sample comprised 348 participants in total, aged between 18 and 37 years (*M* age = 19.34, *SD* = 2.19; 244 females, 103 males, 1 non-binary). For a breakdown of demographics and baseline ratings for each strategy sample, see Table 6. Ethics approval was obtained from the Human Research Ethics Committee (ID 1955772.1) of the University of Melbourne, and the study was conducted in accordance with the Declaration of Helsinki.

Table 6

Experiment 2 Demographics and Baseline Negative Emotionality Ratings for Each Sample

	Reappraisal Sample (N = 120)	**Distraction Sample (N = 111)**	**Increase Sample (N = 117)**
	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
Age	19.58 (2.62)	19.47 (2.03)	18.96 (1.77)
Hours Since Last Meal	4.53 (4.29)	4.67 (4.56)	5.44 (5.41)
Hours Since Last Snack	5.90 (7.05)	6.56 (7.17)	7.08 (7.14)
Positive Emotional Rating[a]	65.04 (21.91)	64.65 (22.53)	66.54 (22.93)
PANAS-X Positive Affect[b]	28.50 (7.12)	28.38 (5.69)	28.82 (5.72)
	***N* (%)**	***N* (%)**	***N* (%)**
Gender			
Male	35 (29.17)	28 (25.22)	40 (34.19)
Female	85 (70.83)	82 (73.87)	77 (65.81)
Non-Binary	0 (0.00)	1 (0.90)	0 (0.00)
Highest Level of Education			
Incomplete Secondary School	0 (0.00)	0 (0.00)	2 (1.71)
Secondary School	92 (76.67)	84 (75.68)	88 (75.21)
Bachelor/Undergraduate	26 (21.67)	22 (19.82)	26 (22.22)
Bachelor with Honours	1 (0.83)	3 (2.70)	1 (0.85)
Masters	0 (0.00)	0 (0.00)	0 (0.00)
Postgraduate	1 (0.83)	2 (1.80)	0 (0.00)

[a] Ratings were given at baseline (before emotion induction) on a scale from 0 to 100.

[b] Possible scores range from 10 to 50, with higher scores indicating greater negative affect.

3.1.2 Stimuli

In the rating stage, the same set of 60 food images from Experiment 1 was used (Food-Pics; Blechert et al., 2014). The experimental stage again comprised three sets of stimuli: 60 food images, 20 neutral images, and 50 positive images. The food and neutral stimuli were the same as in Experiment 1. The positive images were taken from the Nencki Affective Picture System (NAPS; Marchewka et al., 2014), all rated as positive valence (> median; see Supplementary 5) and selected to cover a range of image categories (landscapes, animals, people, faces, objects). All images were resized to 450 x 348 pixels.

3.1.3 Experimental Paradigm

The experimental paradigm was almost identical to that of Experiment 1, with the same two stages: the rating stage and the experimental stage. In the rating stage, participants rated each food image on taste and health.

Before the experimental stage, participants read the instructions. The description for "Look" was the same as in Experiment 1. The description for participants in the distraction sample was almost identical to those in Experiment 1, asking participants to think about something neutral and unrelated to the image on the screen, such as their plans for the rest of the day. For participants in the reappraisal sample, the description of "Regulate" was similar, but adapted to apply to the goal of decreasing the intensity of positive emotions. As mentioned above, an Increase regulation sample was added. When participants in this sample saw the word "Regulate", they were told to reinterpret the image in a way that increased their positive emotional response (Kim & Hamman, 2007). The instructions given for each cue and strategy are displayed in Supplementary Table S9. Other than "Regulate" replacing

"Decrease" as an instruction (to capture all regulation processes), the task structure and format were identical to those of Experiment 1. There were 20 Look-Positive, 20 Look-Neutral, and 20 Increase- or Decrease-Positive trials, as well as 10 catch trials (Look-Catch and Regulate-Catch).

3.1.4 Procedure

Participants first completed a questionnaire involving demographic information, dietary requirements, and hunger levels. They then rated their current level of overall positive emotion, again on a continuous scale (with an underlying range of 0 to 100). They then completed a subset of the PANAS-X (Watson & Clark, 1994), however, unlike in Experiment 1, items measuring general positive affect (e.g., "enthusiastic") were included, as well as those measuring general negative affect. They were then allocated to an ER strategy sample (either increase, distraction, or reappraisal) and proceeded to the rating and experimental stages, as in Experiment 1. In total, the task for Experiment 2 also took approximately 30 minutes. At the end, participants were compensated with course participation credits.

3.1.5 Analysis

Linear mixed effects model analyses were performed for each strategy sample separately, to determine whether WTC ratings differed by trial type (Look-Positive, Look-Neutral, Regulate-Positive), taking into account hunger, taste, and health ratings. The analysis approach was the same as that of Experiment 1.

3.2 Results

3.2.1 Descriptive Statistics

Descriptive statistics and correlation coefficients for taste, health, and hunger are displayed in Table 8. In all three samples, there was a positive correlation between taste and health, suggesting that participants showed taste preferences for foods that they considered to

be healthy. As in Experiment 1, the small to moderate correlations between taste and heath are unlikely to have affected the results of the mixed effects models (Schielzeth et al., 2020).

Table 8

Means and Standard deviations for Each rating, Grouped by Strategy Sample

Strategy	Rating	M	SD	R_{Taste}	R_{Health}	R_{Hunger}
Reappraisal	Taste	62.82	24.92	1	-	-
	Health	46.84	31.53	.23*	1	-
	Hunger	1.68	1.63	.04	-.06	1
Distraction	Taste	63.86	24.19	1	-	-
	Health	48.47	29.84	.31**	1	-
	Hunger	1.68	1.49	.14	.08	1
Increase	Taste	64.61	25.15	1	-	-
	Health	47.09	31.09	.20*	1	-
	Hunger	1.83	1.70	.03	.03	1

* $p < .05$; ** $p < .01$; *** $p < .001$

Note. Taste and health ratings were given on a continuous sliding scale, ranging from 0 to 100. Hunger ratings were given on a Likert-type scale from 1 (not at all hungry) to 7 (extremely hungry).

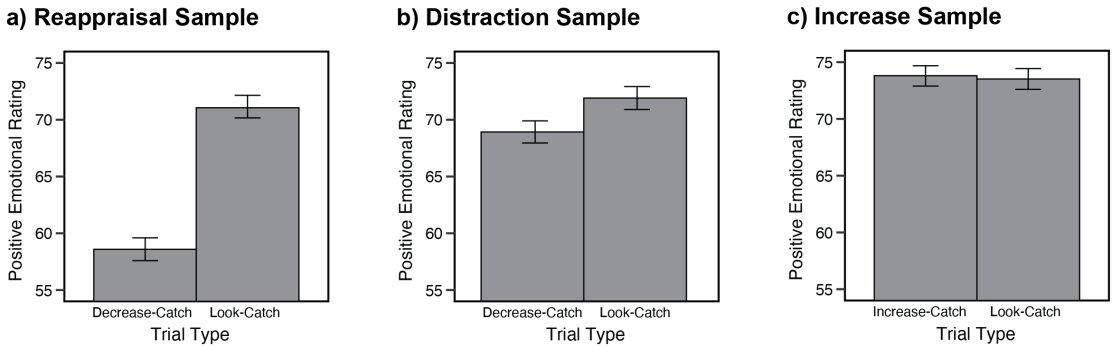
3.2.2 Preliminary Analyses

The catch trial data were aggregated, with a mean "positive emotion" rating for Look-Catch and Decrease- or Increase-Catch trials computed for each participant. A repeated measures *t*-test was then conducted separately in each sample of participants. This showed that on average, participants reported feeling significantly less positive in Decrease-Catch

trials compared to Look-Catch for both the distraction, $t(110) = 2.35$, $p = .020$, 95%CI[0.47, 5.50] and reappraisal samples, $t(120) = 7.58$, $p < .001$, 95%CI[9.21, 15.72] (see Figure 5). This suggests that participants in these samples successfully decreased their positive emotions as instructed. However, no significant difference was found between Look-Catch and Increase-Catch trials for participants in the Increase sample, $t(115) = -1.10$, $p = .273$, 95%CI[-3.05, 0.87], although they showed a trend toward the expected pattern, with positive emotionality ratings qualitatively being slightly higher for Increase-Catch than Look-Catch trials.

Figure 5

Mean Positive Emotion Ratings for Each Condition in the Catch Trial Analysis



Note. Note. Error bars represent standard error of the mean. Ratings were given on a scale of 0 to 100, with higher scores indicating more positive emotion.

3.2.3 Linear Mixed Effects Model Results

Linear mixed effects model analyses were performed, only including regular trials (as catch trials were only used for control analyses). As in Experiment 1, this process was repeated separately for each strategy sample. See Supplementary 7 for the full steps of model comparisons.

3.2.3.1 Reappraisal

The null model was specified with participant, food image, and positive image as random effects. Only participant (ICC = .15) explained a substantial amount of variance, therefore food image (ICC = .03) and positive image (ICC = .01) were not included in subsequent models. Hunger did not significantly improve model fit, but taste and health both did individually. Adding trial type (Look-Positive, Look-Neutral, or Regulate-Positive) as a predictor significantly improved fit, as did a two-way trial type * health interaction. Adding a trial type * taste interaction did not significantly improve model fit, nor did a three-way interaction (trial type * taste * health). The R^2 values for the best fitting model showed that the fixed effects explained 26.31% of the variance in WTC, and fixed and random effects combined explained 36.31%. Beta values for this model were calculated and analysed (see Table 9). As expected, taste and health positively predicted WTC ratings.

Positive Emotional State. The main effect of trial type (Look-Neutral) showed that participants reported lower WTC for both Look-Neutral than Look-Positive trials (see Figure 6). This suggests that positive emotions increased WTC. This effect remained constant, regardless of a food's perceived taste or health.

Emotion Regulation. There was a significant main effect of trial type (Decrease-Positive), which showed that decreasing positive emotions via reappraisal also decreased WTC. There was also a significant trial type (Decrease-Positive) * health interaction, showing that the higher the perceived health of a food, the more strongly reappraisal decreased WTC (see Figure 6B). The relevelled analysis (with Look-Neutral as the baseline) showed no significant main effect of trial type (Decrease-Positive), suggesting that once reappraisal had been applied to positive emotions, WTC was returned to a "baseline" level, no different from when neutral images were viewed. However, this analysis also showed a significant trial type (Decrease-Positive) * health interaction, b = -0.04, SE = 0.02, t(7098) = -

2.00, p = .045, 95%CI[-0.07, -0.01]. For foods perceived as unhealthy, participants indicated similar WTC for Look-Neutral and Decrease-Positive trials. However, as perceived health increased, WTC increased to a greater extent in Look-Neutral trials than Decrease-Positive, such that for foods perceived as healthy, WTC was lower when reappraisal was used, compared to when neutral images were viewed. This suggests that for healthy foods, decreasing positive emotions via reappraisal reduced WTC to an extent beyond that experienced when no emotions were induced.

Table 9.

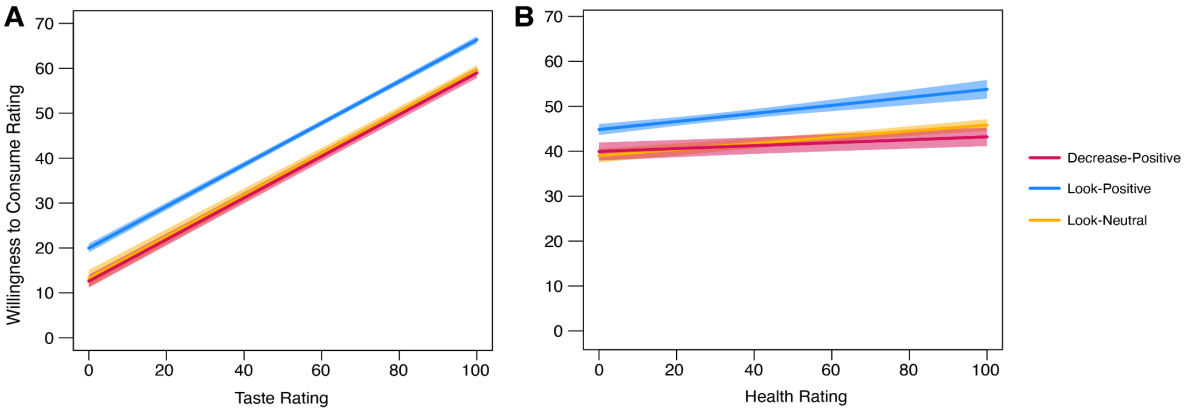
Beta Estimates for the Best Fitting Model for Participants in the Reappraisal Sample

Predictor	Estimate	*SE*	*t*	*p*	95%CI
Intercept	17.22	1.24	13.91	< .001***	[7.18, 9.50]
Taste	0.50	0.01	46.97	< .001***	[0.48, 0.52]
Health	0.10	0.01	7.20	< .001***	[0.07, 0.12]
Trial Type (Look-Neutral)	-6.21	1.06	-5.86	< .001***	[-8.30, -4.14]
Trial Type (Decrease-Positive)	-5.24	1.07	-4.89	< .001***	[-7.34. -3.14]
Trial Type (Look-Neutral) x Health Rating	-0.02	0.01	-1.21	.226	[-0.06, 0.01]
Trial Type (Decrease-Positive) x Health Rating	-0.06	0.01	-3.22	.001**	[-0.10, -0.02]

Note. Look-Positive used as a reference condition.

Figure 6

Regression Plots for Main and Interaction Effects of Trial Type in the Reappraisal Sample



Note. Shaded areas represent bootstrapped 95% confidence intervals. Ratings were given on a scale of 0 to 100.

3.2.3.2 Distraction

When the null model was specified with participant, food image, and positive image as random effects, only participant (ICC = .20) explained substantial variance, therefore food image (ICC = .04) and positive image (ICC = .01) were not included in subsequent models. Hunger, taste, and health as predictors each individually improved model fit. The addition of trial type (Look-Positive, Look-Neutral, or Regulate-Positive) significantly improved model fit. No two- or three-way interactions between trial type, taste, and health ratings had any effect on model fit. The pseudo-R^2 values for the best fitting model showed that fixed effects explained 26.48% of the variance in WTC, and the fixed and random effects combined explained 41.93%. The beta values (see Table 10) showed a positive main effect of taste, health, and hunger.

Positive Emotional State. The main effect of trial type showed that participants reported significantly lower WTC for Look-Neutral trials, compared to Look-Positive, suggesting that again, positive emotion induction resulted in higher WTC (see Figure 7).

Emotion Regulation. WTC did not differ significantly between Look-Positive and Look-Regulate trials, meaning that there was no evidence that ER via distraction influenced

WTC. The relevelled analysis (with Look-Neutral as the baseline) showed a significant effect of trial type (Decrease-Positive), $b = 3.85$, $SE = 0.62$, $t(6548) = 6.25$, $p < .001$, further suggesting that WTC was higher when positive emotions were induced, even with attempts to regulate these emotions using distraction.

Table 10

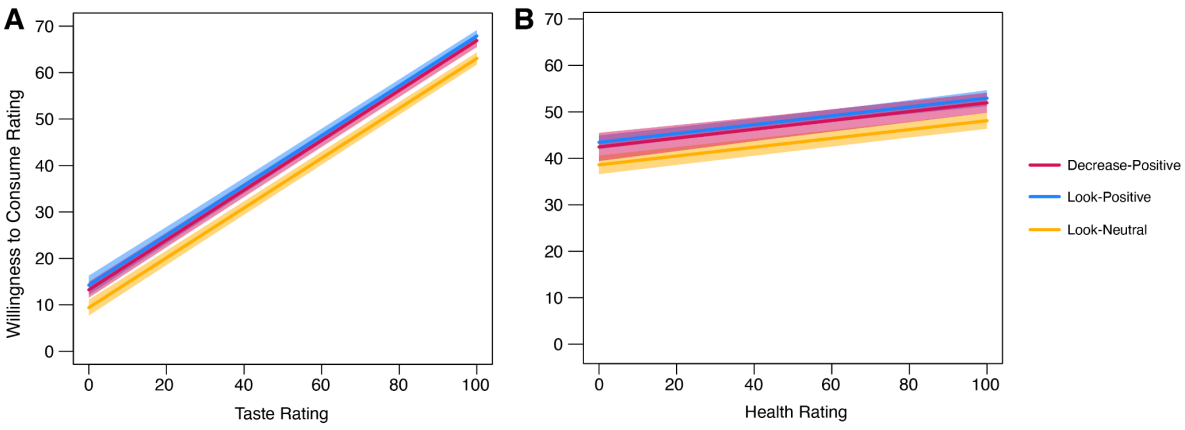
Beta Estimates for the Best Fitting Model for Participants in the Distraction condition

Predictor	Estimate	*t*	*SE*	*p*	95%CI
Intercept	8.33	4.62	1.81	< .001***	[4.77, 11.89]
Taste	0.54	47.22	0.01	< .001***	[0.52, 0.56]
Health	0.10	10.94	0.01	< .001***	[0.08, 0.11]
Hunger	1.49	2.13	0.70	.036*	[0.10, 2.87]
Trial Type (Look-Neutral)	-4.85	-7.87	0.62	< .001***	[-6.05, -3.64]
Trial Type (Decrease-Positive)	-1.00	-1.62	0.62	.106	[-2.02, 0.21]

Note: * $p < .05$; *** $p < .001$; For Trial Type, Look-Positive was used as a point of comparison.

Figure 7

Regression Plots for Main and Interaction Effects of Trial Type in the Distraction Sample



Note. Shaded areas represent bootstrapped 95% confidence intervals. Ratings were given on a scale of 0 to 100.

3.2.3.3 Increase

The null model was specified with participant, food image, and positive image as random effects. Of these, only participant (ICC = .14) explained a substantial amount of variance, therefore food image (ICC = .03) and positive image (ICC = .01) were not included in subsequent models. Hunger, taste ratings, and health ratings were then added as predictors. All individually improved model fit. Adding trial type (Look-Positive, Look-Neutral, or Regulate-Positive) also significantly improved model fit. Adding two-way trial type * taste and trial type * health interactions improved model fit, whereas the three-way (trial type * taste * health) interaction did not. The R^2 values for the best fitting model showed that fixed effects explained 25.76% of the variance in WTC, and fixed and random effects combined explained 38.17%. Beta values for the best fitting model were also calculated and analysed (see Table 11). Hunger, taste, and health all positively predicted WTC ratings.

Positive Emotional State. Although trial type (Look-Neutral) had no main effect on WTC, it showed a significant interaction effect with both taste and health. For foods rated low on tastiness and healthiness, the difference between Look-Neutral and Look-Positive was minimal. As the ratings of both attributes increased, this difference also increased, such that WTC was higher for Look-Positive than Look-Neutral trials (see Figure 8). Together, these interactions show that incidental positive emotions increased desire for foods, particularly those considered tasty and healthy.

Emotion Regulation. There was a significant main effect of trial type (Increase-Positive), with WTC ratings significantly higher for Increase-Positive than Look-Positive trials (see Figure 8). This suggests that upregulating positive emotions led to greater WTC.

There were no significant interactions between trial type (Increase-Positive) and taste nor health, suggesting that increasing positive emotions increased WTC for foods regardless of their perceived attributes. Finally, the relevelled analysis showed that with Look-Neutral as a reference condition, there was a significant trial type (Increase-Positive) * health interaction effect, $b = 0.07$, $SE = 0.02$, $t(2916) = 3.18$, $p = .002$, 95%CI[0.03, 0.11].

Table 11

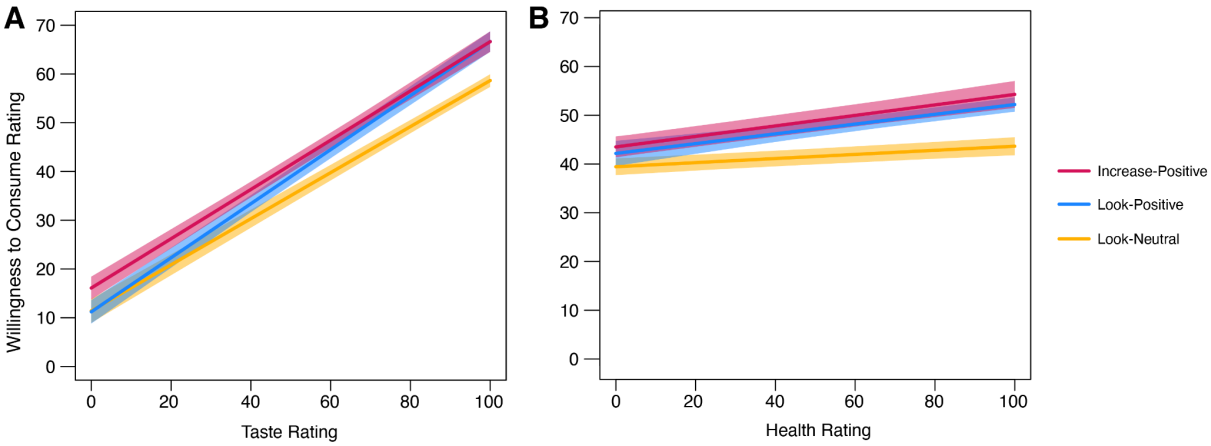
Beta Estimates for the Best Fitting Model for Participants in the Increase Sample

Predictor	Estimate	*SE*	*t*	*p*	95%CI
Intercept	9.48	1.99	4.90	.014*	[0.99, 8.80]
Taste	0.56	0.02	30.20	< .001***	[0.52, 0.59]
Health	0.10	0.01	6.85	< .001***	[0.07, 0.13]
Hunger	1.92	0.55	3.46	< .001***	[0.82, 3.01]
Trial Type (Look-Neutral)	2.70	1.99	1.36	.175	[-1.20, 6.60]
Trial Type (Increase-Positive)	4.58	2.02	2.27	.023*	[0.62, 8.54]
Trial Type (Look-Neutral) x Taste	-0.08	0.03	-3.27	.001**	[-0.13, -0.03]
Trial Type (Increase-Positive) x Taste	-0.05	0.03	-1.91	.056	[-0.10, 0.00]
Trial Type (Look-Neutral) x Health	-0.06	0.02	-2.84	.004**	[-0.10, -0.02]
Trial Type (Increase-Positive) x Health	0.01	0.02	0.36	.720	[-0.03, 0.05]

Note: * $p < .05$; *** $p < .001$; For Trial Type, Look-Positive was used as a reference condition.

Figure 8

Regression Plots for Main and Interaction Effects of Trial Type in the Increase Sample



Note. Shaded areas represent bootstrapped 95% confidence intervals. Ratings were given on a scale of 0 to 100.

3.2.4 Preliminary Summary

In summary, the effect of simply experiencing positive emotions was the opposite to that of negative emotions in Experiment 1: participants across all three samples reported greater WTC after viewing positive images, compared to neutral. In one group, this effect was particularly strong for healthy foods. The results from the increase and reappraisal samples also suggest that WTC can be increased by intentionally increasing or decreased by intentionally downregulating the positive emotional response, respectively. Attempting to decrease positive emotions via distraction, however, did not change WTC.

4 Discussion

The aim of the present study was to examine the effects of emotional states on desire for foods. The results of Experiment 1 suggested that, contrary to what was hypothesised,

negative emotions decreased WTC. This effect was stronger for foods perceived as highly tasty, compared to those considered less tasty. ER modified emotional state, with both distraction and reappraisal leading to lower negative emotional ratings; however, neither had a significant effect on WTC. In Experiment 2, the non-regulated experience of positive emotions had the opposite effect on WTC: compared to neutral, a positive emotional state resulted in increased WTC, as hypothesised. Further, for the increase sample only, this non-regulated effect of experiencing positive emotions interacted with perceived health and taste: the higher the perceived health and taste of a food, the more strongly positive emotions increased WTC. Compared to naturally experiencing positive emotions, attempting to decrease them via reappraisal and distraction led to lower positive emotional ratings; however, only reappraisal led to a decrease in WTC, which was stronger for foods considered healthy. Compared to naturally experiencing them, deliberately attempting to increase positive emotions did not lead to significant changes in reported emotional state, but it did lead to further increases in WTC for all food items, regardless of perceived health and taste.

4.1 Negative Emotions and Regulation

In Experiment 1, we found that experiencing negative emotions decreased WTC, compared to a neutral emotional state. This effect was strongest for foods perceived as tasty. This likely reflects the fact that taste preference strongly drives food choices (Dana et al., 2021), leading to a floor effect for foods considered “not tasty”. When no emotions were induced, WTC for low-taste foods was already low, and perhaps could not be decreased substantially by negative emotions. No interaction effects with perceived health were found. These findings are inconsistent with previous studies showing that negative emotions increase food intake (Cardi et al., 2015) and unhealthy food choices (Ferrer et al., 2020; Garg et al., 2007). A potential explanation for this relates to the conceptualisation of emotions, which can be either dimensional or discrete (Lerner & Keltner, 2000). The present study took

the former approach, restricting the image set of Experiment 1 to those inducing negatively-valenced emotions. However, within the category of negative emotions are discrete emotion categories (e.g., sadness, anger), which may differ in their impacts on decision-making (Lefevbre et al., 2019; Remington et al., 2000; Yik et al., 2011). A previous study found that the most common discrete emotions that negatively affect eating behaviour were stress, depression, and sadness (Devonport et al., 2019). However, in emotional stimuli sets, images evoking sadness and disgust tend to be associated with the strongest negative emotional ratings (Riegel et al., 2015). As the present study specifically targeted images with strong negative emotional ratings, these emotion categories may have been overrepresented. Previous studies have found that disgust is associated with food avoidance (Randler et al., 2017). Therefore, the negative emotions induced in our participants may have been dominated by feelings of disgust, which prompted avoidance of the food stimuli that followed.

Another explanation for the effect of experiencing negative emotions on WTC is that experiencing general negative emotions changed participants' mindset or perceptions of the foods. There is evidence that negative stimuli can prompt an *avoidance-motivation*, which means that people are less likely to perform behaviours that draw them toward stimuli or goals (Phaf, 2014; Carver, 2004). Therefore, negative emotions could bias people away from consuming foods. Supporting this idea, Veling et al. (2011) found that when people viewed fearful facial expressions, they inhibited their motor responses to rewarding food stimuli. A similar phenomenon may have occurred in the present study, with the induced negative emotions putting participants into a temporary state of avoidance-motivation that prompted them to withdraw from the food items. Alternatively, negative emotions may have changed perceptions of the foods themselves. Some negative emotions, such as sadness, are associated with slowing of cognitive processes and decreased interest in external stimuli (Macht, 2008).

A previous study found that induced sadness resulted in decreased pleasantness ratings of consumed chocolate (Macht et al., 2002). Therefore, in the present study, negative emotions may have led participants to perceive the food stimuli as less appealing, which drove the observed decrease in WTC.

We also found that although both distraction and reappraisal lowered negative emotional ratings, neither significantly changed WTC. This suggests that although ER strategies may shift a person's emotional state to being less negative, they do not necessarily change dietary decisions. These results are consistent with Evers et al. (2010), who found no effect of reappraisal on food intake, but inconsistent with Morawetz et al.'s (2020) finding that reappraisal increases desire for healthy foods. However, in Morawetz et al.'s (2020) study, the set of investigated food items were all very palatable, whereas in our study there was greater variance in taste perception. Given that our effects of negative emotion on WTC were only found for very tasty foods, there might have been differences in statistical power between studies to detect changes after ER for this relevant category of food items. The lack of an effect in the present study also may have been due to the relatively small changes in negative emotion following ER. The reappraisal sample showed a trend toward significance in that after regulating, WTC ratings became more positive, shifting slightly closer to WTC in a neutral emotional state. It must be considered that ER in a lab environment might be stronger than in an online study where it is impossible to create a distraction-free environment. It is therefore still possible that regulating emotions has a "ripple effect" on desire for food, and that greater changes in emotional state than achieved here would lead to significant changes in dietary decisions. In future studies, more effective ER may be achieved by giving participants more training in how to use strategies, by replicating our study in an in-person lab experiment, or by giving greater incentive to regulate by inducing stronger emotions.

The findings from Experiment 1 also have implications for practice, particularly for using ER as a strategy for combatting emotional eating. Our findings suggest that in the general population, it might be insufficient to train people to regulate their emotional state if it is generally negative. While our study, as well as many others before (Gross, 1998; 2015), clearly shows that both distraction and reappraisal are effective strategies to improve one's emotional state, there was no noteworthy change in desire to consume foods. It could therefore be useful to target only specific negative emotions that lead to overeating, rather than negative emotions in general. As there are differences in patterns of ER between different discrete emotions (Rivers et al., 2007), it is also plausible that ER might influence food choice when applied to some types of discrete emotions, but not others. For example, disgust has associations with disease and contamination (Consedine & Moskowitz, 2007), and therefore may have a more persistent effect on eating behaviours than other emotions, such as sadness. However, given that disgust is rarely related to emotional eating, other specific emotions might be worthwhile investigating in detail.

Our study protocol might also provide a valuable platform to expand our findings in clinical setting, because results – both for the effect of negative emotions and ER – might look very different for people actually diagnosed with eating disorders. Another aspect to consider is that while much research focuses on emotional overeating (Turton et al., 2017), there is also evidence that emotional *under*eating, i.e., restricting food intake in response to emotions, occurs in response to negative emotions, particularly in people with symptoms of anorexia nervosa (Engel et al., 2013; Macht, 2008; Schnepper et al., 2020). The healthy participants in our study showed relatively small effects of negative emotions on WTC, which may explain why ER had no significant effect – if *experiencing* emotions has a small effect, there is little room for ER-related change, unless ER increases WTC beyond that reported in the baseline condition. However, participants with anorexia nervosa may show

greater decreases in WTC following a negative emotional experience, which would create a greater margin for change if ER were applied. There is a large body of evidence identifying ER deficits as a risk factor for restrictive eating disorders (for a review, see Lavender et al., 2015), and some treatments that specifically target these deficits already exist (Racine & Wildes, 2014; Schmidt et al., 2012). Our study's paradigm could be useful for testing the specific components of ER that increase desire for particular foods, which would help to further inform the development of such interventions. This might involve further investigating reappraisal and distraction in a clinical sample, as well as incorporating other adaptive strategies such as *expressive engagement*, which involves engaging in the expression of emotions with the purpose of changing the internal emotional response (Kennedy-Moore & Watson, 2001).

4.2 Positive Emotions

We will first discuss the results for experiencing positive emotions without ER for all three samples (note that we still refer to these samples as distraction, reappraisal and increase samples, but the specific effects of ER will be discussed in the following section). Across all samples in Experiment 2, experiencing positive emotions resulted in higher WTC, relative to neutral emotions. In the reappraisal and distraction samples, this effect remained constant regardless of perceived health. As WTC is the precursor to consumption, this finding can be considered consistent with previous studies showing that positive emotions are associated with increased food intake (Cardi et al., 2015; Evers et al., 2018). This may occur because positive emotions, in contrast to negative emotions, evoke an *approach-motivation*, prompting people to take actions, including consuming food (Gable & Dreisbach, 2021; Macht, 2008). Therefore, opposite to the proposed avoidance-motivation in Experiment 1, positive emotion induction may have encouraged an approach-motivation in participants, biasing them toward consuming more food. Another explanation is that, as predicted by the

ATF, positive emotions prompted participants to appraise the foods in a way consistent with their emotional state, and therefore increased the perceived pleasantness of the foods. This is also consistent with previous studies that suggest experiencing happiness leads to a more pleasant experience when consuming foods or imagining their consumption (Macht, 2008; Otake & Kato, 2016).

In the increase sample, we found a significant interaction with health, showing that experiencing positive emotions increased desire to a greater extent for healthy than unhealthy foods. This finding supports previous studies suggesting that positive emotions lead to healthier food choices (Cameron et al., 2015; Lyman, 1982; Winterich & Haws, 2011), and suggests that this mechanism works by increasing desire for healthy foods, rather than decreasing desire for unhealthy foods. Previous studies have shown that positive emotions can make people more open-minded and willing to consider other perspectives by broadening the scope of their attention (Cameron et al., 2015). Further, there is also evidence that positive emotions increase future-oriented thinking (Pyone & Isen, 2011). Together, these studies suggest that positive emotions may prompt people to consider a broader range of beneficial future outcomes of choosing to eat healthy foods (Cameron et al., 2015). This may explain the boost in preference for healthy foods that resulted from experiencing positive emotions in the present study. However, the health interaction for emotion experience was not found for the distraction and reappraisal samples, although the effect of positive and neutral emotion experience was the same. This might be because for the distraction and reappraisal samples, trials that involved experiencing positive emotions were interspersed with trials in which participants were instructed to decrease these emotions. This repeated process of decreasing positive emotions could have led to a difference in *sustained* positive emotion throughout the whole task without participants becoming aware of this process. Therefore, unlike participants in the increase sample, those in the distraction and reappraisal

sample may not have received these potential health benefits of experiencing positive emotions because they were also constantly required to dampen those emotions. This switching between positive emotions and downregulating them might have put additional cognitive demands on participants, while increasing an already experienced (positive) emotion could have been easier and allowed participants to better process health aspects of the foods when simply experiencing emotions.

We now discuss the effects of the specific strategies used by each sample to down-regulate (distraction, reappraisal) or up-regulate (increase) their positive emotions. We found that WTC could be increased by intentionally amplifying positive emotions, and decreased by downregulating them via reappraisal. Interestingly, although participants in the increase sample showed an increased preference for healthy foods after *emotion induction*, intentionally increasing their positive emotions led to further increases in WTC all foods, regardless of perceived health. This suggests that while positive emotion induction from an external source can boost preferences for healthy foods, attempting to deliberately amplify these emotions might not have this same differential effect. It may be that increasing positive emotions from one's internal resources does not broaden attention toward positive health outcomes in the same way that induced positive emotions are thought to (Cameron et al., 2015), and instead only increases approach-motivation or perceived pleasantness of stimuli, as discussed above. Therefore, our study raises the important question of whether a person's internal resources are sufficient to create positive emotions that carry benefits for decision-making, or whether we need to rely on external stimuli to induce such emotions.

The results from the reappraisal sample suggest that attempting to decrease positive emotions via reappraisal decreases WTC. This effect was present for all foods, regardless of their perceived attributes, but was particularly strong for healthy foods. This suggests that the potential effects of reappraising positive emotions are both beneficial and detrimental - it may

reduce overall WTC, potentially countering the increase in food intake sometimes seen with positive emotions (Cardi et al., 2015; Evers et al., 2018), but may also reduce the likelihood of healthy food choices. The general decrease in WTC is consistent with Zou et al.'s (2017) finding that people with difficulties downregulating positive emotions were more likely to engage in impulsive behaviours. Our findings could suggest that reappraising positive emotions decreases the likelihood of impulsive food consumption.

Although both distraction and reappraisal significantly decreased positive emotional states, distraction had no effect on WTC. There are two plausible explanations for this. The first rests on the assumption that the change in WTC in the reappraisal sample occurred due to changes in emotional state; i.e., ER has a "ripple effect" on dietary decision-making, with the magnitude of emotional change corresponding to changes in WTC. The catch trial analysis showed that the change in positive emotion seemed stronger for the reappraisal sample, compared to the other two. This might suggest that strategies that decrease positive emotional state more effectively have stronger effects on dietary decisions, whereas strategies that lead to only small changes in emotional state have little to no effect. However, a second explanation is that the decreased WTC in the reappraisal sample occurred not only due to emotional changes, but also from the mechanism of ER (Grecucci & Sanfey, 2014). There is evidence that general forms of self-control positively predict successful ER (Paschke et al., 2016), suggesting a link between the two processes. Further, another study found that decreasing incidental negative emotions via reappraisal led to changes in risk-taking decisions, even when negative emotional ratings did not change (Morawetz et al., 2019). These studies suggest a "spillover" effect of ER, with self-control mechanisms that generalise to other domains. In the present study, it is possible that this occurred for the reappraisal sample; i.e., when positive emotions were decreased, the self-control processes generalised to the subsequent dietary decision. As distraction is a less deliberate way of decreasing

emotions, and takes less cognitive and physiological effort (Sheppes et al., 2009), the self-control mechanism in that sample may have not been strong enough to influence the food choice domain. However, this explanation seems at odds with our findings that neither ER strategy was associated with a change in WTC when applied to negative emotions in Experiment 1. Ultimately, given that reappraisal reduced positive emotions more strongly than distraction, and that positive emotions led to increases in WTC, it is most likely that the decrease in WTC after reappraisal resulted from changes in emotional state, rather than the regulation process itself.

Overall, Experiment 2 provides strong evidence that positive emotions increase desire for food, and some evidence that they influence the weighting of perceived health in dietary decisions. In particular, the result from the reappraisal sample has implications for potential interventions designed to target people who overeat when experiencing positive emotions. Previous studies have shown that people with BED, as well as those who show a strong tendency for emotional eating, may overeat in response to not only negative but also positive emotions (Bongers et al., 2013; Dingemans et al., 2009). Therefore, the main effect of reappraisal in our study suggests that using this strategy to decrease positive emotions may have beneficial effects for these populations, as our findings suggest reappraising can decrease desire for foods in general. However, reappraisal of positive emotions may also have detrimental effects on dietary decisions, as we found that it reduced desire particularly for healthy foods. Therefore, if incorporating reappraisal in eating behaviour interventions, it is important to consider whether the individual's goal is to decrease food intake or increase healthy food choices; our results suggest that reappraisal is useful for the former, but not the latter. On the other hand, for individuals who instead wish or need to *increase* their food intake, such as those with restrictive eating disorders or stress-related appetite loss (Adam & Epel, 2007), our results suggest that intentionally increasing positive emotions may be a

helpful strategy. Overall, a key implication of Experiment 2's results is that it might be useful for interventions for restrictive eating disorders to incorporate cognitive strategies that not only help downregulate negative emotions (Racine & Wildes, 2014; Schmidt et al., 2012), but also those that teach individuals to capitalise on naturally-occurring positive emotions and increase their amplitude.

4.3 The Limitation of Individual Differences

We note that these experiments did not take into account individual differences in eating patterns. Although people with extreme patterns of eating behaviour (i.e., those diagnosed with eating disorders) were excluded from participating, there is still considerable variation in the general population in eating behaviours such as restrained, external, and emotional eating (Shagar et al., 2019; Van Strien et al., 1986). Individual differences in these tendencies may influence how people's food intake or dietary decisions change in response to emotions. For instance, there is evidence that restrained eaters (i.e., people with the tendency to restrict their food intake to lose weight) show increased food intake in response to negative emotions (Evers et al., 2018) but decreased food intake in response to positive emotions (Turner et al., 2010) – the opposite pattern to what was found in the present study. In the general population, people also vary in trait levels of emotional eating, which is the tendency to eat in response to emotions, and external eating, which is the tendency to eat in response to external food cues (e.g., appetising smells; Van Strien et al., 1986). It is plausible that these traits would also influence the strength and direction of the effect of emotional states on food intake. However, Evers et al. (2018) showed that while some studies found that those scoring high on emotional eating measures showed particularly strong increases in food intake after negative emotion induction, these findings were inconsistent, and meta-analyses showed no overall differences from those who scored lower on the measure. Therefore, it will be

important for future studies to address the question of whether individual differences in eating behaviours influence the effects of emotions on food intake and dietary decisions.

4.4 General Implications and Conclusions

The results from both experiments shed light on the ability of short-lived, rapidly changing emotions to influence unrelated decisions. In the real world, emotions are considered relatively short-lived by nature, but can last from seconds to several hours or longer (Verduyn et al., 2015). This is different from moods, which usually occur without an identifiable trigger and last from several hours (Johnson et al., 2008) to weeks (Nolen-Hoeksema et al., 1993). Although previous studies suggest that mood has stronger effects on decision-making than emotions (Västfjäll et al., 2016), the present study adds to a growing body of literature showing that even short-lived emotions induced by images or film clips can influence decision-making (Evers et al., 2010; Morawetz et al., 2020; Taut et al., 2012). However, the disadvantage to such lab- and online-based studies is that the findings are not guaranteed to generalise to real-life dietary decision-making. In reality, incidental emotions would not usually change so rapidly between neutral and negative or positive. Further, in the present study's experimental setting, decisions were made seconds after each emotional stimulus appeared, whereas the time elapsed between incidental emotions and dietary decisions is often longer in the real-world, and by the time a person makes a dietary decision, the emotion may have already passed. Finally, although the present study did control for the effects of hunger, real-world food choices are influenced by other factors that we could not account for, such as convenience, price, and social pressures (Dana et al., 2021). Therefore, in the real world, the link between emotions and dietary decision-making is likely less consistent than that observed in our experiment. However, we found some similar effects of negative and positive emotions to previous studies that used more naturalistic methods such as experience sampling (e.g., Ashurst et al., 2018), and the basic cognitive processes in the

present study are likely to operate similarly in the real world (DeSteno et al., 2013). Therefore, there is a strong possibility that our results, including those related to ER, would be useful for real-life dietary decision-making. In fact, some real-world emotions would be experienced more strongly than those induced in the present study; for example, negative emotion after performing poorly on an examination would be more personally relevant, and thus more strongly experienced than emotions from mildly negative images (Ellard et al., 2021). Whether such strong, real-world emotions have a more dramatic effect on dietary decisions is an important question for future studies to address.

In the present study, we examined how dietary decisions are affected by negative and positive emotions, and the regulation of these emotions. Together, the results of our two experiments suggested that a more negative emotional state decreased WTC, whereas the opposite pattern was found for more positive emotional states. WTC could not be changed by regulating negative emotions, neither by distraction nor reappraisal, which makes it unlikely that the lack of an effect was a strategy-specific finding. However, WTC could be increased by intentionally increasing positive emotions, and decreased by decreasing positive emotions via reappraisal. We also found some evidence that positive incidental emotions boost desire for healthier foods. These results have implications for real-world interventions aiming to change eating behaviours. However, future research is still required to investigate the differential effects of discrete emotions and emotion regulation on eating behaviour. As the present study only involved hypothetical food choices, further research is also needed to determine whether these results will generalise to real-world dietary decision-making. Together, the results of both experiments contribute toward the basis for future research investigating more formal ER interventions, and how they may change real-world eating behaviour.

Author Contributions

E.S., S.B. conceptualised and designed the research. E.S. programmed the task, collected the data, and analysed the data. E.S., S.B. wrote the paper. Both authors contributed to revisions of the manuscript, discussed the results, and have approved the final article.

Data Availability

Datafiles for both experiments are available at https://osf.io/7qjke/.

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3.3 Supplementary Materials

SUPPLEMENTARY MATERIALS

Positive Incidental Emotions and their Upregulation Increase Willingness to Consume Healthy Foods

Elektra Schubert[1], Stefan Bode[1*]

[1] Melbourne School of Psychological Sciences, The University of Melbourne, Australia

* Corresponding author: Stefan Bode, Melbourne School of Psychological Sciences, The University of Melbourne, Parkville, VIC, 3010, Australia; email: sbode@unimelb.edu.au

Supplementary 1 – Participants from Different Recruitment Sources in Experiment 1

Supplementary Table S1

Demographics and descriptive statistics for participants recruited via Prolific.co and the University of Melbourne's Research Experience Program (REP) in Experiment 1.

	REP (*N* = 289)	**Prolific.co (*N* = 193)**
	***M* (*SD*)**	***M* (*SD*)**
Age	19.68 (2.75)	30.15 (9.63)
Taste Rating	63.40 (24.79)	67.11 (26.75)
Health Rating	46.31 (32.65)	46.47 (32.18)
Willingness to Consume Rating	37.14 (29.72)	40.57 (27.69)
Gender	***N* (%)**	***N* (%)**
Male	70 (24.22)	122 (63.21)
Female	219 (75.78)	69 (35.75)
Other	1 (0.01)	2 (0.01)

Note. Taste, health, and willingness to consume ratings were given on a continuous sliding scale, ranging from 0 to 100.

Supplementary 2 – Food and Negative Image Stimuli used in Experiment 1

Food Images

Food images were selected from Blechert et al.'s (2019) Food-Pics database (see Supplementary Figure S1). Normative ratings of palatability and craving (Blechert et al., 2019) are displayed in Supplementary Table S2.

Supplementary Table S2

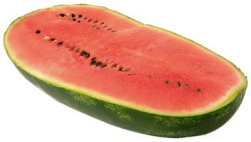
Normative ratings for attributes of food images used in Experiments 1 and 2

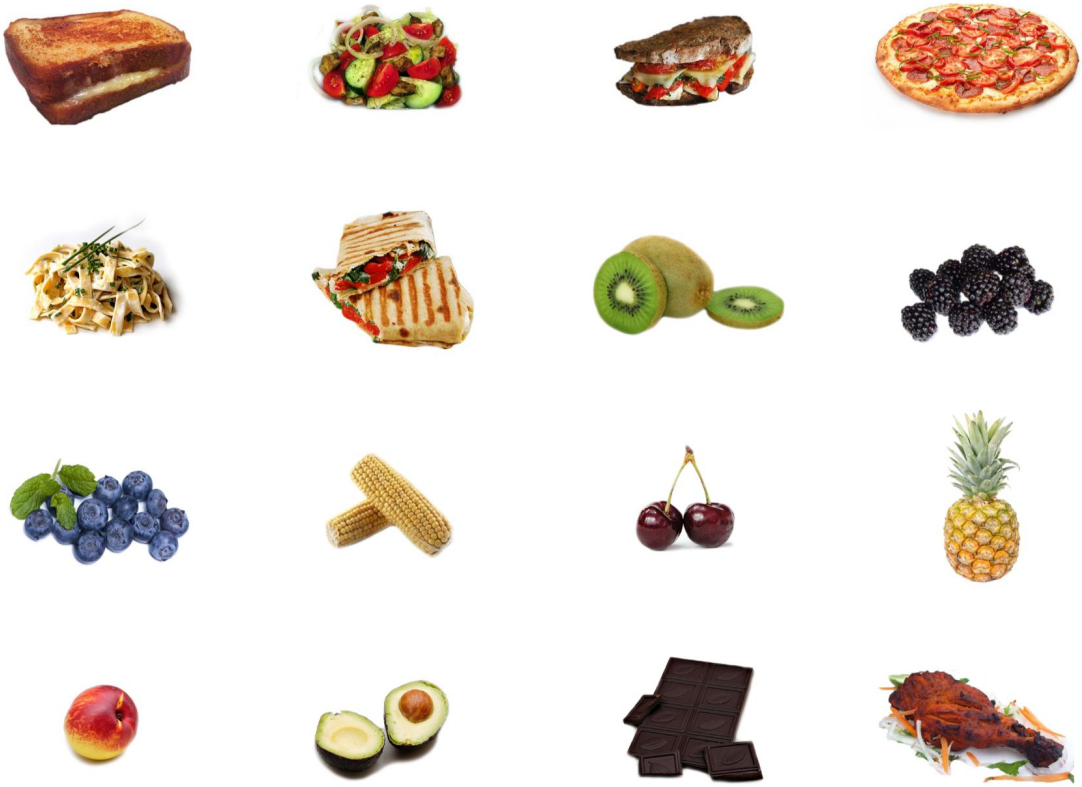
	M	*SD*
Palatability	65.80	6.14
Craving	41.00	7.67

Note. Palatability and craving ratings were given on a scale from 0 to 100.

Supplementary Figure S1

Food Stimuli used in Experiments 1 and 2





Negative and Neutral Images

Negative and neutral images were taken from two databases. First, the Nencki Affective Picture System (NAPS; Marchewka et al., 2014) was used for negative (see Supplementary Figure S2) and neutral images (see Supplementary Figure S3). For normative ratings of the NAPS images, see Supplementary Table S3). Second, the Socio-Moral Image Database (SMID; Crone et al., 2018) was used for negative images only (see Supplementary Table S4; Supplementary Figure S4).

Supplementary Table S3

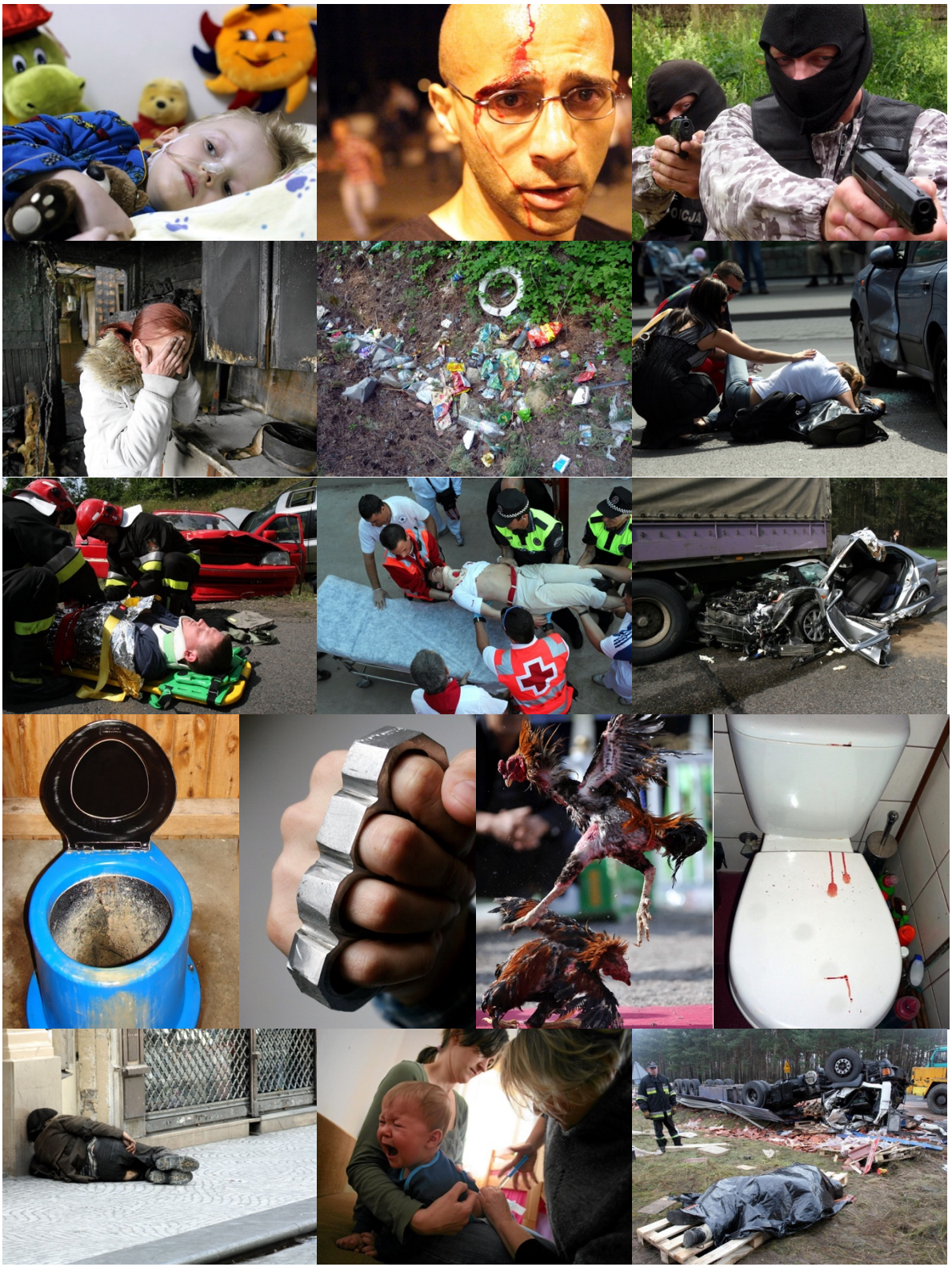
Normed Valence and Arousal Ratings for Negative and Neutral NAPS Images

	Negative Images (N = 25)		Neutral Images (N = 20)	
	M	SD	M	SD
Valence	3.35	1.34	5.44	1.05
Arousal	5.34	1.38	4.67	1.20

Note. Ratings were given on a scale from 1 (*very negative*) to 9 (*very positive*), with a middle value of 5 = *neutral*.

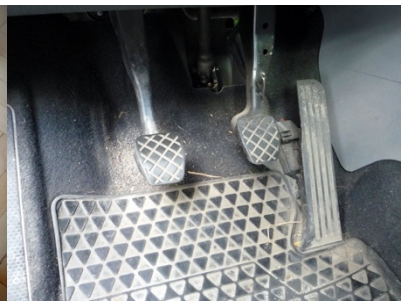
Supplementary Figure S2

Negative Images Drawn from the Nencki Affective Picture System



Supplementary Figure S3

Neutral Images Drawn from the Nencki Affective Picture System



Supplementary Table S4

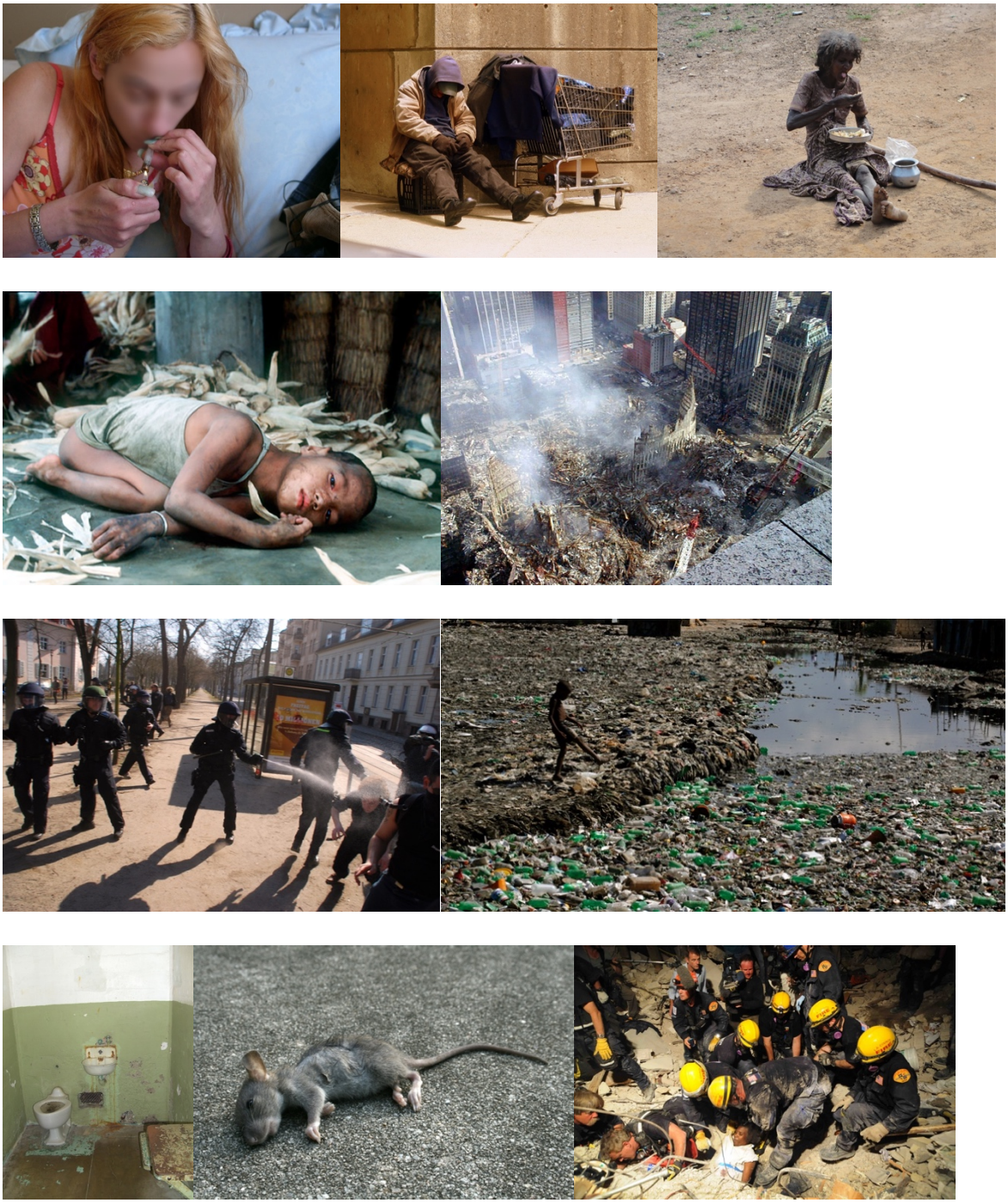
Normed Valence and Arousal Ratings for Negative SMID Images

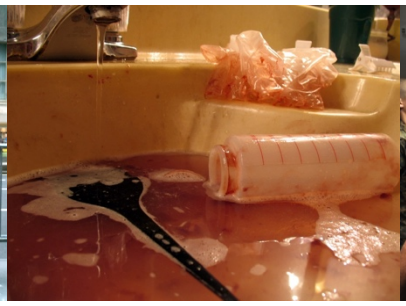
	Negative Images (N = 25)	
	M	SD
Valence	1.52	0.81
Arousal	3.71	1.13

Note. Valence ratings were given on a scale of 1 (*unpleasant or negative*) to 5 (*pleasant or positive*). Arousal ratings were given on a scale of 1 (*calming*) to 5 (*exciting*).

Supplementary Figure S4

Negative Images Drawn from the SMID





NELSON GROCERY STORE

Supplementary 3 – Instructions used in Experiment 1

Supplementary Table S5

Instructions and Example for Look and Decrease in Each Sample in Experiment 1

Cue		
Look (Both Samples)	Instruction	"*Passively view the image on the screen, allowing any emotions you may experience to naturally unfold."*
	Example	*"If you are instructed to LOOK in response to this image, keep your attention focused on the image, and let any thoughts or emotions that you have naturally unfold."*
Decrease (Reappraisal Sample)	Instruction	*"Reinterpret the meaning of the image, in a way that lessens its emotional impact. For example, you may imagine that the situation depicted in the image will improve, or try to see it in a more positive light."*
	Example	*"If you are instructed to DECREASE, you might imagine that instead of a bushfire, this image is depicting routine burning that actually helps to prevent bushfires at a later date. Please note that the exact way in which you use this strategy will not be the same for each image - you will need to adapt to whatever is displayed. Please do your best to engage with this process, and only use this type of strategy to decrease your emotions."*
Decrease (Distraction Sample)	Instruction	*When you see DECREASE, please continue to look at the image, but focus your attention on something neutral and*

	unrelated to the image on the screen, such as your plans for the rest of the day.
Example	*If you are instructed to DECREASE you would continue to look at the image on the screen, but think about, for example, the groceries you need to buy from the supermarket today, or the work you need to do later.*

Supplementary 4 – Experiment 1 Model Steps

Supplementary Table S6

Each Model Tested for the Reappraisal Sample in Experiment 1

$Model_1$	Comparison	Chi-sq	*p*
Null Model	n/a	n/a	n/a
Hunger	Null Model	8.17	.004**
Hunger + Taste	Hunger	1954.60	< .001***
Hunger + Taste + Health	Hunger + Taste	130.77	< .001***
Hunger + Taste + Health + Trial Type	Hunger + Taste + Health	892.69	< .001***
Hunger + Taste + Health + Trial Type + Trial Type x Taste	Hunger + Taste + Health + Trial Type	96.50	< .001***
Hunger + Taste + Health + Trial Type + Trial Type x Taste[a]	**Hunger + Taste + Health + Trial Type + Trial Type x Taste**	**88.57**	**< .001*** **
Hunger + Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health	Hunger + Taste + Health + Trial Type + Trial Type x Taste	1.16	.560
Hunger + Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Taste x Health	Hunger + Taste + Health + Trial Type + Trial Type x Taste	3.45	.328

[a] Final, best-fitting model.

Supplementary Table S7

Each Model Tested for the Distraction Sample in Experiment 1

$Model_1$	Comparison	Chi-sq	*p*
Null Model	n/a	n/a	n/a
Hunger	Null Model	18.54	< .001***
Hunger + Taste	Hunger	2460.60	< .001***
Hunger + Taste + Health	Hunger + Taste	122.96	< .001***
Hunger + Taste + Health + Trial Type	Hunger + Taste + Health	896.05	< .001***
Hunger + Taste + Health + Trial Type + Trial Type x Taste[a]	**Hunger + Taste + Health + Trial Type**	**88.57**	**< .001*** **
Hunger + Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health	Hunger + Taste + Health + Trial Type + Trial Type x Taste	0.01	.999
Hunger + Taste + Health + Trial Type + Trial Type x Taste x Health	Hunger + Taste + Health + Trial Type	0.01	.999

[a] Final, best-fitting model.

Supplementary 5 – Positive Image Stimuli and Normative Ratings

Supplementary Table S8

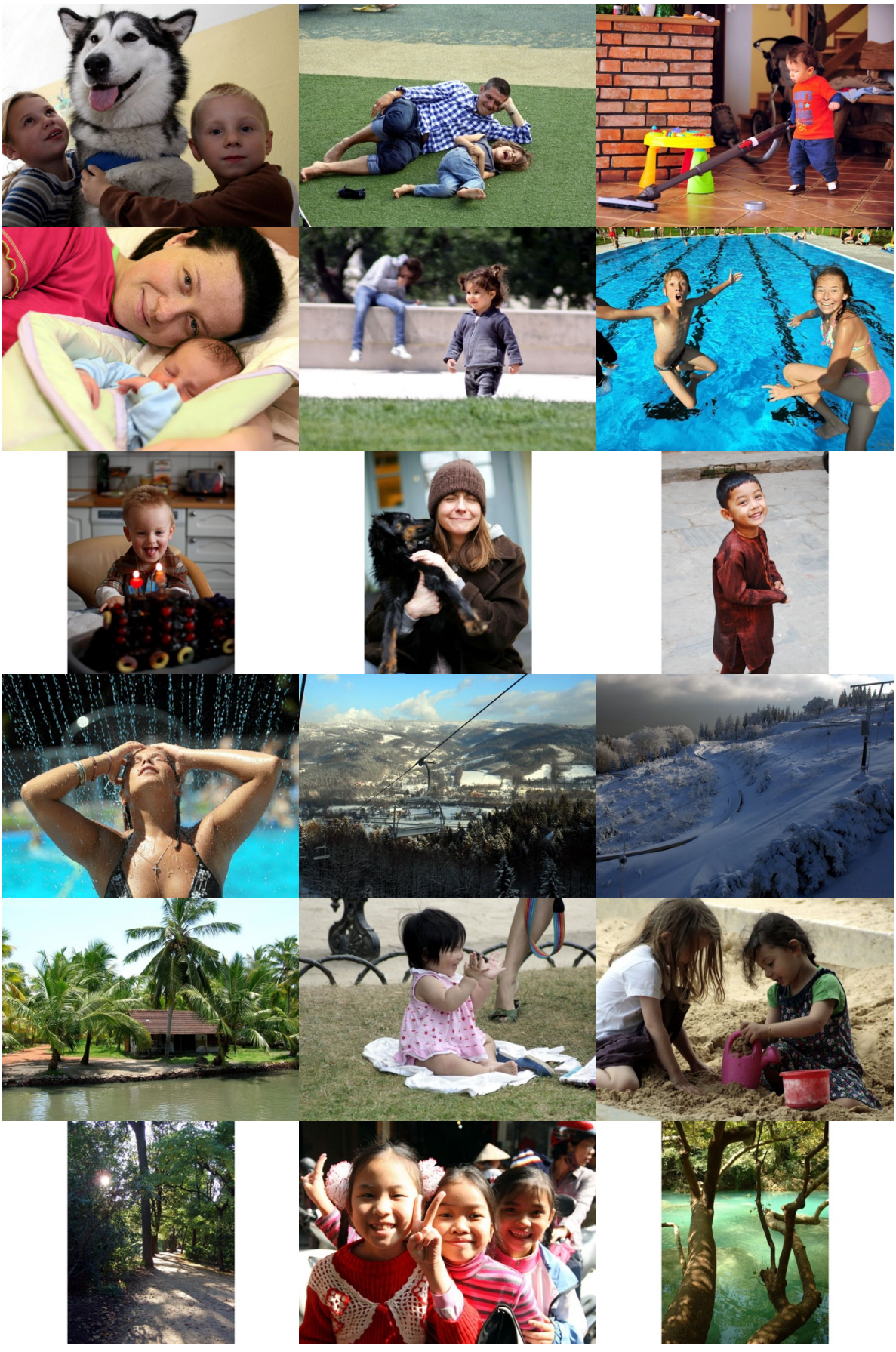
Valence and Arousal Ratings for the Positive Stimuli used in Experiment 2

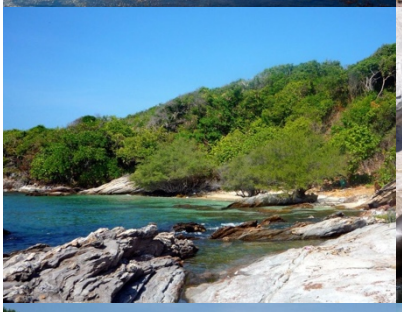
	M	SD
Valence	7.71	1.20
Arousal	4.04	2.27

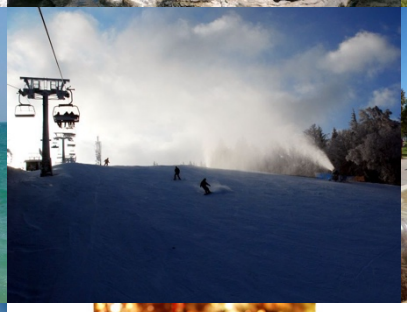
Note. Ratings were given on a scale from 1 (*very negative*) to 9 (*very positive*), with a middle value of 5 = *neutral*.

Supplementary Figure S5

Positive Images Drawn from the Nencki Affective Picture System







Supplementary 6 – Instructions used in Experiment 2

Supplementary Table S9

Instructions and Example for Look and Decrease in Each Sample for Experiment 2

Cue		
Look (All Samples)	Instruction	"*Passively view the image on the screen, allowing any emotions you may experience to naturally unfold."*
	Example	*"If you are instructed to LOOK in response to this image, keep your attention focused on the image, and let any thoughts or emotions that you have naturally unfold."*
Decrease (Reappraisal Sample)	Instruction	*"When you see DECREASE, please reinterpret the meaning of the image, in a way that lessens its positive emotional impact."*
	Example	*"If you are instructed to DECREASE you might imagine that these puppies are at a lost dogs home, and do not have owners. Please note that the exact way in which you use this strategy will not be the same for each image - you will need to adapt to whatever is displayed. Please do your best to engage with this process."*
Decrease (Distraction Sample)	Instruction	*When you see DECREASE, please continue to look at the image, but focus your attention on something neutral and unrelated to the image on the screen, such as your plans for the rest of the day.*
	Example	*"If you are instructed to DECREASE you would continue to look at the image on the screen, but think about, for example,*

		the groceries you need to buy from the supermarket today, or the work you need to do later."
Increase (Increase Sample)	Instruction	*"When you see INCREASE, please engage with the image on the screen in a way that increases its positive emotional impact. For example, you may imagine that you are holidaying in the pleasant place depicted, or that the animal on the screen is your pet."*
	Example	*"If you are instructed to INCREASE you might imagine that this dog is your own pet, and imagine playing with it and taking it for walks. Please note that the exact way in which you increase your emotions will not be the same for each image - you will need to adapt to whatever is displayed. Please do your best to fully engage with this process."*

Supplementary 7 – Experiment 2 Model Steps

Supplementary Table S10

Each Model Tested for the Reappraisal Sample in Experiment 2

$Model_1$	Comparison	Chi-sq	*p*
Null Model	n/a	n/a	n/a
Hunger	Null Model	1.89	.170
Taste	Null Model	1899.30	< .001***
Taste + Health	Taste	74.71	< .001***
Taste + Health + Trial Type	Taste + Health	223.58	< .001***
Taste + Health + Trial Type + Trial Type x Taste	Taste + Health + Trial Type	6.41	.041*
Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health	Taste + Health + Trial Type + Trial Type x Taste	9.45	.008**
Taste + Health + Trial Type + Trial Type x Health[a]	**Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health**	**5.31**	**.070**
Taste + Health + Trial Type + Trial Type x Health + Trial Type x Health x Taste	Taste + Health + Trial Type + Trial Type x Health	6.60	.086

[a] Final, best-fitting model.

Supplementary Table S11

Each Model Tested for the Distraction Sample in Experiment 2

$Model_1$	Comparison	Chi-sq	*p*
Null Model	n/a	n/a	n/a
Hunger	Null Model	6.75	.009**
Hunger + Taste	Hunger	1876.70	< .001***
Hunger + Taste + Health	Hunger + Taste	118.90	< .001***
Hunger + Taste + Health + Trial Type[a]	**Hunger + Taste + Health**	**68.65**	**< .001*** **
Hunger + Taste + Health + Trial Type + Trial Type x Taste	Hunger + Taste + Health + Trial Type	1.46	.483
Hunger + Taste + Health + Trial Type + Trial Type x Health	Hunger + Taste + Health + Trial Type	0.72	.698
Hunger + Taste + Health + Trial Type x Health x Taste	Hunger + Taste + Health + Trial Type	1.70	.636

[a] Final, best-fitting model.

Supplementary Table S12

Each Model Tested for the Increase Sample in Experiment 2

$Model_1$	Comparison	Chi-sq	*p*
Null Model	n/a	n/a	n/a
Hunger	Null Model	13.05	< .001***
Hunger + Taste	Hunger	1744.60	< .001***
Hunger + Taste + Health	Hunger + Taste	90.28	< .001***
Hunger + Taste + Health + Trial Type	Hunger + Taste + Health	132.74	< .001***
Hunger + Taste + Health + Trial Type + Trial Type x Taste	Hunger + Taste + Health + Trial Type	10.97	.004**
Hunger + Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health	**Hunger + Taste + Health + Trial Type + Trial Type x Taste**	**12.21**	**.002****
Hunger + Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health + Trial Type x Taste x Health	Hunger + Taste + Health + Trial Type + Trial Type x Taste + Trial Type x Health	1.26	.738

[a] Final, best-fitting model.

Supplementary References

Crone, D. L., Bode, S., Murawski, C., & Laham, S. M. (2018). The Socio-Moral Image Database (SMID): A novel stimulus set for the study of social, moral and affective processes. *PloS one*, *13*(1), e0190954. https://doi.org/10.1371/journal.pone.0190954

Marchewka, A., Żurawski, Ł., Jednoróg, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behavior Research Methods*, *46*(2), 596-610. https://doi.org/10.3758/s13428-013-0379-1

4.4 Summary

In this study, we investigated how dietary decisions are affected by the experience and regulation of incidental emotions. Our results indicated that negative emotions decreased WTC foods in general, regardless of perceived healthiness. Positive emotions increased WTC foods, in line with our expectations, and one of the three groups showed that positive emotions led to an increased preference for healthy foods. This overall pattern of results, while not fully consistent with our initial predictions, supports the ATF (Lerner & Keltner, 2000), which proposes that people tend to appraise objects in a way that is consistent with their current emotional valence. In other words, our results could suggest that negative emotions encourage people to perceive foods as less pleasant, whereas positive emotions encourage the opposite. Regarding emotion regulation, we found no effect of down-regulating negative emotions on WTC via either strategy. However, down-regulating positive emotions using reappraisal resulted in decreased WTC compared to passively experiencing the emotions, with a particularly strong decrease for healthy foods. Compared to experiencing positive emotions, up-regulating led to further increases in desire for food, regardless of perceived healthiness. These findings suggest that regulating positive emotions has the potential to change dietary decisions, however, the utility of regulation may depend on a person's health goals (e.g., decreasing or increasing food intake, or making healthy choices).

Chapter 5: General Discussion

This thesis had two main goals: first, to understand neural representations of taste and health attributes and how they are integrated into dietary decisions; and second, to investigate two potential ways to change dietary decisions: graphic HWLs and incidental emotion regulation. To address these goals, three studies were conducted. In Study 1 (Chapter 2), we investigated whether neural representations of health and taste attributes could be decoded from multivariate patterns of ERPs during the first second of a dietary decision. In Study 2 (Chapter 3), we tested the ability of graphic HWLs to encourage healthier beverage choices and change the neural processing of taste and health attributes of sugary drinks. Finally, in Study 3 (Chapter 4), we investigated the effects of incidental emotions and the regulation of these emotions on dietary choices. In this final chapter, I will review the findings from each empirical chapter and position them within the existing body of literature. I will then discuss the general implications for the representation of health and taste attributes in the brain, for the link between emotions and dietary decisions, and for interventions to improve food choices. Finally, I will discuss the limitations of the present work and suggestions for future research.

5.1 Review of Key Findings

5.1.1 Study 1: Neural Representations of Taste and Health

In Study 1 (Chapter 2), we investigated neural representations of dietary decisions during the first second of viewing food cues or decision-making. This involved testing whether individual, trial-by-trial tastiness and healthiness perceptions could be decoded from distributed patterns of ERPs. In Experiment 1, participants viewed food images and were explicitly instructed to rate the tastiness and healthiness of each food. The results showed that tastiness could be decoded from neural activity from 530 ms after image presentation, and healthiness was

decodable from 640 ms. Although we could not statistically test for differences in the timing of decoding onset of taste versus health, this pattern of results is consistent with previous studies showing that taste is processed earlier than health, using mouse-tracking (Lim et al., 2018; Sullivan et al., 2015) and eye-tracking (Motoki et al., 2018) techniques. More broadly, the finding that both attributes were decodable at all is consistent with previous studies showing that ERP components occurring in the first second of viewing a food cue, such as the N1, P3, and LPP, reflect perceptions of tastiness and healthiness (Asmaro & Liotti, 2014; Rosenblatt et al., 2018b), as well as related information such as caloric value (Carbine et al., 2018; Meule et al., 2013; Schwab et al., 2017; Toepel et al., 2009). Taken together with these previous studies, the findings from Experiment 1 suggest that perceptions of both taste and health are processed quickly upon presentation of visual food cues.

In Experiment 2, we investigated the same neural representations of tastiness and healthiness during dietary decisions, rather than simple viewing. This involved re-analysing data from a previously published study (Rosenblatt et al., 2018b) with a similar task to that of Experiment 1. However, instead of rating tastiness and healthiness, participants indicated how much they wanted to consume each food (decision strength), with no immediate, explicit instruction to consider specific attributes. We found that previously-given tastiness and healthiness ratings, as well as decision strength, could be decoded from neural activity occurring at 740 ms, 530 ms, and 830 ms, respectively. This result supports the finding from Experiment 1 that the tastiness and healthiness of visual food cues are processed within the first second of encountering the cue, consistent with previous ERP studies (Asmaro & Liotti, 2014; Carbine et al., 2018; Meule et al., 2013; Rosenblatt et al., 2018b; Schwab et al., 2017; Toepel et al., 2009). Notably, we also found that representations of taste and health became decodable *before* decision

strength (i.e., how much participants wanted to consume each food). This may suggest that dietary decision-making occurs in stages, with individual attributes processed and then integrated into an overall decision. This would be consistent with Furst's (1996) theoretical model of food choice (see Section 1.1), as well as several empirical studies (Hajihosseini & Hutcherson, 2021; Hare et al., 2009) which identify a process of value negotiations whereby aspects of the food, including sensory perceptions and health considerations, are weighed up before contributing toward the final decision. However, Study 1 only examined decoding of taste, health, and decision strengths separately, and did not directly examine how taste and health are integrated into decisions. To support the theory that taste and health are processed individually, then integrated into decisions, future studies will be needed with more complex analyses (e.g., computational modelling) that examine taste, health, and decision strength decoding in conjunction with one another.

5.1.2 Study 2: General and Specific Health Warning Labels

In Study 2 (Chapter 3), our focus shifted from simple processes involved in dietary decisions to interventions that may improve decisions. The first intervention examined was graphic HWLs, with a focus on encouraging reduced or healthier SSB consumption. While EEG was recorded, participants rated SSBs on health and taste, then viewed either control, general, or product-specific HWLs. They then viewed the SSBs again and indicated how much they wanted to consume each one. The first aim was to determine whether HWLs can reduce SSB consumption or encourage healthier decisions. Our results showed that both general and specific SSBs were effective at reducing WTC, particularly for SSBs considered to be tasty. This implies that HWLs may reduce SSB consumption. The second aim of Study 2 was to compare general and specific HWLs. Although we did not find any direct differences in WTC between the two

HWL conditions, there was a three-way interaction effect between health, taste, and HWL condition for the general group, but not the specific group. This showed that general HWLs had a smaller effect on WTC for healthy SSBs than unhealthy, whereas the effect of specific HWLs was constant regardless of healthiness. The third and final aim was to examine neural activity occurring in response to SSBs and whether this can be changed by HWLs. The EEG results showed that although perceived healthiness and tastiness of SSBs were reflected in the N1 and LPP components respectively, the amplitudes of these ERP components were not affected by HWLs.

Both general and specific HWLs reduced desire for SSBs considered to be tasty. This result suggests that the findings of previous studies demonstrating the effectiveness of graphic, negatively-framed HWLs for reducing tobacco (Blanton et al., 2014; Cho et al., 2018; Noar, Francis, et al., 2016) and unhealthy snack (Clarke et al., 2020b; Rosenblatt et al., 2018a; Rosenblatt et al., 2019) consumption can be extended to apply to sugary drinks. Our results support several previous studies that also found HWLs to reduce SSB consumption (Billich et al., 2018; Bollard et al., 2016; Donnelly et al., 2018; Grummon et al., 2019b; Taillie et al., 2020). Importantly, unlike some previous studies that were fully online and hypothetical (e.g., Billich et al., 2018; Bollard et al., 2016), our participants were told that they would receive a real-life beverage based on their choices in the experiment. This means that our task may have reflected real-world behaviour more accurately than a purely hypothetical task. Therefore, in having stronger ecological validity, our results not only replicate the previous studies but also strengthen their conclusions.

The second major finding from Study 2 was the significant interaction between HWLs, taste, and health that was present for general HWLs, but not for specific HWLs. This effect

showed that for participants who viewed general HWLs, the effect of HWLs was reduced for SSBs considered to be healthy. On the contrary, for those who viewed specific HWLs, the effect remained constant regardless of perceived healthiness. People's perceptions of the healthiness of SSBs may not be accurate (Miller et al., 2019); therefore, general HWLs may not be effective at reducing consumption of SSBs that people consider healthy, even if they are actually "unhealthy" (e.g., some fruit juices are marketed as healthy but are high in sugar). This may suggest that HWLs specifically mentioning SSBs are superior to those that refer to the consequences of a general unhealthy diet. Our study was the first to directly compare general versus product-specific HWLs for sugary drinks. However, we add to a broader existing body of literature suggesting that more specific or tailored messages tend to be more effective at prompting behaviour change (Blackwell et al., 2018; Casado-Aranda et al., 2022; Pettigrew et al., 2016; Ryan et al., 2019), potentially due to increased personal relevance associated with more specific messages (Thrasher et al., 2012; Winstock et al., 2020).

Finally, the EEG results of Study 2 showed that ERP components reflected healthiness and tastiness but did not directly reflect the effects of HWLs, despite their behavioural efficacy. First, the N1 component was more negative for drinks perceived as unhealthy versus healthy, consistent with Rosenblatt et al.'s (2018) study on snack foods. Other studies have found the N1 to reflect early and automatic allocation of attention (Vogel & Luck, 2000). Taken together with previous studies, our results may suggest that the healthiness of SSBs is perceived quickly, with greater attention allocated to unhealthy drinks. On the other hand, tastiness was not reflected in the N1, but seemed to be reflected in the LPP component, which was higher for drinks considered to be tasty, compared to less tasty ones. This finding is consistent with previous studies that found the LPP to be an index of a craving or arousal response to food products

(Carbine et al., 2018; Rosenblatt et al., 2018b). Our results show that this may also be the case for packaged beverage products. However, although the N1 and LPP components reflected attributes of the SSBs in the task, we found no difference in either component between the control group and either of the HWL groups. This result is contrary to Rosenblatt et al.'s (2018) finding that HWLs changed the amplitude of the LPP occurring in response to snack foods. While this finding may have occurred due to low statistical power or noise in the data, it may also suggest that although HWLs can change behaviour, their effects are not strong enough to change neural indices of automatic attentional allocation or craving for SSBs. In other words, it may be that the effects of the drink stimuli on these components outweighed potentially more subtle effects of HWLs.

5.1.3 Study 3: Incidental Emotions and Emotion Regulation

In Study 3 (Chapter 4), we investigated the effects of incidental emotions (i.e., emotions unrelated to food cues) and emotion regulation on dietary decisions. Experiment 1 was focused on negative emotions. In separate samples, we examined two different emotion regulation strategies, distraction and reappraisal. In the main online task, participants viewed an instructional cue (either "Look" or "Regulate"), followed by an emotion-inducing or neutral image, then a food image, where they indicated WTC. In Experiment 2, we focused on positive emotions and their down- *and* up-regulation. Positive images were used instead of negative, and an additional sample was added with the instruction to *increase* their positive emotions upon seeing the "Regulate" cue. The overall pattern of results showed that negative emotions reduced subsequent desire for foods, whereas positive emotions led to an increase. We also found some evidence that positive emotions increased preferences for healthy foods, although this effect was only present in one of the three positive emotion samples. The regulation of negative emotions,

compared to passively experiencing them, had no effect on dietary decisions. However, down-regulating positive emotions via reappraisal led to decreased desire for foods, with a particularly strong decrease for foods higher in perceived healthiness. Intentionally up-regulating positive emotions had an opposite effect, with increased desire for all foods regardless of perceived tastiness and healthiness. Overall, these results suggest that (a) the more positive a person's emotional state, the greater their indicated desire for food, and (b) the regulation of positive emotions, but not negative, can lead to a reduction in desire for food, compared to when each emotion is passively experienced.

A major pattern of results in Study 3 was that desire for food was decreased by negative emotions and increased by positive emotions. The finding that positive emotions increased overall WTC foods is consistent with previous findings that positive emotion induction increased food intake in healthy participants (Cardi et al., 2015; Evers et al., 2018). Regarding the quality of dietary decisions, previous studies have found conflicting results, with some suggesting that positive emotions prompt healthier decisions (Cameron et al., 2015; Cao et al., 2020; Winterich & Haws, 2011), and others showing that they lead to unhealthy choices (Ashurst et al., 2018; Evers et al., 2013; Reichenberger et al., 2018). Our results lean toward supporting the former: in one participant group, the effect of positive emotional experience on WTC food became stronger as perceived healthiness increased. Therefore, our results may indicate that positive emotions encourage healthier food choices, supporting studies by Cameron et al. (2015), Cao et al. (2020), and Winterich and Haws (2011).

In contrast, negative emotions led to decreased desire for food. Although this effect was contrary to our hypothesis, it is consistent with some previous literature; for example, studies have shown that negative emotions induced via images decreased desire for various foods

(Arend et al., 2022), and that unrelated aversive visual stimuli decreased food wanting (Ventsel et al., 2022). However, our results are inconsistent with others who found that negative emotions led to an increase (Aguiar-Bloemer & Diez-Garcia, 2018; Chao et al., 2012; Garg & Lerner, 2013; Moss et al., 2021) or no effect (Cardi et al., 2015; Evers et al., 2018) on food intake. These inconsistencies suggest that it is important to consider other factors that may explain the effect of negative emotions on eating behaviour. This may include emotion specificity, as some types of emotions may be more likely to decrease food intake (e.g., disgust) than others (e.g., sadness; Motoki & Sugiura, 2018).

We also found that although regulating negative emotions led to changes in emotional state, it did not change desire for food, via reappraisal nor distraction. This result is inconsistent with previous studies showing that the reappraisal of negative emotions led to decreased food intake (Taut et al., 2012) and healthier food choices (Morawetz et al., 2020b), compared to passively experiencing emotions. However, Evers et al. (2010) found similar results to the present study, showing no effect of reappraisal on food intake. It is possible that the inconsistency with Taut et al. (2012) and Morawetz et al. (2020b) arose due to the relatively small changes in WTC food that resulted from negative emotions in our study, meaning that if negative emotions had a small effect, the potential effects of emotion regulation were limited. Alternatively, as the changes in negative emotional state that we observed were also relatively small, the non-significant effect of emotion regulation could also be explained by insufficient training or incentives to regulate. Overall, our results do not provide any evidence that the regulation of mild negative emotions influences dietary decisions in the general population.

On the other hand, regulating positive emotions seemed more likely to lead to changes in eating behaviour, compared to negative emotions. In Study 3, down-regulating positive emotions

via reappraisal led to decreases in WTC foods, particularly healthy foods. This suggests that downregulating positive emotions may not only discourage food intake, but also steer people away from healthy decisions. A potential explanation for this effect is that reappraisal requires effort (Sheppes et al., 2009), and could take up cognitive resources that may otherwise be used to resist unhealthy foods. When participants were instructed to instead up-regulate their positive emotional responses, an opposite pattern occurred, whereby participants reported greater WTC foods, regardless of their perceived tastiness and healthiness. This suggests that intentionally increasing a positive emotional response via one's own internal resources may decrease intended food intake, but is less likely to prompt healthier choices.

5.2 Implications

So far, I have presented the results of three studies focused on dietary decision-making. In this section, I will discuss implications of the findings across three recurring themes. The first is the neural representations of the perceived healthiness and tastiness of food and beverage products, which was a large component of Studies 1 and 2. Second, the role of emotions in dietary decision-making was investigated extensively in Study 3, and in Study 2 (albeit less directly) through graphic HWLs. Finally, Studies 2 and 3 were centered on influences on dietary decisions, a theme which has implications for eating-related interventions.

5.2.1 Neural Representations of Health and Taste Attributes

The first recurring theme of this thesis was the neural representation of tastiness and healthiness during dietary decisions. In this section, I will discuss implications based on the results of Studies 1 and 2, regarding (a) the finding that tastiness and healthiness were reflected in neural activity during the first second of food cue presentation; and (b) the relative timing at which we found evidence for these representations.

The results of Studies 1 and 2 suggest that perceptions of both taste and health are represented in neural activity at an early stage. In Study 1 (Chapter 2), this was evidenced by the successful decoding of both attributes from patterns of ERPs recorded while participants viewed food images and made decisions. In Study 2 (Chapter 3), separate ERP components differed for drink stimuli that were high versus low in perceived healthiness (N1) and tastiness (LPP). Although the analytical approach differed between the two studies, both involved the examination of neural activity during the first second of viewing a visual food or beverage cue. Notably, we examined both tastiness *and* healthiness perceptions in separate analyses, and found that both were represented in the brain during the first second of decision-making. Previous ERP studies largely focused on caloric content, with some studies finding higher amplitudes for particular ERP components (e.g., LPP) in response to high- versus low-calorie foods (Asmaro & Liotti, 2014; Carbine et al., 2018). However, this high- versus low-calorie approach does not clearly indicate whether the differences occurred because of variations in perceived healthiness, tastiness, or another attribute. Our approach is more nuanced, reflecting the importance of individual perceptions, preferences, and opinions on healthiness for making dietary decisions.

Our finding of early neural representations of taste and health may have promising implications for interventions that aim to modify health attribute processing, such as HWLs and nutrition labelling. Some previous studies suggested that only tastiness is processed quickly and automatically (Motoki et al., 2018). This could imply that even if interventions prime healthiness perceptions, they may not be able to override the more salient, quickly-processed tastiness perceptions. However, our results provide a more optimistic perspective. Across Studies 1 and 2, we found evidence that healthiness representations were available at a similar time to those of tastiness. Some of our results even suggested that healthiness can be processed earlier than

tastiness; for example, it was possible to decode healthiness at an earlier stage than tastiness in Experiment 2 of Study 1, and the earliest ERP component that we examined in Study 2 (the N1) reflected perceived healthiness but not tastiness. This suggests that during the early stages of dietary decision-making, health is neurally processed as well as taste. Nonetheless, an important caveat is that earlier processing does not necessarily mean more changeable representations, therefore, these representations must be investigated in further detail before they can be properly used to inform interventions.

Regarding the timing of the cognitive processing of taste and health attributes, our studies produced patterns of results that were inconsistent, but nonetheless have implications for future research. While Experiment 1 of Study 1 showed that tastiness could be decoded earlier than healthiness, Experiment 2 showed the opposite pattern. Although Study 2 involved univariate analyses instead of multivariate, the pattern of results aligned with the latter experiment of Study 1: the healthiness of sugary drinks was reflected in the N1 component, whereas tastiness was reflected in the later LPP component. This inconsistency across our experiments may have been because both Studies 2 and 1 (Experiment 2) involved HWLs. Although participants had not yet viewed these labels at the time of the EEG recording, they had been informed that the study would involve health warnings in the recruitment materials, plain language statement, and consent forms. This may have primed them to consider health more salient, compared to Study 1 (Experiment 1), which involved a simpler task where participants viewed food images and rated tastiness and healthiness - therefore, the recruitment materials for this study presented both attributes as equally important. However, this explanation in itself may have implications for the neural processing of tastiness and healthiness attributes. If the inconsistency between experiments arose from a priming effect of HWLs, this may suggest that the strength and timing

of neural representations of health and taste attributes *can* be changed by interventions aimed at improving dietary decision-making. Our results highlight the potential for future studies to directly test whether the timing of taste and health decoding performance can be shifted by interventions that aim to, for example, make health processing more salient.

5.2.2 Implications for Emotions and Dietary Decision-Making

The second theme in this thesis was incidental emotions and their effect on dietary decisions. This theme was the main focus of Study 3; however, Study 2 may have also indirectly involved negative emotions elicited by the graphic images shown with the HWLs, as shown by previous studies (Donnelly et al., 2018; Rosenblatt et al., 2019). Therefore, in this section it will be assumed that the changes elicited by HWLs in Study 2 can be attributed at least partially to the induction of negative emotions. The general pattern of results in these studies was that negative emotions decreased desire for foods and beverages, whereas positive emotions led to an increase. In Study 3, we also found some evidence for a link between positive emotions and healthier dietary choices. In the following paragraphs, I will discuss the implications of these results for emotions and their effect on decision-making.

The finding that desire for food is decreased by negative and increased by positive emotions was not fully in line with our predictions, but is nonetheless important. Although we did not investigate the reasons for the effects of emotions on dietary decisions, our pattern of results can be used to draw implications about the mechanisms underlying these changes. First, our results could be interpreted as supporting the ATF (Lerner & Keltner, 2000), which proposes that people appraise stimuli as consistent with the valence of their emotional state. Therefore, this theory predicts that when a person feels positive, they are likely to appraise foods and drinks as more pleasant, whereas the opposite would occur when the person feels negative. Our results

supported this prediction, as we consistently found that desire to consume foods and drinks was lower after viewing negative images (Study 3, Experiment 1) and graphic HWLs (Study 2), but higher after viewing positive images (Study 3, Experiment 2). These effects could have been driven by changes in perceived pleasantness of the products. Alternatively, our results could suggest that emotions change a person's "mindset" in other ways, such as encouraging an approach- or avoidance-motivation. Previous studies have suggested that positive emotions are associated with approach-motivation, and negative with avoidance-motivation (Elliot et al., 2013). Our results were consistent with this pattern and may suggest that positive emotions inspire people to seek out stimuli, including food, whereas negative emotions lead to withdrawal. However, this tendency may vary according to discrete types of emotions, whereas in the present thesis, we only examined general negative emotionality. However, it is possible that the images used in both Studies 2 and 3 elicited disgust, as the HWLs in Study 2 contained visceral images (e.g., rotting teeth) and some of the negative images in Study 3 involved potentially disgusting content such as blood and insects. Experiencing high levels of disgust is also likely to lead to reduced desire to consume foods (Motoki & Sugiura, 2018). Our findings provide a basis for future studies to determine the more precise mechanisms through which negative and positive emotions, both generally and in discrete categories, influence dietary decisions.

Next, I will discuss the effects of incidental emotions on the quality of dietary decisions (i.e., preferences for healthy versus unhealthy foods). Overall, our results suggest that positive emotions are more likely than negative to improve dietary decisions. Studies 2 and 3 showed that when compared to a neutral state, negative emotional stimuli led to lower WTC foods and drinks overall; however, this effect generally did not depend on perceived healthiness. One exception was the effect of general HWLs, as we found that general HWLs led to a particularly strong

decrease in WTC tasty, unhealthy drinks. However, this effect may have occurred for other reasons such as the priming of health goals (Rosenblatt et al., 2019), and was not necessarily attributable to emotions. Overall, our results therefore show little evidence that negative emotions improve or worsen food choices. However, we found some evidence that a positive emotional state leads to healthier food choices, as in Study 3 (Experiment 2), as one participant group showed an increased preference for healthier foods after viewing positive images. Although this pattern of results did not replicate in the other two groups, those participants were required to constantly down-regulate their positive emotions, which may have spilled over to other trials – that is, these groups may have unintentionally dampened their positive emotions even when they were not instructed to regulate. The group that showed an interaction with health did not down-regulate their positive emotional response at all, and therefore may have had greater capacity to properly experience positive emotions. We found further evidence for a link between positive emotional state and healthy food choices in another participant group, who reported a decreased preference for healthy foods after down-regulating their positive emotions. The general pattern implied by these findings is that a more positive emotional state can prompt healthier choices, whereas less positive emotions may have an opposite effect. Previous studies have suggested that positive emotions lead people to consider a broader range of beneficial future outcomes that will arise from decisions (Cameron et al., 2015; Pyone & Isen, 2011), which may explain our findings: positive emotions may have made the potential benefits of eating healthy foods more salient, leading to healthier choices.

5.2.3 Implications for Interventions to Improve Eating Behaviours

Finally, an important theme in this thesis concerns real-world interventions for public health and clinical practice. Studies 2 and 3 examined two ways in which dietary decision-

making could be changed: (a) graphic HWLs; and (b) emotion regulation strategies. In this section, I will begin by describing the implications of our results for implementing real-world HWLs on SSBs, and will then discuss how our results could inform interventions that aim to target early, subclinical eating behaviours that may result from emotions.

Overall, we found promising evidence that graphic HWLs may reduce the consumption of unhealthy drinks, particularly with specific messages. Compared to the control condition, both general and specific HWLs led to a reduction in WTC sugary drinks. This suggests that both labels may be effective at decreasing sugary drink consumption. Displaying these labels in supermarkets may lead to reduced SSB purchase and consumption, subsequently improving health outcomes for society. We also found some evidence that specifically mentioning SSBs in HWLs may be more effective than referring to a poor diet more generally. The effect of general HWLs on desire for SSBs was smaller for drinks considered to be healthy, whereas the effect of specific warnings was constant regardless of perceived healthiness. Individual healthiness perceptions of SSBs may not always be accurate (Brownbill et al., 2020). Therefore, HWLs that decrease consumption of SSBs overall would be superior to those that only work for drinks considered unhealthy. There is evidence from existing studies that HWLs reduce parents' choice of SSBs for their children by correcting misperceptions of healthiness (Moran & Roberto, 2018). Our results suggest that specific HWLs work in a similar way for personal SSB decisions, prompting people to consider a wider range of SSBs unhealthy. Without a specific mention of SSBs in the HWLs, misperceptions may remain, and the warnings may only reduce consumption of drinks viewed as unhealthy. Therefore, in designing HWLs with the intention of reducing sugary drink consumption, policy makers should consider including specific mentions of SSBs in the accompanying text.

Our results may also have implications for the integration of emotion regulation in clinical interventions to improve eating behaviour, for both people who overeat and undereat. However, it is important to note that the participants in our Study 3 were from the general population and were not necessarily dieting or experiencing an eating disorder. Therefore, our findings will first need to be replicated in participants who come from the target populations of such interventions. Nonetheless, a major finding in relation to positive emotions was that up-regulating these emotions led to an overall increase in WTC foods, regardless of perceived health and taste. This finding may have implications for people with insufficient food intake, such as those with restrictive eating disorders or reduced appetite due to stress (Adam & Epel, 2007). In designing interventions to help these people increase their food intake, it may be useful to train them to capitalize on positive emotions that occur from stimuli in the environment, increasing the intensity of such emotions.

Another major finding was that positive incidental emotions led to increases in WTC foods, but down-regulating these emotions via reappraisal seemed to counter-act this effect. This could suggest that integrating the reappraisal of positive emotions into interventions (e.g., cognitive training) may help decrease excessive food intake that occurs in response to positive emotions, which may occur for people with BED or a tendency toward emotional eating (Bongers et al., 2016; Dingemans et al., 2017).

However, this suggestion is complicated by the fact that positive emotions are generally considered desirable, with existing research showing associations between positive emotions and several beneficial outcomes, including satisfaction with life (Cohn et al., 2009), emotional well-being (Fredrickson & Joiner, 2002), and physical health (e.g., heart health; Kok et al., 2013). However, there is evidence that positive emotional experiences and expression are not always

beneficial (Gruber et al., 2011); for example, happiness can negatively impact concentration and goal pursuit (Allen et al., 2013), positive emotions can lead people to be more gullible and susceptible to scams (Forgas & East, 2008), and expressing positive emotions in certain contexts can have social costs (e.g., the expression of pride can lead people to appear less likeable; Greenaway & Kalokerinos, 2017; Scopelliti et al., 2015).

Any potential eating-related interventions that build on our Study 3 results must therefore consider the context in which the positive incidental emotions occur and, importantly, whether downregulating these emotions will result in a net gain or loss for the individual. Future studies may further investigate whether there are certain discrete positive emotions or contexts that are maladaptive in a variety of domains. For example, if there are particular emotions that both negatively impact concentration *and* increase food intake, with no benefit to emotional wellbeing, it may be useful for interventions to specifically target these emotions with the intention of improving eating behaviour. An increased understanding of the outcomes of discrete positive emotions will broaden opportunities for future studies to build on our Study 3 paradigm, using it as a foundation to test the effects of positive emotions and their up- and down-regulation on food choices and intake.

5.3 Limitations and Future Directions

The results of the studies in this thesis should be interpreted with the consideration of some limitations. In this section, I will outline several limitations that applied to all three studies in this thesis involving generalizability to real-world behaviour, different demographics, and clinical populations. After discussing each limitation, I will provide suggestions for how future studies might overcome it. I will end this section by discussing some additional next steps for future studies that stem from the results of the present thesis.

The first limitation is that all studies in this thesis were either lab-based (Studies 1 and 2) or online (Study 3), involving mostly hypothetical dietary decisions. Although these types of studies have some advantages, such as allowing the detailed examination of underlying processes in a controlled way, they also come with the limitation that the decisions made in these tasks may not reflect real-world behaviours. In Study 2, participants were told they would receive a real SSB based on their responses in the task, in attempt to prompt more naturalistic decisions. However, this is not the same as a real-world decision. Participants also received financial reimbursement for participating in the study, therefore the SSB was not their primary reward and may have not strongly influenced their decisions in the task. Real-world cravings may be stronger and more difficult to override. Further, participants may have been conscious of judgement from the experimenter on their choice of beverage and reported a higher than usual preference for healthier beverages. Study 3 also involved hypothetical decisions only, and because the task was fully online, participants had no incentive to give accurate responses when indicating their desire to consume the foods in the task. There may have also been issues with the emotion induction process. As the images in the task were not necessarily personally relevant and were more fleeting than many real-world emotional stimuli (Verduyn et al., 2015), they likely induced only weak emotions. Further, real-world emotions are more nuanced than simply high or low valence (positive or negative), and our Study 3 did not consider potential differential effects of discrete emotional categories (e.g., disgust, anger) on food choice.

Overall, to overcome the limitation of relevance to real-world decision-making, future studies should consider using more naturalistic methods of data collection, such as experience sampling. For instance, participants could be cued to report naturally occurring emotional states and subsequent food choices, or be prompted with an electronic health warning before making a

dietary decision. To extend upon the EEG findings in this thesis, future studies may use methods that more accurately simulate real-world behaviour. For example, portable EEG recording sets could be useful for recording neural activity in food choice settings such as supermarkets or restaurants (Soufineyestani et al., 2020). However, this may not allow for clear recordings, and MVPA may not be possible due to the smaller number of electrodes in these sets. Another option may be to record neural activity while participants perform virtual reality tasks (e.g., supermarket simulations; Xu et al., 2021). However, this may also result in noisier data and carry additional complications (e.g., the "onset of a food cue" in a real-world supermarket context may be less straightforward than in a laboratory environment). Nonetheless, future advances in EEG recording technology may make the use of these techniques possible for extending on the results of the present thesis.

A related limitation is that although our studies were focused on taste and health perceptions, which are important for dietary decisions, real-world decisions are more complex and multi-faceted, involving additional factors that were beyond the scope of this thesis. In Study 1, the decoding of taste and health may have only been possible because both attributes were explicitly mentioned either in the task itself, or in the recruitment and ethics materials. In real-world decision-making, although taste and health impact dietary decisions (Dana et al., 2021; Furst et al., 1996), they may not be represented in the brain at such an early time without any explicit cues. Other attributes, such as price and convenience, may be similarly important for driving food choices (Dana et al., 2021). Therefore, even though we found evidence that positive emotions and HWLs lead to an increased preference for healthier foods and decreased SSB consumption respectively, if unhealthy foods tend to be cheaper and more convenient, these effects could be reduced. This is problematic because special price reduction promotions in

supermarkets tend to be applied disproportionately to unhealthy foods in several Western countries, including Australia and the United States (Bennett et al., 2020). It would therefore be beneficial for future studies to consider other factors that influence food choice, particularly price and convenience.

Another element of dietary decisions that we did not account for is habitual behaviour, which is a component of Furst's (1996) model of food choice. It may be more difficult to change food choices when they are habitual (Chance et al., 2014). Therefore, even though our results suggest that HWLs decrease SSB consumption, if a person is in the habit of buying one before work every day, this effect may be reduced. In future studies, experience sampling methods may again be helpful for determining a person's usual patterns of unhealthy food or SSB consumption. This would allow for the investigation of the effectiveness of interventions (e.g., HWLs, emotion-related interventions) for habitual versus non-habitual decisions. However, as previously discussed, methods that simulate a real-world environment carry additional complications. Therefore, future studies should be conducted to complement those performed in a controlled, laboratory-based environment, rather than replace them.

All studies in this thesis are also limited by the participant demographics and sampling procedure, as each study involved healthy, non-clinical samples, primarily recruited via university portals and undergraduate research participation programs. This means that many participants were young adults (aged 18 to 25) who likely came from a privileged, educated background with high socioeconomic status (SES). It is unclear whether our results would generalise to participants with lower SES backgrounds. This may be particularly problematic for Studies 1 and 2. There is evidence that for people who are not financially privileged, healthiness is less important for driving food choices than other factors such as price (Kershaw et al., 2019;

Robinson et al., 2022). Therefore, the findings from Study 1 that both health and taste are processed during early food cue viewing may not generalise to low-SES populations, if health is less important for them. Further, previous studies have suggested that HWL interventions for tobacco smoking are less effective for people from lower SES backgrounds (van Meurs et al., 2022). Although in Study 2 we did explore whether the effects of HWLs differed depending on demographics, including SES and education, the fact that our overall sample was likely above average on at least one of these factors may have led to the observed lack of effects. Therefore, our results do not necessarily imply that HWLs would be effective at reducing SSB consumption for people from low-SES or -educational backgrounds. People from low-SES backgrounds tend to consume more SSBs than those from high-SES backgrounds (Han & Powell, 2013; Miller et al., 2020), and are therefore an important target population for public health interventions such as HWLs. Therefore, it would be problematic if HWLs were not effective on this population, and it is important that future studies address this question.

Another limitation related to generalisability is that our participants were not generally overweight, dieting, or trying to lose weight. We aimed to examine dietary decision-making in the general population, however, as participants were recruited via advertisements, it is possible that people with a particular interest in health were disproportionately likely to respond. Similarly, people who were overweight or ashamed of their eating habits may have been unwilling to participate. In each study, the mean BMI of the sample fell into "average range" at approximately 23, whereas in 2018, the average Australian had a BMI of about 26, classified as "overweight". This suggests that the proportion of overweight participants in our samples may not represent that of the general population. This limitation could threaten the generalisability and application of our results, particularly for Study 2. First, there is evidence that people who

are overweight and obese show different neural responses to food cues in brain regions related to reward processing and self-control, compared to people who are not overweight (Morys et al., 2018; van Meer et al., 2016). If people with obesity have heightened cognitive responses to food, these responses may be more resistant to change from public health interventions. Therefore, the effectiveness of HWLs on dietary decisions will need to be tested in samples of overweight or obese participants. Nonetheless, there are merits to examining dietary decision-making in the "healthy weight" population, because encouraging healthier dietary choices in the general population could help protect against eventual obesity or other health issues that result from a poor diet.

Another limitation, also stemming from our focus on the general population, is that our findings may not generalise to clinical populations with eating disorders (e.g., AN or BED). This limitation is particularly relevant for Study 3, as there is a role of both positive and negative emotions in eating disorders that is established but not fully understood (Espeset et al., 2012; Fox, 2009; Tchanturia et al., 2015). For example, compared to healthy controls, people with AN and BED have reported greater difficulty with regulating their emotions (Harrison et al., 2010) and describing the emotions of themselves and others (Bydlowski et al., 2005). Therefore, if a similar paradigm to our Study 3 were conducted in a clinical population, the effects of incidental emotions and emotion regulation on food choice may differ. One study found that induced negative emotions resulted in increased food cue reactivity (including desire to eat) for people with BED but not AN or healthy controls (Schnepper et al., 2021). Therefore, it would be useful for future studies to use a paradigm similar to our Study 3 in participants with BED, to determine whether regulating these emotions can counter-act the increases in desire for food that result from negative emotions in this population. Further, it will be important for future studies to

investigate the role of positive incidental emotions in food choices for these clinical populations. In particular, if our findings that positive emotion experience and up-regulation increases desire for food are replicated in those living with AN, it would have valuable implications for interventions and strategies to improve food intake in AN patients.

A final potential limitation, specific to Study 3, is that data collection took place during the COVID-19 pandemic. In particular, the data for Experiment 1 were collected between September and December 2020, when the state of Victoria was under strict stay-at-home orders and travel restrictions applied across Australia (Australian Institute of Health and Welfare, 2021). There is evidence that isolation and reduced social contact during lockdowns, as well as pandemic-related stress, lead to increased negative emotion (Carvalho et al., 2022), reduced craving control (Buckland et al., 2020), and changes to eating behaviours, in the form of increased emotional eating for some people (Cecchetto et al., 2021) and reduced appetite for others (Owen et al., 2020). Therefore, it is possible that participants' responses to the emotional and food stimuli in the study differed from how they would be outside of the pandemic or lockdowns. For example, if participants were already experiencing more negative emotion than usual, or were emotionally preoccupied as a result of the lockdowns, this may have weakened the effect of the negative stimuli in the study. As the world moves beyond the COVID-19 pandemic, future studies will be able to test whether the effects seen in Study 3 will still apply to participants who are not locked down or experiencing pandemic-related stress.

5.3.3 Future Directions

So far, I have discussed several suggestions for future studies to overcome the limitations discussed. First, using more naturalistic methods of data collection will allow future studies to obtain results that accurately reflect real-world behaviour. Second, future studies on

interventions to improve food choice will need to consider factors beyond taste and health, such as price, convenience, and habitual behaviour. Third, it will be important for future studies to determine whether the patterns of results that we observed generalise to overweight, obese, and other clinical populations. In this final section, I will suggest some further directions for future studies that may build upon the conclusions of this thesis.

First, to build on the findings from Study 1, future studies may use the decoding of food attributes to examine the effects of interventions and other factors (e.g., emotions) on the processing of visual food cues. This may involve examining how the strength or onset of neural taste and health representations change under certain circumstances. For example, future studies could use a similar procedure to our Study 3 paradigm to further investigate incidental emotions. This would involve inducing emotions followed by a food choice, and testing whether the decoding of taste and health during the decisions differs by emotional valence. For instance, if positive emotions prompt healthier food choices through future-oriented thinking, healthiness representations may become stronger following positive emotion induction. Future studies could also test whether interventions aimed at increasing the salience of healthiness (e.g., HWLs, nutrition labelling), shift the relative decoding of attributes; for example, by shifting healthiness to be earlier than tastiness.

Investigating individual differences in decoding may give insight into how different types of people process food cues. This may involve testing whether health and taste decoding differs for participants with obesity or BED, compared to healthy controls. One study found no difference between obese and non-obese participants in the decoding of food palatability and caloric content from fMRI data (Pimpini et al., 2022). However, EEG decoding allows for detailed investigation into the timing of attribute processing, and may yield different results.

Another population of interest may be people experiencing *orthorexia* – a pattern of eating characterised by obsessively restricting food based on diet quality, rather than quantity (Dunn & Bratman, 2016). Although not formally recognised as an eating disorder in the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013), there has been recent growth in interest in orthorexia in eating behaviour research, and the cognitive mechanisms underlying the disorder are not well understood (Cena et al., 2019; Dunn & Bratman, 2016). Our decoding approach could be used to determine whether people with this pattern of eating show stronger neural representations of healthiness and investigate interventions to change these representations. Despite these promising possibilities, future studies must establish a stronger, clearer baseline of decoding onset and strength before examining changes to decoding patterns. In our Study 1, tastiness and healthiness were not consistently decodable at the same time, in the same order, nor with the same strength across Experiments 1 and 2. This may have been due to variation in decoding patterns between participants, caused by individual factors such as different levels of noise in the EEG signal. Advances in decoding techniques may help make this process easier (e.g., an analysis that takes into account different decoding onsets between participants) and allow for extensions to our finding that tastiness and healthiness could be decoded from early neural activity.

A second important step for future studies will be to build on our findings from Studies 2 and 3 by incorporating them into formal public health interventions to test their effectiveness. For HWLs, a first step will be to test whether they prompt behaviour change in real-world supermarket, convenience store, and vending machine settings. The design of the HWLs will also be important. Based on previous studies, the most effective HWLs are negatively-framed and accompanied by graphic images (Gupta et al., 2021; Rosenblatt et al., 2019). Our results

from Study 2 add that specifically mentioning the target product (e.g., SSBs) in HWLs may boost their effectiveness. However, our findings must be replicated in a real-world setting to determine whether the benefits of SSB-specific labels outweigh any potential additional costs associated with the time and effort taken to produce labels specific to SSBs (as more general labels could also be used for other products, e.g., unhealthy snack foods).

Further, the real-world implementation of HWLs may involve additional challenges that were not investigated in Study 2. For instance, there is some evidence that the effectiveness and impact of HWLs on cigarette packets may decline over time, as people become desensitised to the messages (Hitchman et al., 2014; Swayampakala et al., 2018). It is unknown whether this decline would also occur for HWLs on SSBs, and whether switching out the images or labels could overcome it. Another challenge is that HWLs on unhealthy drinks would often be competing with advertising messages that aim to sell the product, and can influence SSB consumption (Hennessy et al., 2015). It will therefore be important for future studies to investigate how HWLs and advertisements for unhealthy foods stack up against each other. Another potential challenge is psychological, as there is evidence that HWLs may lead to weight stigma (Hayward & Vartanian, 2019). One study found that graphic HWLs (specific to SSBs) were perceived as stigmatising by the majority of a sample of overweight or obese participants, and led to lower mood and self-esteem (Hayward & Vartanian, 2019). Although the study did not examine whether the *effectiveness* of HWLs differed between overweight and non-overweight participants, there is evidence from other studies that experiencing weight stigma leads to negative consequences such as increased food intake (Vartanian & Porter, 2016). Therefore, further research is needed to ensure that the potential psychological costs of HWLs do

not negate or outweigh the benefits observed in this thesis, and to determine whether HWLs will still be effective with the added challenges of real-world implementation.

Finally, future studies may build on our Study 3 results by developing emotion-focused interventions to improve food choices in the general population, particularly by building on our results regarding positive emotions. Targeting the general population could help people develop strategies that will protect against developing eating pathology later on (Armitage, 2015; Evans, 2017). Before such interventions can be tested, future studies should aim to replicate our results using different emotion induction techniques (e.g., vignettes, mood induction using music), and investigating specific, discrete emotions (e.g., happiness vs. excitement), going beyond negative and positive valence. If these studies produce similar results, subsequent research may go further by developing app- or internet-based interventions. This may involve extensions to existing apps, such as *MyFitnessPal*, a health-focused app that allows users to register their health goals (e.g., calories, nutrients) and track their daily food intake, exercise, and more (Evans, 2017). These extensions may encourage users to be aware of and track emotional food triggers (e.g., positive emotions, as per our Study 3 results). Future research on ways to counter-act the increases in food intake that result from positive emotions may allow these apps to also incorporate cognitive strategies or interventions into their interface.

5.4 Conclusion

In summary, this thesis examined dietary decisions and how they can be improved, across three studies. More specifically, we addressed the overarching goals of (a) determining how the brain processes visual food cues and (b) investigating ways of improving food choices. In Study 1 we found that fine-grained representations of tastiness and healthiness could be decoded from neural activity during the first second of both viewing visual food cues and making a

hypothetical dietary decision. Both attributes were decodable at a slightly earlier stage the strength of the decision itself. These findings suggest that taste and health attributes are processed quickly and possibly automatically, before being integrated into decisions. In Studies 2 and 3, we shifted the focus to ways of improving dietary decisions. Study 2 showed that graphic HWLs reduced desire to consume sugary drinks, and that messages referring specifically to SSBs may be more effective than general HWLs, as they led to decreased desire for all drinks, not only those considered to be unhealthy. Finally, in Study 3 we found that negative incidental emotions decreased desire for various foods, whereas positive emotions had an opposite effect, and particularly increased willingness to eat healthy food. Down-regulating negative emotions had no effect on WTC, but when positive emotions were up- and down-regulated, they led to respective increases and decreases in willingness to eat foods.

Across these three studies, I have highlighted the role of health and taste perceptions in driving dietary decisions and the importance of taking these attributes into account when examining interventions to change eating behaviour. I have provided several suggestions for how future studies may build on our findings to investigate how the strength and timing of neural health and taste representations can be changed by interventions. These may involve health-related messaging, such as HWLs, or training in recognising emotional triggers of food intake. Future research will need to develop these interventions more formally and test them in real-world dietary decision-making settings. These strategies will be important for preventing and improving the outcomes of those who experience obesity, eating disorders, and related health issues, leading to improved mental and physical health in society.

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