Implicit markers of food choice

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Colophon

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Toelichting illustraties cover en hoofdstukken: Wat zijn impliciete markers van voedselkeuze? Je meet niet het daadwerkelijke gedrag (de voedselkeuze). Ook vraag je niet hoe iemand zelf zijn of haar voedselkeuze verklaart. Impliciete markers van voedselkeuze zijn reacties (hersenactiviteit, oogbewegingen, reactietijden) die samenhangen met de voedselkeuze en waarmee je verwacht meer inzicht te krijgen in de onderliggende motieven. In de illustraties (olieverfschilderijen) is de voedselkeuze zelf niet afgebeeld, maar enkel het zichtbare gevolg hiervan: bijvoorbeeld de schaduw van een hand die naar een taartje reikt (cover, Hoofdstuk 2 en 5) of overgebleven lege snoeppapiertjes (Hoofdstuk 1 en 7). De impliciete markers zetten letterlijk een schijnwerper op de voedselkeuze, met elke marker zijn eigen invalshoek en kleur (cover, Hoofdstuk 4). Op de grensvlakken van de lichtbundels vindt een interessant kleurenspel plaats. Gelijk aan hoe licht additief mengt — licht in de drie primaire kleuren mengt samen tot de meest onvervuilde kleur (wit) — verwacht je dat een combinatie van impliciete markers de meest accurate benadering van de werkelijkheid geeft. Meer informatie over de illustraties: www.nynkevanderlaan.nl

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Impliciete markers van voedselkeuze

(met een samenvatting in het Nederlands)

Proefschrift

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Contents

Chapter 1

Introduction

Summary The general aim of this thesis was to establish the potential of implicit markers (1) to predict food choice and (2) to gain insight into the decision-making processes underlying food choice. To introduce the topic, this chapter starts with a discussion on the relevance of identifying such implicit markers. Next, definitions and background information are given about the methodologies evaluated in this thesis. Further, an overview of the factors relevant in food choice is given, followed by our hypotheses regarding the added value of implicit markers in the study of food choice. Finally, an outline of the topics discussed in this thesis is provided.

1.1 Why are implicit markers for food choice needed?

Eating unhealthy, that is, eating too much energy dense and nutrient poor foods, is a major problem in the Western world, as well as in developing countries (Mendez et al., 2005; WHO/FAO, 2002). A positive energy balance, i.e., higher energy intake than energy expenditure, leads to weight gain in the long term. With the increasing number of public health problems related to obesity (Haslam and James, 2005), it is of importance to better understand how healthy food choices can be promoted.

Because most food choices are made by habit, without conscious deliberation, individuals are often not able to correctly verbalize the motives for their choice (Verhoeven et al., 2012; Hofmann et al., 2005a; Nisbett and Wilson, 1977; Bargh, 2002; Fitzsimons et al., 2002). Explicit verbal measures, such as questionnaires or interviews, only tap into that specific part of the motive that individuals are conscious of. In addition, explicit measures are highly susceptible to demand characteristics, social desirable responding, misattribution of emotional and visceral states, and attempts to resolve cognitive dissonance about food choices that are not in line with one's healthy eating goals (Fazio and Olson, 2003; Nordgren et al., 2006; Hofmann et al., 2005b). Moreover, explicitly asking for motives at the moment of choice focuses attention on these motives, which may in turn affect their choice. These factors render explicit verbal measures suboptimal for predicting everyday food choices and gaining insight into food choice processes.

Considering these aforementioned reasons, there lies great potential in techniques that do not depend on explicitly asking the motives for choice. These measures are hereafter referred to as implicit markers. Theoretically, all measurable responses that occur between the moment of exposure to a food and the decision to either eat it or not, could potentially provide insight into the processes that steer this decision. Measurable responses include cognitive (e.g., reaction time), attentional (e.g., fixation duration), central (brain activation), physiological (e.g., skin conductance, heart rate frequency), and hormonal (e.g., ghrelin, leptin) responses. Although the sight of food does elicit physiological responses like changes in heart rate, heart rate variability, salivation, blood pressure, skin conductance, and gastric activity (Nederkoorn et al., 2000), there is debate about how valence-specific these responses are. For example, skin conductance and heart rate responses appear to respond to any strong emotion, either positive or negative (Kreibig, 2010). Therefore, these measures might be sensitive enough to predict liked from disliked foods (De Wijk et al., 2012), but are expected to be less accurate in predicting smaller differences in preference. Although several hormones have shown to be associated with body weight and long-term food intake (Williams and Elmquist, 2012), the response time (minutes to hours) is generally too long to be used as predictor of single choices. Therefore, in this thesis we focus on cognitive, attentional, and central markers as the main predictors of decision-making processes in food choice. The first measure of interest is choice reaction time, which is regularly used as indicator for cognitive processing in psychological experiments. A second line of potentially useful measures are attentional measures. Measures such as fixation duration and location of first fixation reflect attention allocation and provide information on which stimuli or packaging elements attract most attention. A third measure of interest is brain activation. Since all aspects of decision-making are integrated in the brain, neural measures are expected to have an extraordinary potential for predicting choice and gaining more insight into the underlying processes. These measures are elaborated on further in Section 1.3.

Developing implicit measures that enable a more accurate overview of the motives for food choice could ultimately suggest new approaches to interventions stimulating healthy food choices. Therefore, the overarching goal of this thesis was to establish the potential of implicit markers to (1) predict choice and (2) gain insight into the decision-making processes underlying food choice.

1.2 The ideal implicit marker

The ideal implicit marker should be able to predict choice with a 100% accuracy and perfectly reveal underlying decision-processes. In addition, the measurement itself should not disrupt the naturally occuring choice processes and should perfectly extrapolate to actual choices in the supermarket or cafeteria. Thus, important features of an implicit marker of food choice are its prediction accuracy, interpretability and the invasiveness of measurement. These features are addressed in the following subsections.

1.2.1 Prediction accuracy

An important aspect of prediction accuracy is that the implicit marker should have a quantitative relation with the behavior of interest, in this case food choice. Having a quantitative relation with choice is essential to construct a predictive model that incorporates the score derived from the implicit marker. A regularly used indicator of accuracy is the percentage of correct predictions of the mathematical model with the implicit marker. Obtaining accurate predictors of choice is particularly relevant for neuromarketing purposes since this would enable companies to forecast the market success of a product, provided that laboratory results can be extrapolated to the supermarket or cafetaria. Considering the high percentage of failing product/packaging combinations each year (Griffin and Page, 1996), it is relevant to find more accurate predictors than the currently applied marketing research methods. In Chapter 3 we assessed the accuracy of functional Magnetic Resonance Imaging (fMRI) in conjunction with multivariate pattern analysis (MVPA) to predict food choice.

1.2.2 Interpretability

It is important to note that an accurate predictor of food choice does not necessarily provide insight into which specific motives or processes led to that choice. As described in more detail in Section 1.4, making a food choice is a complex trajectory which can involve either automatic or conscious processing (or both), depending on the specific choice set, situation, and the personal goals of the individual (e.g., losing weight). The choice can encompass several aspects of the product (e.g., tastiness, healthiness, packaging) and eating-situation (e.g., appropriateness, time of day). All relevant factors are integrated and ultimately lead to the decision to either eat the food or not. Therefore, when an implicit marker has a mathematical association with choice, it could reflect any (or a combination) of the potential underlying processes. For example, when activation in a certain brain region predicts choice, this might reflect the expected pleasure that will be experienced during consumption of the product. However, it could also be a correlate of a different factor that was relevant for the decision (e.g., considering the product's healthiness). It could be speculated that the more accurate a predictor of choice is, the more likely it reflects processes in the last phase of the decision process in which the final decision is made.

For an implicit marker to be used as an indicator of decision-making processes, interpretability is an important feature. All implicit markers described in this thesis are multi-interpretable. For example, reaction times can be used both as an indicator of response conflict and as an indicator of goal-activation, depending on the specific task in which they are measured (Kroese et al., 2009; Panayiotou and Vrana, 2004). With respect to fMRI this is illustrated by previous findings that activity in the striatum can reflect both valence and arousal (Litt et al., 2011). For interpretability of the implicit marker, it is crucial to choose a task instruction and choice set that evokes a certain (expected) process of interest and rules out alternative interpretations. For instance, the aim of Chapter 5 is to investigate the level of experienced conflict during the food choice. To be able to measure conflict, choice sets are required to pose either a self-control dilemma or not. In this chapter, fMRI, eye-tracking and choice reaction times are used as process indicators. In Chapter 4, the role of task instruction in the interpretability of eye-tracking measures was assessed.

1.2.3 Invasiveness of the measurement

Another important feature of implicit markers is the invasiveness of the measurement, or the extent to which the measurement itself affects the subject and thereby disrupts the natural choice process. As mentioned above, explicitly asking for motives during the choice moment will most likely influence the choice because the natural automatic choice process is disrupted and instead, conscious deliberations will start playing a role. Measuring food choice in a laboratory, instead of in the supermarket or cafeteria, could also influence natural choice processes and thereby limit the external validity of the results for real life situations outside the lab, such as the supermarket or cafeteria.

1.3 Potential implicit markers of food choice

This section describes the measurement techniques evaluated in this thesis.

1.3.1 Reaction time as a marker of cognitive processing

Reaction time is the elapsed time between the presentation of a stimulus and the subsequent behavioral response (the button press). In experimental and cognitive psychology, reaction time is used to infer the content, duration, and temporal sequencing of cognitive operations during a task. The reaction time indicates how fast the cognitive processes in the task can be performed, i.e., the processing efficiency (Jensen, 2006). As such, reaction time indicates which task-related factors disrupt or foster cognitive processing. It is well established that reaction times are higher in difficult tasks (Panayiotou and Vrana, 2004). Concerning preference decisions there are a few studies showing that difficult decisions (choosing between equally liked options) are accompanied by higher reaction times than easy decisions (choosing between two options that differ in liking) (e.g., Sharot et al., 2009).

In a lexical decision task, reaction time is used to asses the strength of the mental representation of a particular construct, for example a dieting goal. During a lexical decision task, the participant is presented with targets: strings of letters that are either existing words or pseudowords (non existing words). The participant has to indicate with a button press whether the target is an existing word or not. To investigate the mental accessibility of a dieting goal both neutral and diet target words are presented. The faster the reaction time to diet target words (compared to neutral), the stronger the mental accessibility of the dieting goal is thought to be.

When lexical decision tasks are combined with primes, i.e., presenting a prime word shortly before the target word, the influence of this prime on the accessibility of the target, i.e., the association between prime and target, can be determined. It is assumed that reaction times to targets are faster when preceded by a prime that is cognitively associated with the target. Previous studies have employed primed lexical decision tasks to show that in some dieters, temptation cues increase the mental activity of, or 'activate', the dieting goal (Kroese et al., 2011; Papies et al., 2008).

In Chapters 4 and 5 reaction times accompanying preference decisions were used as a marker for choice difficulty. In Chapter 5, a lexical decision task was used to investigate temptation-goal associations.

1.3.2 Eye tracking

1.3.2.1 Measuring visual attention

Eye trackers are used to measure visual attention. An eye tracker typically exists of a light source (usually infrared) and a camera. Mathematical algorithms are used to locate the position of the pupil. The data is used to extrapolate the rotation of the eye and ultimately the point of gaze (the spot someone is looking at). Eye movements can be classified into fixations and saccades; maintaining the gaze in a stable direction, and moving the gaze to a different location, respectively. From a time series of eye movements during a choice, several measures of visual attention can be derived, namely the location of the first fixation (the product that was looked at first), the total fixation duration (the duration that a stimulus was looked at), last fixation (the product that was looked at last before the choice was made) and the number of switches between products.

1.3.2.2 Application in choice research

It is well established that emotion and reward circuits are closely linked with attentional systems in the brain (Vuilleumier, 2005). Specifically, it has been suggested that both attention and emotional valence modulate processing of visual stimuli by enhancing neuronal responses at different levels of visual processing: both in early visual processing and in later phases such as recognition (Gerdes et al., 2010; Kastner and Ungerleider, 2000; Lane et al., 1999).

Only recently, a series of eye tracking studies has investigated the role of visual attention in food perception, but with mixed results. In general, people appear to have increased attention for food versus nonfood cues (Nummenmaa et al., 2011; Castellanos et al., 2009). However, there is uncertainty about how visual attention to food cues is modulated by individual BMI, current hunger status and the food's energy content (Castellanos et al., 2009; Nummenmaa et al., 2011; Werthmann et al., 2011; Graham et al., 2011; Tapper et al., 2010; Gearhardt et al., 2012).

In current models of visual attention in value-based decision making, fixation duration is attributed solely to the build-up of reward value for the stimulus that is fixated on (*Gaze cascade model*, Simion and Shimojo, 2006; Shimojo et al., 2003; Glaholt and Reingold, 2009, *Krajbich-Armel-Rangel model*, Krajbich et al., 2010). Consequently, fixation duration is interpreted as a direct proxy for product preference. Also, commercial market research companies often use fixation duration to indicate the prosperity of a packaging design. However, eventual selection of the item on which fixation duration was longest is not specific for value-based decision making but also occurs in objective decision making. This complicates the interpretation of fixation duration in value-based decision-making. In Chapter 4 we investigated two factors driving fixation duration namely the stimulus reward value (preference) and the decision goal (task instruction).

1.3.3 Functional MRI

1.3.3.1 The measurement of neural activation

Magnetic Resonance Imaging (MRI) is the most common technique for imaging brain anatomy and brain activation. During MRI scanning a subject is laying inside of the bore of the MRI scanner (Figure 1.1). MRI takes advantage of the magnetic properties of tissues and physiological processes to generate images. Whereas

Figure 1.1: MRI setup: scanner and screen.

anatomical MRI scans provide structural images of brains, fMRI provides an in vivo measure of brain activation. Blood Oxygen Level Dependent (BOLD) functional MRI measures changes in oxygen levels of the blood in the brain. The basic principle is that changes in neural activity are accompanied by changes in blood flow (for more details on fMRI data acquisition and analysis, see Haacke et al., 1999; Friston et al., 2007). A stronger BOLD signal reflects increased oxygenated blood flow caused by increased neuronal activity. The spatial resolution of a typical fMRI scan ranges between $2 \times 2 \times 2$ mm and $4 \times 4 \times 4$ mm, which allows a moderately fine coursed localization of brain activation. Unlike electroencephalography (EEG), in which mainly derivatives of activity in the cortex (outer layer of the brain) can be measured, fMRI can also image the inner limbic structures, which are involved in reward processing (Blevins and Baskin, 2010; Carlezon Jr. and Thomas, 2009). Unlike Positron Emission Tomography (PET), a technique that measures brain activity indirectly (i.e., perfusion), fMRI is relatively uninvasive since no radioactive isotopes are required to image brain activity. These advantageous characteristics of fMRI make neural activation (as measured by fMRI) a good basis for an implicit marker of food choice.

1.3.3.2 Application in food choice research

The number of studies on the neural correlates of consumer choice and decision-making processes is rapidly growing (Ariely and Berns, 2010). Food is one of the primary reinforcers (i.e., necessary for survival) and is therefore widely used to investigate the basal neural mechanisms underlying reward processing. The sight of food elicits a wide range of physiological, emotional, and cognitive responses. To gain more insight into the neural processes underlying these processes, many studies have aimed to establish the brain regions that are activated in response to food (versus nonfood) (e.g., Cornier et al., 2009; Fuhrer et al., 2008; Santel et al., 2006; Simmons et al., 2005; St-Onge et al., 2005). Also, a wide range of factors that might modulate the neural response to food pictures has been identified: the food's energy content, hunger state, individual differences in age, mood, gender, genotype, and behavioral traits like disinhibition, dietary restraint, and the tendency towards external eating behavior (Fuhrer et al., 2008; LaBar et al., 2001b; Passamonti et al., 2009; Kaurijoki et al., 2008; Beaver et al., 2006; Coletta et al., 2009; Martin et al., 2009; Killgore and Yurgelun-Todd, 2005a,b, 2006; Stoeckel et al., 2008; Uher et al., 2006). Despite the large number of studies, there is a lot of variation in brain regions that have been identified. In Chapter 2 we aimed to identify which brain regions consistently respond to food cues across studies. Since implicit markers of choice are expected to reflect preference (aside from other relevant factors), we also aimed to establish the brain regions responding to highly hedonic, i.e., high energy (HE), foods.

The studies described above all used passive viewing paradigms. Although one study showed that similar valuation-related brain areas are activated during active choice and passive viewing (Levy et al., 2011), a growing number of studies implements choice paradigms to investigate the neural correlates of specific choice processes, such as self-control (e.g., Hare et al., 2009). Although there was not much evidence at the start of this work in 2009, a few studies have now assessed to what extent neural activation can predict a consumer choice. The first study that assessed the potential of fMRI to predict consumer choice, yielded a prediction accuracy of up to 61% (Knutson et al., 2007). Successors have shown comparable accuracies (e.g., Levy et al., 2011). The recent application of MVPA to fMRI data has a large potential to improve the prediction of choices. Although this novel analysis method can accurately predict to which stimulus category a visual stimulus belongs (Haxby et al., 2001; Sterzer et al., 2008), to date its potential to predict consumer choices was only assessed in one study on predicting the hypothetical choice for a car (Tusche et al., 2010). In Chapter 3 we assess the potential of fMRI in conjunction with MVPA to predict package based food choices.

1.4 Eating behavior

1.4.1 Food choice

Eating behavior constitutes several types of decisions, namely what to eat, when to start and when to stop eating. These decisions together determine meal frequency, meal size, and, ultimately, the nutrient composition of the total diet. Food choice is a complex behavior, which is affected by a wide range of (interacting) factors. Without attempting to give a complete description, we will list a few here: physiological (e.g., hunger, body weight, sensory specific satiety), social (e.g., presence of others, appropriateness, social norms), environmental (availability, portion size, variety, packaging) and personal factors (habits, preferences, personal goals, personality traits) (Verhoeven et al., 2012; De Ridder et al., 2012; Stok et al., 2012; Mela, 2001; Wansink, 2004; Smeets et al., 2012). In spite of the apparent complex interaction of factors, most people do not perceive food choices as difficult because many of these influences appear to operate at a basal level that people are not aware of (Levitsky and Pacanowski, 2012; Wansink, 2004). Similar to many other daily repeated behaviors, it is thought that food choices are mainly the result from 'automatic' processes and habits, that is, choices are made without conscious reasoning (Levitsky and Pacanowski, 2012; Wansink, 2004; Verhoeven et al., 2012; Bargh, 2002; Fitzsimons et al., 2002).

In this thesis we only focus on the decision what to eat and not on the decisions to start or stop eating. Firstly, plates of food are usually finished in its totality. Moreover, when portion sized packages are opened, they are generally completely consumed (Wansink, 2004). Therefore, the choice for the type of food (e.g., HE or low energy (LE) snack) has a major impact on energy intake. However, other studies have focused on the neural correlates of (sensory specific) satiation and satiety which contributes to the decisions to start and stop eating (e.g., Spetter et al., 2012; Smeets et al., 2006).

In addition, we only focus on snacking behavior. Reasons for this are twofold. Firstly, people have multiple snack occasions every day. Consequently, snacks provide 30% of the total energy intake (Voedingscentrum, 1998). Secondly, research showed that snacks have a weak satiety effect and, consequently, energy intake from snacks is not compensated for during meals (Chapelot, 2011). Because of these reasons, interventions aimed at snack choice have a large potential for influencing energy intake.

1.4.2 Self-control

As described in the previous section, it is assumed that food choices mainly result from 'automatic' processes or habits. However, the observation that only 3-24% of the Dutch population eat enough vegetables and fruit and that 86-92% consume too much saturated fatty acids suggests that not many people eat healthily ‘automatically’ (RIVM, 2011).

Approximately 80% of the Dutch population reports that they value healthy living (including healthy eating) (TNS NIPO, 2007) and one of the major self-reported motives for food choice is health (Carrillo et al., 2011). Moreover, approximately 50% of the Western female population has the explicit goal to limit their energy intake (Fayet et al., 2012; Rideout and Barr, 2009). For these individuals food choice involves conflicting motivational pressures, namely between the momentary allurement of consuming tasty HE snacks and the long term goal of living healthy (or limiting energy intake). Therefore, food choice is regarded as a classic self-control dilemma involving the trade-off between immediate eating enjoyment and the long term goal of being slim or healthy. Since eating HE snacks is not in line with their long term goal, these individuals should override the automatic tendency to indulge in HE snacks in order to behave in line with their intentions. To resolve this dilemma, self-control should be exercised (Baumeister and Heatherton, 1996; Fishbach et al., 2003).

Hence, successful self-control constitutes two crucial steps: firstly, the self-control dilemma has to be detected and secondly, it has to be resolved by exercising cognitive control. In Chapters 5 and 6 we employed implicit markers to investigate which processes might underly self-regulatory failure in weight-concerned women.

1.4.3 Food packaging

Since most foods and consumer goods are packaged nowadays, packages are the main source of information that individuals can base their choices on. Accordingly, it has been shown that packaging has a major influence on purchasing decisions and food acceptance (Ampuero and Vila, 2006; Imram, 1999). The impression that a package is intended to create in the mind of the consumer is affected by package characteristics like size, shape, color, images, and text. It is outside of the scope of this thesis to extend on all packaging cues that influence the perception of a product. Here, we highlight three important cues relevant for the studies described in this thesis, namely the perceived healthiness, attractiveness, and familiarity of the package.

1.4.3.1 Perceived healthiness

A first topic of interest is the influence of packaging on the perceived healthiness. One of the current trends in food packaging design is to put emphasis on the healthiness of foods by highlighting nutritional information or health logos. Research from our project-partners at the University of Twente, The Netherlands, showed that packaging cues indeed have an enormous influence on the perception of healthiness (for a description of cues giving a healthy or unhealthy impression, see Stimuli section of Chapter 3).

Consumers themselves state that health is an important determinant of food choice (Carrillo et al., 2011). However, studies on the association between perceived healthiness and preference have yielded ambiguous results. Some studies suggest that labeling a food as healthy decreases behavioral preference for the food (Raghunathan et al., 2006), while others show no (Borgmeier and Westenhoever, 2009; Feunekes et al., 2008) or a positive effect (Provencher et al., 2009; Sabbe et al., 2009). Therefore, it is not clear whether emphasizing healthiness is helpful in promoting healthy food choices.

A complicating factor is that there is no straightforward definition of healthiness in the consumer's mind (Ronteltap et al., 2012; Lappalainen et al., 1998). A European survey showed that as much as 89 broad groupings of healthy eating definitions exist (Lappalainen et al., 1998). For simplicity, these were reduced to eight major definitions of healthy eating, of which the following were mentioned most often: (1) eating a low fat diet (49% of respondents), (2) eating more fruit and vegetables (42%), (3) eating balanced and varied (41%), and (4) eating fresh and natural foods (28%). However, these percentages differed greatly between countries.

Recent studies have shown that distinct attributes of healthy eating have contradicting effects on product acceptance. For example, labeling a product as light or low-fat appears to lower both expected and experienced taste pleasantness (Yeomans et al., 2001). In contrast, labeling a food as organic increases expected taste and preference (Lee et al., 2011). Further support for these differential effects from distinct attributes of healthy eating on food reward comes from neuro-imaging studies. That is, labeling a milkshake as light decreases activation in reward areas during tasting in obese women (Ng et al., 2011). In contrast, labeling a food as organic increases activation in reward areas during viewing of food pictures (Linder et al., 2010).

1.4.3.2 Aesthetics

A second important packaging feature which has been shown to affect consumer choices is its aesthetic value (Silayoi and Speece, 2004, 2005). Packaging aesthetics is influenced by several factors, including basal visual characteristics. A famous phrase states that "beauty is in the eye of the beholder". However, despite individual differences in the appreciation of the aesthetic aspects of packaging, there are also colors that are uniformly preferred. For example, the colors blue, green and white (bright colors) are liked most on average, even across cultures (Adams and Osgood, 1973; Grieve, 1991; Madden et al., 2000; Wiegersma and Van der Elst, 2011). Also, it has been shown that people prefer colors that are relatively close or exactly match within the color spectrum (Deng et al., 2010). Moreover, consumers generally prefer a small palette over a higher number of colors within one design (Deng et al., 2010). Other visual cues that influence the attractiveness of packaging designs are unity (congruity among the elements of a design) and prototypicality (which relates strongly to familiarity, Section 1.4.3.3) (Veryzer and Hutchinson, 1998).

Besides these straightforward visual characteristics, also higher order attributes inferred from the attractiveness contribute to the consumer experience. Multiple studies suggest that attractiveness could influence general product preference by triggering positive responses and by increasing the expected quality, luxury, and price of products in several consumption domains (Dawar and Parker, 1994; Forsythe et al., 1996; Orth et al., 2010).

To date, most studies on the brain mechanisms involved in the aesthetic experience have focused on art, music, and faces (Thakral et al., 2012; Ishizu and Zeki, 2011; O'Doherty et al., 2003). An initial study on the neural correlates of packaging aesthetics showed that there was stronger activation in the striatum and ventromedial prefrontal cortex during viewing of aesthetic (versus standard) packages (Reimann et al., 2010). In Chapter 3 we assesed the influence of both healthiness and packaging attractiveness on food choice.

1.4.3.3 Familiarity

A third important packaging characteristic is familiarity. Through years of daily exposure to packages, people have developed strong mental representations of what packages of a particular product category or (preferred) brand look like (Veryzer and Hutchinson, 1998). For example, the prototypical pack of milk in the Netherlands is colored in white and blue and has a picture of a cow on it. It is thought that the visual characteristics of specific stimulus categories (e.g., prototypical packages or brands) are strongly represented in the brain (e.g., Haxby et al., 2001), which fosters an efficient detection and recognition (e.g., in the supermarket). Familiar packaging designs are generally perceived as more attractive and more trustworthy than unfamiliar (novel) packages (Loken and Ward, 1990), although there are some exceptions (e.g., very expensive and rare products can be atypical but also highly wanted, Veryzer and Hutchinson, 1998). Because mental representations of packages are strongly encoded in memory, a very small packaging-manipulation (e.g., a different typography or color) can already break the packaging conventions and thereby influence recognizability and preference. Although this topic is of major interest to marketing, it was outside the scope of this thesis. However, acknowledging this important influential effect, we ruled out potential confounding effects by using only unfamiliar packages in the studies described in this thesis. That is, in Chapter 3 we used customly designed packages and in Chapter 4 we used packages from foreign countries.

1.5 Added value of implicit measures in the study of food choice

We expect the added value of implicit markers for the study of food choice to be twofold. Firstly, implicit measures are less susceptible to demand characteristics and socially desirable responding (Fazio and Olson, 2003), which is ubiquitous in self-reports concerning eating behavior. For example, it is well established that women underreport their weight and energy intake (Merrill and Richardson, 2009; Scagliusi et al., 2009). The caveat of socially desirable responding is especially relevant for weight-concerned women who might be inclined to let their responses reflect their intention to limit their food intake rather than their actual behavior. Parallel with how anthropometrical and physiological measures (e.g., measured weight, double-labeled water for energy intake) are superior to self-reports, we expect that implicit measures of food choice will prove to be more accurate measures of the underlying motives for food choice.

Secondly, we expect that implicit measures can reveal motives that people themselves are not aware of. As we touched upon earlier, food choice is a daily repeated behavior which relies greatly on automatic processing. Every day, people are exposed to an abundant variety of foods to choose from. However, people are not aware of how exposure to food and packaging cues, unconsciously activates cognitive processes which, in turn, could influence their choice.

To illustrate, at the heart of self-regulation theory lies the assumption that if someone with the long-term goal to limit intake is exposed to a food that challenges the accomplishment of this goal, this results in internal conflict (Fishbach et al., 2003). Since recognizing the self-control dilemma is considered to be a prerequisite for acting upon it (i.e., actually performing self control), the internal conflict is considered as a crucial element of successful self-control. Although the notion of conflict has a role in many theories on self-control, the assumption that a dilemma involving two opposing motivational pressures evokes internal conflict has so far remained untested. As the perception of conflict is not necessarily a conscious phenomenon, implicit measures are expected to be particularly suitable to study conflict. We will address this topic in Chapter 5.

In support of the notion that implicit cognitive responses to food stimuli can alter choice, research has shown that successful and unsuccessful self-controllers deviate in their automatic cognitive responses to tempting food cues. Exposure to temptations is typically thought to promote indulgence by inhibiting the opposing goal (Stroebe et al., 2008). That is, if a person has two incompatible incentives or goals (e.g, immediate eating enjoyment versus the goal of weight control), these two goals compete for mental accessibility. Consequently, it follows that if one goal or incentive is activated, the opposing goal is automatically inhibited. Therefore, exposure to a tasty snack primes the immediate incentive of eating enjoyment and decreases the accessibility of the weight-control goal, and thereby increases the likelihood of indulgence. Although this mechanism explains how exposure to a tasty unhealthy snack results in self-regulatory failure, a recent line of research on counteractive control theory has shown that exposure to tasty unhealthy snacks can also promote healthy choices (Trope and Fishbach, 2000; Kroese et al., 2011). Successful self-controllers appear to have an implicit cognitive link between temptations and opposing goals, which they acquired through repeated attempts at self-control. By this pathway, exposure to a temptation prime leads to automatic activation of the long term goal and thereby promotes the long-term goal congruent choice (Papies et al., 2008).

As we elaborated on in Section 1.4.3.1 packaging designs can have a large influence on perceived healthiness. Although people can be aware of packaging cues that signal healthiness, they are likely to be unaware of the process by which the perceived healthiness (or energy content) implicitly activates cognitive processes that influence preference and food choice. Raghunathan et al. (2006) showed that people have the implicit belief that unhealthy foods are tastier than healthy foods: even people who reported not believing that unhealthy food is tastier make judgments and choices as if they did have that belief. Labeling a food as healthy or low-fat also influences inferred energy content (Wansink and Chandon, 2006). This might explain why people appear to eat more of foods which are assumed to be healthy (Provencher et al., 2009; Wansink and Chandon, 2006). However, another study even showed that people erroneously believe that eating healthy foods in addition to unhealthy ones can decrease total calorie count (Chernev, 2011)

The presence of healthy alternatives might also implicitly influence the perception of the self-control dilemma. The vicarious goal fulfillment theory posits that the mere presence of a healthy option already fulfills health-related goals (Wilcox et al., 2009), irrespective of whether this healthy option was actually chosen or not. From this it follows that the presence of a healthy option in the choice set might already resolve the self-control dilemma (because the health-related goal has the potential to be fulfilled), thereby resulting in a lack of experienced conflict. Consequently, the presence of the healthy alternative likely increases the chance that someone indulges in tempting HE snacks. Indeed, research has shown that preference for HE snacks is higher when presented together with a LE snack and research showed that adding a LE dish to a restaurant menu increases the money spent on HE side dishes (Fishbach and Zhang, 2008; Chandon and Wansink, 2007; Wilcox et al., 2009). Acknowledging how the presence of alternative options can influence the self-control dilemma, we investigated self-control both in a binary food choice paradigm in which they had to choose between a HE and LE snack (Chapter 5) and in a paradigm in which they only had to consider one snack at a time (Chapter 6)

In summary, we have two hypotheses regarding the added value of employing implicit markers in food choice research. Firstly, since implicit measures are not prone to socially desirable answering, we expect that these measures are more accurate predictors of food choice. Secondly, we expect that implicit markers can be used to assess the unconscious responses to foods which influence preference formation and self-control processes and, ultimately, food choice.

1.6 Outline of the thesis

The general aim of the studies described in this thesis was to establish the potential of implicit markers to (1) predict choice and (2) gain insight into the decision-making processes underlying food choice.

The first step in determining the potential of fMRI as implicit marker was synthesizing results from previous studies. **Chapter 2** shows results from a meta-analysis on the neural correlates of processing visual food cues. Moreover, the current evidence on the modulation of neural response by energy content and hunger state, was evaluated.

Chapter 3 describes a study in which the accuracy with which fMRI in conjunction with MVPA, can predict package-based food choice. In addition, we investigated how self-reported measures (i.e., verbal measures of perceived healthiness and attractiveness of the packaging design) relate to choice and neural activation.

Research on the role of visual attention in consumer choice relies on the implicit assumptions that consumer choice can be easily influenced and that fixation duration is a proxy for product preference. The aims of the study described in **Chapter 4** were (1) to investigate the influence of the first fixation on consumer choice, and (2) to disentangle two factors driving fixation duration, namely the stimulus reward value (preference) and the decision goal (task instruction).

A key assumption of self-regulation theory is that if someone with the long-term goal to limit intake is exposed to a food that challenges the accomplishment of this goal, this results in internal conflict. However, this assumption has so far remained untested. Therefore, it is unknown whether self-regulatory failure results from either the inability to detect a self-control dilemma (experience conflict), or the inability to act upon it. In **Chapter 5** brain activation, eye tracking, and reaction times were used as process indicators of self-control induced conflict, during food choices in weight-concerned women.

In **Chapter 6** the results from Chapter 5 were extended by using fMRI to investigate how neural processing differs between choices concerning healthy and unhealthy snacks. Since single and multiple choice types differ due to the presence of alternatives that might influence the perception of the self-control dilemma (e.g., vicarious goal fulfillment), we aimed to test whether self-control failure was also prevalent when they only had to consider one snack. Since it is particularly difficult to resist highly tasty HE snacks, we investigated whether temptation strength (i.e., the tastiness of the HE snack) modulated the neural response. In addition, to gain more insight into the brain regions that might be involved in self-regulation, it was investigated whether individual differences in self-regulatory success modulate the neural responses during food choice.

Finally, in **Chapter 7**, the results of all experiments are discussed in relation to the general aim of the thesis.

Chapter 2

The first taste is always with the eyes: a meta-analysis on the neural correlates of processing visual food cues

Summary Food selection is primarily guided by the visual system. Multiple studies have examined the brain responses to food pictures. However, the results of these studies are heterogeneous and there still is uncertainty about the core brain regions involved in the neural processing of viewing food pictures. We performed three Activation Likelihood Estimation (ALE) meta-analyses on data from normal weight subjects to determine the concurrence in the brain regions activated in response to viewing pictures of food (17 studies) and to assess the modulating effects of hunger (five studies) and energy content (seven studies). The most concurrent brain regions activated in response to food pictures were the posterior fusiform gyrus, the lateral orbitofrontal cortex (OFC) and the middle insula. Hunger modulated the response in the amygdala and OFC. Energy content modulated the response in the hypothalamus/ventral striatum. The concurrence between studies was moderate: at best 41% of the studies contributed to the most concurrent clusters. Future research should elucidate effects of methodological and physiological factors on between-study variations.

Based on: Van der Laan, L.N., De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. (2011) The first taste is always with the eyes: a meta-analysis on the neural correlates of visual food cues. *Neuroimage*, 55:296-303.

2.1 Introduction

In modern societies people are continuously exposed to food cues since there is an abundant availability of palatable foods at virtually every moment of the day. Like other primates, humans have a highly developed visual system. Food selection, like many other behaviors, is primarily guided by the visual system (Laska et al., 2007; Linne et al., 2002). Not without reason, an ancient quote attributed to Apicius (first century) states that the first taste is always with the eyes.

The sight of food elicits a wide range of physiological, emotional and cognitive responses. Firstly, it is a cue for the body to prepare itself for subsequent food ingestion with accompanying anticipatory physiological responses, such as a cephalic phase release of insulin and changes in heart rate (Drobes et al., 2001; Wallner-Liebermann et al., 2010). Secondly, it can elicit emotional responses like a desire to eat (Ouwehand and Papies, 2010). It is thought that positive emotions, such as pleasure, evolved as a biological mechanism to promote behaviors that support survival, like eating (Berthoud and Morrison, 2008; Van den Bos and De Ridder, 2006). Thirdly, the sight of a food gives rise to cognitive processes, such as memory retrieval and hedonic evaluation, based on information that was stored during previous experience(s) with the food (Berthoud and Morrison, 2008; Shin et al., 2009). In addition, exposure to food cues can trigger inhibitory cognitive processes like self-regulation, e.g. processes involved in resisting the temptation of palatable foods in order to maintain a healthy body weight (Kroese et al., 2009; Van den Bos and De Ridder, 2006).

Multiple neuro-imaging studies have investigated the brain mechanisms subserving the response to visual food cues in order to provide insight in the neural correlates of eating behavior (e.g., Cornier et al., 2009; Fuhrer et al., 2008; Santel et al., 2006; Simmons et al., 2005; St-Onge et al., 2005). These studies have shown that a diverging network of brain regions is activated in response to viewing food pictures (compared to viewing pictures of nonfoods). Although there seems to be fair concurrence among studies in some regions (e.g., the occipital cortex and insula), other regions are only reported by a few studies (e.g., the hippocampus) (Cornier et al., 2009; Fuhrer et al., 2008; Santel et al., 2006; Simmons et al., 2005; St-Onge et al., 2005). Hence, it is still unclear which are the core brain regions that are activated in response to viewing food pictures.

A principal reason for this may be that between-study variability is high: study designs, tasks and stimuli differ between studies, and the sample sizes are generally small. In addition, the acquisition and analysis of neuro-imaging data is affected by many factors such as the particular scan sequence and the type of preprocessing algorithms used (Bennett and Miller, 2010). Given the high between-study variability caused by these factors it would be advantageous to identify the brain responses that are concurrent across studies, i.e., those responses that are relatively unaffected by between-study differences.

Novel meta-analysis techniques allow for integrating findings from multiple studies more precisely compared to previously employed methods like counting anatomical labels. In this study we employed the Activation Likelihood Estimation (ALE) meta-analysis technique (Eickhoff et al., 2009). This is a quantitative voxel-wise meta-analysis technique that compares the results of neuro-imaging studies using reported coordinates in a standardized 3D atlas space.

The inconsistencies among studies have also served as a basis to investigate a wide range of factors that might modulate the brain response to viewing food pictures. Two of the most frequently investigated factors are the food's energy content and the hunger state of the individual. Behavioral studies have shown that these factors influence eating behavior, e.g., people have a higher preference for energy-rich foods (Drewnowski and Greenwood, 1983), and foods are rated as more pleasant when people are hungry (Cabanac, 1979). This suggests that energy content and hunger state will modulate the neural responses to viewing food pictures. However, the neuroimaging studies that have addressed these factors have not yielded consistent results (e.g., Fuhrer et al., 2008; Killgore and Yurgelun-Todd, 2005b; LaBar et al., 2001b; Passamonti et al., 2009). Therefore, we included these two primary modulators in our meta-analysis.

Evidently, there are more potential modulating factors. These include individual differences in age, gender, mood, genotype and behavioral traits like reward sensitivity, disinhibition, dietary restraint and the tendency toward external eating behavior (Kaurijoki et al., 2008; Beaver et al., 2006; Coletta et al., 2009; Martin et al., 2009; Passamonti et al., 2009; Killgore and Yurgelun-Todd, 2005a,b, 2006; Stoeckel et al., 2008; Uher et al., 2006). However, research into these factors is relatively young, i.e., only (very) few studies have specifically investigated these factors. Therefore, it is not yet possible to perform a meta-analysis on these factors.

In summary, our aims were to determine the concurrence in the brain regions activated in response to viewing pictures of food in normal-weight individuals and to assess the modulating effects of hunger state and the food's energy content.

2.2 Methods

2.2.1 Study and experiment selection

Studies were selected by searching the Pubmed database (www.pubmed.org) using the following keyword search (all fields): (brain OR neural) AND (food OR nutrition) AND (pictures OR images). Additional studies were found by examining references of relevant articles. The inclusion criteria were that studies 1) were published in a peer-reviewed journal, 2) employed a task involving the visual presentation of pictures of food, 3) reported the coordinates in Montreal Neurological Institute (MNI) (Evans et al., 1993) or Talairach space (Talaraich and Tournoux, 1988), 4) reported coordinates of activation in the whole brain (i.e., not only selected regions of interest) and 5) included healthy normal-weight participants (Body Mass Index (BMI) between 18.5 and 25 kg/m^2). Experiments from these studies were selected as follows: to be included in the meta-analysis for the contrast between food and nonfood, the data had to be analyzed using a contrast between food and nonfood pictures (e.g., tools, scenery, flowers, animals). For experiments to be included in the meta-analysis on the modulation of neural responses to food by hunger state, coordinates of activation in response to food pictures had to be reported for a contrast between a hungry and a satiated state. For the meta-analysis on the contrast between high energy (HE) and low energy (LE) foods, coordinates for a contrast of neural activation in response to viewing foods high versus low in fat, sugar or energy content had to be reported.

Tables 2.1 and 2.2 show an overview of the studies and experiments included in the three meta-analyses. All studies used functional Magnetic Resonance Imaging (fMRI). For the contrast between food and nonfood pictures, 18 experiments from 17 studies, with a total of 246 participants (133 females) and 189 reported coordinates were included. For the interaction with hunger state, five experiments (from five studies) with 57 participants (27 females) and 48 foci remained. These studies reported the contrast of activation by viewing food pictures between a hungry and a satiated state. The duration of fasting in the hungry state ranged between 4 and 14 hours across the included studies. In the satiated state, subjects were scanned within 1 hour following the last consumption. For the meta-analysis on the contrast between HE and LE foods, seven experiments (seven studies) with 112 participants (70 females) and 90 foci remained. Three of these studies reported a contrast between high- and low-calorie foods, two studies contrasted appetizing with bland foods, and one study contrasted foods with a high and a neutral hedonic value. The appetizing or high-hedonic food category typically contained foods high in energy (e.g., hamburgers, ice cream) and the bland or neutral-hedonic food category consisted of foods lower in energy (e.g., whole grain products, potatoes, vegetables). Thus, the bland or neutral-hedonic food categories did not only contain very low energy foods, such as fruit and vegetables, but also some low/moderate energy foods, such as bread and potatoes. Still, these foods are less calorie-dense than the foods in the highly appetizing and high-hedonic value category.

The statistical thresholds employed in the different experiments ranged between $p < 0.001$ uncorrected and $p < 0.01$ corrected for multiple comparisons. Some of the included studies involved patient groups (e.g., anorectic patients) and/or pharmacological interventions. However, of these studies, only experiments concerning healthy participants in the control condition were included in the meta-analyses.

Table 2.1: Studies and experiments included in the ALE meta-analysis: food > nonfood.

	Study (author/year of publication)				
Experiments: food > nonfood		Nonfood	Time fasted	n	No. of foci
1	Simmons et al. (2005)	Locations, buildings	Not reported	9	6
2	LaBar et al. (2001b)	Tools	> 8 h and < 1 h	17	3
3	Killgore et al. (2003)	Rocks, trees, flowers	> 1.5 h, median 3.9 h	13	12
4	Killgore and Yurgelun-Todd (2005b)	Rocks, trees, flowers	> 1 h	8	14
5	Rothemund et al. (2007)	Rocks and flowers	> 1.5 h	13	1
6	Beaver et al. (2006)	Objects (videocassettes, iron)	> 2 h	12	16
7	Cornier et al. (2007)	Animals, trees, furniture, buildings	Overnight fast	25	2
8	Fuhrer et al. (2008)	Objects (watch, pen, calculator)	1 h and 14 h	12	20
9	Schienle et al. (2009)	Household articles	> 12 h	19	12
10	Santel et al. (2006)	Objects (tools, make-up, pencils)	12 h and 1 h	10	7
11	Uher et al. (2006)	Objects (brushes, car, flower)	> 3 h (mean 3.5 h)	18	5
12	Miller et al. (2007)	Animals, tools	10 min after oral glucose load[3]	8	2
13	Cornier et al. (2009)	Animals, trees, furniture, buildings	Overnight fast	22	23
14	Holsen et al. (2005)	Animals	< 1 h and 4 h	9	17
15	Davids et al. (2009)	Landscapes, work-related sceneries	7 subjects within 2 h, 15 subjects > 2 h after meal	22	15
16a	Malik et al. (2008)[1]	Scenery, landscapes	3 h (after standardized breakfast)	12	11
16b	Malik et al. (2008)[2]	Scenery, landscapes	3 h (after standardized breakfast)	8	10
17	Holsen et al. (2006)	Animals	< 1 h and 4 h	9	13
			Total:	*246*	*189*

[1] Control condition of control/ghrelin group

[2] Control/control group

[3] Oral glucose load of 75 g sugar dissolved in water

Table 2.2: Studies and experiments included in the meta-analyses on hunger state and energy content.

	Study (author/year of publication)				
Experiments: hungry > satiated state		Nonfood	Time fasted: hungry vs. satiated	n	No. of foci
1	Fuhrer et al. (2008)	Objects (watch, pen, calculator)	14 h vs. 1 h	12	7
2	LaBar et al. (2001b)	Tools	> 8 h vs. < 1 h	17	5
3	Santel et al. (2006)	Objects (tools, make-up, pencils)	12 h vs. 1 h	10	3
4	Holsen et al. (2005)	Animals	4 h vs < 1 h	9	24
5	Mohanty et al. (2008)	Tools	> 8 h vs. < 1 h	9	9
			Total:	*57*	*48*
Experiments: HE > LE foods		Food stimuli: HE and LE content	Time fasted	n	No. of foci
1	Killgore et al. (2003)	High calorie: french fries, ice cream Low calorie: salads, whole grain cereals	> 1.5 h, median 3.9 h	13	7
2	Killgore and Yurgelun-Todd (2005b)	Equal as in Killgore et al. (2003)	> 1 h	8	5
3	Beaver et al. (2006)	Appetizing: chocolate cake, ice cream Bland: uncooked rice, potatoes	> 2 h	12	16
4	Passamonti et al. (2009)	Equal as in Beaver et al. (2006)	> 2 h	21	13
5	Cornier et al. (2007)	High hedonic value: waffles, cake, whipped cream, plate with egg/bacon Neutral hedonic value: fruit, bread, cereals	Overnight fast	25	7
6	Goldstone et al. (2009)	High calorie: burgers, cake, chocolate Low calorie: salads, fruit, fish	Overnight fast (mean 15.9 h), fed (mean 1.6 h)	20	42
7	Rothemund et al. (2007)	High calorie: burgers, pancakes Low calorie: fruit, vegetables	> 1.5 h	13	0
			Total:	*112*	*90*

2.2.2 ALE meta-analyses

To determine the concurrence in reported coordinates across studies, we conducted three ALE meta-analyses, using the Brainmap GingerALE software. We used the revised version of the ALE approach (Eickhoff et al., 2009) for coordinate-based meta-analysis of neuroimaging results (Turkeltaub et al., 2002; Laird et al., 2005a). The input for the first meta-analysis consisted of the coordinates of brain regions that were activated in response to viewing pictures of foods compared to pictures of nonfood products. For the second meta-analysis, coordinates of brain regions that were modulated by hunger status were used. The third meta-analysis included coordinates of the contrast between HE and LE foods.

We converted coordinates reported in Talaraich space to the standard space of the MNI template using the Brainmap GingerALE software. ALE modeling uses reported coordinates as the center of a 3-dimensional Gaussian kernel function to create a modeled activation (MA) map for each individual experiment. Because the uncertainty of the spatial localization can be due to between-template and to between-subject variance, both these components are used to compute the parameters of the Gaussian kernel function. The algorithm takes differences in sample size into account by weighing the between-subject variance by the number of subjects in the experiment. Subsequently, the MA-maps are combined to calculate an experimental ALE map. This experimental ALE map is tested against an ALE null distribution map. This map represents the null-hypothesis that there is a random spatial association between the results of the experiments, while regarding the within-experiment distribution as fixed. The ALE analysis implements a random effects inference, i.e., the inference is focused on the above-chance concurrence between experiments, and not on the clustering of coordinates within experiments. The null distribution map is derived from a permutation procedure and is created on basis of the same number of experiments and reported coordinates as the experimental map. We used a statistical threshold of $p < 0.05$ False Discovery Rate (FDR) corrected for multiple comparisons and a minimum cluster size of 100 mm^3 (Genovese et al., 2002). ALE maps were overlaid onto an MNI anatomical template using the MRIcroN software (http://www.cabiatl.com/mricro/mricron/index.html).

Because our aim was to identify the most concurrent regions, i.e., those that are most robustly activated across experiments with different designs and tasks, we initially applied an extra criterion to the results, namely that clusters would only be reported if 50% or more of the included experiments contributed to them. This cutoff value seemed reasonable given the inherently low reproducibility of fMRI results (Bennett and Miller, 2010). However, because there were no clusters for the contrast between food and nonfood with 50% or more experiments contributing, this criterion was liberalized such that the results section now reports all significant ALE clusters. In the discussion only the clusters with 33% or more contributing experiments are discussed.

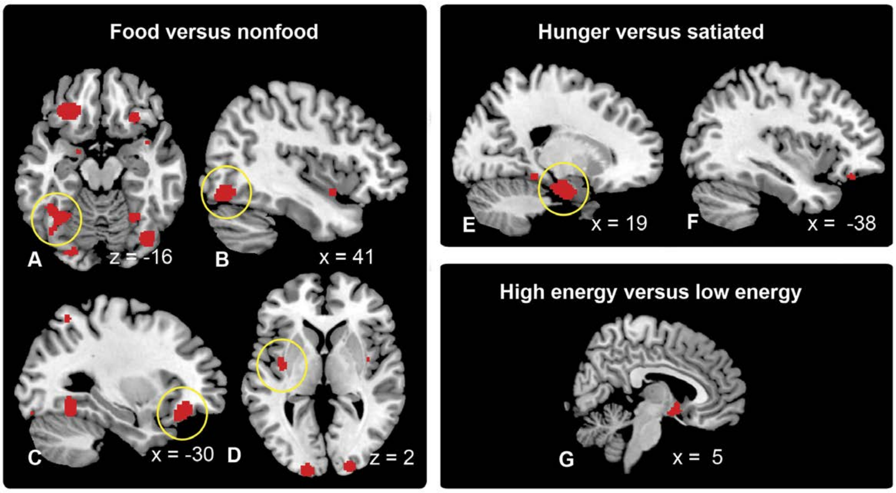

Figure 2.1: Results of the ALE meta-analysis showing clusters with significant ALE maxima ($p < 0.05$, FDR-corrected for multiple comparisons, cluster size > 100 mm^3). Clusters to which at least 33% of the experiments contributed are indicated with a circle and anatomical labels of these clusters are given. (A – D) ALE clusters for the contrast food > nonfood: (A) A cluster stretching from the left posterior fusiform gyrus to the inferior occipital gyrus, (B) right posterior fusiform gyrus, (C) left lateral OFC (inferior frontal gyrus) and (D) left middle insula; (E – F) ALE clusters for the contrast of viewing food pictures in a hungry versus a satiated state: (E) a cluster stretching from the right parahippocampal gyrus to the right amygdala, (F) left lateral OFC (inferior frontal gyrus); (G) ALE cluster for the contrast of viewing pictures of HE versus LE foods stretching from the hypothalamus to the caudate.

2.3 Results

2.3.1 Significant ALE clusters for food versus nonfood pictures

The ALE analysis revealed 16 significant clusters for the contrast between viewing food and nonfood pictures, i.e., regions responding stronger to pictures of food than to pictures of nonfood products (Figures 2.1, 2.2, Table 2.3). However, only four of these clusters met the 33% contributing experiments criterion. The three most concurrent clusters, which were contributed to by seven of the 17 experiments (41%), were located in the posterior fusiform gyrus (bilaterally) (left ALE peak at MNI (-30, -56, -10), ALE value = 2.37×10^{-3}, volume = 3056 mm^3; right ALE peak at MNI (38, -74, -14), ALE value = 2.78×10^{-3}, volume = 2592 mm^3) and the left lateral orbitofrontal cortex (OFC, inferior frontal gyrus; ALE peak at MNI (-26, 32, -14), ALE value = 3.15×10^{-3}, volume = 2440 mm^3). Concurrence was also found in the left middle insula (ALE peak at MNI (-38, -4, 6),

Table 2.3: Locations (MNI) of clusters with significant ALE values for the contrast of food versus nonfood[1].

	Anatomical label[2]	MNI[3]			Cluster size (mm^3)	ALE value ($\times 10^{-3}$)	No. of contributing experiments	
		x	y	z				%
1	Posterior fusiform gyrus L	-30	-56	-10	3056	2.37	7	41
	Inferior occipital gyrus L	-46	-72	-6		1.98		
	Posterior fusiform gyrus L	-40	-52	-18		1.87		
2	Posterior fusiform gyrus R	38	-74	-14	2592	2.78	7	41
3	Inferior frontal gyrus L / lateral OFC	-26	32	-14	2440	3.15	7	41
4	Middle insular cortex L	-38	-4	6	1264	1.96	6	35
	Middle insular cortex L	-40	4	-10		1.63		
	Middle insular cortex L	-38	-2	-4		1.35		
5	Superior parietal gyrus R	28	-62	60	992	1.85	5	29
	Inferior parietal gyrus R	30	-54	52		1.63		
6	Middle occipital gyrus L	-16	-100	0	1120	2.43	3	18
7	Superior parietal gyrus L	-38	-50	62	456	1.71	3	18
	Superior parietal gyrus L	-32	-58	58		1.45		
8	Middle insular cortex R	38	-8	10	360	1.49	3	18
9	Amygdala L	-20	-2	-20	280	1.51	3	18
	Amygdala L	-18	0	-14		1.18		
10	Fusiform gyrus L	28	-56	-12	968	2.80	2	12
11	Calcarine gyrus L	22	-96	4	592	2.35	2	12
12	Lingual gyrus L	10	-92	-8	360	1.81	2	12
13	Middle insular cortex R	38	6	-12	352	2.08	2	12
14	Middle occipital cortex L	-24	-84	-14	280	1.54	2	12
15	Inferior parietal gyrus L	-46	-38	50	248	1.59	2	12
16	Inferior frontal gyrus L	-42	38	10	144	1.38	2	12

[1] Reported ALE clusters were thresholded at $p < 0.05$ (FDR-corrected for multiple comparisons), cluster size >100 mm^3.

[2] L, left hemisphere; R, right hemisphere.

[3] Peak voxel coordinate in MNI space.

ALE value = 1.96×10^{-3}, volume = 1264 mm^3) with six contributing experiments (35%). Significant clusters that did not meet the criterion of 33% contributing experiments are listed in Table 2.3.

2.3.2 Modulation by hunger state and energy content

Table 2.4 and Figure 2.1 show the results of the meta-analysis on the modulation by hunger state and the energy content of the food. The meta-analysis on the modulation by hunger state revealed two significant ALE clusters which also met the 33% contributing experiments criterion. In these two regions neural activation during viewing of food pictures was stronger in the hungry compared to the satiated state. The largest cluster was located in the right parahippocampal gyrus and extended to the amygdala and was contributed by three (60%) of the five studies (ALE peak at MNI (18, -12, -22), ALE value = 1.96×10^{-3}, volume = 2224 mm^3). A second

Table 2.4: Locations (MNI) of clusters with significant ALE maxima for the modulation by hunger state and the food's energy content[1].

	Anatomical label[2]	MNI[3]			Cluster size (mm^3)	ALE value ($\times 10^{-3}$)	No. of contributing experiments	
		x	y	z				%
Experiments: hungry > satiated state								
1	Parahippocampal gyrus / Amygdala L	18	-12	-22	2224	1.96	3	60
2	Inferior frontal gyrus / lateral OFC L	-36	42	-20	224	0.88	2	40
	Inferior frontal gyrus / lateral OFC L	-36	36	-16		0.86		
Experiments: HE > LE foods								
1	Hypothalamus	6	6	-6	448	1.21	3	43
	Ventral striatum	6	0	-12		1.19		
2	Cerebellum R	30	-40	-32	392	1.51	2	29
3	Middle frontal gyrus L	-26	50	32	352	1.43	2	29
4	Middle occipital gyrus L	-48	-66	0	280	1.37	2	29
5	Inferior temporal gyrus R	50	-64	-10	256	1.25	2	29

[1] Reported ALE clusters were thresholded at $p < 0.05$ (FDR-corrected for multiple comparisons), cluster size > 100 mm^3.

[2] L, left hemisphere; R, right hemisphere.

[3] Peak voxel coordinate in MNI space.

cluster with two contributing studies (40%) was located in the left lateral OFC (inferior frontal gyrus; ALE peak at MNI (-36, 42, -20), ALE value $= 0.88 \times 10^{-3}$, volume $= 224$ mm^3).

For the contrast between HE and LE foods the meta-analysis yielded five clusters where neural activation was higher during viewing of HE compared to LE foods. Only one cluster met the 33% contributing experiments criterion. This cluster was contributed by three of the seven studies (43%) and was located in a region stretching from the right hypothalamus to the right ventral striatum (ALE peak at MNI (6, 6, -6), ALE value $= 1.21 \times 10^{-3}$, volume $= 448$ mm^3). The other four clusters are listed in Table 2.4.

A conjunction map of the contrasts *hunger versus satiated* and *HE versus LE foods* did not show overlapping brain regions between the contrasts (results not shown).

2.4 Discussion

We determined the most concurrent brain regions activated in response to viewing pictures of food in healthy normal-weight individuals. Our ALE meta-analysis yielded a diverging range of concurrent brain regions in terms of ALE values. However, despite highly significant ALE values, the percentage of contributing experiments can be regarded as moderate: at best 41% (seven out of 17) of the included experiments contributed to the clusters for the contrast between food and nonfood. Most

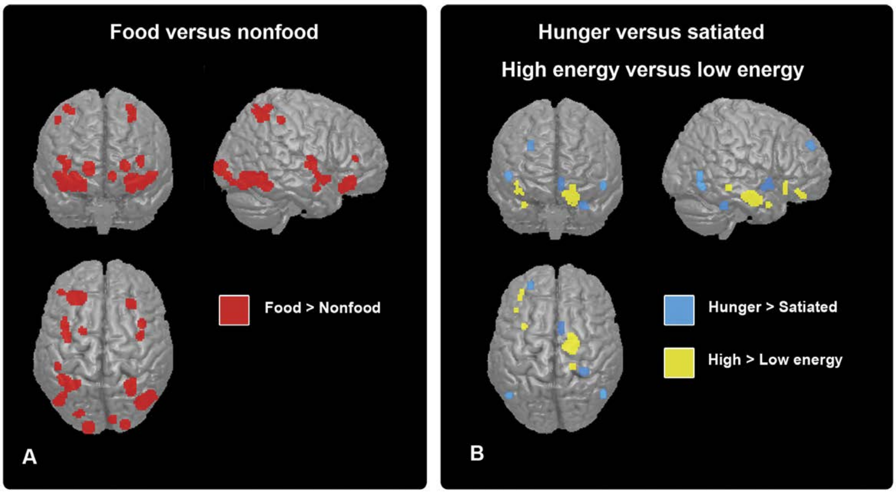

Figure 2.2: The results of the ALE meta-analysis shown as a projection of significant ALE clusters ($p < 0.05$, FDR-corrected for multiple comparisons, cluster size > 100 mm^3) on a 3-D rendering of a single-subject brain in MNI space. (A) ALE clusters for the contrast food > nonfood. (B) ALE clusters for the contrast of viewing food pictures in a hungry > satiated state and for viewing HE > LE foods.

meta-analyses base their conclusions only on the significance of the concurrence, i.e., on the proximity between reported coordinates. However, one can argue that the percentage of contributing experiments is equally important: when only two out of 17 experiments report that a particular brain region is activated in response to viewing foods, this response is probably very specific to the design characteristics (e.g., details of the fMRI task design and stimuli) of those experiments. It would then not be appropriate to draw conclusions about the neural process of interest as a whole, in this case food perception. Compared to other ALE meta-analyses (e.g., Turkeltaub and Coslett, 2010; Wiener et al., 2010), the maximum percentage of contributing experiments in our study (41%) can be regarded as moderate.

The moderate concurrence in brain activation that we found is in line with recent findings of Bennett and Miller (2010) who showed that the reproducibility of fMRI results was only 50%, even for the same task and stimuli in the same group of participants. Reproducibility of studies with different tasks, study populations and stimuli can be expected to be lower. In addition, some brain regions are more prone to signal loss (OFC) or habituation (OFC, amygdala) than others, which might result in an underestimation for these structures (LaBar et al., 2001a; Weiskopf et al., 2006). Furthermore, there are several sources of between-study variation which are specific to food perception. The present meta-analysis showed that the brain responses to viewing food pictures are indeed modulated by the food's energy content and by the hunger state of the participant. Moreover, other studies have shown that several other factors, like serum leptin concentration, gender, age and mood, can modulate the brain response to viewing food pictures (Killgore and Yurgelun-Todd, 2005a,b, 2006; Stoeckel et al., 2008; Uher et al., 2006).

Additional modulating factors are personality characteristics and behavioral traits like reward sensitivity, disinhibition, dietary restraint and a tendency toward external eating behavior (Beaver et al., 2006; Coletta et al., 2009; Martin et al., 2009; Passamonti et al., 2009). Also individual differences in genotype have been shown to modulate the neural response to viewing food pictures: Kaurijoki et al. (2008) showed that subjects that are homozygous for the long allele of the serotonin transporter gene show stronger posterior cingulate activation when viewing pictures of food compared to the persons that are heterozygous or homozygous for the short allele.

Another important modulating factor is body weight. Multiple neuro-imaging studies showed that overweight and obese subjects respond differently to food pictures compared to normal-weight subjects (e.g., Martin et al., 2009; Rothemund et al., 2007; Stoeckel et al., 2008). Killgore and Yurgelun-Todd (2005a) showed that, even within the normal range of BMI, differences in BMI can alter the OFC responses to viewing pictures of food, that is, OFC activation correlates negatively with BMI. So although we included only studies with participants in the normal range of BMI, this suggests that BMI may still have affected our meta-analysis results, in particular in the OFC.

Apart from the above-mentioned subject-specific factors, additional variance can arise from differences in task instruction and the experimental paradigm. For example, Siep et al. (2009) showed that explicit evaluation of the food, i.e., attending to the food and judging the palatability, is essential for detecting activation in the amygdala and medial OFC. Of the studies included in the meta-analysis on the contrast between food and nonfood pictures, seven used an event-related design and ten used a block-design. Further inspection showed no bias related to the type fMRI design. The task instructions were diverse and ranged from specific instructions like memorizing or categorizing the stimuli to no instruction at all. There was too much variation in the type of instructions to be able to attribute any effects to that factor.

In conclusion, multiple modulating factors and sources of variability may explain the moderate concurrence we found. However, because information on many factors is not reported (and usually also not measured, especially genotypic and personality characteristics), it was not possible to account for these factors in our analyses. Therefore, in order to elucidate the modulating effects of such factors on the neural response to viewing food pictures, many more studies are needed, along with more advanced (e.g., multivariate) meta-analysis techniques.

In the following sections we discuss the most concurrent brain regions, i.e., significant clusters that met the additional 33% contributing experiments criterion.

2.4.1 Lateral orbitofrontal cortex

The highest ALE value for the contrast between viewing food and nonfood pictures, and thus the most dense concentration of activation foci, was found in the left lateral OFC (left inferior frontal gyrus). Multiple studies have shown that activation in the lateral OFC correlates with the subjective pleasantness ratings of the taste and smell of food (Kringelbach et al., 2003; Rolls and Grabenhorst, 2008). For example, Kringelbach et al. (2003) showed that activation in a cluster located near the cluster found in the present study (MNI -22, 34, -8) correlated with pleasantness ratings of liquid food stimuli. A study of O'Doherty et al. (2002) showed that the lateral OFC was not only activated during exposure to a pleasant taste, but also during anticipation to receiving this taste.

In summary, the activation of the lateral OFC in response to food pictures may reflect the expected pleasantness of the food. This is also supported by the significant ALE cluster for the modulation by hunger state, which was located at the same location as the cluster for the contrast between food and nonfood pictures. This cluster may thus reflect the higher desirability of food in the hungry state (Cabanac, 1979). This finding also implies that variability in hunger state in the studies included for the contrast between viewing food and nonfood pictures can induce variability in OFC activation and thereby lowers the convergence across studies. Therefore, it is important to take hunger status into account.

2.4.2 Lateral occipital complex

The two other most convergent clusters, both with seven contributing experiments (41%) for the contrast between food and nonfood pictures, were located in the Lateral occipital complex (LOC) (bilaterally) and stretched from the posterior fusiform gyrus to the inferior occipital gyrus. The LOC is part of the visual association cortex, which is mainly known for its role in object recognition (Grill-Spector et al., 2001). The clusters in the LOC cannot be explained by a difference in visual characteristics between the food and nonfood stimulus categories, since in the majority of studies that contributed to this cluster the different stimuli were matched on visual characteristics like color, luminance and visual complexity. An alternative, and more likely, explanation why food pictures elicit a stronger activation in the LOC is that emotionally salient stimuli like food lead to heightened attention and thereby more extensive visual processing (Killgore and Yurgelun-Todd, 2007). The amygdala and anterior cingulate have been proposed as the mediators of this top-down regulation of visual processing, as these structures are sensitive to the motivational salience and project back to the visual cortex (Lang et al., 1998). The cluster that we found in the LOC may reflect this attention effect. The high concurrence in this area is also in line with multiple studies (e.g., Harrington et al., 2006; Peelen and Downing, 2005) that showed a relatively high (compared to other brain regions) within- and between-subjects reproducibility of activation in the fusiform gyrus and other visual areas.

2.4.3 Middle insular cortex

We found convergent regions of activation for the contrast between food and nonfood pictures in the bilateral middle insula. The cluster in the left middle insula also survived the additional 33% contributing experiments criterion. Whereas functions of the anterior insula (i.e., taste processing) and the posterior insula (i.e., cephalic phase responses such as gastric distention) are well documented (e.g., Small, 2006; Tomasi et al., 2009), the function of the middle insula is less well understood. A diverse range of food-related processes has been associated with activation of the middle insula, including imagining the taste of food, craving for food, and the mouth feel of water and oil (De Araujo et al., 2003; De Araujo and Rolls, 2004; Pelchat et al., 2004). In addition, several studies have suggested that activation of the middle insula represents memory retrieval of previous experiences with the food (Levy et al., 1999; Pelchat et al., 2004). Hence, the middle insula ALE cluster we found might also reflect the latter.

2.4.4 Amygdala

With only three of the 17 experiments contributing to the ALE cluster in the left amygdala, this was one of the least concurrent (yet significant) clusters for the contrast between food and nonfood pictures. However, the meta-analysis on the interaction with hunger state yielded a significant cluster in the right amygdala/parahippocampal gyrus with more than 33% contributing experiments. The amygdala is often a region of interest because of its role in reward processing. It is thought to be involved in weighing the importance and arousal evoking potential of both positive and negative stimuli (Baxter and Murray, 2002; Bechara et al., 1999). The stronger amygdala activation in response to food pictures compared to nonfood pictures could thus be the result of the higher arousal by or the higher salience of foods compared to nonfoods. In line with this, we found that hunger, which induces a higher motivational salience of foods, increases amygdala activation by viewing food pictures.

2.4.5 Striatum

Our meta-analysis yielded a convergent region of activation stretching from the ventral striatum to the hypothalamus for the contrast between HE and LE foods. The hypothalamus is a key region involved in the regulation of food intake, whereas the ventral striatum plays a prominent role in reward processing (Blevins and Baskin, 2010; Carlezon Jr. and Thomas, 2009). The ALE cluster in the ventral striatum might reflect the greater (metabolic) reward value of the HE foods. However, in most studies the stimuli were not matched on palatability (the HE foods were rated higher in tastiness or appeal than the LE foods). Therefore, future studies should try to disentangle effects of expected (metabolic) reward and hedonic value (expected palatability).

For the contrast between viewing food and nonfood pictures, no significant concurrent clusters were identified in the striatum. This has previously been explained by arguing that passively viewing pictures may not be rewarding enough to elicit a striatal response, i.e., for striatal activation actual reward receipt or anticipation to a real impending reward is required (Piech et al., 2009). However, the results of this meta-analysis suggest that the mere sight of food can elicit a striatal response, albeit only in response to HE (versus LE) foods.

2.4.6 Strengths and limitations

To our knowledge this is the first study that employed a voxel-based method to systematically determine concurrence across studies on the response to viewing food pictures. An ALE meta-analysis has a greater level of spatial accuracy compared with the previously employed more global characterization method of counting anatomical labels (Laird et al., 2005b). The principal strength of a quantitative meta-analysis is that it is based on multiple peer-reviewed studies, in our case with a total of almost 300 participants. Thus, the results from the present food-related brain activation maps are more robust than those of any individual imaging study. A limitation of the ALE analysis is that it only includes reported local maxima and does not take into account the level of statistical significance and the cluster size. However, we do not think that the variation in statistical thresholds has significantly biased our results because false positives from a single study will be averaged out when multiple studies are combined.

2.5 Conclusions

In conclusion, concurrence between studies on the brain response to viewing pictures of food was moderate: at best 41% of the experiments contributed to the clusters for the contrast between food and nonfood. The most concurrent brain regions activated in response to viewing pictures of food in normal-weight individuals were the lateral OFC, the LOC and the left middle insula. This study provides evidence for the modulation by hunger state (lateral OFC and amygdala) and by the food's energy content (hypothalamus/ventral striatum). Future research should further elucidate the separate effects of methodological and physiological factors on between-study variations. Findings from this study can be used to support hypothesis-driven neuro-imaging studies on the responses to visual food cues and eating behaviors like food selection.

Chapter 3

Appearance matters: neural correlates of food choice and packaging aesthetics

Summary Neuroimaging holds great potential for predicting choice behavior from brain responses. In this study we used both traditional mass-univariate and state-of-the-art multivariate pattern analysis (MVPA) to establish which brain regions respond to preferred packages and to what extent neural activation patterns can predict realistic low-involvement consumer choices. More specifically, this was assessed in the context of package-induced binary food choices. Mass-univariate analyses showed that several regions, among which the bilateral striatum, were more strongly activated in response to preferred food packages. Food choices could be predicted with an accuracy of up to 61.2% by activation patterns in brain regions previously found to be involved in healthy food choices (superior frontal gyrus) and visual processing (middle occipital gyrus). In conclusion, this study shows that mass-univariate analysis can detect small package-induced differences in product preference and that MVPA can successfully predict realistic low-involvement consumer choices from functional MRI data.

Based on: Van der Laan, L.N., De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. (2012) Appearance matters: the neural correlates of food choice and packaging attractiveness. *PLoS ONE*, 7:e41738.

3.1 Introduction

Despite the public fear of evil marketers tapping into the consumers brain to obtain hidden information, the usage of neuroimaging in consumer research is rising (Ariely and Berns, 2010). Most commercial and scientific studies on consumer behavior still employ self-report measures, such as questionnaires, to evaluate products and packages (Ares et al., 2010; Feunekes et al., 2008). However, the potential of neuroimaging techniques, especially functional Magnetic Resonance Imaging (fMRI), to gain more insight into consumer decision-making processes appears to be high. The pioneering study of Knutson et al. (2007) showed that a logistic regression model with neural activation of the insula and the nucleus accumbens could predict the decision to buy a wide range of consumer products with 61% accuracy. Recent fMRI studies employing the general linear model, i.e., traditional mass-univariate analysis, have shown comparable accuracies (e.g., an average of 56% accuracy, Levy et al. 2011) or yielded important insights in the neural underpinnings of consumer choices (Chib et al., 2009; Kang et al., 2011). For instance, Chib et al. (2009) showed that there is a common representation of the value of different consumer goods in the brain and Kang et al. (2011) showed that the computation of both hypothetical and real decisions regarding consumer products involves the same brain areas. In addition, fMRI studies using mass-univariate analyses have focused on specific product characteristics, such as perceived healthiness (Hare et al., 2009), organically grown logos (Linder et al., 2010) and packaging aesthetics (Reimann et al., 2010).

A promising development in the field of consumer neuroscience is the recent application of multivariate pattern analysis (MVPA) to fMRI data (Tusche et al., 2010). The advantage of MVPA over the traditional mass-univariate analysis is that they employ associations between voxels (activation patterns) and that they allow for differential responses across individual voxels (Pereira et al., 2009). It is well-acknowledged that this makes MVPA more sensitive than traditional mass-univariate fMRI analyses (Pereira et al., 2009). Tusche et al. (2010) were the first that applied MVPA to fMRI to predict consumer choice. They showed that the hypothetical decision to buy a car could be predicted with 70 - 82% accuracy by activation patterns in the insular and medial prefrontal cortices.

It is impressive that the choice for a high involvement consumer product, like a car, can be predicted with such high accuracy. However, it is yet unknown how accurately lower involvement every-day decisions, such as those made during grocery shopping can be predicted by MVPA. Therefore, we here assess the accuracy of such techniques for predicting low-involvement consumer decisions. To our knowledge, we are the first to use MVPA to investigate realistic low-involvement package-based consumer choices. A good test-case for this category of decisions is food choice. A first important characteristic of food choice (and low-involvement consumer decisions in general) is that they typically involve choices between relatively homogeneous sets of alternatives with much smaller variations in value. For instance, when someone stands in front of the cookie shelf, the decision to buy cookies, and not another type of snacks, has already been made. The next decision is which kind of cookies to choose from the relatively homogeneous set of alternatives.

A second important characteristic of food choices is that foods are usually packaged. Thus, product characteristics have to be inferred from the package. The impression that a package is intended to create in the mind of the consumer is affected by package characteristics like size, shape, color, images and text. Several studies with unpackaged foods have shown differential neural responses to high and low hedonic foods (Van der Laan et al., 2011). However, it is unknown whether this also holds for package-induced differences in preference. One of the current trends in food packaging design is to emphasize the healthiness of foods by highlighting nutritional information or health logos. This is believed to be an effective strategy to promote buying, because consumers themselves state that the healthiness of a food is an important motivation for their food choices (Carrillo et al., 2011). However, studies on the association between perceived healthiness and preference have yielded ambiguous results. Some studies suggest that labeling a food as healthy decreases behavioral preference for the food (Raghunathan et al., 2006), while others show no (Borgmeier and Westenhoever, 2009; Feunekes et al., 2008) or a positive effect (Provencher et al., 2009; Sabbe et al., 2009). Therefore, it is not clear whether emphasizing healthiness is helpful in promoting healthy food choices. Another packaging feature which has been shown to affect consumer choices is its aesthetic value (Silayoi and Speece, 2004, 2005). However, the effects of aesthetic value have not been studied in the context of healthy food choice.

In the present study, our first aim was to replicate the brain regions that respond to preferred food packages by using traditional mass-univariate analysis. Our second aim was to investigate to what extent brain activation can predict everyday food choices, with the use of MVPA. We employed a realistic food choice paradigm in which subjects had to choose between two alternatives of the same snack food with different packaging designs. More specifically, the choice was between two alternatives in which the packaging either emphasized the healthiness of the food or not. To gain more insight in the underlying factors of choice and the underlying neural processes, a more exploratory third aim was to assess the predictive value of perceived healthiness as well as other self-report measures involved in food choice (e.g., attractiveness, purchase intention), and to what extent the strongest self-reported predictors of choice correlate with neural activation. To localize brain regions that respond to preferred food packages and that correlate with the main self-reported predictors of food choice, we used both mass-univariate and state-of-the-art MVPA. Traditional analyses were employed to replicate previous findings. The major contribution of the present study is to apply MVPA to predict choices for food items that vary in their packaging.

3.2 Methods

3.2.1 Ethics statement

The study was approved by the Medical Ethical Committee of the University Medical Center Utrecht and subjects provided written informed consent.

3.2.2 Subjects

The study comprised twenty women as subjects (age range 19−29; mean age 22.4 years; Body Mass Index (BMI) range 19.2−24.7; mean BMI 21.7 kg/mm^2). Inclusion criteria were being female, having an age between 18 and 30 years, being right-handed and having a healthy weight (BMI between 18.5 and 25 kg/m^2). Only female subjects were included because research showed that the brains of males and females respond differently to food stimuli (Frank et al., 2010; Uher et al., 2006) and that they differ in their eating behavior (Westenhoefer, 2005). Exclusion criteria were smoking, having a food allergy, having an eating disorder, having a current alcohol consumption of $>$28 units per week, having a history of medical or surgical events that might significantly affect the study outcome, such as metabolic or endocrine disease, or any gastro-intestinal disorder. We excluded women that followed a diet in the past six months or that had weight fluctuations of more than five kg in the past six months, so as to exclude subjects which might show biases in their food choices for weight management reasons. In addition, women were excluded if they indicated a low ($<$ 5 on a 9-point scale) liking for cookies or dairy products in the screening questionnaire. Subjects were recruited with posters at the University Medical Center Utrecht and the adjacent university campus. At the time of recruitment, the aim of the study was not disclosed to the subjects because this could influence their responses. The cover story was that subjects were needed for a study on neural processing of novel foods. They would be required to view and evaluate pictures of novel food products and would receive one of these products as afternoon snack. At the end of the study participants were informed about the actual aim of the study.

3.2.3 Procedures

The study consisted of two sessions, at least one week apart. During the first session, subjects completed a computer task in which they evaluated the expected tastiness of the stimuli, i.e., the pictures of food packages. During this task, each stimulus was shown for four seconds, after which subjects had to indicate on a 9-point scale how tasty they thought the food product would be. This was done in order to ensure that none of the participants had an aversion towards the stimuli. During the second session, subjects were scanned using fMRI while performing a food choice task. Subjects were instructed to refrain from eating and drinking (except water) for at least three hours (mean 205 ± 27 min) prior to this session.

Before and immediately after scanning, subjects rated hunger, thirst and satiety on a visual analog scale. After scanning, subjects were seated behind a computer to evaluate the stimuli on expected tastiness, perceived healthiness, fat level of the food, attractiveness of the packaging and purchase intention, on a 9-point scale ranging from 1 = very untasty/unhealthy/etc to 9 = very tasty/healthy/etc. Also, subjects indicated the price (€) that they would be willing to pay for the product.

3.2.4 Stimuli

The visual stimuli consisted of 38 color images of food packages: 19 food products (nine dairy products and ten types of cookies) in two different designs. The packages were designed so that they varied in perceived healthiness. Health is an important self-reported motivation for food choice (Carrillo et al., 2011) and health aspects are currently highlighted in advertising and packaging trends. Packaging designs were manipulated by varying the following packaging cues: typography, pictures, textual information and logos, resulting in healthy and unhealthy designs (Feunekes et al., 2008; Raghunathan et al., 2006). For healthy packaging alternatives the following packaging cues were used: white, green, blue and low intensity colors, elegant, cursive and slim typography, pictures of ingredients (e.g., grains for cookies), pictures/silhouettes of active persons, textual information (e.g., healthy) and the Dutch Healthy choice logo. For unhealthy packaging alternatives, the following cues were used: yellow, red, brown and high intensity colors, playful/bold fonts, textual information (e.g., With real butter). Manipulations were based on research from the Department of Packaging Design and Management of the University Twente in which the association between these packaging cues and perceived (un)healthiness was established in Dutch consumers (Gelici-Zeko et al., 2012a,b). Stimuli were selected on basis of healthiness ratings in a pretest (n = 15 females who did not participate in the study). The only aspects that were systematically kept identical within a pair of packages were their shape and the photo of the product depicted on the package. Since we were interested in the influence of packaging itself and to avoid effects of familiarity and previous experience with the products, novel packaging designs were used. Table 3.1 shows that design manipulations were effective in altering the perceived healthiness.

3.2.5 fMRI task

During the fMRI scan, subjects carried out a food choice task (Figure 3.1). In this task, subjects made a total of 38 choices between the two package designs, i.e., each of the 19 pairs was presented twice. During each trial the images of the two designs were presented subsequently (product periods, duration 4000 ms each), separated by an inter-stimulus interval of 2000 ms (fixation cross). After that, both alternatives were shown side by side (choice period, duration 4000 ms) and subjects were instructed to indicate with the left or right button of a button box which of the two products they would prefer to eat at that moment. Each trial ended

Table 3.1: Mean (SEM) self-reported ratings[1] of the packages designed to look healthy/unhealthy.

	Healthy designs	Unhealthy designs	p
Attractiveness	5.37 (0.10)	4.74 (0.11)	0.03
Healthiness	5.25 (0.09)	4.09 (0.08)	< 0.01
Fat level	5.23 (0.11)	6.14 (0.09)	< 0.01
Tastiness first session	6.10 (0.10)	6.03 (0.10)	0.85
Tastiness second session[3]	6.26 (0.09)	6.36 (0.09)	0.73
Purchase intention	5.21 (0.10)	4.90 (0.11)	0.19
Price willing to pay (€)	1.31 (0.02)	1.26 (0.03)	0.42

[1] All measures rated on a 9-point scale ranging from 1 = not at all tasty/healthy/etc. to 9 = very tasty/healthy/etc., except for price willing to pay.

[3] Tastiness rating was obtained after the fMRI scan.

[2] P value for difference between healthy and unhealthy designs.

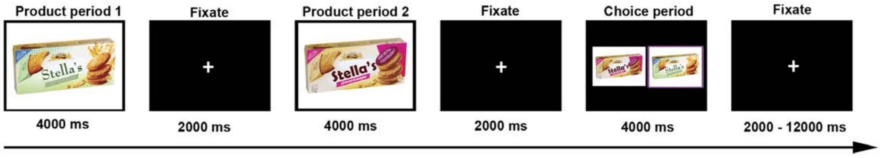

Figure 3.1: Food choice task trial structure. The first package is the healthy and the second the unhealthy version.

with a fixation cross (random inter-trial interval with duration of 2000−12000 ms). The order of the product presentations and the location of the products during the choice period (left/right) were randomized. In order to make the choices more realistic, subjects were told that one of the trials would be randomly selected and that they would receive the product chosen in that trial as a snack at the end of the study session. In reality, all subjects received the same snack (a commercially available cookie).

3.2.6 Behavioral data analysis

Al self-reported ratings (expected tastiness, perceived healthiness, fat level of the food, attractiveness of the packaging, purchase intention and price willing to pay) were normally distributed. Associations between the various self-reported measures were calculated by bivariate correlation analyses performed with SPSS 16.0. Logistic regression analyses were performed to determine associations between the self-reported measures and choice. Since choice pairs (level 1) were nested within participants (level 2) a series of multi-level logistic regression analyses were performed to examine which self-report measures were associated with choosing a package. The dependent variable in these models was the choice for the second stimulus shown (either the package was chosen or not) and the explanatory measures were the difference in ratings between the two packages of the pair (i.e., attractiveness rating of the second image shown (product period 2) minus the attractiveness rating of the first image (product period 1) for each of the self-reported measures. First, models were constructed with each of the self-report measures as single predictor. After that, models with multiple self-reported measures were constructed. Logistic regression analyses were performed with the statistical software package R (http://www.r-project.org/).

3.2.7 Image acquisition and preprocessing

MRI scanning was performed on a 3 Tesla scanner (Philips Achieva, Philips Healthcare, Best, The Netherlands), equipped with a SENSE head coil. A T_1-weighted structural image was acquired at a resolution of $1 \times 1 \times 1$ mm (TR = 8.4 ms, total scan duration = 284 s). Functional scans were acquired with a 3DPRESTO SENSE sequence (TR/TE = 22.5/33 ms, flip angle = 10°, voxel size = $4 \times 4 \times 4$ mm, acquisition time of one 3D volume = 607.5 ms) (Golay et al., 2000). The total number of volumes acquired differed between subjects because of the random inter-trial interval (range: 1370−1528 volumes). Data were preprocessed and analyzed using the SPM8 software package (Wellcome Department of Imaging Neuroscience, London, United Kingdom) run with MATLAB 7.5 (The Mathworks Inc, Natick, MA). Functional images were realigned to the first image of the time series. Functional and structural images were co-registered and normalized (retaining $4 \times 4 \times 4$ mm voxels) to Montreal Neurological Institute (MNI) space by using linear and nonlinear transformations. Unsmoothed data were used for the MVPA. For the multivariate prediction analysis only data from the first half of the choice trials were used because each choice pair was repeated during the second half of the task. Responses might be biased by post-choice shifts in preferences (Sharot et al., 2009) and thus might not be valid for use in prediction analyses. For the other analyses, all data were used and functional images were smoothed with a Gaussian kernel of 8 mm full width at half maximum.

Data from the first and second product presentation period of the trial were analyzed separately in all analyses because the processes occurring during these periods are not identical. In a sequential binary choice paradigm as used here, the expected value of the first product is evaluated in isolation (the absolute value) whereas the expected value of the second product is evaluated with the first product still in mind (the relative value) (De Martino et al., 2009; Kahneman and Tversky, 1979).

3.2.8 Traditional mass-univariate fMRI data analyses

3.2.8.1 Subject level analyses

Statistical maps were generated for each subject by fitting a boxcar function to the time series, convolved with the canonical hemodynamic response. Data were high-pass filtered with a cutoff of 128 s. Three conditions were modeled for each trial: the first product presentation period, the second product presentation period and the choice period. For each subject, four separate general linear models were build to perform analyses of the neural activation during the two product presentation periods: (1) To establish the brain regions that respond differently to chosen and not-chosen packages we performed a mean subtraction analysis between chosen and not chosen packages, (2) To identify brain regions of which activation correlates with the self-reported perceived healthiness rating we performed a parametric analysis with perceived healthiness as parametric modulator, (3) To identify brain regions of which activation correlates with the absolute attractiveness we performed a parametric modulation analysis with the self-reported attractiveness as parametric modulator, (4) To identify brain regions in which activation correlates with the relative attractiveness we performed a parametric modulation analysis on the second image period with the relative attractiveness of the second product (i.e., the attractiveness rating of the second package minus that of the first package). In all analyses, the responses during the choice screen (in which the subjects pressed the button for their choice) were modeled but not analyzed. In summary, the subject level analyses yielded seven images for each subject: (1) a contrast image of the chosen versus not chosen packages for the first product presentation period, (2) a contrast image of the chosen versus not chosen packages for the second product presentation period, (3) a contrast image of the parametric modulation of activation by perceived healthiness for the first product presentation period, (4) a contrast image of the parametric modulation of activation by perceived healthiness for the second product presentation period, (5) a contrast image of the parametric modulation of activation by absolute attractiveness for the first product presentation period, (6) a contrast image of the parametric modulation of activation by absolute attractiveness for the second product presentation period, and (7) a contrast image of the parametric modulation of activation by relative attractiveness for the second product presentation period.

3.2.8.2 Group level analyses

To determine which brain regions show differential activation for chosen and not-chosen products, the contrast images in question were entered into a one-sample t-test. To determine the brain regions whose activation is modulated by self-reported healthiness, the contrast images of modulation by healthiness were entered into a one-sample t-test. To determine the brain regions whose activation is modulated by self-reported attractiveness, the contrast images of modulation by absolute and relative attractiveness were entered into a one-sample t-tests. The resulting statistical parametric maps were thresholded at $p<0.05$ Family Wise Error (FWE) corrected for multiple comparisons at the level of a priori regions of interest (i.e., small-volume corrected). Regions of interest (ROIs) were brain areas reported in two studies relevant to food choice: brain regions that respond differentially to highly hedonic versus neutral/bland unpackaged foods (Van der Laan et al., 2011) and brain regions activated during food choices based on healthiness or tastiness (Hare et al., 2011): left inferior frontal gyrus, the bilateral inferior parietal lobule, the bilateral middle temporal gyrus, bilateral superior frontal gyrus, bilateral middle frontal gyrus, right inferior temporal gyrus, bilateral middle occipital gyrus, right culmen and the bilateral putamen, caudate and pallidum. ROI masks were generated using the AAL-atlas (Tzourio-Mazoyer et al., 2002) as implemented in WFU-pickatlas toolbox (Maldjian et al., 2003).

3.2.9 Multivariate Pattern Analysis

MVPA was used to localize brain regions which contain predictive information. Analyses were performed using the PyMVPA software package (Hanke et al., 2009), in combination with LibSVMs implementation of the linear support vector machine (http://www.csie.ntu.edu.tw/cjlin/libsvm/). We used the default configuration, in which the parameter C (trade off parameter between width of the margin and the number of support vectors) is automatically scaled according to the norm of the data for each searchlight.

Trial-wise linearly detrended and z-scored functional scans that were acquired between 3–6 seconds after onset of the product presentation period were averaged to speed up analysis (Pereira et al., 2009). This time frame was chosen because the peak of the hemodynamic response is known to occur 4–5 seconds after stimulus onset (Neumann et al., 2003). This resulted in one average image for the chosen product and one average image for the not-chosen product, for each of the 19 trials.

For both product presentation periods, a whole brain searchlight analysis was performed, which is a method particularly suitable to localize brain regions that contain predictive information (Pereira et al., 2009). A sphere with a radius of 10 mm was centered at each voxel. With voxel size $4 \times 4 \times 4$ mm this results in spheres of 27 voxels, i.e., 27 features. For each sphere, a 19-fold leave-one-out cross-validation was performed with a linear support vector machine to estimate the prediction accuracy of each voxel. Thus, for each sphere the classifier was trained on 18 of the 19 trials. More specifically, a model of the associations between the voxel values and the categories (chosen or not-chosen) in the training trials was constructed. Subsequently, this prediction model was tested on the remaining trial. Accuracy was calculated as the percentage of correctly categorized chosen and not-chosen products in the remaining test trial. For each subject, the searchlight analysis yielded a three-dimensional map of prediction accuracies. Each value of this accuracy map represents the average cross-validated prediction accuracy of the searchlight surrounding that voxel.

Table 3.2: Mean (SEM) ratings[1] for chosen/not chosen packages.

	Not chosen	Chosen	p
Attractiveness of the package design	4.17 (0.10)	5.81 (0.09)	< 0.01
Healthiness	4.45 (0.09)	4.84 (0.09)	< 0.01
Fat level	5.75 (0.10)	5.63 (0.09)	0.43
Tastiness first session	5.97 (0.10)	6.14 (0.09)	0.22
Tastiness second session[2]	5.93 (0.10)	6.64 (0.08)	< 0.01
Purchase intention	4.45 (0.10)	5.57 (0.10)	< 0.01
Price willing to pay (€)	1.20 (0.02)	1.36 (0.02)	< 0.01

[1] All measures rated on a 9-point scale ranging from 1 = not at all tasty/healthy/etc. to 9 = very tasty/healthy/etc., except for price willing to pay.

[2] Tastiness rating was obtained after the fMRI scan.

To identify brain regions that were predictive of choice across subjects, we performed a t-test as implemented in SPM8 to contrast the accuracy maps of all participants against chance level (50% accuracy) for both analyses. The resulting statistical maps were thresholded at $p < 0.05$ FWE corrected for multiple comparisons at the level of ROIs (same as the mass-univariate analysis).

3.3 Results

3.3.1 Behavioral results

Table 3.1 shows that packaging design manipulations were effective in altering perceived healthiness and fat level while keeping expected tastiness constant. The attractiveness of healthy packaging designs was significantly higher. This was expected because visual cues that give a package a healthy appearance are partially overlapping with those that are most preferred. For instance, the colors blue, green and white (bright colors) give a package a healthy appearance, but these are also the colors that are liked most, even across cultures (Adams and Osgood, 1973; Grieve, 1991; Madden et al., 2000; Wiegersma and Van der Elst, 2011).

Attractiveness correlated with several other self-report measures, such as purchase intention ($r = 0.65$, $p < 0.001$), price willing to pay ($r = 0.35$, $p < 0.001$), expected tastiness (first session: $r = 0.24$, $p < 0.001$, second session: $r =0.46$, $p < 0.001$) and perceived healthiness ($r = 0.15$, $p < 0.001$). The results did not differ between the two food categories (cookies and dairy foods); therefore, data from these categories were combined in all subsequent analyses.

Table 3.2 shows the means of the self-report measures for the chosen and not-chosen packages. Chosen packages were rated as significantly more attractive, tastier and healthier. Purchase intention and the price subjects were willing to pay were also significantly higher for chosen packages. Choices were consistent over

Table 3.3: Multi-level logistic regression results: self-report measures associated with food choice.

Model effect	Estimate	Std. Error	Z-value	p	VIF[1]
Fixed effects					
Intercept	0.025	0.131	0.191	0.849	
Attractiveness	0.397	0.078	5.082	< 0.001	1.32
Healthiness	0.125	0.103	1.212	0.226	1.93
Fat level	0.026	0.101	0.257	0.797	1.84
Purchase intention	0.230	0.105	2.203	0.028	1.42
Price willing to pay	0.118	0.405	0.293	0.770	1.15
Tastiness session 1	0.132	0.125	1.061	0.289	1.03
Tastiness postscan	0.311	0.125	2.486	0.013	1.33
Random effect (subject)	Variance	SD			
Intercept (level 2)	9.105×10^{-11}	9.953×10^{-6}			
Log-likelihood model	-179.6				

[1] VIF = variance influation factor is a measure of multicollinearity. A variance inflation factor above 5 indicates high multi-collinearity.

repeated presentations: only in 6.8% of the presented choices a different package was chosen the second time. There was no order effect on choice: in 50.7% of the trials the image presented in the second product presentation period was chosen, in 49.3% of the trials the image presented in the first product presentation period.

The logistic regression analyses with each self-report measure as single predictor showed that the perceived healthiness (parameter estimate ± SEM: 0.17 ± 0.05), attractiveness (0.60 ± 0.07), purchase intention (0.68 ± 0.08), price willing to pay (1.87 ± 0.32) and tastiness post-scan (0.73 ± 0.10) were significantly (positively) associated with food choice ($p < 0.05$). In a model with all self-report measures, only attractiveness, tastiness post-scan and purchase intention remained significant predictors (Table 3.3), i.e., these measures have an independent component that is associated with choice. This combined model shows that attractiveness has the largest independent component associated with choice. To control for design-category (i.e., healthy or unhealthy design), the analysis was repeated with design category as extra dummy variable. This did not change the results of the logistic regression (results not shown).

To disambiguate the effects of perceived healthiness and attractiveness on choice we compared the models with attractiveness and perceived healthiness as single predictors with a model with both variables. Whereas the model with both predictors explained significantly more variance than the model with healthiness as single predictor ($-2\log\Lambda = 134.5$, df = 1, $p < 0.0001$), the combined model did not explain more variance than the model with attractiveness as single predictor ($-2\log\Lambda = 0.4$ df = 1, $p = 0.40$). This means that adding healthiness as a variable

Table 3.4: Peak voxel coordinates[1] of brain regions stronger activated in response to chosen versus not chosen packages during the second image period in regions of interest.

Anatomical label	Side[2]	MNI-coordinates x	y	z	Cluster size voxels	Z
Middle temporal gyrus	R	50	-72	18	14	3.77
Putamen	L	-14	12	-2	18	3.60
	L	-22	8	-10		3.17
Caudate	L	-14	16	-2	17	3.22
Pallidum	L	-14	8	-2	5	3.32
Inferior parietal gyrus	L	-58	-40	46	19	3.32
Middle occipital gyrus	R	46	-76	14	4	3.95
Putamen	R	26	8	-10	11	3.30

[1] Peaks reported are significant at $p < 0.05$ FWE-corrected for the respective ROI.
[2] L = left hemisphere, R = right hemisphere.

when attractiveness was already in the model, did not significantly improve the model. Moreover, adding attractiveness to the model decreased the parameter estimate of healthiness from 0.17 to 0.06, while adding healthiness to a model with attractiveness did not affect the parameter estimate of attractiveness. Thus, healthiness did not have an independent component associated with choice while attractiveness did.

Additional likelihood ratio tests were performed to test whether the effects of attractiveness, purchase intention and tastiness varied across participants. This was done by comparing the models with the self-reports treated as fixed effects versus models with random slopes. None of these tests showed a statistically significant improvement of the model. With a likelihood ratio test comparing a model with a fixed intercept to the empty model with a random intercept (subject level 2), we tested whether the intercept was statistically different between subjects. This was also not the case.

3.3.2 fMRI results

3.3.2.1 Chosen versus not-chosen packages

The subtraction analysis of chosen versus not-chosen packages in the second product presentation period showed that activation was stronger for chosen packages in the bilateral striatum (right putamen, left putamen, pallidum and caudate), in the left inferior parietal gyrus, in the middle temporal gyrus and in the right middle occipital gyrus (Table 3.4, Figure 3.2). There were no brain regions activated stronger in response to not-chosen packages.

For the first product presentation period, there were no brain regions with a significantly stronger activation in response to chosen packages at $p < 0.05$ FWE-corrected for multiple comparisons at Region of interest (ROI) level. Borderline significant clusters were found in the middle frontal gyrus ($p = 0.076$ FWE-corrected, $Z = 3.26$, MNI (-26, 20, 58)), the left putamen ($p = 0.089$ FWE-corrected, $Z = 2.64$, MNI (-18, 16, 2)) and caudate ($p = 0.076$ FWE-corrected, $Z = 2.73$, MNI (-14, 8, 10)).

3.3.2.2 Parametric modulation by perceived healthiness & attractiveness

There were no brain regions in which activation was modulated by perceived healthiness at $p < 0.05$ FWE-corrected for multiple comparisons at ROI level.

We performed a parametric modulation analysis to establish in which brain regions activation was modulated by attractiveness, because the behavioral results showed that attractiveness of the packaging design was strongly associated with choice (see section 3.3.1). Brain regions where activation was positively modulated by absolute attractiveness during the first product presentation period were: a cluster in the left superior frontal gyrus ($p = 0.002$ FWE-corrected, $Z = 4.26$, MNI (-18, 24, 58) stretching to the left middle frontal gyrus ($p= 0.014$ FWE-corrected, $Z = 4.83$, MNI (-22, 24, 54)) (Figure 3.2). In the second product presentation period, there were no brain regions in which activation was modulated by absolute attractiveness (i.e., the attractiveness rating of the second product). However, there was a borderline significant cluster in the left pallidum ($p = 0.092$ FWE-corrected, $Z = 2.41$, MNI (-10, 8, -2)) in which activation was positively modulated by relative attractiveness (i.e., the attractiveness of the second product minus the attractiveness rating of the first product). In neither of the image periods was brain activation modulated negatively by absolute or relative attractiveness.

3.3.2.3 Prediction of food choice with MVPA

To identify activation patterns that predict choice, MVPA was performed for the first and second product presentation period (Table 3.5, Figure 3.3). In the first product presentation period, brain activation patterns in the in the medial part of the right superior frontal gyrus significantly predicted food choice (peak accuracy: 60.0%). For the second product presentation period, activation patterns in the left middle occipital gyrus significantly predicted food choice (peak accuracy 61.2%).

To ensure the validity of the results, the analyses were repeated with shuffled labels. When samples were randomly provided with a chosen or not chosen label, no statistical significant prediction of food choices could be attained. In addition, in a control region (left fusiform gyrus), which is not usually found in value encoding analyses, we did not find any statistical significant prediction accuracies (maximum accuracy 52.2%). These findings speak against potential methodological concerns such as the over-fitting of noise or insufficient corrections for multiple comparisons.

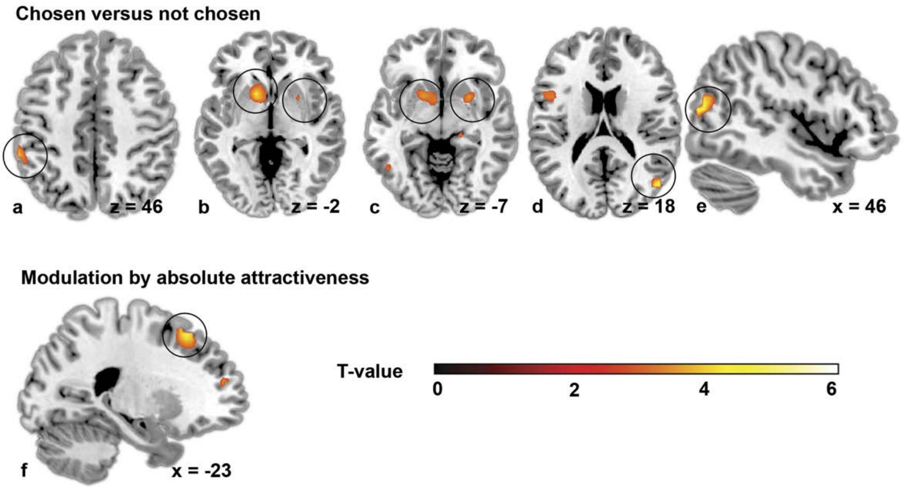

Figure 3.2: Results from the traditional mass-univariate fMRI analysis. (A–E) Brain regions stronger activated in response to chosen vs. not chosen packages: (A) Left inferior parietal gyrus; (B/C) left caudate/putamen/pallidum and right putamen; (D/E) Border of right middle occipital gyrus and middle temporal gyrus. (F) Brain regions modulated by absolute attractiveness in the first product presentation period: a cluster stretching from the left superior frontal gyrus to the middle frontal gyrus. For visualization purposes, all images are thresholded at T-value > 2.86.

Table 3.5: Brain regions[1] encoding product choice.

Anatomical label	Side[2]	Accuracy[3]	MNI x	MNI y	MNI z	Z-value
First image period						
Superior frontal gyrus, medial part	R	60.0	10	52	46	3.47
Second image period						
Middle occipital gyrus	L	61.2	-46	-72	14	4.31

[1] Peaks reported are significant at $p < 0.05$ FWE-corrected for the respective ROI.
[2] L = left hemisphere, R = right hemisphere.
[3] Peak accuracies of clusters are reported.

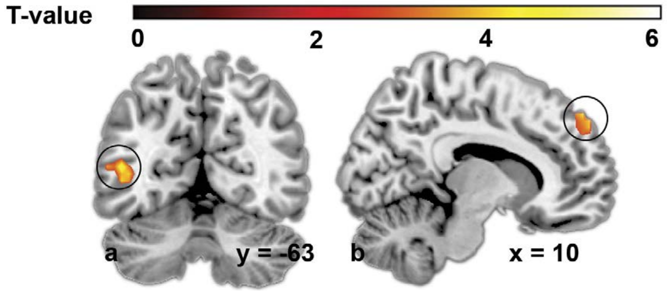

Figure 3.3: Brain regions predictive of choice. (A) left middle occipital gyrus; (B) right superior frontal gyrus, medial part. For visualization purposes, images are thresholded at T-value > 2.86.

3.4 Discussion

This study is the first to investigate both the neural correlates and predictors of choice between two food items that only differ in their packaging.

3.4.1 Chosen versus not chosen packages

Our first aim was to replicate brain regions found in previous studies that respond to preferred food packages. The mass-univariate analysis contrasting chosen with not-chosen packages yielded several regions stronger activated in response to chosen packages, among which the bilateral striatum. This finding concurs with our recent meta-analysis (Van der Laan et al., 2011), which showed that appetizing foods yield a consistently higher activation in the striatum than neutral or bland foods. The studies included in this meta-analysis compared two very different groups of unpackaged foods. Our results show that the same finding holds for package-induced variations in preference within the same product, which presumably are smaller than variations between different products. A recent study of Litt et al. (2011) has suggested a role for the striatum in both value and saliency (arousal) computations during food choice. Because we did not include any aversive (negatively valenced but arousing) products we cannot differentiate between these two processes. Thus, the striatal activation in the present study could reflect both value and salience computations.

The finding that clusters in the inferior parietal gyrus and the middle temporal gyrus are more strongly activated during chosen versus not-chosen packages, is in line with previous work. Activation of parietal regions during decision-making has been associated with the valuation of different options and a recent meta-analysis has shown that inferior parietal regions were more consistently activated during reward anticipation than during the reward outcome (Liu et al., 2011). Thus, the inferior parietal gyrus activation during the second image period could reflect response selection, since all alternatives are known at that moment. Activation in the middle temporal gyrus during the decision period has previously been found to correlate with stimulus value (but not saliency) (Litt et al., 2011).

3.4.2 Prediction of food choice with MVPA

3.4.2.1 Brain regions predictive of food choice

Our second aim was to investigate to what extent brain activation can predict food choice. To our knowledge, we are the first to use MVPA to investigate realistic low-involvement consumer choices, such as food choices. Previous studies using traditional analysis techniques investigated the neural correlates of consumer choice (e.g., Hare et al., 2009; Knutson et al., 2007) and of specific product characteristics (e.g., aesthetics, Reimann et al., 2010). However, none of these studies used both traditional analysis and MVPA. It is well-acknowledged that MVPA is more sensitive than traditional mass-univariate fMRI analyses (e.g., Pereira et al., 2009). One pioneering study (Tusche et al., 2010) showed the high potential of this novel technique in predicting the hypothetical choices for a high-involvement product (a car). However, until now it was unknown whether this technique could also accurately predict low-involvement consumer choices. Therefore, we assessed how accurately this type of consumer choices, such as those made during grocery shopping, can be predicted by MVPA. These are choices in which the differences in preference are assumed to be much smaller than in infrequent high-involvement choices, such as those for a car. By employing a linear support vector machine, we showed that MVPA is also sensitive enough to predict everyday food choices: food choice could be predicted with up to 61.2% accuracy on group level with activation patterns in the right superior frontal gyrus (medial part) and the left middle occipital gyrus. Given that the choice was between two similar foods, which only differed in their packaging design, this can be considered as a high accuracy. Similar accuracies have been found in studies that used traditional mass-univariate analysis methods to predict choice (e.g., Knutson et al., 2007; Levy et al., 2011). The only other study on consumer choice that utilized MVPA, reported prediction accuracies in the range of 72—80% with patterns in the right middle frontal gyrus, medial frontal gyrus, left orbitofrontal cortex, bilateral dorsal anterior cingulate, bilateral posterior cingulate, and left insula (Tusche et al., 2010). However, as mentioned above, that study used a very different category of consumer products, namely cars. A decision for a car is probably much more distinct than the low-involvement everyday decision for a snack food: cars are bought less often and less easily than foods. Another difference between the studies is that in the study of Tusche et al. (2010), all stimuli were familiar. Since we were interested in the influence of the packaging itself and to avoid effects of familiarity and previous experience with the product, we used novel packages as stimuli. Another explanation for the difference in findings is that the question posed in the study of Tusche et al. (2010) was to either buy the car or not. Thus, the value of just one car had to be taken into consideration, while in our study subjects had to make a binary choice. That is, preferences for two similar products had to be compared and decisions were thus not based on the absolute value of the products, but on the difference in value between the two options (i.e., the relative value, which will be elaborated on in section 3.4.2.2).

In the first image period, brain activation patterns in the medial part of the right superior frontal gyrus predicted choice. This is in line with other studies showing that activation in this region correlates with value (Litt et al., 2011) and willingness to buy (Linder et al., 2010) during decision-making. Also, interestingly, a cluster at approximately the same coordinates was found to be activated during food choices in which the participants were asked to specifically consider the healthiness of the food (Hare et al., 2011). This suggests that this region could be involved in the consideration of product features such as healthiness.

For the contrast between chosen and not-chosen packages as well as for the MVPA, we found involvement of the middle occipital gyrus, although for the prediction analysis the cluster was lateralized to the left and for the mass-univariate analysis to the right. This region is primarily known for its role in visual processing. Differential middle occipital activation for preferred versus not-preferred items has previously been observed in studies with food stimuli, e.g., our meta-analysis showed that across studies, the right middle occipital gyrus is stronger activated in response to highly hedonic versus bland/neutral foods (Van der Laan et al., 2011). Although it cannot be ruled out that differential activation in regions involved in color processing such as the middle occipital gyrus and the inferior parietal gyrus, is partly due to color differences between the stimuli (Conway, 2009; Shapley and Hawken, 2002), an equally likely explanation could be that these findings reflect modulation of visual processing by emotional valence. A recent study showed higher middle occipital activation in response to high energy (HE) compared to low energy (LE) foods, even though the pictures were matched on visual properties (Frank et al., 2010). It has been widely acknowledged that both attention and emotional valence modulate processing of visual stimuli by enhancing neuronal responses at different levels of visual processing, i.e., in early visual processing and in later phases such as recognition (Gerdes et al., 2010; Kastner and Ungerleider, 2000; Lane et al., 1999). Accordingly, we speculate that the observed activation of visual processing brain areas reflects increased attention to, or emotional valence of preferred packages. Future research should elucidate the exact role of the middle occipital gyrus in emotional valence and value calculation.

3.4.2.2 Absolute and relative value calculation

It is important to note that our results show that predictions can be derived from brain activation during both product presentation periods. However, it should be noted that evaluation processes differ between the two periods: whereas the expected value of the first product is evaluated in isolation (the absolute value), the expected value of the second product is evaluated with the first product still in mind (the relative value). Therefore, the value of the first product serves as a frame of reference against which the second product is weighed. Given our sequential binary choice design one would expect that the neural encoding of chosen and not chosen products is influenced by ordering effects within a trial (i.e., in the first product presentation period the absolute value of the product is computed whereas in the second product presentation period the relative value is computed). There is evidence to suggests that value is more often computed with respect to a reference point, rather than in isolation (Kahneman and Tversky, 1979). This notion is also supported by psychological literature on contrast effects (e.g., Novemsky and Ratner, 2003), as well as evidence from fMRI and neuronal recording studies which show ordering effects of comparative valuation in brain areas involved in decision-making (e.g., Deco et al., 2010), and differential brain regions involved in encoding of absolute and relative value (De Martino et al., 2009). We therefore argue that evaluation in the second product presentation period is influenced by the preceding stimulus while this is not the case in the first period. Therefore, the brain regions activated during the first image period most likely reflect the absolute value calculation of the product. In contrast, activation during the second image period likely reflects a comparative calculation in which the second product is weighed against the first product, which serves as a reference. Our findings, that the ventral part of the striatum is more strongly activated in response to chosen versus not chosen packages in the second product presentation period, and that activation in the ventral striatum tends to correlate with the relative attractiveness, is in line with findings of De Martino et al. (2009). They also found that ventral striatum activation correlates with the relative value in a buying/selling fMRI paradigm. In addition, although borderline significant, we found that a more dorsal part of the striatum was stronger activated for chosen compared to not chosen packages in the first image period. This is also in line with the finding of De Martino et al. (2009) that a more dorsal part of the striatum correlates with the absolute value.

In the fMRI task, subjects indicated their choice when presented with a separate choice screen, shown to them after the first and second product presentation period. This design may complicate the interpretation of the results for the second product presentation period because due to this separate choice screen, we cannot be completely sure whether subjects made their decisions during the second product presentation periods or at the moment they were presented with the choice screen. Nevertheless, we decided to use a separate choice screen in order to avoid biases due to motor responses accompanied with the button press in the evaluation processes that take place during the product presentation periods. Several studies using a sequential design indicate that the decision process starts during the period when the second stimulus is presented (e.g., Deco et al., 2010). Thus, although the design of our study does not allow to exactly determine when subjects made their choice (either during the second product period or during the choice screen), we argue that it is likely that decisions were made during the second product period. Even though, evaluation and decision signals were confounded during the second presentation period, we do know that most likely relative value computations are taking place in the second product presentation period. Considering its ecological relevance (e.g., Kahneman and Tversky, 1979), the differentiation between absolute and relative value computation in the brain is an important topic for future research.

3.4.2.3 Difference mass-univariate analysis and MVPA

We compared brain activation during chosen and not-chosen products with the use of both traditional mass-univariate analysis and MVPA. The results of the traditional analysis enabled a comparison with results from previous studies. However, this kind of analysis alone, without any validation, is deemed unsuitable to establish a predictive relationship between neural activation and choice (Cohen et al., 2010). To be able to establish the predictive performance of a technique (either univariate or multivariate), it is required to validate the model, for instance with independent testing and training data sets (Pereira et al., 2009). Several studies showed that traditional mass-univariate analyses indeed can also yield brain regions predictive of choice, e.g. with the use of cross validation (Knutson et al., 2007) or by using a functional localizer task to identify predictive regions of interest (Levy et al., 2011). In our study, we did not find direct overlap between the results of the traditional analysis comparing chosen and not chosen packages and the brain regions predictive of choice in the MVPA. A likely explanation for the lack of overlap between the two techniques is that the underlying calculations are not the same: The main difference between the two methods is that the mass-univariate method tests for differences in level of activation of each voxel separately, while MVPA establishes whether activation patterns (i.e., interactions between multiple voxels) are associated with an outcome measure.

More specifically, differences in brain regions identified by mass-univariate analyses and MVPA likely arise from the fact that (1) different information is taken from the data (i.e., differences in the degree of activation in single voxel vs. interactions between multiple voxels) and (2) differences in the preprocessing and analysis trail associated with (1). The preprocessing and analysis trail of mass-univariate analysis is optimized for detecting spatially extended differences in the degree of activation (i.e., differences in the same direction), while the preprocessing and analysis trail of MVPA is optimized for detection of pattern-based information. For mass-univariate analysis, images are smoothed for improving the signal-to-noise ratio, making the error-distribution more normal and accommodating functional variations between subjects. However, a drawback of smoothing is that it reduces the spatial resolution of the data. In MVPA, on the other hand the focus is on fine-grained activation patterns, therefore data for MVPA are not smoothed. To optimize data for MVPA, z-scoring (setting the mean to zero and standard deviation to 1) is performed to homogenize voxel intensities. Because z-scoring involves scaling all voxel intensities into approximately the same range and removing the mean, the difference in activation level between conditions can be diminished. Therefore, a likely explanation of why we find evidence for involvement of the striatum in the mass-univariate analysis but not in the MVPA results is that (although there are differences in average activation for chosen versus not chosen stimuli), the activation patterns in the striatum do not contain (detectable) information that differentiates between conditions. For the regions that we found with MVPA but not with mass-univariate analysis (clusters in middle occipital gyrus, superior frontal gyrus) the opposite holds: although average activation in these regions did not differ for the chosen and not chosen stimuli, activation patterns did contain information that could distinguish between chosen and not chosen stimuli (and could predict this with up to 61.2% accuracy).

The few studies that have employed both methods have also shown different results for mass-univariate analysis and MVPA. For instance, Lee et al. (2012) found different cortical areas involved in categorical speech processing with mass-univariate analysis and MVPA, and Tusche et al. (2010) did not find any brain regions significantly associated with consumer choice with a mass-univariate analysis, while the MVPA did differentiate. The fact that mass-univariate and MVPA results do not necessarily concur does not have implications for the interpretation of mass-univariate imaging data to date, i.e., these data remain valid in their own right, but it does highlight that other information can be gained with more sophisticated techniques. It seems likely that for purposes like choice prediction a combination of both mass-univariate analysis and MVPA will become the preferred approach because these two analysis methods complement each other.

3.4.2.4 Improving prediction accuracy

Prediction accuracy might be further improved by more trials for training and testing. It is hard to determine the optimal number of trials. More training data usually produce a better model and more test samples increase the power of the test for significance of the accuracy (Pereira et al., 2009). In our analyses, we used cross-validation to maximize the number of data for training. However, performing MVPA with many features (voxels) and relatively few trials entail a risk of overfitting, especially with complex classification models (Pereira et al., 2009). We avoided this by using a searchlight analysis to reduce the number of features and by employing a simple linear model (linear support vector machine) as classifier. Moreover, the validity of the MVPA results was supported by the finding that the analysis with the shuffled labels did not yield any significant prediction accuracies, and the fact that no significant prediction accuracies were found in a control region (left fusiform gyrus).

3.4.3 Ventromedial prefrontal cortex

The ventromedial prefrontal cortex (vmPFC) has also been implicated in decision-making and activation in this region has been found to correlate with measures of preference (e.g., Chib et al., 2009; Knutson et al., 2007; Litt et al., 2011). In our study, however, there was no significant association between vmPFC activation and the variables of interest, like attractiveness or choice. A possible explanation for this is that ventral prefrontal areas are prone to signal loss due to susceptibility artifacts.

Visual inspection of the mean inclusive functional masks showed that there was indeed an (unexpectedly) low signal from ventral prefrontal regions. The specific scanning sequence we used, is known to be very sensitive and has a fast acquisition time (Golay et al., 2000). However, the signal in the vmPFC was unexpectedly low. Alternative explanations for not finding vmPFC-involvement could be that we performed no analyses that assessed the trial by trial correlation with values for the food items that would directly replicate the analyses that have identified vmPFC correlations with stimulus or decision value. We did correlate neural activation with self-reported attractiveness. However, this is only one component of stimulus value. A third explanation could be that our design does not allow one to exactly know at what moment subjects decided. As argued previously, it seems most likely that decisions were made during the second product presentation period, although we cannot rule out the alternative explanation that they were made later, i.e., when the decision screen was presented. Previous work has shown that vmPFC activation correlates more strongly with stimulus value (willingness to pay) when subjects are engaged in active decision making compared to forced responses (Plassmann et al., 2007). Therefore, a lack of vmPFC correlation with our measures of preference could be due to the unknown timing of the decision.

3.4.4 Perceived healthiness and attractiveness

Our third aim was to investigate how self-reported measures relate to food choice. We found that the attractiveness of the packaging design was the strongest predictor of choice, and that perceived healthiness did not have an independent component associated with choice while attractiveness did. This suggests that, when people choose between two alternatives of a certain type of product with which they are not familiar, the aesthetic value of the package is decisive. That is, an attractive package increases the general preference for the alternative. This could be exploited in promoting healthy eating behavior. Instead of the current strategy of putting emphasis on the healthiness of foods (e.g., by low-fat labels or health logos), it might be more effective to present healthy products in attractive packages. Our study does not allow for determining how attractiveness influences choice, i.e., whether subjects just chose the most attractive package or whether attractiveness influenced the expected value of the food. However, other studies suggest that attractiveness could influence general product preference by triggering positive responses and by increasing the expected quality, luxury and price of products in several consumption domains (Dawar and Parker, 1994; Forsythe et al., 1996; Orth et al., 2010). As the stimuli we used were unfamiliar to the subjects, it could be that they used attractiveness as a proxy for quality. This would explain why in our study attractiveness is the strongest self-reported predictor of choice. Future research should investigate how attractiveness can influences choice and whether attractive packaging could indeed promote healthy food choices.

We found that brain activation in a region stretching from the left middle frontal gyrus to the superior frontal gyrus was modulated by ratings of packaging attractiveness. This is in line with other studies which found that activation in this region correlates with product preference ratings (Izuma et al., 2008; Knutson et al., 2007), goal values (Plassmann et al., 2010) and willingness to buy (Linder et al., 2010). Also, an additional parametric analysis with self-reported purchase intention (results not shown) showed that neural activation in the same region correlated with purchase intention, a measure which correlated to a fair extent (r = 0.65) with attractiveness. From this we speculate that the modulation of activation in the superior frontal gyrus stretching to the middle frontal gyrus reflects a more general preference evaluation which is driven by the attractiveness. This topic deserves more investigation.

The self-reports of healthiness, attractiveness, perceived fat content, purchasing intention and price willing to pay were measured after the choice-task. This has limitations because the act of choosing may induce changes in product preference, such that they better match with their prior decision (Sharot et al., 2009). However, we nevertheless decided to measure product characteristics after choice, because measuring them before choice focuses attention on them which may also affect their choice. Since we were interested in subjects spontaneous choice, we chose to avoid priming them with the characteristics of interest before their choice. A second reason why these measures were not collected before the choicetask was to limit exposure to the stimuli and avoid a thorough evaluation of the stimuli before the choice because we wanted the evaluation processes to take place during the fMRI task.

3.5 Conclusions

In conclusion, the present study showed that mass-univariate analysis can detect small package induced differences in preference and that binary food choices could be predicted with an accuracy of up to 61.2% by activation patterns in brain regions previously attributed to healthy food choices (medial superior frontal gyrus) and visual attention processes (middle occipital gyrus). This study confirms the importance of aesthetics in packaging design and suggests that healthy food choices could be promoted by presenting healthy foods in more attractive packages.

Chapter 4

Do you like what you see? The role of first gaze and gaze duration in consumer choice

Summary Research on the role of visual attention in consumer choice relies on the implicit assumptions that consumer choice can be easily influenced and that fixation duration is a proxy for product preference. The study aims were (1) to investigate the influence of the first fixation on consumer choice, and (2) to disentangle two factors driving fixation duration, namely the stimulus reward value (preference) and the decision goal (task instruction). Participants chose between two products during an eye tracking recording. To investigate the influence of first fixation location on choice, first fixation location was manipulated in half of the trials. To disentangle effects of the stimulus reward value and the decision goal, participants selected either the product they wanted, or the product they did not want. Manipulating the first fixation towards an alternative did not influence the likelihood of it being chosen. Although fixation duration was mainly determined by the decision goal, it was also influenced by the stimulus reward value. The results have important implications for the interpretation of eye tracking results and in-store marketing.

Based upon: Van der Laan, L.N., Hooge, I.T.C., De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. Do you like what you see? Associations between first gaze, gaze duration and consumer choice *(submitted)*.

4.1 Introduction

It is generally known that a product has to be noticed on the shelf, to have a chance of making it into the basket. Consequently, commercial interest in the application of measures of visual attention in market-research is growing. However, research on the role of visual attention in consumer choice relies on implicit assumptions that so far have remained untested. Here, we will assess two of these assumptions, namely (1) that consumer choice can be easily manipulated, and (2) that fixation duration is a proxy for product preference. Results of this study have important implications for the interpretation and design of both fundamental and market-oriented eye tracking studies.

4.1.1 The role of the first fixation in consumer choice

It is assumed that consumer choice can be easily manipulated. Indeed, it has been shown that choices can be influenced by manipulating visual characteristics of a package, such that it 'pops out' (e.g., Milosavljevic et al., 2012). However, it is unknown through which mechanisms this occurs. Whereas a higher visual saliency could result in a higher likelihood that the product is the first to catch the eye (location of first fixation), it could also result in sustained attention to this item (i.e., longer total fixation duration) and thereby increase preference (Krajbich et al., 2010). Moreover, the visual manipulation itself (making a package brighter/darker) could also influence preference by increasing attractiveness (Van der Laan et al., 2012).

It has been shown that experimentally increasing the fixation duration on an item increases the likelihood of it being chosen (Armel et al., 2008 Shimojo et al., 2003), but the role of the location of the first fixation is less clear: some studies have shown that people have a bias towards choosing the item that they fixated on first (e.g., Krajbich et al., 2010) while other studies (e.g., Armel et al., 2008) found no association between first fixation location and choice. Some authors have proposed that the location of the first fixation is influenced by pre-existing preferences (e.g., for palatable high energy foods, Werthmann et al., 2011), while others posit that the location of the first fixation is mainly driven by factors that are uncorrelated with value, such as visual attributes (e.g., color contrast, Milosavljevic et al., 2012) or cultural norms (e.g., reading from left to right, Krajbich et al., 2010). Thus, it is unknown whether first fixation location is associated with preference and, if so, in which direction (i.e., is the first fixation location determined by pre-existing preferences or did the first fixation influence preference).

To our knowledge no studies have experimentally investigated whether consumer choice can be influenced by manipulating the first fixation to a product. Therefore, our first aim was to investigate whether manipulating the first fixation towards an alternative increases the likelihood of it being chosen.

4.1.2 Disentangling the effects of decision goals and stimulus reward value on fixation duration

Current models of visual attention in value-based decision making attribute fixation duration solely to the build-up of reward value for the stimulus that is fixated on (*Gaze cascade model*, Simion and Shimojo, 2006; Shimojo et al., 2003; Glaholt and Reingold, 2009, *Krajbich-Armel-Rangel model*, Krajbich et al., 2010). Consequently, fixation duration is interpreted as a proxy for product preference. However, eventual selection of the item on which fixation duration was longest is not specific for value-based decision making but also occurs in objective decision making. For instance, when the decision goal is to indicate the roundest face from a range of faces, subjects fixate longest on the roundest face (Shimojo et al., 2003; Simion and Shimojo, 2006). Similarly, when the goal is to evaluate the healthiness of products, health logos are fixated on longer (Orquin and Scholderer, 2011). Since it is not likely that fixation duration is instigated by value comparison in these objective decision making tasks, it can be questioned whether the fixation bias (fixating longer on the selected item) in value-based decisions can be attributed to the product reward value or, alternatively, whether it is just a result from the specific decision goal. Hence, the underlying causes of fixation duration are unclear. We hypothesize that both the decision goal and the stimulus reward value will influence the fixation duration during consumer choice.

A difficulty in disentangling the effects of the decision goal and the stimulus' reward value is that they usually concur when someone is asked to indicate the products he or she would prefer. However, negating the question enables disentangling these separate effects. Figure 4.1 shows the fixation duration under the assumption that both the decision goal and the stimulus reward value influence fixation duration in a binary choice. If the question is "Which product do you want to have?", the selected product is the product with the highest reward value and the product is in line with the decision goal. Hence, both effects boost fixation duration for the selected product. The product that is not selected has both the lowest reward value and is not in line with the decision goal. Therefore, both effects diminish the fixation duration for this product. Consequently, there would be a large difference in fixation duration between the selected and not selected product. If the question is "Which product do you not want to have?", the effects of decision goal and reward value counteract each other because the selected product has the lowest reward value but this product is in line with the decision goal. In contrast, the not selected product has the highest reward value but the product is not in line with the decision goal. Consequently, a small or absent difference in fixation duration between the selected and not selected product would be expected. Because we cannot predict the exact strength of the effects, confidence intervals are added in the figure depicting the hypothesized pattern of fixation duration (Figure 4.1).

Disentangling the effects of decision-goals and reward value is relevant since fixation duration in marketing-oriented eye tracking research is often used as a proxy for product preference, while this might not be a correct interpretation. Therefore, our second aim was to disentangle the effects of decision goal and stimulus reward value on the fixation bias in value-based decision making.

4.2 Material and methods

4.2.1 Participants

Twenty-three right-handed females (age in years: M = 22.3, SD = 3.2) with a normal body weight (BMI in kg/m^2: M = 21.4, SD = 1.5), participated in the study. Participants were recruited by means of posters at the Utrecht University campus, The Netherlands. Exclusion criteria were being a smoker, being pregnant, having a food allergy, having a medically prescribed or slimming diet in the past six months, and having lost or gained more than five kg of bodyweight in the past

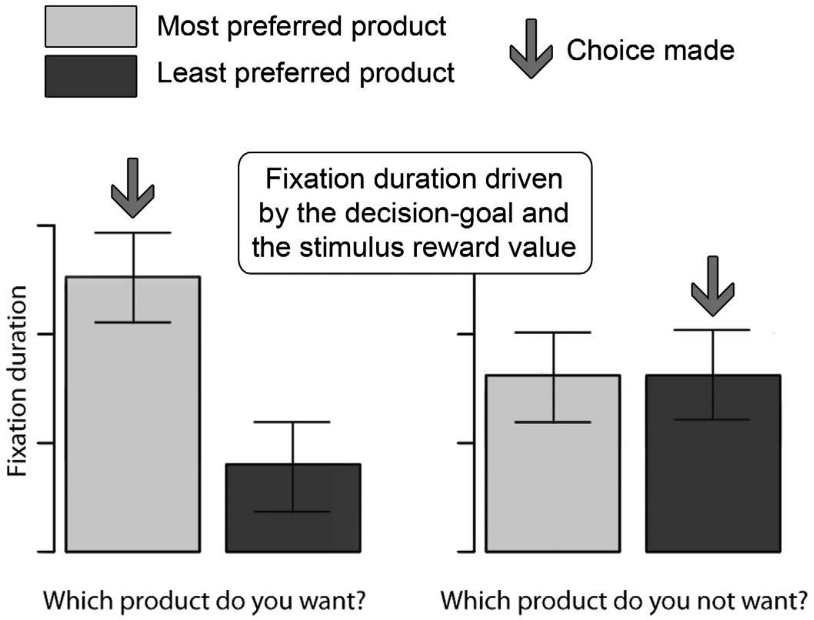

Figure 4.1: Hypothesized pattern of fixation duration under the assumption that both decision goal and stimulus reward value influence fixation duration in a binary choice. When the question is, "Which product do you want to have", both effects are in the same direction, resulting in a large difference in fixation duration between the most and least preferred product. When the question is "Which product do you not want to have", the effects counteract each other, resulting in a small/absent difference between the most and least preferred product.

six months. For one participant no eye tracking data could be acquired. This participant was excluded from all analyses, which resulted in 22 datasets.

4.2.2 Procedures

The study consisted of one study session of approximately 45 minutes in the afternoon (between 1 pm and 5 pm). Participants were instructed to refrain from eating and drinking (except for water) for three hours before the session to ensure that food was a relevant stimulus. Upon arrival, the participants filled out an informed consent. The study was presented to the participants as a market-oriented study on snacks and cleaning agents that was conducted in cooperation with partners from industry. In order to have a realistic choice paradigm and to ensure task involvement, participants were told that they would actually receive one of the products they preferred. After the instruction, participants first indicated for all products the extent to which they wanted to have them. Participants did so by answering the question “How much do you want to have this product?” on a 9-point scale ranging from $1 =$ not at all, to $9 =$ very much. After that, participants placed their chin on a chin rest at 58 cm distance from the monitor (screen resolution: 1280×1024 pixels) and performed a product choice-task while their eye movements were recorded by means of an Easygaze$^{\text{TM}}$ eye tracker (52 Hz).

4.2.3 Choice task design

A within-participants design with 2 manipulations (first fixation / control) × 2 product categories (food / nonfood) × 2 decision types (most wanted / least wanted) was employed . In total, participants made 144 choices (i.e., 144 trials). The structure of the choice task was as follows: In each trial, participants chose between two products, displayed left and right on the computer screen, by pressing the left or right arrow key on the keyboard (Figure 4.2). A trial lasted as long as it took the subject to make a choice ($M = 3035$ ms, $SD = 2229$ ms).

Participants chose either between two snack products (food condition: 72 trials per subject) or two dish washing agents (nonfood condition: 72 trials). Trials were presented in two separate blocks of 72 trials of the least wanted and the most wanted decision type. In the most wanted decision-type participants had to indicate which of the products they wanted to have. In the least wanted decision type participants had to indicate which of the products they did not want to have. The order of the blocks was counterbalanced across participants, i.e., half of the participants started with the most wanted and half started with the least wanted decision type.

To assess the influence of the first fixation, the initial fixation direction at the onset of the trial was manipulated (Figure 4.2). To manipulate the fixation direction a calibration sign was presented either in the middle of the screen (control condition), or at the location of one of the two items (i.e., left or right, first fixation manipulation condition) 500-1000 ms before each choice-trial began. To ensure the

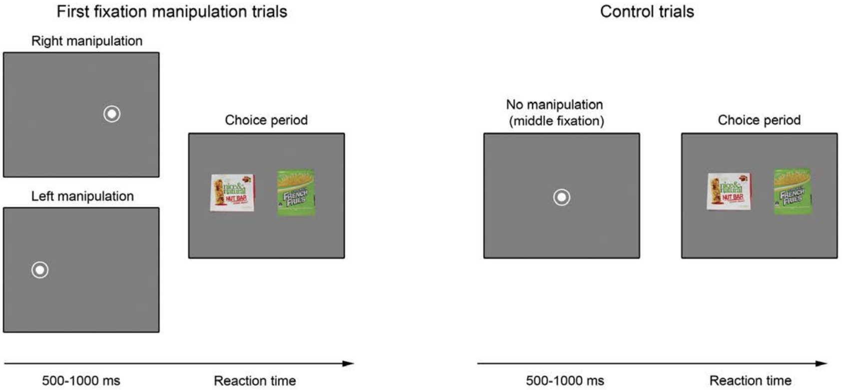

Figure 4.2: Choice task trial structure

effectiveness of the manipulation, participants were instructed that the calibration sign was presented before each trial to fine tune the calibration of the eye tracker and that they are required to look at it. Participants were not aware that the purpose of the calibration sign was to manipulate their first fixation. The first fixation manipulation was considered as successful if the first fixation was on the object on the same side of the screen as the manipulation sign (e.g., first fixation on the right product if the manipulation sign was on the right). The first fixation manipulation was successful in 86.8% of the manipulation-trials. Only successful manipulation trials were included in the analyses of the effect of the first fixation manipulation.

Choice pairs were matched on preference because it was expected that choice would be primarily driven by pre-existing preference and the effect of the first fixation manipulation would be relatively small. The pairs were matched by ranking the participant's preference ratings (as indicated earlier in the session) of all stimuli of the respective category (food/nonfood) and then combining two consecutive stimuli. This was done for each participant. Thus, every participant had a different set of choices, matched with her own preference-ratings. This approach resulted in 95.3% (3155) of the pairs being exactly matched and 4.6% (153) of the pairs having one point difference. In 0.1% (4) of the pairs the difference in rating between the two options was two points or larger. To maximize the power to detect an influence of the first fixation manipulation, only choices between products with no difference in pre-existing (self-reported) preference were included in the analyses.

4.2.4 Stimuli

Stimuli were 144 images of packaged food products and 144 images of packaged nonfood products that were introduced in the U.S., Canada, U.K., and Australia between 2005 and 2010. Food stimuli included pictures of snack foods, such as cookies, crisps, and muesli bars. The nonfood category consisted of pictures of bottled dish washing liquids. This type of nonfood was chosen as a low involvement product. It was expected that, if existent, the effect of the first fixation manipulation would be more pronounced in a low involvement product because people are rather indifferent in which one they will obtain. Non-Dutch products were used to avoid that people would recognize and choose products that they normally use. Each stimulus was only used once in the choice task. All pictures were presented on a neutral gray background (RGB: 128, 128, 128) to avoid large changes in luminance between the trials, which can decrease eye tracking data quality.

4.2.5 Measures

Fixation detection was established by marking fixations with an adaptive velocity threshold method. Velocities were obtained by fitting a parabola through three subsequent data points. We used the derivative of this fitted parabola to estimate the value of the velocity of the second (center) data point. In the present analysis, all eye movements that are not a saccade, are considered a fixation. To remove the saccades from the signal we calculated the average and standard deviation of the absolute velocity signal. All data points having absolute velocities higher than the average velocity plus two times the standard deviation were removed from the signal. This procedure was repeated two times. The lower cut-off for fixation duration was 58 ms.

To analyze fixation behavior, the screen was divided into four regions of interest, namely: *right*, the outline of the right product; *left*, the outline of the left product; *middle*, a circular area 2.5° around the center of the fixation point; and *not*, everywhere else on the screen. A fixation was defined as the first fixation if it was indeed the first fixation on a product during that trial, but also if it was preceded by a fixation in the *middle* or *not* regions. A fixation was defined as last fixation if it was the fixation preceding the choice button press. Fixation duration was defined as the sum of the durations of all individual fixations on a product in a trial (hereafter referred to as fixation duration).

4.2.6 Data-analysis

Because reaction times were not distributed normally, a log transformation was applied. For ease of interpretation, however, means and standard errors were transformed back to seconds. Trials with extreme reaction times (> 3 SD) were set to missing. Since stimuli were nested within trials, and trials were nested within participants, a series of multi-level regression analyses were performed to investigate which variables predicted choice and fixation duration. Multi-level analyses are appropriate when there are repeated measurements of individuals. For outcomes on the stimulus level (the stimulus being chosen or not and fixation duration) three-level regression analyses were performed, and for outcomes on

Table 4.1: Multi-level logistic regression results: effects of first fixation manipulation and interaction with decision type and product category.

Model effect	Estimate	Std. Error	Z-value	p
Fixed effects				
Intercept	-0.03	0.06	-0.56	0.58
Manipulation	0.16	0.11	1.44	0.15
Manipulation × decision type	0.01	0.11	0.07	0.94
Manipulation × category	-0.21	0.11	-1.85	0.06
Random effects	Variance	SD		
Intercept (level 2 trial)	2.0863×10^{-15}	4.5676×10^{-8}		
Intercept (level 3 subject)	0	0		
Log-likelihood model	-1764			
AIC	3540			

the trial level (reaction times) two-level regression analyses were performed. For continuous outcome variables (fixation duration, reaction times) linear regression analyses were performed. For binary outcome variables (the stimulus being chosen or not) logistic regression analyses were performed. The statistical program R (packages lme4 and languageR) was used to perform multi-level regression analyses (http://www.r-project.org/).

4.3 Results

4.3.1 First fixation manipulation

The target product (the product towards which the first fixation was manipulated) was chosen in 50.8% of the manipulation trials. Logistic regression analysis (Table 4.1) showed that that there was no significant effect of manipulating the first fixation to a product on the likelihood of it being chosen ($p = 0.15$). The results show no significant interaction with decision type ($p = 0.94$), which indicates that the (non-significant) effect of the manipulation did not differ between the most and least wanted decision type. A marginally significant interaction-term of manipulation with product category ($p = 0.06$) was found: In 48.2% of the food trials the target was chosen, compared to 53.4% of the non-food trials.

4.3.2 Reaction times during choice

The regression analysis (Table 4.2) showed that reaction times were significantly higher for the food ($M = 2659$ ms, $SE = 1023$ ms), compared to the nonfood category ($M = 2240$ ms, $SE = 1023$ ms, $p < 0.01$). Also, reaction times were

Table 4.2: Multi-level logistic regression results: association between (log) reaction times and decision type and product category.

Model effect	Estimate	Std. Error	T-value	p
Fixed effects				
Intercept	1.04	0.10	10.85	< 0.01
Decision type	-0.12	0.02	-7.48	< 0.01
Category	-0.17	0.02	-10.03	< 0.01
Random effects	Variance	SD		
Intercept (level 2 subject)	0.19808	0.44506		
Log-likelihood model	-1922			
AIC	3854			

significantly higher for the least- (M = 2616, SE = 1023 ms) compared to the most wanted decision type (M = 2279 ms, SE = 1023 ms, $p < 0.01$).

4.3.3 First and last fixation in control trials

In the control trials, the item first fixated on was chosen in 50.4% of the trials. The logistic regression analysis (Table 4.3) showed that stimuli that were fixated on first, were not more likely to be chosen (p = 0.88). The results show no significant interaction of first fixation with decision type (p = 0.92) and product category (p = 0.30), which indicates that the (non-significant) effect of the first fixation does not differ between the decision types and the product categories.

The product last fixated on was chosen in 66.6% of the trials. A logistic regression analysis (Table 4.4) showed that the product last fixated on was chosen significantly more often ($p < 0.01$). This effect of last fixation did not differ between food and nonfood stimuli (p = 0.42). However, in the most wanted decision type, participants significantly more often fixated on the chosen item last compared to the least wanted decision type (most wanted: 69.3%; least wanted: 63.9%, p = 0.03).

4.3.4 Fixation duration in control trials

The regression analysis (Table 4.5) showed a significant fixation bias in both conditions (p = 0.03): participants fixated longer on the chosen items (M = 964 ms; SE = 24 ms) than on the not chosen items (M = 844 ms; SE = 22 ms). Important to note is that the chosen item in the most wanted decision type is the preferred item, while in the least wanted condition the chosen item is the less preferred one. There was a significant interaction between choice and decision type ($p < 0.01$, Figure 4.3): the difference in fixation duration on chosen versus not chosen items

Table 4.3: Multi-level logistic regression results: association between first fixation and choice in control trials and interaction with decision type and product category.

Model effect	Estimate	Std. Error	z-value	p
Fixed effects				
Intercept	-0.02	0.05	-0.31	0.76
First fixation	-0.02	0.10	-0.16	0.88
First fixation × decision type	-0.01	0.10	-0.10	0.92
First fixation × category	0.11	0.10	1.03	0.30
Random effects	Variance	SD		
Intercept (level 2 trial)	0	0		
Intercept (level 3 subject)	0	0		
Log-likelihood model	-2076			

Table 4.4: Multi-level logistic regression results: association between last fixation and choice in control trials and interaction with decision type and product category.

Model effect	Estimate	Std. Error	z-value	p
Fixed effects				
Intercept	-0.63	0.05	-11.85	< 0.01
Last fixation	1.25	0.11	11.29	< 0.01
Last fixation × decision type	0.24	0.11	2.16	0.03
Last fixation × category	-0.09	0.11	-0.81	0.42
Random effects	Variance	SD		
Intercept (level 2 trial)	9.05×10^{-13}	9.52×10^{-7}		
Intercept (level 3 subject)	0	0		
Log-likelihood model	-1920			

Table 4.5: Multi-level logistic regression results: association between fixation duration and choice and interaction with decision type.

Model effect	Estimate	Std. Error	t-value	p
Fixed effects				
Intercept	940.453	112.33	8.37	< 0.01
Choice	59.06	27.10	2.18	0.03
Decision type	-206.00	37.47	-5.5	< 0.01
Choice × decision type	122.97	38.25	3.22	< 0.01
Random effects	Variance	SD		
Intercept (level 2 trial)	251662	501.66		
Intercept (level 3 subject)	262329	512.18		
Log-likelihood model	-23810			

was larger in the most wanted decision type (chosen minus not chosen M = 183 ms, SE = 26 ms) compared to the least wanted decision type (chosen minus not chosen M = 59 ms, SE = 28 ms; Figure 4.4). Thus, although in both conditions participants fixated longer on the product they chose, the bias was larger in the most wanted decision type.

4.4 Discussion

Our results reveal that manipulating the first fixation does not influence consumer choice, neither for food, nor for nonfood products, and irrespective of the instruction. Thus, to our knowledge, we are the first to show that the location of the first fixation does not influence preference. Whereas other studies showed that consumer choice can be altered by manipulating the packages' visual attributes (e.g., Milosavljevic et al., 2012), it was unknown which factor was responsible for this effect. Our experimental manipulation enabled us to investigate the influence of manipulating the location of the first fixation, without altering visual attributes of the stimulus itself. Our experimental design was optimized to detect even the smallest effect of the manipulation. Firstly, since we expected that choice is mainly based on pre-existing preference, we matched choice pairs on self-reported preference. Secondly, we did not only include 'high-involvement' consumer product, but also low-involvement products (dish-washing liquids). For the latter we assumed that participants are indifferent about which one to obtain, and thus choice would be more easily biased. The indifference for dish-washing liquids was also evident in the shorter response time for the dish-washing trials compared to the food trials. Hence, it is evident that manipulating the first fixation does not influence choice. However, since studies employing a free viewing paradigm found that products that were fixated on firstly were more likely to be chosen (e.g., Krajbich et al., 2010), this

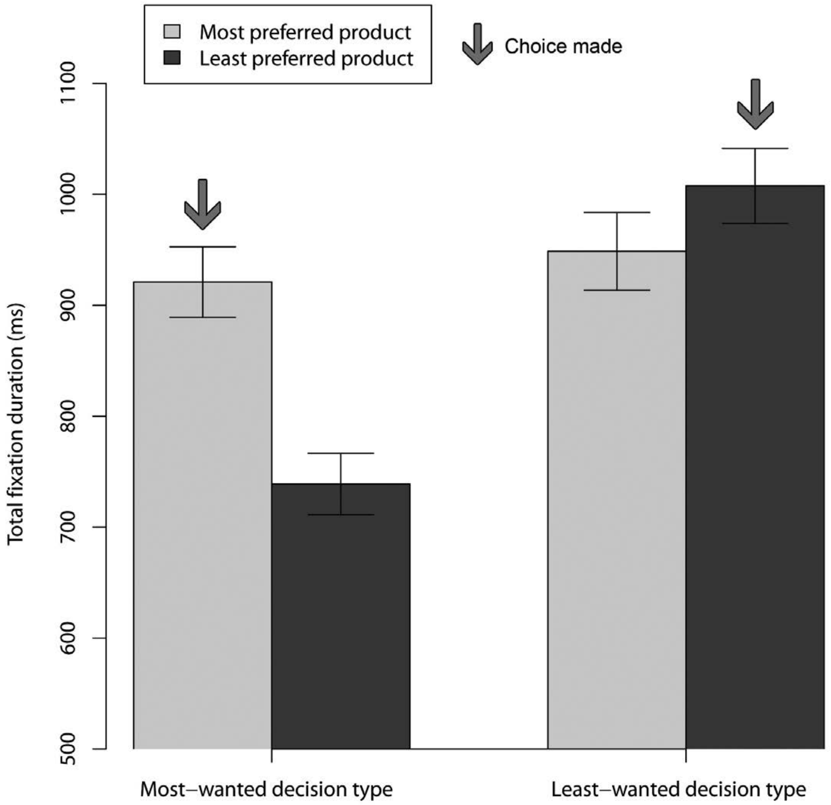

Figure 4.3: Sum fixation duration (mean ± SE) of chosen and not chosen stimuli by decision type

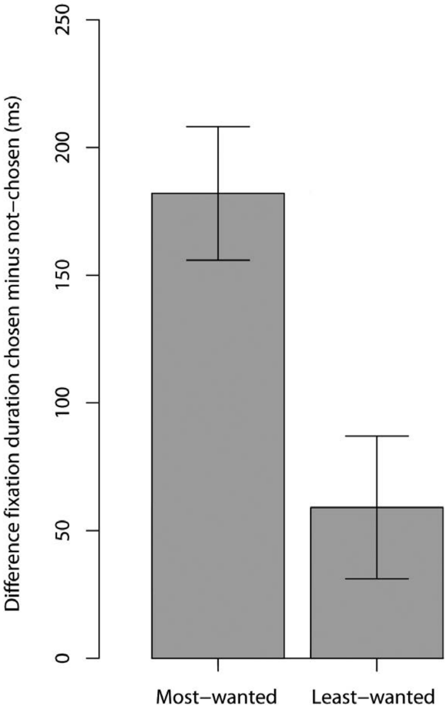

Figure 4.4: Difference in fixation duration (mean ± SE) for chosen minus not chosen stimuli by decision type

raises the question whether it could be the other way around, i.e., that pre-existing preference drives the first fixation (and pre-existing preferences drive choice). In the control trials of the present study, we did not find evidence that participants were more likely to choose the product they first fixated on. This is plausible since we matched the stimuli on self-reported preference, such that no pre-existing preferences for either one of the two items in the choice pair were present. Hence, if pre-existing preferences drive the location of the first fixation, this only occurs if differences in preference are large (i.e., larger than 1 point difference on a 9-point scale). An important implication of these findings for in-store marketing is that it is not needed to catch the first gaze of the consumer. Since other studies showed that preference can be manipulated by increasing the fixation duration (Armel et al., 2008; Shimojo et al., 2003), it could be more effective to design packages that draw sustained attention.

We found that both in the most wanted and the least wanted decision type the product of choice was fixated on longest. This suggests that the decision goal is the main driver of the fixation bias. It is important to note that the chosen item is the preferred one in the most wanted decision type but the least preferred one in the least wanted decision type. However, the difference in fixation duration between chosen and not chosen items was larger in the most wanted compared to the least wanted decision type. Thus, although participants fixated longer on the product they chose in both conditions, the fixation bias was larger in the most wanted decision type. This is in line with the hypothesis that both decision goal and stimulus reward value affect fixation duration: in the most wanted decision type, these effects are in the same direction, augmenting the fixation bias, while in the least wanted decision type these effects counteract each other. This finding is partly in line with the findings of Schotter et al. (2010), who investigated fixation duration in a choice task in which participants had to indicate the most/least beautiful face. However, in their study, the effect of stimulus reward value completely canceled out the fixation bias in the dislike decision type because there were large differences in (pre-existing) preference between the items in the binary choice sets. Our slightly deviating result can be explained by the fact that we matched the stimuli on preference and, consequently, the effect of stimulus reward value was less pronounced.

Results from this study have important implications for the interpretation and design of marketing oriented eye tracking studies as it suggests that the fixation bias in these studies is mainly driven by the decision goal (i.e., the task requirements), and to a smaller extent by the stimulus reward value. This emphasizes the importance of the instruction in these studies. From our results it could also be speculated that an individual's decision strategies could confound marketing-oriented eye tracking research because the type of decision strategy determines the decision goal. Broadly, these strategies can be divided into two types, namely reward-maximizing and loss-minimizing strategies. In reward-maximizing strategies (also termed as additive strategies, Reisen et al., 2008), products are compared on several product attributes and the decision goal is to select the option with the highest reward value. In loss-minimizing strategies (also termed elimination-strategies, Reisen et al., 2008) the decision goal is to eliminate inferior alternatives. Thus, individuals with a loss-minimizing strategy might therefore look longer at the inferior alternative, while individuals with a reward-maximizing strategy might look longer at the preferred alternative. This topic deserves more investigation.

We found that in the majority of the trials (66,6%), the last fixation was on the selected product. This is in line with other studies that also found that last fixations are more likely to be on the item eventually selected (Glaholt and Reingold, 2011; Simion and Shimojo, 2006). This effect has been attributed to verification just prior to and following the response. Our data indicates that in the least wanted decision type, participants were less likely to fixate last on the selected product (note that the selected product is least preferred in the least wanted decision type). This suggests that to verify their decision, individuals have a tendency to look at the most preferred item.

4.5 Conclusion

We showed that manipulating the location of the first fixation does not influence food and nonfood binary choices. This suggests that it is not necessary to catch the first gaze of the consumer. We found that fixation duration is mainly determined by the decision goal and to a smaller extent by the stimulus reward value. This finding emphasizes the importance of task instruction in marketing oriented eye tracking research. In conclusion, the results of this study suggest that it is not as easy to influence consumer choice as often is assumed, at least not by manipulating the first fixation, and that fixation duration cannot be interpreted as a direct proxy for preference.

Chapter 5

Sweet lies: neural, visual, and behavioral measures reveal a lack of self-control conflict during food choice in weight-concerned women

Summary Despite their intentions, weight-concerned individuals generally fail to control their eating behavior. However, it is unknown whether this failure is due to a lack of effortful self-control, or to the absence of experiencing an internal conflict between weight goals and food temptations. The present study used fMRI, eye tracking and reaction times to assess the degree of conflict experienced by weight-concerned women during food choices that posed either a self-control dilemma (i.e., requiring a choice between healthy and palatable foods), or not. Contrary to the common assumption in self-control theory that food choices posing a self-control dilemma evoke internal conflict, we found that choices requiring self-control induced no conflict, as demonstrated by lower reaction times, fixation durations, number of gaze switches between snacks, and lower activation of the anterior cingulate cortex. Self-control failure might be due to a lack of experienced conflict, rather than to failing to act upon the perception of such conflict. This implies that weight maintenance interventions should focus on increasing the ability to detect a self-control dilemma.

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5.1 Introduction

Approximately 50% of the Western female population guard themselves against the risks of the obesogenic environment by attempting to limit their energy intake (Fayet et al., 2012; Rideout and Barr, 2009). However, despite their intentions, weight-concerned individuals generally fail to control their food intake: they do not eat less than non-weight-concerned counterparts (De Witt Huberts et al., 2012a; Stice et al., 2004, 2007, 2010) and their ratings of weight concerns even predict future weight gain (French et al., 1994; Mann et al., 2007).

The absent relation between self-reports of weight-consciousness and food intake has led to interpreting high scores on restraint and weight-concerns rather as a measure of intention than as a predictor of behavior (e.g., Stice et al., 2010). For weight-concerned individuals, choosing between healthy and (more tasty) unhealthy foods is regarded as a classic self-control dilemma involving the trade-off between immediate eating enjoyment and the future benefits of being slim and healthy (Fishbach et al., 2003). In order to resolve this dilemma and behave in line with their intentions, self-control should be exercised (Baumeister and Heatherton, 1996; Fishbach et al., 2003). Examples of such self-control strategies are bolstering the value of the long-term goal or using other cognitive strategies aimed at keeping the long-term goal in the focus of attention (e.g., Metcalfe and Mischel, 1999; Peake et al., 2002).

At the heart of self-regulation theory lies the assumption that if someone with the long-term goal to limit intake is faced with a food choice that threatens the accomplishment of this goal, this results in the experience of an internal conflict (Fishbach et al., 2003). Consequently, self-regulatory failure is usually attributed to the subsequent inability to resolve the conflict in favor of the long term goal. This has led to a large number of studies aimed at improving individuals' ability to overcome the self-control dilemma (e.g., by cognitive strategies, Giuliani et al., 2013; Siep et al., 2012). However, the assumption that a self-control dilemma evokes internal conflict has so far been untested and therefore it remains unknown whether self-regulatory failure is due to a lack of cognitive control, or to the absence of experienced conflict. This topic is of major relevance for interventions aimed at weight loss or maintenance since it will elucidate whether interventions should aim at strengthening self-regulatory capacity and cognitive control or at strengthening the ability to detect a self-control conflict.

In response to this, the study aim was to investigate the levels of conflict experienced by weight-concerned women during food choices that posed either a self-control dilemma or not. As the perception of conflict is not necessarily a conscious phenomenon, we used measures that assess implicit cognitive (reaction times during food choice, reaction times in a lexical decision task), attentional (eye tracking) and neural processes (functional Magnetic Resonance Imaging (fMRI)). Previous studies have demonstrated that response conflict in a task (i.e., task difficulty) is accompanied by higher reaction times (e.g., Panayiotou and Vrana, 2004), more gaze switches between items (Causse et al., 2011), and stronger activation of the anterior cingulate cortex (Botvinick et al., 2001; Van Veen et al., 2001). Implicit measures are less susceptible to demand characteristics and socially desirable responding (Fazio and Olson, 2003). This especially relevant for weight-concerned women who might be inclined to have their responses be reflective of their intention to limit their food intake rather than their actual behavior.

5.2 Methods

5.2.1 Ethics statement

The study was approved by the Medical Ethical Committee of the University Medical Center Utrecht and participants provided written informed consent.

5.2.2 Participants

The study comprised of 20 women as participants (age in years: M = 21.2, SD = 2.8; BMI in kg/m^2: M = 21.3, SD = 1.7). As self-control conflict is only relevant for individuals who are weight-concerned, inclusion criteria consisted of a restraint-score above average or high (Dutch Eating behavior questionnaire reference table for female students, Van Strien et al., 1986) and a rating of 6 or higher on each of two questions: "To what extent are you weight-concerned?" and "To what extent are you occupied with being slim?" (ranging from 1 = not at all to 9 = very much; adapted from Fishbach et al., 2003). Additional inclusion criteria were having an age between 18 and 30 years, being right-handed and having a normal weight (BMI between 18.5 and 25 kg/m^2). Exclusion criteria consisted of having a food allergy, having an eating disorder, and having a history of medical or surgical events that might significantly affect the study outcome, such as metabolic or endocrine disease, or any gastro-intestinal disorder. Smokers and individuals having a current alcohol consumption of $>$ 28 units per week were excluded because these factors have been shown to affect the neural response to rewarding stimuli. We excluded women that followed a medically prescribed diet in the past six months or that had weight fluctuations of more than five kg in the past six months so as to exclude participants who may show biases in their food choices for medical reasons. Participants were recruited with posters at the University Medical Center Utrecht, The Netherlands and the adjacent university campus.

5.2.3 Procedures

The study consisted of two sessions (on two separate days with $1 - 8$ days in between). During the first session, participants completed several questionnaires and computer tasks, including a primed lexical decision task. Moreover, participants evaluated the expected tastiness and energy content of one portion of food stimuli (presented on pictures) on 9-point scales ranging from 1 = very untasty/very low in energy to 9 = very tasty/very high in energy.

In order to make sure that participants would be craving for a snack at the experimental session, they were instructed to refrain from eating and drinking (except water) for at least two hours prior to the second session. Upon arrival, participants received instructions and rated hunger, thirst and satiety on a visual analog scale. Subsequently, to ensure the relevance of their weight-concerns participants filled out a questionnaire about a pro-claimed new type of snack-biscuit (questions about expected tastiness, expected energy content and to what extent eating the biscuit is appropriate for individuals who are watching their weight). Thereafter, participants were scanned using fMRI while performing a food choice task. During this task, eye movements were recorded using an MR-compatible eye-tracker (Nordic Neurolabs, 60 Hz). Besides the food choice task reported here, participants also performed another unrelated food choice task (reported in Chapter 6). Immediately after scanning, participants again rated hunger, thirst and satiety. Finally, participants received a snack of their choice, were thanked and reimbursed.

5.2.4 Lexical decision task

Since temptation-goal associations have been shown to mediate successful self-control, a primed lexical decision task (Figure 5.1) was used to measure the extent that the study population had temptation-goal associations. The lexical decision task (adapted from Kroese et al., 2011) consisted of 144 trials comprising a fixation cross (1000 ms), a forward mask ('XXXXXX'; 500 ms), a prime word (50 ms), a backward mask ('XXXXXX'; 500 ms), and a target letter string. The target letter string stayed on the screen until participants pressed the z or m button of the keyboard to indicate that the target was a word or a nonword, respectively. Half of the 144 targets were nonword targets (12 nonwords, each repeated 6 times), 54 were neutral targets (9 neutral words, e.g., bell, purple, finding, each repeated six times), and 18 were diet targets (3 diet related words, i.e., dieting, slim, thin, each repeated six times). Three temptation primes were used (i.e., chocolate, feasting ('smullen') and eating candies ('snoepen'), each repeated 6 times) and 21 neutral primes (e.g., letter, contact, normal, each repeated six times). The temptation and neutral primes were matched on word length, as were the diet-related and neutral targets.

The primes and targets were combined such that four trial categories of interest were created: (1) a neutral prime with a diet target (nine trials), (2) a temptation prime with a neutral target (nine trials), (3) a temptation prime with a diet target (nine trials), and (4) a neutral prime with a neutral target (45 trials).

5.2.5 Stimuli

The visual stimuli consisted of 100 pictures of snack foods on plates: 50 foods that were high energy (HE) (energy content in kcal / 100 gram: M = 419, SD = 103) and 50 foods that were low energy (LE) (M = 56, SD = 37). To avoid biases in visual neural response and visual attention measures resulting from variation

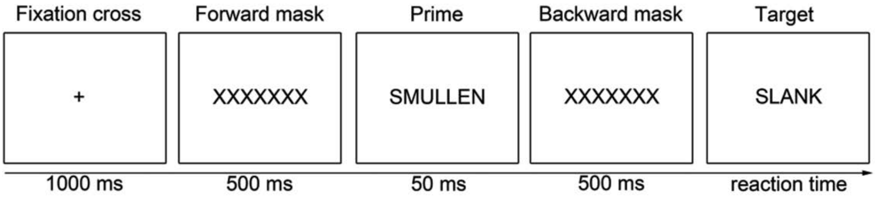

Figure 5.1: Task structure of primed lexical decision task measuring temptation-goal associations.

in visual characteristics, the plates were almost fully covered with the respective foods.

5.2.6 fMRI binary food choice task

During the fMRI scan, participants carried out a food choice task (Figure 5.2). In this task, participants made a total of 100 choices. In every trial, a HE and a LE snack were shown side by side and participants had 3000 ms to indicate which of the two products they would most like to eat a portion of by pushing the left or right button of the MR-compatible button box. After indicating their choice, a yellow box appeared around the chosen product for 500 ms. The trials were interspersed with a random interval between 2000 and 5000 ms. Reaction times during this task were recorded.

In order to make the choices realistic, participants were instructed that one of the trials counted for real and that they would receive the product chosen in that trial as a snack at the end of the study session. For this purpose, the task started with a dummy trial in which participants chose between gingerbread and biscuits. Thus, participants actually received one snack they chose.

To investigate response conflict during food choice participants were required to choose between pairs of HE and LE snacks matched as such (on basis of the tastiness-ratings given in the first session) that either a self-control dilemma was posed or not. In half of the trials, LE snacks were combined with HE snacks rated two or three points higher on tastiness (Self-Control required (SC) trials), posing a self-control dilemma concerning the trade-off between immediately eating enjoyment (choosing the appealing HE snack) and weight watching intentions (choosing the less appealing LE snack). In the other half of the trials, the LE and HE snacks were matched on tastiness (equal or ± 1 point in tastiness rating; No Self-Control required (NSC) trials), such that no trade-off between eating enjoyment and weight watching intentions was needed to choose the long-term superior, yet equally tasty LE snack.

It is important to note that for non-weight-concerned individuals (i.e., individuals for whom energy content does not play a role in food choice), the NSC trials pose a hedonic conflict since they are required to choose between two equally liked snacks.

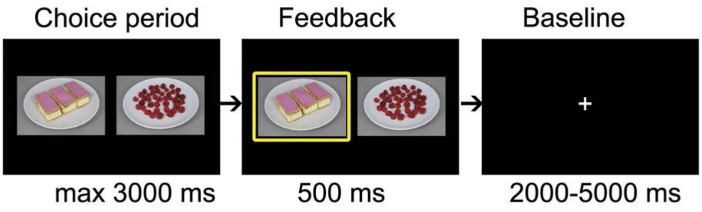

Figure 5.2: Binary food choice task structure.

In contrast, the SC trials pose no hedonic conflict since there is a large difference in tastiness between the options.

To avoid that participants chose between products that they have an aversion to, only stimuli with a tastiness rating of four or higher were used. For two participants, the tastiness ratings allowed to construct only 40 SC trials (instead of 50) without repeating stimuli more than 10 times.

Successful SC trials were those in which the LE snack was chosen and unsuccessful SC trials were those in which the HE snack was chosen.

5.2.7 Eye tracking data

Fixation detection was established by marking fixations with an adaptive velocity threshold method (Arrington Research). The lower cut-off for fixation duration was 75 ms. In order to analyze fixation behavior, the X-coordinate of the fixation was used. The screen was divided in three regions, namely: *right product*, the right 42% of the screen; *left product*, the left 42% of the screen and *middle*, the middle 16% of the screen.

A fixation was defined as the first fixation if it was indeed the first fixation on a product during that trial, but also in the case where it was preceded by a fixation in the *middle* region. A fixation was considered last fixation if it was the final fixation on a product preceding the button press indicating the participants' choice. Fixation duration was defined as the sum of the durations of all individual fixations on a product in a trial (hereafter referred to as fixation duration).

For four participants no stable eye tracking data could be acquired. These participants were removed from the analyses concerning eye tracking data.

5.2.8 Behavioral data analysis

In the food choice task stimuli were nested within trials, and trials were nested within participants. Therefore, a series of multi-level regression analyses were performed to investigate how visual measures relate to choice. For outcomes on the stimulus level (the stimulus being chosen or not, fixation duration on HE/LE snacks and first/last fixation) three-level regression analyses were performed, and for outcomes on the trial level (reaction times and fixation duration for HE and LE snack summed) two-level regression analyses were performed. For continuous outcome variables (fixation duration and reaction times) linear regression analyses were performed. For binary outcome variables (the stimulus being chosen or not) logistic regression analyses were performed.

To correct for a non normal distribution, natural log-transformed reaction times were used in all analyses. Extreme reaction times ($>$ 3 SD from the (log-transformed) mean) were set to missing.

For responses in the lexical decision task, (log) reaction times were aggregated over participants, prime (neutral or temptation) and target type (diet target or neutral target). A two-level (trial types nested within participants) regression model was performed with prime type, target type and the effect of interest: the interaction between prime and target.

The statistical program R (packages lme4 and languageR) was used to perform multi-level regression analyses (http://www.r-project.org/).

5.2.9 fMRI data

5.2.9.1 Image Acquisition and Preprocessing

MRI scanning was performed on a 3 Tesla scanner (Philips Achieva, Philips Healthcare, Best, The Netherlands), equipped with a SENSE head coil. A T_1-weighted structural image was acquired at a resolution of 1 × 1 × 1 mm (TR = 8.4 ms, TE = 3.8 ms, total scan duration = 284 s). Functional scans were acquired with a 2D-EPI sequence (TE = 23 ms, flip angle = 70°, nr slices = 30, voxel size = 4 × 4 × 4 mm, acquisition time of one 3D volume = 1400 ms). The total number of volumes acquired differed between participants because of the random inter-trial interval. Data were preprocessed and analyzed using the SPM8 software package (Wellcome Department of Imaging Neuroscience, London, United Kingdom) ran with MATLAB R2012A (The Mathworks Inc, Natick, MA). Functional images were realigned to the first image of the time series. Functional and structural images were co-registered and normalized (retaining 4 × 4 × 4 mm voxels) to MNI space (Evans et al., 1993) by using linear and nonlinear transformations.

5.2.9.2 Participant level analysis

Statistical maps were generated for each participant by fitting a boxcar function to the time series, convolved with the canonical hemodynamic response function. Data were high-pass filtered with a cutoff of 128 s. Two conditions were modeled: the choice periods of the SC trials and the choice periods of the NSC trials. For each participant, two contrast images were calculated: (1) to establish the brain regions that responded more strongly during SC food choices, we performed a mean subtraction analysis between SC and NSC trials, (2) to establish the brain regions that respond stronger during NSC food choices, we performed a mean subtraction analysis between NSC and SC trials.

5.2.9.3 Group level analysis

To determine which brain regions show differential activation for SC and NSC trials, the contrast images were entered into a one-sample t-test ROI analysis. For Region of interest (ROI)s a statistical threshold of $p < 0.05$ Family Wise Error (FWE)-corrected (peak significance on ROI level) was used. ROIs were brain areas reported to be involved in conflict monitoring (Van Veen et al., 2001) and brain regions identified in a meta-analysis on the neural response to food cues (Van der Laan et al., 2011): anterior cingulate cortex, posterior fusiform gyrus, inferior frontal gyrus - orbital part, insular cortex, superior parietal gyrus, middle occipital gyrus, amygdala, calcarine gyrus, lingual gyrus, inferior parietal gyrus, parahippocampal gyrus, (hypo)thalamus, ventral striatum, culmen, middle frontal gyrus and inferior temporal gyrus. ROI masks were generated using the AAL-atlas (Tzourio-Mazoyer et al., 2002) as implemented in the WFU-pickatlas toolbox (Maldjian et al., 2003).

5.3 Results

5.3.1 Choice behavior

In the NSC condition, 45.9% HE choices were made and 54.1% were LE choices. In the SC condition, 78.9% were HE choices and 21.1% were LE choices.

5.3.2 Reaction time

Mean reaction time during the food choice task was 1412 ms (SD = 452 ms). Regression analysis showed that reaction time was significantly higher for NSC (M = 1462 ms, SD = 460 ms) compared to SC trials (M = 1363 ms, SD = 439 ms, $p < 0.01$, Figure 5.3a). The regression analysis revealed that in the successful SC trials reaction times (M = 1430 ms, SD = 468 ms) were significantly higher compared to unsuccessful SC trials (M = 1345 ms, SD = 429 ms, $p < 0.01$, Figure 5.4a).

5.3.3 Fixation duration and number of fixations

The regression analysis showed that total fixation duration (sum of fixation durations on left and right product summed) was higher in the NSC (M = 973 ms, SD = 450 ms) compared to the SC trials (M = 873 ms, SD = 437 ms, $p < 0.01$, Figure 5.3b). The same pattern was found for the number of fixations (Figure 5.3c)

A regression analysis explaining fixation duration in SC trials with factors energy content of product fixated on (HE or LE), and success (i.e., successful if LE is chosen and unsuccessful if HE is chosen), and an interaction term of energy content × success revealed a significant interaction ($p < 0.01$) between energy content and success. That is, in successful SC trials LE stimuli were fixated on longer than in unsuccessful SC trials. This interaction effect is plotted in Figure 5.4c. The same pattern was found for the number of fixations (Figure 5.4d).

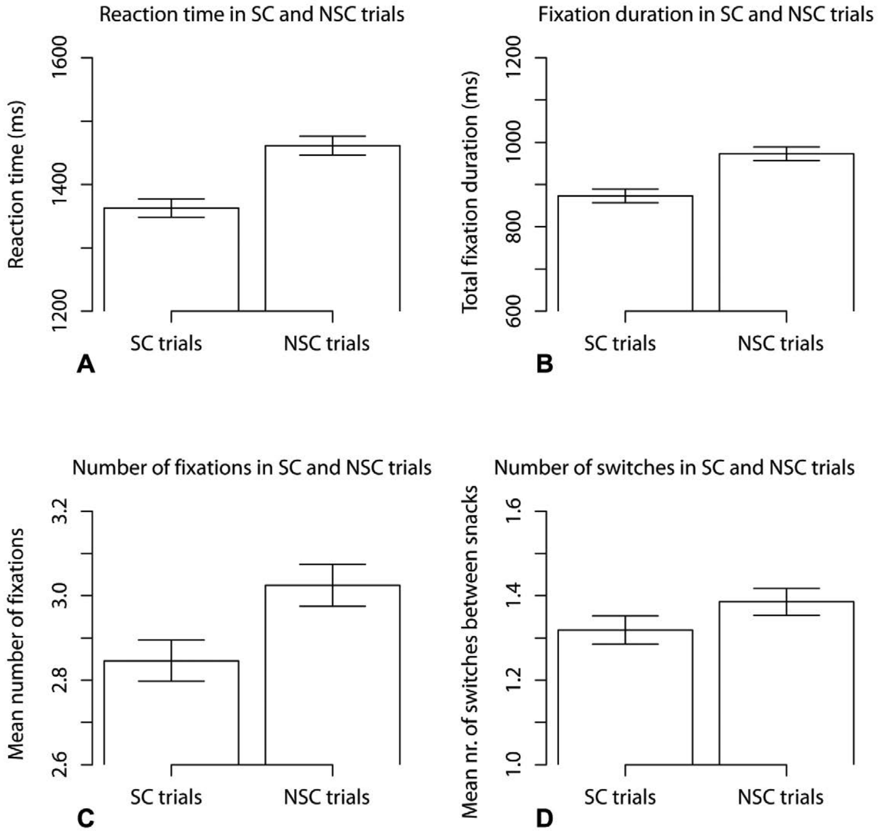

Figure 5.3: Mean reaction times (A), fixation duration on HE and LE snack summed (B), number of fixations on HE and LE snack summed (C) and number of switches between HE and LE snacks (D), for SC and NSC trials. Barplots show mean ± SEM.

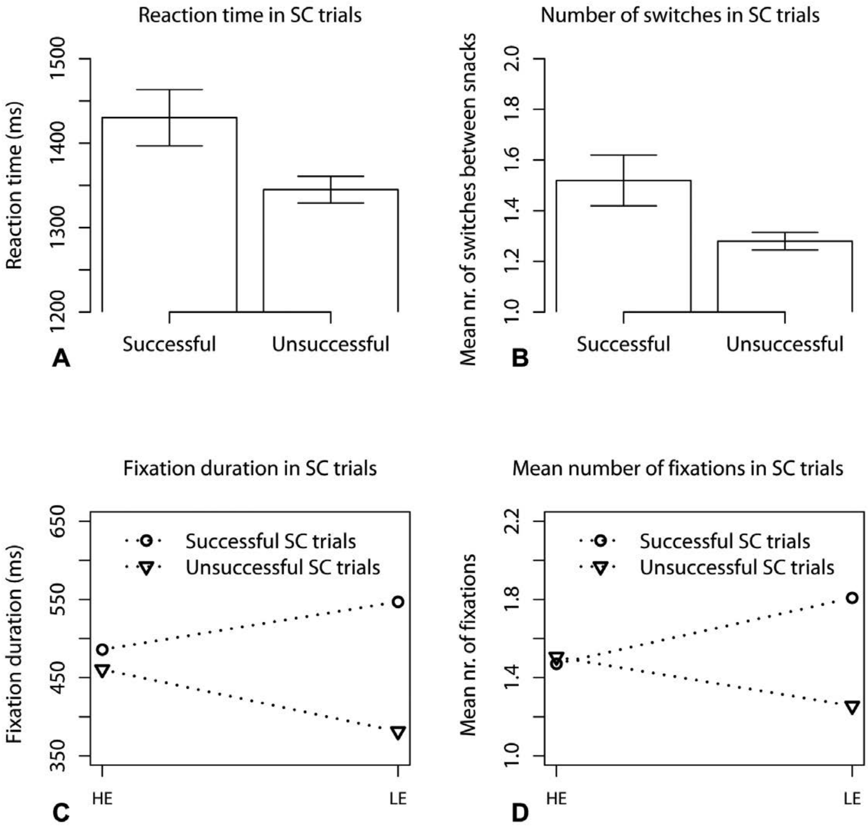

Figure 5.4: Mean reaction times (A) and number of gaze switches between snacks (B) in successful and unsuccessful SC trials. Barplots show mean ± SEM. Mean fixation duration (C) and number of fixations (D) on HE and LE snacks in successful and unsuccessful SC trials.

5.3.4 Number of switches between items

The regression analysis showed that the number of gaze switches between snacks was higher in the NSC (M = 1.4, SD = 0.9) than the SC condition (M = 1.3, SD = 0.9, $p < 0.05$, Figure 5.3d). In successful SC trials (M = 1.5, SD = 1.0) participants switched their gaze significantly more often between snacks than in unsuccessful SC trials (M = 1.3, SD = 0.9, $p < 0.01$, Figure 5.4b).

5.3.5 Location of first and last fixation

The first fixation was on a HE snack in 54.0% of the trials. The last fixation was on a HE stimulus in 50.3% of the trials. To investigate whether visual patterns differed between successful and unsuccessful SC trials, we conducted a regression analysis explaining last fixation location in SC trials with factors energy content of product fixated on last (HE or LE), and success (i.e., successful if LE is chosen and unsuccessful if HE is chosen) and an interaction term of energy content × success. This analysis revealed a significant interaction ($p < 0.01$) between energy content of last product fixated on and success. That is, in successful SC trials, the last fixation was in 70.2% of the trials on the LE snack (29.8% on HE snack); in unsuccessful SC trials, the last fixation was in 40.5% of the trials on the LE snack (59.5% on HE).

5.3.6 Temptation-goal associations

Reaction times in the lexical decision task were used to establish temptation-goal associations. If the prime activates the weight-watching goal, the reaction to diet targets preceded by a temptation prime would be quicker than the reaction to diet targets preceded by a neutral prime. Therefore, we conducted a linear regression (trial type nested within participants) on reaction time with target (diet or neutral), prime (temptation or neutral) and the interaction term of target × prime. This analysis showed that neither the effect of interest (the interaction between target and prime; $p = 0.83$), nor the main effects of target ($p = 0.64$) and prime ($p = 0.63$) were significant.

5.3.7 fMRI results

The subtraction analysis of SC minus NSC trials revealed a cluster in the inferior parietal gyrus that was stronger activated during SC compared to NSC trials (Table 5.1, Figure 5.5). The subtraction analysis of NSC minus SC trials revealed that clusters in the anterior cingulate, the opercular part of the inferior frontal gyrus, and the bilateral insula were stronger activated during NSC compared to SC trials.

Table 5.1: Brain regions differentially activated for SC versus NSC trials.

	Brain region	x	y	z	Z-value	p-value[1]
SC vs. NSC trials						
1	Inferior parietal gyrus R	62	-36	46	3.25	0.034
NSC vs. SC trials						
1	Anterior cingulate gyrus L	-10	28	26	3.51	0.017
2	Inferior frontal gyrus, opercular part	-42	8	22	3.91	0.003
3	Insula L	-42	16	-2	3.27	0.046
4	Insula R	34	28	-2	3.31	0.041

[1] FWE-corrected p-value on ROI level.

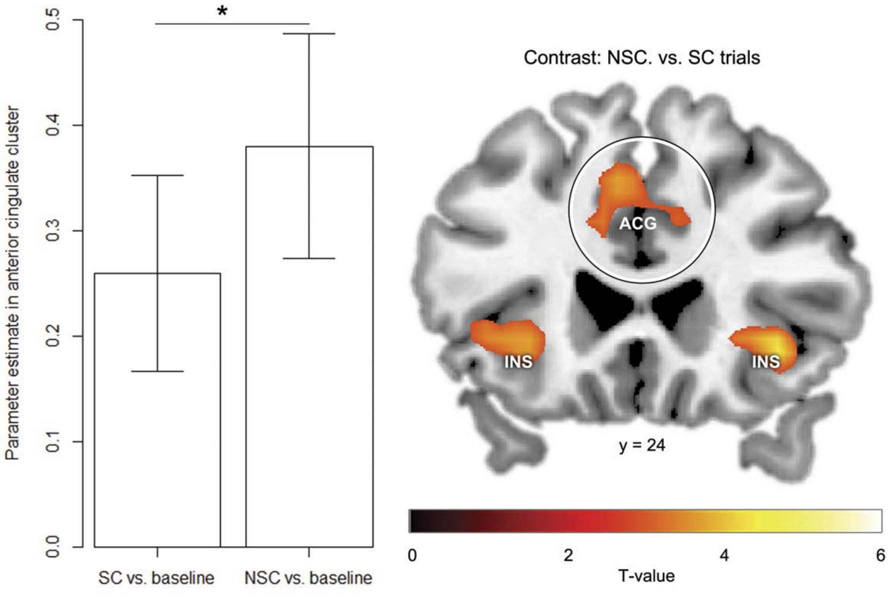

Figure 5.5: fMRI results reveal stronger ACG activation in NSC vs. SC trials. Left panel: Mean ± SEM parameter estimates in ACG cluster for both conditions versus baseline. Right panel: fMRI results for contrast NSC vs. SC trials. Circle indicates ACG cluster. For visualization purposes, fMRI-results are thresholded at $T > 2.87$, $p < 0.005$ uncorrected. ACG, Anterior cingulate cluster; INS, Insula.

5.4 Discussion

Our aim was to investigate levels of experienced conflict during food choices made by weight concerned women. In accordance with previous studies (Stice et al., 2007, 2004), we found that participants were generally unsuccessful in choosing in line with their long term weight-watching goal: the LE snack was chosen in only 21.2% of the trials posing a self-control dilemma and in 54.1% of the NSC trials. Our results showed that during the choices that posed no self-control dilemma the reaction times, fixation duration and number of gaze switches (switching the gaze between the HE and LE item) were higher compared to trials that did pose a self-control dilemma. It is well established that reaction times are higher in difficult tasks requiring the recruitment of cognitive resources (Panayiotou and Vrana, 2004). Longer fixation durations and more gaze switches have also been shown to accompany difficult decisions (Causse et al., 2011). Furthermore, a cluster in the anterior cingulate cortex, which has previously been shown to activate during the perception of conflict (Botvinick et al., 2001; Van Veen et al., 2001), was more strongly activated during trials that did not pose a self-control dilemma (NSC trials). Likewise, we found stronger bilateral activation in the anterior insula during the NSC trials. Activation in this region has previously been shown to activate during performance monitoring conditions, such as pre-response conflict (Ullsperger and von Cramon, 2001).

Hence, in sharp contrast with psychological theories on self-control, the behavioral, eye tracking and neural findings suggest that a stronger response conflict was experienced during the trials in which no self-control dilemma was posed (NSC trials). For weight-concerned individuals the NSC choices should have constituted an easy choice that requires no self-control because the LE snack was as tasty as the HE snack while being in line with their weight-watching goal. In contrast, the SC trials should have constituted a difficult choice because the preferred HE snack is not conducive to their weight-watching goal and thus self-control was required to choose the LE snack over the tastier HE snack. Our findings suggest that weight-concerned women do not experience difficulty or internal conflict during choices posing a self-control dilemma. This supports the notion that self-regulatory failure might be due to a lack of experienced internal conflict rather than a failure to act upon the perception of such conflict.

Importantly, the present study is distinct from earlier neuroimaging studies on self-control because we focused specifically on conflict-monitoring in response to choice sets that either threaten the accomplishment of the long-term goal or not. Conflict monitoring is the process by which the brain determines when control is required (Botvinick et al., 2001) and thus precedes the actual act of self-control. Other neuroimaging studies on self-control have established how factors such as healthiness and tastiness are incorporated in the brain during food choices and how explicitly cueing people to consider healthiness of foods influences the neural response during food choice (Hare et al., 2009, 2011).

Having established that self-regulatory failure might be due to a lack of internal conflict, the question arises why self-proclaimed weight-concerned women do not experience internal conflict when confronted with a self-control dilemma. From theory it follows that having a long-term goal is a prerequisite for perceiving an internal conflict in response to a self-control dilemma (e.g., Fishbach et al., 2003). Therefore, the finding that our participants did not experience conflict questions whether they are truly dedicated to restrict their energy intake. Interesting to note is that we found exactly what would be expected for individuals who are not weight-concerned (i.e., people without the goal to limit their energy intake). For non-weight-concerned individuals, tastiness is the main predictor of choice, while the energy content of the food does not play a role (Arvola et al., 1999; Ayres et al., 2012). Therefore, the SC trials would be easy since there is a large difference in tastiness between the options, and energy content is relatively irrelevant. The NSC trials on the other hand would pose a hedonic dilemma for non-weight-concerned individuals since they were required to choose between two equally liked snacks. Thus, intriguingly, both the choice patterns and the responses on the implicit measures in our population of self-proclaimed weight-concerned women resemble those expected for non-weight-concerned individuals. However, because we used stringent inclusion criteria (above average/high DEBQ restraint scores and a score > 6 on the weight-concern questions (Van Strien et al., 1986; Fishbach et al., 2003)), it is most likely that our study population had an authentic long-term goal to watch their weight.

A second, more likely, explanation is that the participants genuinely had the long-term goal to watch their weight, but that exposure to the highly appealing HE snack decreases the accessibility of this goal. A proposed mechanism for the facilitating role of temptations on indulgence has been provided by the goal-conflict model (Stroebe et al., 2008), which posits that exposure to temptation inhibits the accessibility of the opposing long-term goal. However, there is a contrasting line of research based on counteractive-control theory (Trope and Fishbach, 2000) that posits that temptations may assist, rather than undermine, long-term goal attainment (Kroese et al., 2011). That is, temptation cues activate rather than inhibit long-term goal accessibility. To investigate how exposure to tempting HE foods might have influenced the accessibility of the long term goal, we implemented a primed lexical decision task to measure the temptation-goal activations. This task revealed that exposure to temptation cues did not activate the long term weight-watching goal. This is in line with an earlier study that showed that temptation cues activate long term goals only in successful, and not in unsuccessful self-controllers (Papies et al., 2008). Thus, our results indicate that the lack of experienced conflict might be explained by the absence of temptation-goal associations, implying that exposure to highly appealing HE snacks did not increase the accessibility of the weight-watching goal.

Another explanation for the lack of experienced conflict comes from a recent line of research on vicarious goal fulfillment (Wilcox et al., 2009). Multiple studies have shown that the addition of a healthy option to a choice set can increase preference for indulgent HE alternatives also present in that choice set (Fishbach and Zhang, 2008; Wilcox et al., 2009). The vicarious goal fulfillment theory posits that the mere presence of a healthy option fulfills health-related goals (Wilcox et al., 2009), irrespective of whether the healthy option was actually chosen. From this it follows that the presence of a healthy option in the choice set resolves the self-control dilemma (because the health related goal is already fulfilled by the presence of the LE alternative), thereby resulting in a lack of experienced conflict. The presence of the healthy alternative provides a license to indulge in tempting HE snacks.

Although the number of successful SC trials (SC trials in which the LE snack was chosen) was low, the eye tracking data revealed interesting patterns that shed light on a possibly effective strategy for successful self-control. The higher reaction times and number of gaze switches during successful compared to unsuccessful SC trials confirm the general assumption that it is difficult to choose a LE snack over a tastier HE alternative. The findings that participants fixated longer on LE than HE items in the successful SC trials and that the last fixation was significantly more often on the LE snack might have increased preference for the LE snack. Research has shown that fixation duration both reflects and influences preference. That is, people look longer at preferred items (Chapter 4) and manipulating gaze duration for an option increases preference for it (Shimojo et al., 2003), i.e., there is a positive feedback loop between looking and liking. Directing attention away from preferred HE snacks and allocating attention to less-preferred LE snacks could break this loop and help people choose LE snacks. It could be speculated that directing attention away from momentarily allurements might facilitate long term goal attainment. This topic deserves further investigation.

Our findings have important implications for weight management interventions. Since recognizing the self-control dilemma is a prerequisite for acting upon it, this study implies that weight management interventions should focus on increasing the ability to detect a self-control dilemma rather than on increasing self-regulatory capacity and cognitive control. Evidently, if no conflict is experienced in the first place, improving the ability to perform effortful self-control is likely to be ineffective. As outlined above, a possible explanation for the lack of experienced conflict during food choice could be that the relevance of the long-term goal is inhibited by the exposure to tempting foods. Therefore, a useful strategy could be to strengthen temptation-goal associations to change the automatic response to tempting foods to activating the long-term goal, rather than inhibiting it. Forming such implementation intentions as an intervention has proven successful in strengthening temptation-goal associations (e.g., Kroese et al., 2011).

The lack of experienced conflict in response to a food choice set posing a self-control dilemma may extrapolate to other behavioral domains involving a trade-off between direct impulses and future goals, such as smoking cessation, financial management, interpersonal relations and aggression. Future studies should elucidate whether a lack of experienced conflict also accounts for self-regulatory failure in these domains.

5.5 Conclusion

In sharp contrast with the common assumption that food choices posing a self-control dilemma evoke an internal conflict in weight-concerned women, we found that these choices induced no conflict, as indicated by lower reaction times, lower fixation durations, lower number of gaze switches between snacks, and decreased activation of the anterior cingulate cortex. These findings provide support for the notion that self-regulatory failure might be due to a lack of experienced conflict, rather than failing to act upon the experience of such conflict. Since recognizing the self-control conflict is a prerequisite for acting upon it, this study implies that weight maintenance interventions should focus on increasing the ability to detect a self-control dilemma rather than on increasing self-regulatory capacity and cognitive control.

Chapter 6

One at a time: temptation strength and self-regulatory success modulate activation in inhibitory brain regions during food choice in weight-concerned women

Summary The aims were to investigate which brain regions are activated in response to food choices concerning high energy (HE) and low energy (LE) snacks and to investigate the influence of tastiness (temptation-strength) and self-regulatory success on the neural correlates of food choice. To this end, 20 weight-concerned women had to indicate for 100 HE and LE snacks whether they wanted to eat them, while their brains were scanned using fMRI. Results showed that HE snacks were refused more often than (equally liked) LE snacks. HE snacks elicited stronger activation in reward-related brain regions. Highly tasty HE snacks were more difficult to resist and, accordingly, activation in inhibitory areas was modulated negatively by tastiness. More successful self-controllers showed increased activation in the supplementary motor area (SMA) during HE food choices.

Based upon: Van der Laan, L.N., De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. One at a time: temptation strength and self-regulatory success modulate activation in inhibitory brain regions during food choice in weight-concerned women *(submitted)*.

6.1 Introduction

Approximately 50% of the Western female population guard themselves against the risks of the obesogenic environment by attempting to limit their energy intake (Fayet et al., 2012; Rideout and Barr, 2009). Opposing to what their self-proclaimed status of being weight-concerned would suggest, these individuals do not eat less than their non-weight-concerned counterparts (De Witt Huberts et al., 2012a; Stice et al., 2004, 2007, 2010) and their ratings of weight-concerns even predict future weight gain (French et al., 1994; Mann et al., 2007).

For weight-concerned individuals, food choice is regarded as a classical self-control dilemma involving the trade-off between immediate eating enjoyment and the long term goal of being slim and healthy. Since eating high energy (HE) snacks is not in line with their weight-watching goal, these individuals should override the tendency to indulge in HE snacks in order to behave in line with their intentions. Using self-control to override this tendency is particularly vital when these HE snacks are very tasty. Thus, successful self-control constitutes two crucial steps: firstly, the self-control dilemma has to be detected and secondly, the dilemma has to be resolved by exercising self-control. Therefore, self-regulatory failure could result from either the inability to detect a self-control dilemma, or the inability to act upon it. Previous research has shown that there are large individual differences in self-regulatory success, in food choice as well as in other behavioral domains (De Ridder et al., 2012).

In previous work we showed that weight-concerned women do not experience conflict during food choices requiring self-control, as demonstrated by reaction times, eye-tracking measures, and functional Magnetic Resonance Imaging (fMRI) (Chapter 5). These findings suggest that a lack of experienced conflict when confronted with a self-control dilemma could explain why weight-concerned women do not succeed in limiting their intake. Because individuals had to choose between a HE and low energy (LE) snack, there always was a healthy alternative present in the choice set. Vicarious goal fulfillment theory posits that the mere presence of a healthy option already fulfills health-related goals (Wilcox et al., 2009), irrespective of whether the healthy option is actually chosen or not. From this it follows that the presence of a healthy option in the choice set might already resolve the self-control dilemma (because the health-related goal has the potential to be fulfilled), thereby resulting in a lack of experienced conflict. Consequently, the presence of a healthy alternative increases the chance that someone indulges in tempting HE snacks. Research has shown that preference for HE snacks is indeed higher when presented together with a LE snack and that adding a LE dish to a restaurant menu increases the amount of money spend on HE side dishes (Fishbach and Zhang, 2008; Chandon and Wansink, 2007; Wilcox et al., 2009).

Although we previously showed that weight-concerned women are generally unsuccessful in making long-term goal-congruent choices in a binary choice between HE and LE snacks, it is unknown whether this also holds when choosing to either eat a single HE snack or not. When a HE snack is presented as single option, the conflict is not resolved by the mere presence of the LE (Wilcox et al., 2009). Therefore, offering a HE snack on its own might induce a conflict and thereby make it more likely that it is rejected.

The first aim of this study was to investigate the food choices made by weight-concerned women when they had the choice to either accept or refuse single HE and LE snacks. Since it is particularly difficult to resist a HE snack when it is very tasty, it was expected that activation in brain regions involved in conflict and self-control would be modulated by the snacks' tastiness. Therefore, our second aim was to establish the brain regions in which activation was modulated by the tastiness. As stated before, some individuals are more successful in pursuing their long-term goal than others. Therefore, a third aim was to investigate in which brain regions activation covaries with self-regulatory success (as indicated by the amount of refused HE snacks).

6.2 Methods and materials

6.2.1 Ethics statement

The study was approved by the Medical Ethical Committee of the University Medical Center Utrecht and subjects provided written informed consent.

6.2.2 Participants

The study comprised of 20 weight-concerned women as participants (age in years: M = 21.2, SD = 2.8; BMI in kg/m^2: M = 21.3, SD = 1.7), who are described in more detail in Chapter 5.

6.2.3 Study procedures

The study consisted of two sessions. During the first session, participants evaluated the expected tastiness of one portion of all food stimuli (presented on pictures) on 9-point scales ranging from 1 = very untasty to 9 = very tasty.

To make sure that participants were craving for a snack, they were instructed to refrain from eating and drinking (except water) for at least two hours prior the second session. To ensure the relevance of their weight-concerns, participants filled out a questionnaire about an allegedly new type of biscuit (giving ratings of expected tastiness, expected energy content, and to what extent eating the biscuit is appropriate for individuals who are watching their weight). Next, participants were scanned using fMRI while performing a food choice task. Besides the food choice task reported here, they also performed another food choice task (see Chapter 5). At the end of the second session, participants received a snack of their choice, were thanked, and reimbursed.

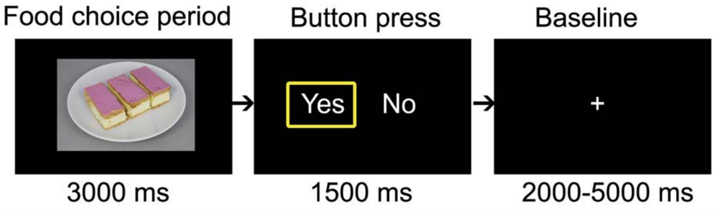

Figure 6.1: Single food choice task trial structure

6.2.4 Stimuli

The visual stimuli consisted of 100 pictures of snack foods on plates: 50 HE foods (energy content in kcal / 100 gram: M = 419, SD = 103) and 50 LE foods (M = 56, SD = 37).

6.2.5 fMRI single food choice task

During the functional MRI scan, participants performed a food choice task (Figure 6.1). In this task, participants made 100 choices. In every trial, they viewed one of the study stimuli (3000 ms, choice period) and subsequently had to indicate with a button press (1500 ms, button press period) whether they wanted to eat a portion of the snack or not. During the button press period the words 'yes' and 'no' were shown left/right (randomized) on the screen. After indicating their choice, a yellow box appeared around the yes or no. Participants were instructed to make their choice already during the period that the image was shown. To ensure that their choices were actually made in direct response to the food pictures, the button press period was so short that it only allowed them to locate whether they had to push the left or right button. The choice trials were interspersed with a random interval (2000 and 5000 ms). At the beginning, halfway (after 50 trials) and at the end an additional baseline period of 30000 ms was included in the task.

In order to make the choices realistic, participants were instructed that one of the trials counted for real and that they would receive a portion of the snack chosen in that trial at the end of the study session.

6.2.6 Behavioral data analysis

In the food choice task trials were nested within participants. Therefore, a series of two-level logistic regression analyses were performed to investigate how tastiness and stimulus category (HE or LE) related to choice (chosen or not chosen). The statistical program R (packages lme4 and languageR) was used to perform multi-level regression analyses.

6.2.7 fMRI data

6.2.7.1 Image Acquisition and Preprocessing

MRI scanning was performed on a 3 Tesla scanner (Philips Achieva, Philips Healthcare, Best, The Netherlands), equipped with an 8-channel SENSE head coil. A T_1-weighted structural image was acquired at a resolution of 1 × 1 × 1 mm (TR = 8.4 ms, TE = 3.8 ms, total scan duration = 284 s). Functional scans were acquired with a 2D-EPI sequence (TR/TE = 1400/23 ms, flip angle = 70°, nr slices = 30, voxel size = 4 × 4 × 4 mm). The total number of volumes (540 − 580) acquired differed between participants because of the random inter-trial interval. Data were preprocessed and analyzed using the SPM8 software package (Wellcome Department of Imaging Neuroscience, London, United Kingdom) ran with MATLAB R2012A (The Mathworks Inc, Natick, MA). Functional images were realigned to the first image of the time series. Functional and structural images were co-registered and normalized (retaining 4 × 4 × 4 mm voxels) to MNI space (Evans et al., 1993) by using linear and nonlinear transformations.

6.2.7.2 Participant level analyses

Statistical maps were generated for each participant by fitting a boxcar function to the time series, convolved with the canonical hemodynamic response function. Data were high-pass filtered with a cutoff of 128 s. Two models were fitted. Four conditions were modeled in the first model: the HE choice periods, the LE choice periods, the button press screen, and the practice trial and missed trials. To establish brain regions that respond differently to HE and LE choice periods, we performed a mean subtraction analysis between HE and LE choice periods, resulting in a contrast image of HE minus LE choice periods and a contrast image of LE minus HE choice periods. Furthermore, a contrast image of HE choice periods versus baseline, and a contrast image of LE choice periods versus baseline, were calculated.

The second model was constructed to identify brain regions in which activation correlates with tastiness. The same four conditions as in the first model were modeled. A parametric regressor with the self-reported tastiness ratings of the respective snacks was added to the HE and LE choice periods. For each participant, two contrast images were calculated: (1) to establish the brain regions that were related with tastiness ratings during HE choice periods we conducted a parametric modulation analysis with the tastiness ratings during HE choice periods; (2) to establish the brain regions that were related with tastiness ratings during LE choice periods we conducted a parametric modulation analysis with the tastiness ratings during LE choice periods.

6.2.7.3 Group level analyses

To determine which brain regions showed differential activation for HE and LE choice periods, the contrast images of HE minus LE choice periods (and vice versa) were entered into one-sample t-test analyses.

To determine brain regions in which activation was positively or negatively related with self-reported tastiness ratings during HE and LE choice periods, the respective contrast images were entered into one-sample t tests.

To establish in which brain regions individual differences in self-regulatory success (i.e., the proportion of accepted or refused snacks) were related with the neural activation during the choice, the contrast images of HE choice periods versus baseline were entered into two one-sample t-tests with as covariate the proportion of accepted and refused HE snacks, respectively. Also, the contrast images of LE choice periods versus baseline were entered into two one-sample t tests with as covariate the proportion of accepted and refused LE snacks, respectively.

For a-priori regions of interest a statistical threshold of $p < 0.05$ Family Wise Error (FWE) corrected (peak significance on ROI level) was used. Region of interest (ROI) were brain areas reported to be involved in conflict monitoring (Van Veen et al., 2001) and brain regions identified in a meta-analysis on the neural response to food cues (Van der Laan et al., 2011): anterior cingulate cortex, posterior fusiform gyrus, inferior frontal gyrus - orbital part, insular cortex, superior parietal gyrus, middle occipital gyrus, amygdala, calcarine gyrus, lingual gyrus, inferior parietal gyrus, parahippocampal gyrus, (hypo)thalamus, ventral striatum, culmen, middle frontal gyrus, and inferior temporal gyrus. ROI masks were generated using the AAL-atlas (Tzourio-Mazoyer et al., 2002) as implemented in the WFU-pickatlas toolbox (Maldjian et al., 2003).

For regions other than those of a-priori interest, we report clusters significant at a more strict statistical threshold of $p < 0.001$ uncorrected and a cluster extent $k > 12$. This threshold resembles an overall significance level of $p < 0.05$, corrected for multiple comparisons across the whole brain based on Monte Carlo simulations of random noise distribution using the 3DClustSim module of AFNI (Cox, 1996; Forman et al., 1995).

6.3 Results

6.3.1 Behavioral results

A two-level logistic regression model (Table 6.1) with as outcome choice (1 = accept, 0 = refuse) and as predictors energy content (LE or HE), and self-reported tastiness of the stimulus, revealed that LE snacks were accepted more often (mean % ± SD: 62 ± 17) than HE (48 ± 24), and the more tasty a snack was (regardless of energy content) the higher the likelihood that it would be accepted. Figure 6.2 shows the proportion of accepted snacks per tastiness rating, for HE and LE snacks.

Table 6.1: Multi-level logistic regression results: energy content and self-reported tastiness predict choice.

Model effect	Estimate	Std. Error	t-value	p
Fixed effects				
Intercept	-6.95	0.43	-16.1	< 0.001
Tastiness rating	1.00	0.05	20.0	< 0.001
Energy content (HE/LE)	0.51	0.12	4.4	< 0.001
Random effects	Variance	SD		
Intercept (level 2 subject)	1.11	1.05		
Log-likelihood model	-932			
AIC	1871			

Tastiness, rated on a 9-point scale ranging from 1 = very untasty to 9 = very tasty, did not differ significantly between LE (mean ± SD: 7.0 ± 0.7) and HE (6.7 ± 0.9) food categories (p = 0.19).

6.3.2 fMRI results

6.3.2.1 HE versus LE choice periods

Several brain regions, including the orbital part of the right superior frontal cortex (medial to middle orbitofrontal cortex (OFC)), the left lingual gyrus, the left parahippocampal gyrus, the left calcarine sulcus, and the left caudate (marginally significant), were activated stronger in response to HE compared to LE food choices (Table 6.2, Figure 6.3a-c). Clusters in the right superior parietal gyrus were activated more strongly during LE compared to HE choice periods (Table 6.2, Figure 6.3d).

6.3.2.2 Modulation by tastiness

There were no brain regions in which activation was positively modulated by tastiness during HE choice periods. Activation in the orbital and a more superior part of the middle frontal gyrus (lateral OFC), the opercular part of the inferior frontal gyrus, and the precuneus was negatively modulated by tastiness in HE choice periods (Table 6.3). There were no brain regions in which activation during LE choice periods was positively or negatively modulated by tastiness.

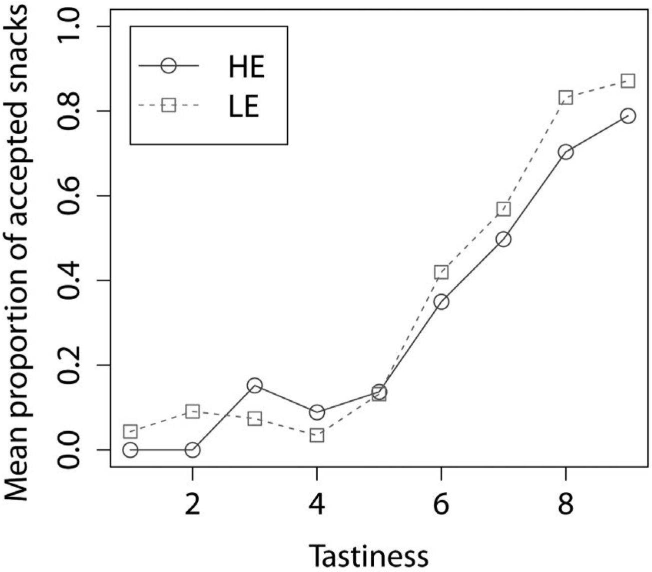

Figure 6.2: Proportion of accepted snacks by tastiness rating, for HE and LE snacks.

Table 6.2: Brain regions differentially activated in response to HE en LE choice periods.

Brain region	Side[1]	x	y	z	Z-value	p[2]
HE versus LE choice periods						
ROIs[2]						
Calcarine sulcus	L	-6	-48	6	3.43	0.033
Caudate	L	-6	-16	-6	2.96	0.058
Superior frontal gyrus[4]	R	18	56	-2	3.18	0.018
Lingual gyrus	L	-6	48	2	3.34	0.042
Parahippocampal gyrus	L	-26	-36	-14	3.08	0.047
Whole brain[3]						
Cerebellum/lingual gyrus	R/L	-2	-44	6	3.56	N.A.
LE versus HE choice periods						
ROIs[2]						
Superior parietal gyrus	R	34	-56	54	2.99	0.031
Superior parietal gyrus	R	30	-64	50	2.84	0.049

[1] L = left hemisphere, R = right hemisphere.

[2] Peaks reported are significant at $p < 0.05$ FWE-corrected on ROI level.

[3] Peaks of clusters significant at $p < 0.001$ uncorrected, $k > 12$ voxels are reported.

[4] Orbital part of superior frontal gyrus.

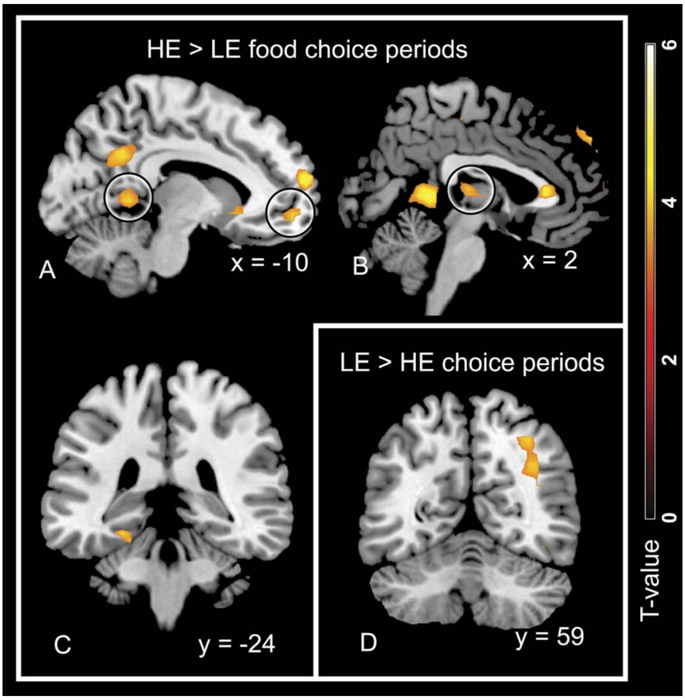

Figure 6.3: Brain regions stronger activated during HE (versus LE) food choice periods: clusters in calcarine gyrus and orbital part of superior frontal gyrus (encircled in A), caudate (encircled in B) and parahippocampal gyrus (C). Brain region stronger activated during LE (versus HE) food choice periods: cluster in superior parietal gyrus (D)

Table 6.3: Brain regions of which activation during HE food choice periods was negatively modulated by tastiness.

Brain region	Side[1]	x	y	z	Z-value	p[2]
ROIs[2]						
Middle frontal gyrus, orbital part	R	34	48	-2	3.16	0.037
Middle frontal gyrus	R	46	32	34	3.94	0.014
Inferior frontal gyrus, opercular part	R	30	4	34	3.68	0.011
Whole brain[3]						
Precuneus	L	-6	-64	46	4.03	N.A.
Precuneus	L	-18	-52	46	3.82	N.A.

[1] L = left hemisphere, R = right hemisphere.

[2] Peaks reported are significant at $p < 0.05$ FWE-corrected on ROI level.

[3] Peaks of clusters significant at $p < 0.001$ uncorrected, $k > 12$ voxels are reported.

Table 6.4: Brain regions of which activation during HE food choice periods covaries positively with the proportion of rejected HE snacks

Brain region	Side[1]	x	y	z	Z-value
Whole brain[3]					
Angular gyrus	R	34	-48	26	5.25
Supplementary motor area	R	14	-20	54	4.66
Middle occipital gyrus	L	-42	-68	6	3.98
Cerebellum	R	26	-76	-38	3.47
Cerebellum	R	34	-72	-34	3.47
Cerebellum	R	42	-58	-34	3.00

[1] L = left hemisphere, R = right hemisphere.

[2] There were no peaks significant in the ROI analysis ($p < 0.05$ FWE-corrected on ROI level).

[3] Peaks of clusters significant at $p < 0.001$, $k > 12$ voxels are reported.

6.3.2.3 Brain regions in which activation covaries with self-regulatory success

There were no brain regions in which activation during HE choice periods covaried positively with the proportion of accepted HE snacks. Activation in the angular gyrus, the supplementary motor area (SMA), the middle occipital gyrus, and the cerebellum during the HE choice periods covaried significantly (positive) with the proportion of rejected HE snacks (Table 6.4, Figure 6.4). Thus, participants who rejected more HE snacks had significantly stronger activation in these areas during HE choice periods.

To rule out the alternative explanation that participants who rejected more HE snacks had a lower preference for HE snacks and that activation in the identified regions reflected this, we repeated the analysis while controlling for individual differences in preference for HE snacks. To this end, the participants' mean tastiness rating of HE snacks was added as first and the proportion of rejected HE snacks as second covariate. The clusters in the SMA (Z = 3.94, MNI (14, -20, 54)) and cerebellum (Z = 4.03, MNI (-30, -80, -34)) still significantly covaried with the proportion of rejected HE snacks, indicating that activation in these regions was not due to a lower general preference for HE snacks, but rather due to self-regulatory success.

There were no brain regions of which activation during LE choice periods significantly covaried with the proportion of accepted or rejected LE snacks.

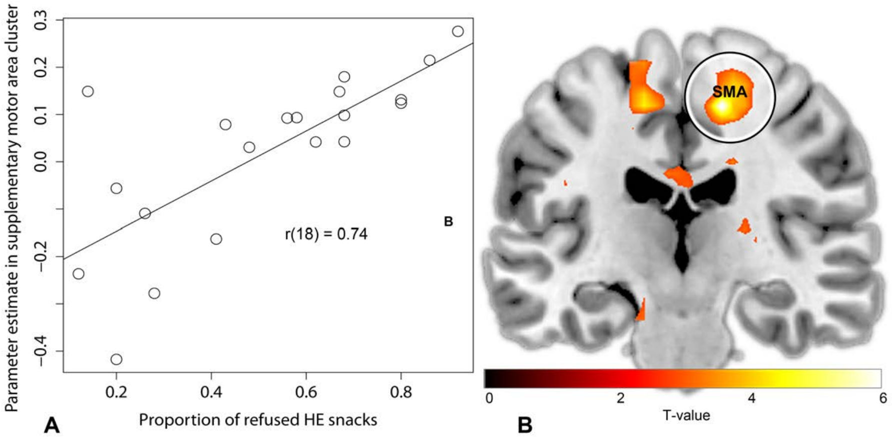

Figure 6.4: Activation in the SMA during the HE choice periods covaries with the proportion of rejected HE snacks. (A) Plot showing correlation between parameter estimate HE vs. baseline in SMA cluster and the proportion of rejected HE snacks. (B) Brain regions in which activation covaries with proportion of rejected HE snacks. Circle indicates SMA cluster. For visualization purposes, fMRI-results are thresholded at T $>$ 2.87.

6.4 Discussion

Our study aims were to investigate the food choices made by weight-concerned women and to assess in which brain regions activation was modulated by tastiness and individual differences in self-regulatory success. Our earlier work (Chapter 5) showed that weight-concerned women generally failed to perform self-control when they chose between HE and LE snacks. Since single and multiple choice types differ greatly due to the presence of alternatives that might influence the perception of the self-control dilemma (e.g., vicarious goal fulfillment theory, Wilcox et al., 2009), we aimed to test whether self-control failure was also prevalent when they had to consider only one snack at a time.

On average, participants were at best moderately successful in choosing in line with their long-term goal since they accepted almost 50% of the HE snacks. The behavioral results revealed that both tastiness and energy content (independently) influenced the likelihood that a snack was accepted or refused. The finding that weight-concerned women refused more HE than LE snacks, or equivalently, accepted more LE than HE snacks which were equal in tastiness, underlines that decision-making for HE and LE snacks constitutes more than only tastiness considerations. While the number of accepted HE snacks is indicative of the extent to which someone adheres to her weight-watching goal, the number of accepted LE is not: eating an LE snack does not contribute to limiting energy intake when this snack does not replace a HE snack that would otherwise be eaten.

The finding that HE snacks were refused more often than equally liked LE snacks might suggest that the participants employed self-control to resist the HE snacks. In line with self-regulation theory, exposure to HE snacks might have supported the need to employ self-control to inhibit the initial tendency to accept them. Another explanation for why more LE than HE snacks were accepted could be that participants perceived LE snacks as healthy and therefore eating them conduces health. Other studies have shown that people eat more of foods which are assumed to be healthy (Provencher et al., 2009; Wansink and Chandon, 2006) and another study even showed that people erroneously believe that eating healthy foods in addition to unhealthy ones can decrease total calorie count (Chernev, 2011).

Although the HE and LE snacks did not differ significantly in tastiness, HE food choices still elicited stronger activation in a cluster in the medial/middle OFC that has consistently been shown to activate during processing and evaluating rewarding stimuli (Hampshire et al., 2012; Kringelbach, 2005; Elliott et al., 2000). Furthermore, a cluster in the caudate tended to activate stronger during HE food choice. This region plays a prominent role in reward processing as it responds to both valence and saliency of rewards (Carlezon Jr. and Thomas, 2009; Litt et al., 2011). Finally, a cluster in the parahippocampal gyrus activated more strongly during HE (vs. LE) food choice. Parahippocampal gyrus activation has been shown to predict subsequent consumer choice and is thought to reflect the expected reward value of a stimulus (Tusche et al., 2010). This region has also been shown to activate during choices in which an immediate (and not when a delayed) reward was available (McClure et al., 2004). Since participants were slightly hungry due to the two hour fast before the scan, it could be that HE snacks had a higher momentary biological reward value due to the energy content, which translates into activation in the OFC, the caudate and the parahippocampal gyrus. This is also in line with the finding that hunger modulates the neural activation to visual food cues in the parahippocampal gyrus (Van der Laan et al., 2011). Altogether, these findings suggest that HE snacks had a higher hunger-dependent reward of the HE foods, which was, importantly, independent of tastiness.

As we touched upon earlier, the finding that HE foods were refused more often (or LE snacks were accepted more often), could either result from performing self-control to resist the HE snacks or from the tendency to accept less tasty LE snacks because they conduce health. The finding that HE compared to LE snacks did elicit stronger activation in reward areas but not in inhibitory areas (that would counteract reward response) suggests that the reward-response to HE snacks was inhibited, but that this inhibition-related activation was not strong enough to be detected in the contrast between HE and LE food choice. This is supported by our behavioral finding that, although HE snacks were refused more often than LE snacks, still almost half of the HE snacks were accepted (and the reward-response apparently was not inhibited in these trials).

Since it is particularly difficult to resist a HE snack when it is very tasty, it was expected that choice-related activation in brain regions involved in conflict and self-control would be modulated by tastiness. Therefore, our second aim was to investigate in which brain regions activation was modulated by tastiness. In line with the behavioral finding that highly tasty HE snacks were indeed resisted less often, we found that activation in the opercular part of the inferior frontal gyrus and the orbital part of the middle frontal gyrus (lateral OFC) was negatively modulated by tastiness during HE choice. That is, activation in these areas was lower for tastier HE snacks. The opercular part of the inferior frontal gyrus has previously been shown to activate during response inhibition (Aron et al., 2004). Studies have shown that the lateral OFC (in contrast to the medial OFC which activates in response to rewards) is involved in response inhibition (Kringelbach, 2005; Elliott et al., 2000). Thus, lower activation in these regions might be explained by their failure to inhibit desire for highly tasty HE snacks. An explanation for why we only identified this cluster for the HE and not for LE snacks might be that LE snacks do not pose a threat to the long-term weight watching goal, and therefore do not elicit inhibitory responses (neither when high, nor when low in tastiness).

Previous research has shown that there are large individual differences in self-regulatory success, in food choice as well as in other behavioral domains (De Ridder et al., 2012). Therefore, our third aim was to investigate whether the neural response during food choices covaried with self-regulatory success as indicated by the number of refused HE snacks. We found that participants who rejected more HE snacks showed stronger activation during HE food choices in several brain regions, including the SMA. The SMA is part of the cortical motor circuit for voluntary action. Many studies have shown SMA activation during response inhibition (Ma et al., 2012; Hendrick et al., 2012). The SMA receives inputs from the striatum, through the pre-SMA, and projects to the primary motor cortex, leading to action (Haggard, 2009). It is thought that reward and higher cognitive factors influence motor action through this pathway. In addition, the pre-SMA, which projects to the SMA, suppresses automatic responding (Haggard, 2009). In our study, it might be that the stronger SMA activation during food choice in participants that refused more HE snacks, reflects inhibition of their initial tendency to accept HE snacks (as indicated by the stronger reward-related striatal and OFC response to HE compared to LE snacks in this study). In line with our finding that SMA activation is associated with resisting HE snacks, Hendrick et al. (2012) showed that lean females had greater SMA activation during stop compared to go trials than obese women in a stop-signal task (i.e., a behavioral paradigm to assess self-control). This suggests that in weight-concerned women who are more successful at employing self-control there is involvement of the SMA in inhibiting the automatic approach response to HE snacks.

Although the SMA has been shown to activate during inhibitory processes (e.g., Hendrick et al., 2012), the exact function of the SMA in response inhibition is relatively poor understood. Classically, it was thought that the SMA merely serves as an intermediate between higher cognitive areas and the motor cortex, which would imply that SMA activation is just reflective of decisions made elsewhere (e.g., in the OFC) (Nachev, 2006). However, the pre-SMA and SMA are increasingly being implicated in immediate executive control (Nachev, 2006). Accordingly, it could be argued that SMA functioning is crucial for self-control since functioning in this brain region determines whether the choices made in higher cognitive areas can actually be executed. Future research using techniques (like transcranial magnetic stimulation (TMS)) that (temporarily) disrupt the function of the SMA and higher cognitive areas, should elucidate the causal role of the SMA in self-control.

6.5 Conclusion

Our findings indicate that HE snacks constitute a motivationally higher reward for weight-concerned women compared to LE snacks, even when they are equally tasty. This might explain why it is so hard for weight-concerned individuals to resist HE snacks. The negative modulation of brain activation in inhibitory areas by tastiness suggests that inhibition fails when HE snacks are very tasty. Finally, women who better adhere to their long term weight-watching goal show increased SMA activation during food choice, which might suggest that SMA functioning explains individual differences in the control of food intake.

Chapter 7

Summary and general discussion

Summary The general aim of this thesis was to establish the potential of implicit markers to (1) predict choice and (2) gain insight into the decision-making processes underlying food choice. This final chapter starts out with a summary of the main findings of this thesis, followed by a general discussion of these findings in relation to the general aim of this thesis. Implications and directions for future research are given. Next, methodological considerations are discussed. Lastly, the most promising approaches for promoting healthy food choices, inferred from our results are discussed.

7.1 Summary of findings

In **Chapter 2** we performed a meta-analysis to determine food-specific brain regions and brain regions of which activation was modulated by hunger state and energy content. Although earlier research had reported an extensive set of brain regions that were activated in response to viewing food pictures, our meta-analysis revealed that only a few of these areas were consistently activated across studies. With at best 41% of the experiments contributing to the most concurrent clusters, concurrency across studies was moderate. The most concurrent brain regions activated in response to viewing food pictures were the bilateral posterior fusiform gyrus, the left lateral orbitofrontal cortex (OFC) and the left middle insula. Hunger modulated the response to food pictures in the right amygdala and left lateral OFC, and energy content modulated the response in the hypothalamus/ventral striatum and middle occipital gyrus.

In **Chapter 3** we assessed the accuracy of functional Magnetic Resonance Imaging (fMRI) in conjunction with the novel analysis technique multivariate pattern analysis (MVPA), to predict food choice. Whereas prior studies were limited to using mass-univariate analysis, or investigated high involvement consumer products, this was the first study to investigate the accuracy of fMRI in conjunction with MVPA to predict every day consumer choices. Food choices could be predicted with an accuracy of up to 61.2% by activation patterns in brain regions previously found to be involved in healthy food choices (superior frontal gyrus) and visual processing (middle occipital gyrus). We found that mass-univariate analysis can detect small package-induced differences in product preference and that MVPA can successfully predict realistic low-involvement consumer choices from fMRI data. Moreover, the behavioral results of the study suggested that healthy food choices might be promoted by presenting healthy foods in more attractive packages.

In **Chapter 4** we investigated two important questions on the association between visual attention and consumer choice. Firstly, prior research has shown that consumer choice can be influenced by manipulating visual characteristics (e.g., brightness), such that it pops out, but it was unknown whether this was due to increased initial (first fixation) or sustained (fixation duration) attention. In this chapter we showed that manipulating the location of the first fixation did not influence consumer choice. Secondly, current models of visual attention in value-based decision making attribute fixation duration solely to the build-up of reward value for the stimulus that is fixated on. However, fixating longer on the eventually selected item is not specific for value-based decision making, but also occurs in objective decision making. Because it is unknown whether the fixation bias (fixating longer on the selected item) in value-based decisions can be attributed to the product reward value or to the specific task instruction, our study aimed to disentangle these two effects. Although fixation duration was mainly determined by the specific task instruction, it was also influenced by the product reward value.

In the last two chapters, the focus of the research shifted to the application of implicit markers to gain more insight into the decision-making processes concerning food, more specifically, into self-regulation. Previous research has shown that weight-concerned women are generally unsuccessful in limiting their intake. At the heart of self-regulation theory lies the common assumption that if someone with the long-term goal to limit intake is exposed to a food choice that threatens the accomplishment of this goal, this results in internal conflict. In **Chapter 5** we used fMRI, eye tracking and reaction times as process indicators to measure experienced conflict by weight-concerned women during binary choices between high energy (HE) and low energy (LE) snacks. In sharp contrast with the common assumption, we found that choices requiring self-control induced no conflict, as demonstrated by lower reaction times, fixation durations, number of gaze switches between snacks, and lower activation of the anterior cingulate cortex. These findings indicate that self-control failure might be due to a lack of experienced conflict, rather than to failing to act upon the perception of such conflict.

Having shown that weight-concerned women were rather unsuccessful in limiting energy intake when they have to choose between HE and LE snacks (**Chapter 5**), we extended our findings in **Chapter 6** to the situation where participants had the choice to either accept or refuse a single snack. Participants were still at best moderately successful in choosing in line with their weigh-watching goal when they had only one snack to consider. Our results suggested that HE foods have a higher reward value than (equally tasty) LE snacks, as corroborated by stronger activation in medial OFC and striatum. Tastier HE snacks were more difficult to resist and, accordingly, activation in inhibitory areas (inferior frontal gyrus, lateral OFC) correlated negatively with tastiness. More successful self-controllers showed increased activation in the supplementary motor area (SMA) during HE food choices. This suggests that differential neural responses during food choice in the SMA might translate into individual differences in self-regulatory success.

7.2 General discussion

7.2.1 Prediction of food choice

We hypothesized that implicit markers would be accurate predictors of food choice, since they are not prone to socially desirable answering and demand characteristics (Fazio and Olson, 2003). Moreover, implicit measures are thought to tap into unconscious determinants of preference formation that people cannot verbalize (Nisbett and Wilson, 1977; Bargh, 2002; Fitzsimons et al., 2002). We indeed found that mass-univariate fMRI analysis can detect small package-induced differences in product preference and that MVPA can successfully predict realistic low-involvement consumer choices (Chapter 3). Although we did not directly compare the prediction accuracy of fMRI and self-reported preference, a different study on hypothetical holiday destination choices has shown that brain activation (in caudate) could differentiate between subsequently chosen and rejected options while standard self-reports did not. Earlier studies have shown that choices for high-involvement products could be predicted with brain activation (e.g., Tusche et al., 2010). Our work made an important contribution to this field by indicating that fMRI in conjunction with MVPA is even sensitive enough to predict the relatively small differences in preference are typical for package-based food choices. In sum, taking our results and those of other studies together, it can be concluded that fMRI is a valid measure for predicting food choices.

Regardless of the exact accuracy of implicit markers, it is of fundamental interest to investigate which brain regions can predict choices or correlate with preference, since it contributes to knowledge on the role of the brain regions that are involved in preference formation. For example, we found that attractive packages triggered activation in a region previously found to correlate with general preference and willingness to pay (Izuma et al., 2008; Knutson et al., 2007; Linder et al., 2010). However, for practical applications like neuromarketing, it is crucial to know what the exact added value of these measures is with respect to predicting choice. If fMRI yields only slightly more accurate predictions, it seems unlikely that fMRI will become the preferred method to screen packages for their potential market success. To justify the high costs of fMRI measurements, the prediction accuracy of fMRI should be substantially higher than that of traditional marketing instruments. Although our finding that fMRI can predict small differences in preference is a major step towards the practical application of fMRI in neuromarketing, future research should quantify the added value in terms of prediction accuracy compared to conventional marketing research methods.

In both Chapters 4 and 5 we found that products of choice are fixated on longer than products that are not chosen. We showed that task instruction is the major driver of fixation duration (Chapter 4), and that the actual stimulus reward value influenced it to a smaller extent. This indicates that fixation duration might predict choice, but one has to be aware that fixation duration mainly depends on the instruction. Thus, the results emphasize the importance of task instruction in eye tracking studies investigating value-based decision-making.

7.2.1.1 Implications and directions for future research on choice prediction

An implication of our study is that combining both traditional analysis and MVPA is the preferred method over the traditional analysis alone. Traditional analysis and MVPA complement each other: whereas traditional analysis tests for differences in level of activation of each voxel separately, MVPA makes use of activation patterns (i.e., interactions between multiple voxels) to differentiate between chosen and not chosen products.

Although predicting food choice with 61% accuracy is good considering the small differences in preference, prediction accuracy might be improved even further by modifying the experimental design. In our current design we used a leave one out approach, i.e., the classifier was trained on the classifier on all but one product and tested the classifier on the remaining product. The classifier was only trained with novel products for which no pre-established preferences/aversions existed. In cases where the tested product deviates from the training set in preference, the classifier is likely to give a poor prediction (since the score is far away from the points in the training set). For instance, when the participant values the training-products as neutral, the classifier might not be able to predict choice for a highly liked product correctly because the activation pattern induced by viewing highly liked products are unknown to the classifier. Therefore, using a training set that spans a larger predefined preference range is expected to improve the prediction accuracy. For example, one could use a personalized training set consisting of reference items that a subject strongly likes and dislikes, and several items with intermediate likings.

The prediction accuracy of fMRI in the lab is promising. Future research should validate predictions from fMRI against actual food choices in the cafeteria or supermarket to establish whether fMRI is a valuable tool to predict behavior in real life.

7.2.2 Insight into decision-making processes

It is a well established finding that many people experience difficulties in coping with the current food environment. This is not only illustrated by the low percentage of people complying with the guidelines for healthy eating and the high prevalence of overweight, but also by the large number of healthy-weight, yet weight-concerned, individuals (Rideout and Barr, 2009; RIVM, 2011). Tasty HE foods are available everywhere, at virtually every moment of the day, constituting a major obstacle for making sensible food choices. We aimed to assess the potential of implicit markers to gain insight into food-related decision-making processes. As we mentioned in the introduction of this thesis, food choice is a behavior that relies greatly on automatic processes (Verhoeven et al., 2012; Fitzsimons et al., 2002). Therefore, we expected that implicit measures could reveal motives that people themselves are not aware of. Accordingly, by using implicit measures in the studies described in this thesis, we indeed yielded important insights into the processes underlying food choice.

That highly tasty HE foods are more rewarding than neutral LE snacks in the general population (Chapter 2) might account for why they are so hard to resist. Our results suggest why this is even more difficult for weight-concerned women: even when HE and LE snacks are equally tasty (as suggested by self-reports of tastiness), still the HE snacks are perceived as more rewarding (as reflected by activation in the OFC and striatum, Chapter 6). Resisting these highly rewarding HE snacks puts a large pressure on self-control mechanisms. Unfortunately, it appeared that weight-concerned women experience no internal conflict when faced with a food choice that threatens their weight-related goal (Chapter 5). Since experiencing the self-control dilemma is a prerequisite for acting upon it, this might explain why weight-concerned women are generally unsuccessful in limiting their intake. This lack of internal conflict might also contribute to their risk for (re-)gaining weight (Mann et al., 2007).

Overall, our studies using implicit measures have yielded important insights into the responses to food exposure and into self-control mechanisms that explicit measures would have been unable to provide. In fact, in Chapter 6 HE and LE snacks were rated as equally tasty, still fMRI revealed a differential reward response accompanying HE and LE food choices. Also, conflict is not necessarily consciously perceived. These insight contribute the knowledge explaining why people generally fail to eat healthy. Fortunately, our findings suggest several important future directions in research that might lead to promising approaches to promote healthy food choices. These are addressed in the next section.

7.2.2.1 Implications and directions for future research on self-control

As the studies reported in this thesis are among the first that have investigated the neural processes of self-control in the food domain, the results point to several interesting directions for future studies concerning self-control. Firstly, since our results indicated that self-regulatory failure most likely results from a lack of internal conflict, further research is needed to determine how people can be trained to detect a self-control dilemma. As we touched upon earlier in Chapter 5, the most likely explanation for the lack of conflict was that exposure to a tasty HE snack temporary inhibited accessibility of the long term goal (Stroebe et al., 2008). Therefore, strengthening temptation-goal associations, that is, changing the automatic response to tempting foods to activating rather than inhibiting the long term goal, might be an effective way to increase self-control dilemma detection. Forming implementation intentions as an intervention has proven successful in strengthening temptation-goal associations (e.g., Kroese et al., 2011) and might therefore be effective in increasing self-control dilemma detection. Future research should test whether strengthening temptation-goal associations indeed increases the internal conflict perceived in response to a food choice posing a self-control dilemma and thereby promote healthy food choices. This could for example be investigated in a randomized controlled trial in which the response (anterior cingulate activation, visual attention and reaction times) to a self-control dilemma is measured both before and after an intervention in which temptation-goal associations are strengthened.

Our weight-concerned participants were at best moderately successful in making long term goal-congruent food choices, as shown by the high amounts of HE snacks chosen in Chapter 5 and 6. Although all participants had a normal weight at present, consistently failing to resist HE foods will inevitably lead to weight gain in the long term. Earlier studies have shown that self-reports of weight-concern predict future weight gain (Mann et al., 2007). Our study suggests that a lack of internal conflict might explain why these individuals do not succeed in controlling their intake. To assess whether a lack of internal conflict is indeed a causal factor in weight gain, a longitudinal study could be performed to test whether a lack of internal conflict at baseline can predict future weight-gain. Moreover, if the lack of internal conflict in normal-weight weight-concerned women is indeed the leading cause of weight gain, one would expect the same lack of internal conflict in overweight and obese women. Therefore, future research should also assess how overweight and obese individuals respond to a self-control dilemma.

The studies in this thesis suggest a possible role for the SMA and anterior cingulate in effective self-control. SMA activation during food choice was lower in unsuccessful self-controllers. There appeared to be a lack of anterior cingulate activation in response to a self-control dilemma. This suggests that upregulating activity in these areas during choice might promote successful self-control. A method that could be effective in increasing activation in these areas during choice is neurofeedback. This is a therapy in which individuals are trained to regulate activity in specific brain regions by informing them (real-time, with fMRI or EEG) about current activation levels. One could try to train individuals to increase activity in the respective regions during food choices. Neurofeedback has already been shown to be effective in reducing cue reactivity in cocaine addicts (Horrell et al., 2010). Future research is warranted to test the effectiveness of real-time fMRI regulation strategies like neurofeedback to improve self-regulatory success in the food domain.

To further investigate the role of the SMA in self-control, an interesting approach might be to investigate the effect of deactivating the SMA on food choice. The location of the SMA at the outside of the brain makes it particularly suitable for studying it with transcranial magnetic stimulation (TMS). TMS is a (noninvasive) method in which a electromagnetic coil is placed against the outside of the scalp. The electromagnet creates an electrical current that stimulates nerve cells in nearby regions in the brain and temporarily deactivates them. In line with the proposed role of the SMA in our findings, an earlier study showed that deactivation of the pre-SMA (which has connections with the SMA) by TMS results in impaired inhibitory capacity in stop-signal tasks (Juan and Muggleton, 2012). To investigate the role of the (pathway including) SMA in food-related self-control it might be interesting to assess whether successful self-controllers make more indulgent food choices when the SMA is deactivated by TMS during food choice.

Since food choice is not the only behavior in which self-control plays a role, future research should investigate whether the findings extrapolate to other behavioral domains involving a trade-off between direct impulses and future goals, like smoking cessation, financial management, interpersonal relations, and aggression.

Considering that most food choices are made automatically (Verhoeven et al., 2012; Fitzsimons et al., 2002), and that weight-concerned women no not detect a self-control dilemma (Chapter 5), there lies great potential in interventions that make the healthy choice the easy or automatic choice (i.e., that does not rely on exerting self-control). Our results (Chapter 3) showed that the attractiveness of the packaging design was the strongest predictor of choice and suggested that healthy food choices might be promoted by simply presenting healthy foods in more attractive packages. Other studies suggested that attractiveness could influence general product preference by triggering positive responses and by increasing the expected quality, luxury, and price of products (Dawar and Parker, 1994; Forsythe et al., 1996; Orth et al., 2010). Although speculative, it might also be that attractive packages result in sustained attention and thereby a further increased preference for them (Chapter 4; Shimojo et al., 2003). That increasing attractiveness influences general preference is supported by our finding that attractiveness correlated with activation in a cluster of the superior frontal gyrus, a region previously found to correlate with general product preference and willingness to buy (Knutson et al., 2007; Izuma et al., 2008; Linder et al., 2010). When the healthy option is most preferred, choosing it is thought to be be less dependent on exerting self-control. Making the healthy choice the easy choice by increasing attractiveness aligns with recently identified approaches aimed at stimulating healthy behaviors without requiring much effort, termed *nudges* (Thaler and Sunstein, 2008). *Nudges* are defined as small alterations in the environment that move consumers towards choosing healthy foods by making them more attractive or the most obvious ('default') option. Importantly, consumers are *nudged* towards healthy foods without banning unhealthy food products or telling consumers what to eat or avoid. Other examples *nudges* are to place unhealthy foods at such a distance that it is less easy to grab (Maas et al., 2012) (and healthy foods closer), and placing healthy items first in each category of a restaurant menu (without labeling them as healthy) (Dayan and Bar-Hillel, 2011). A major strength of these *nudges* is that they go along with the idea that most food choices are made automatically. Future research should aim at finding more ways to increase attractiveness of healthy foods, e.g., by presenting them in attractive displays.

Another interesting direction for future research is the role of visual attention in reward processing. Our combined results suggests that visual attention (fixation duration) might influence preference formation. In accordance with other studies we found that brain regions involved in basic visual processing (middle occipital gyrus, calcarine gyrus) were stronger activated in response to tasty and HE foods (vs. bland and LE foods, middle occipital gyrus, Chapter 2) and preferred products (chosen vs. not chosen products, middle occipital gyrus, Chapter 3). Also, a cluster in the calcarine gyrus was stronger activated during food choice concerning HE (versus equally liked LE) snacks (Chapter 6), and food choice could be predicted with 61% by activation patterns in the middle occipital gyrus. These regions are mainly known for their role in basic visual processing, like discriminating visual orientations, spatial frequencies, and colors (Shapley and Hawken, 2002; Kamitani and Tong, 2006). From an evolutionary perspective it is thought that the visual characteristics of rewarding stimuli are hard-wired in the brain by means of associative learning (Hickey et al., 2010). This mechanism facilitates efficient recognition and attention allocation to rewarding stimuli. Therefore, stronger activation of primary visual (and secondary associative) regions in response to preferred foods is often explained by increased attention to preferred products due to feedback from reward regions to attention related regions (e.g., Gerdes et al., 2010; Kastner and Ungerleider, 2000; Lane et al., 1999). However, our fMRI and eye tracking results combined suggest that activation in these regions might not simply result from a priori differences in preference, but vice versa, that visual attention itself might influence preference. In Chapter 4 we found that people look longer at eventually chosen products, even though a priori preference was equal. In Chapter 5 we showed that in successful self-control trials participants looked longer at the less liked LE snacks and eventually chose them. This might suggest that increased visual attention is not only the result from a priori preferences (as reflected in the brain by feedback from reward-related regions to visual regions), but vice versa, that increased attention (activation in visual processing and attention-related areas) to a stimulus results in increased preference (activation in reward areas). It is well established that occipital and striatal regions are connected and often coactivate in response to rewards. This hypothesis is also supported by a study in which visual attention (fixation duration) was experimentally manipulated and showed that increasing fixation duration on an item increased preference for it (Shimojo et al., 2003). In the same way of reasoning, directing attention away from temptations might decrease activation in visual processing areas and subsequently in reward areas, decreasing the preference of the tempting HE snack. Although highly speculative, attention allocation might be a potentially effective strategy to promote healthy choices. This warrants further investigation.

7.2.3 Methodological considerations

7.2.3.1 Study population

Throughout the studies described in this thesis, the study population comprised of highly educated young females with a healthy weight, either explicitly weight-concerned (Chapter 5 and 6) or not (Chapter 3 and 4). For fMRI measurements, including relatively homogeneous subject groups is crucial to have enough power to detect small effects. This is due to the inherent high noise level of fMRI and relatively low sample sizes. The reason to restrict inclusion to females only is that gender is a large potential source of variation in fMRI studies because of anatomical and functional differences (Luders and Toga, 2010; Frank et al., 2010). Moreover, at the start of this PhD, most studies on the neural response to food cues had included female participants (e.g., Killgore et al., 2003; Killgore and Yurgelun-Todd, 2005a,b; Schur et al., 2009). Therefore, investigating females enabled comparisons with results from previous studies. However, drawing from such a specific population does raise questions about the external validity of the findings to other subgroups of the population (e.g., males). Earlier studies on gender differences in reward processing are ambiguous. For example, Diekhof et al. (2012) showed that males and females showed similarities in the general response of reward-related areas (striatum, ventral tegmental area) to predictors of immediate reward. However, other studies showed that males and females differ in their neural responses to foods (Frank et al., 2010; Geliebter et al., 2012). Although the informative brain regions might deviate slightly due to anatomical and functional differences, we have no reason to assume that fMRI (in conjunction with MVPA) would have a lower prediction accuracy in men than in women. Naturally, future research is to confirm this.

With respect to the Chapters 5 and 6, in which we investigated the self-control processes underlying food choice, we specifically included individuals with a weight-watching goal. Since self-control is only relevant for people that have a goal to restrict intake (or eat healthier), we did not expect that inhibitory brain mechanisms and conflict monitoring would play a role in individuals without an eating or health-related goal.

7.2.3.2 Study setting

Although the original study aim originated from field studies and findings in real life settings (i.e., that people have difficulty with making healthy food choices and that they are not able to correctly verbalize the motives for their choices), it is important to note that all studies described in this thesis were performed in a laboratory setting.

The laboratory setting differs from the normal food choice situation (e.g., in the supermarket or cafeteria) in several aspects. In the fMRI studies, the participants lay horizontally inside of a noisy and relatively small bore. In the eye tracking study, participants sat in front of a computer screen with their chin in a chin-rest while their eye movements were recorded. In all studies, participants sequentially made a large number of food choices on basis of pictures.

To our knowledge, no study has directly compared the brain responses to viewing real foods versus images of foods. Although there have been several studies on tasting foods in the scanner (e.g., Spetter et al., 2012; Smeets et al., 2006), results from these studies cannot be compared to our present findings since they focus on responses related to consumption rather than the food choice (which precedes consumption). Therefore, it is unknown how the use of images instead of real foods might have affected our results. Since real foods are more tangible than pictures it could be speculated that responses to real foods would be more pronounced, that is, real foods would elicit a stronger hedonic response. Indeed, this is an important topic for future research. Although using real foods might have been more realistic, we chose to use images since it is rather unpractical to present real foods and standardize all other factors (like strict timing), especially with the high number of stimuli that we used. Moreover, pictures are an important part of visual advertisements and packages (Seiders and Petty, 2004).

Performing the studies in a laboratory setting also had large advantages. The standardized lab setting enabled to rule out alternative explanations and remove variation that is inherent to field studies. Also, it enabled us to measure brain activity during active decision-making. It is possible to measure brain activation in the field with EEG. However, EEG is less sensitive for activation in inner limbic structures, such as the striatum. Since these regions are particularly relevant for studies on reward, fMRI was the preferred method with regard to our study aims. The recent development of mobile eye tracking glasses make it possible to measure visual attention in real life situations in an uninvasive manner (as opposed to the former invasive heavy weight, head mounted eye trackers). Although we do not expect that basal visual attention processes during choice (i.e., the influence of instruction and reward value on fixation duration, the role of the first fixation) will differ largely between the laboratory and the supermarket, future studies should confirm this.

With respect to the self-control processes studied in Chapter 5 and 6, it is important to note that real life as well as laboratory studies have convincingly shown that weight-concerned women are generally unsuccessful in limiting their energy intake (Stice et al., 2004, 2007, 2010). In these chapters we aimed to gain more insight into the processes underlying this apparent self-regulatory failure. Investigation of these underlying mechanisms required tightly controlled experimental designs with stimuli matched on tastiness and exact timing.

We took several precautions to avoid biases resulting from the laboratory setting. Firstly, in all studies participants made real food choices. Participants were instructed that they would actually receive one of the products of their choice. Additionally, participants were not informed about the actual aim of the study beforehand (they were debriefed afterwards). Instead, they were told a cover story to avoid potential experimenter demand effects on their choice behavior.

7.2.4 Promising approaches for promoting healthy food choices

Several interesting directions for future research and promising approaches to stimulate healthy food choices have been addressed in the previous sections. In this section we will elaborate on how the currently most popular approach to stimulate healthy eating – emphasizing healthiness – might be inadequate, both supported by the findings from our studies and previous literature. Moreover, we discuss the two most promising approaches to stimulate healthy food choices, inferred from our findings, for which future research is recommended.

The currently most popular strategy to promote healthy food choices is to emphasize the healthiness of products. For example, food manufacturers give their products healthy packaging designs or they add labels that refer to the low energy content. Moreover, the food industry (with support of the Netherlands Nutrition Center ('Voedingscentrum')) has developed the 'healthy choice' and 'conscious choice' logos that aim to aid consumers in making healthy choices. This is thought to be an effective strategy because consumers themselves state that health is an important motivation for their food choices (Carrillo et al., 2011). Food manufacturers take their responsibility and attempt to promote healthy choices, supporting the viability of such an approach. However, accumulating scientific evidence suggests that emphasizing the healthiness of a food might impede rather than facilitate eating healthy foods in sensible portions, by means of two unintended adverse effects (for a review, see Chandon, 2013). Firstly, labeling a food as healthy appears to decrease the inferred tastiness and the likelihood that the food will be selected for consumption (e.g., Raghunathan et al., 2006). Secondly, labeling snacks as healthy rather than unhealthy boosts energy intake by $28-35\%$ in the general population, but even more in people who are overweight (Provencher et al., 2009; Wansink and Chandon, 2006). This suggests that emphasizing healthiness might serve as a license to eat (De Witt Huberts et al., 2012b) and could thereby even lead to weight gain when applied to energy-rich foods.

Our results point to two approaches that might be particularly promising for the promotion of healthy food choices without relying on their labeling as 'healthy' choices. The other approaches described in Section 7.2.2.1, such as neurofeedback, are also promising but rather expensive or invasive. Therefore, here we propose two approaches that are most promising both in potential effectiveness and practical application. Firstly, we propose that it might be helpful to make healthy foods more attractive. Increasing the attractiveness makes healthy foods more appealing and thereby makes it easy to choose them. This is in sharp contrast with focusing attention on healthiness, which makes the healthy option 'special', implying that the unhealthy option is the default. Thereby, emphasizing healthiness increases the need for self-control to choose the healthy option instead of going for the 'default', unhealthy snack. Naturally, when the healthy option is preferred, choosing it is less dependent of employing self-control. When the healthy option is preferred over the unhealthy option, the unhealthy option is not regarded as a temptation, and therefore resisting it does not require effort. Therefore, this approach might be effective in the general population for who most food choices are made automatically (Levitsky and Pacanowski, 2012; Wansink, 2004; Verhoeven et al., 2012; Bargh, 2002; Fitzsimons et al., 2002), as well as in weight-concerned individuals who do not detect a self-control conflict. Since this approach does not rely on exerting effortful self-control, its efficacy is not expected to be decreased when cognitive resources are depleted (e.g., after a long day of work, Baumeister and Heatherton, 1996). Instead, since it makes the healthy choice the automatic choice, this approach is particularly suitable for situations in which cognitive resources are low. One could also think of other ways to make healthy eating more attractive, e.g., by means of the way it is presented. However, since people are only to a certain extent able to change their eating environment, the success of this approach is largely dependent of food manufacturers changing the packaging designs or supermarkets presenting healthy foods in aesthetic displays. Eventually, fMRI could be used to test and develop packages that are attractive and trigger brain areas predictive of choice.

The second promising approach focuses on changing the person's response to the food environment, namely increasing the ability to detect a self-control dilemma. In Chapter 6 we found that self-regulatory failure of weight-concerned women may result from a lack of experienced conflict, rather than failing to act upon the experience of such conflict. Since experiencing self-control conflict is considered a prerequisite for acting upon it, there lies great potential in weight-management interventions that focus on increasing the detection a self-control dilemma. The main advantage of this approach is that it does not rely on food manufacturers modifying their packages. It might enable individuals with an eating-related goal to make better food choices within the current food environment which is abundant of tempting HE snacks. A drawback is that an individual should have an eating-related long-term goal and be motivated to put effort into engaging in an intervention that increases his/her ability to detect a self-control conflict. Forming implementation intentions (which might increase experienced conflict to a HE snack by activating the long term goal, see Section 7.2.2.1) as an intervention requires relatively less effort, and therefore we highly recommend future research on its effectiveness in increasing experienced conflict.

Altogether, both approaches are highly promising. The strength of making healthy foods more attractive is that the approach does not rely on effortful self-control, and that it might be helpful in the general population as well as in individuals with an eating-related goal (eating healthy or watching their weight). The strength of increasing the ability to detect a self-control dilemma is that it might enable individuals with an eating-related goal to make more goal-congruent food choices within the current 'obesogenic' food environment. An important difference between the two approaches is how they address the self-control dilemma: by increasing the attractiveness of healthy foods, the self-control dilemma is strongly decreased or even completely avoided. The other approach rather focuses on increasing a person's ability to handle the self-control dilemma. Healthy eating might thus be promoted by either avoiding the self-control dilemma or empowering individuals to detect and overcome the dilemma. Another important difference between the two approaches is that the first approach (increasing the attractiveness of healthy foods) facilitates the choice for a healthy snack (at the expense of choosing unhealthy snacks), while the second approach focuses specifically on the ability to resist unhealthy foods. To promote both the intake of healthy foods and diminish the intake of unhealthy foods, a combination of both methods might be more effective than either of them in isolation. Because of these reasons, we advocate that future research should evaluate both approaches more in depth and in real life settings.

7.3 Conclusion

From the work presented in this thesis it can be concluded that fMRI and eye tracking measures are valuable tools that can differentiate between more and less preferred products, and that fMRI in conjunction with MVPA can be used to predict choice. Moreover, reaction times, eye tracking measures, and fMRI can give more insight into the processes underlying food choice, like self-control, especially when multiple measures are combined.

The studies in this thesis have provided important insights into the causes of self-regulatory failure and also suggest two promising approaches for promoting healthy food choices that warrant further investigation, namely (1) making healthy foods more attractive and (2) increasing the ability to detect a self-control dilemma.

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Abbreviations

OFC	orbitofrontal cortex
ALE	Activation Likelihood Estimation
BMI	Body Mass Index
BOLD	Blood Oxygen Level Dependent
FDR	False Discovery Rate
fMRI	functional Magnetic Resonance Imaging
FWE	Family Wise Error
HE	high energy
LOC	Lateral occipital complex
LE	low energy
MA	modeled activation
MNI	Montreal Neurological Institute
MRI	Magnetic Resonance Imaging
MVPA	multivariate pattern analysis
NSC	No Self-Control required
ROIs	Regions of interest
ROI	Region of interest
vmPFC	ventromedial prefrontal cortex
SC	Self-Control required
SMA	supplementary motor area
TMS	transcranial magnetic stimulation

Samenvatting

Het overkoepelende doel van het onderzoek beschreven in dit proefschrift was het bepalen van de potentie van impliciete markers om 1) de voedselkeuze te voorspellen, en 2) inzicht te krijgen in keuzeprocessen die ten grondslag liggen aan voedselkeuze.

Waarom zijn impliciete markers nodig?

Ongezond eten is een groot probleem in Nederland en andere (Westerse) landen. Een minderheid eet genoeg groente en fruit en een grote meerderheid eet teveel (verzadigd) vet. Het eten van teveel snacks met veel suiker en vet leidt op de lange termijn tot een toename van het lichaamsgewicht indien deze calorie inname niet wordt gecompenseerd door meer beweging. De voedselkeuze speelt dus een belangrijke rol in gewichtsbeheersing. Met het oog op de grote gezondheidsrisico's van overgewicht en ongezond eten, is het van belang om meer inzicht te krijgen in de beweegredenen die ten grondslag liggen aan voedselkeuze. Inzichten in die beweegredenen zouden kunnen helpen om effectievere interventies voor gewichtsbeheersing te ontwikkelen.

De meest voor hand liggende manier om meer inzicht te krijgen in de eerder genoemde beweegredenen is om mensen simpelweg te vragen waarom ze een bepaald product kiezen. Maar zo makkelijk is het helaas niet. Steeds meer onderzoeken laten zien dat voedselkeuzes grotendeels 'automatisch' gemaakt worden. Hiermee bedoelen we dat de voedselkeuze, net als ander dagelijks herhaald gedrag, met name gedreven wordt door onbewuste processen en gewoontes. Expliciete markers, zoals interviews en vragenlijsten, geven enkel inzicht in de beweegredenen waar men zich bewust van is en meten dus maar het topje van de ijsberg. Het is essentieel om juist de invloeden waar men zich niet bewust van is te achterhalen, omdat men met het inspelen op deze invloeden de gezonde keuze mogelijk 'automatisch' zou kunnen stimuleren. Expliciete markers zijn dus niet geschikt om een volledig beeld te krijgen van de factoren van invloed op de voedselkeuze. Nog een nadeel van expliciete markers is dat ze makkelijk beïnvloed kunnen worden door de neiging om sociaal wenselijk te antwoorden. Daarnaast kan het vragen naar beweegredenen op het keuzemoment beïnvloeden welk product gekozen wordt omdat men zich plotseling bewust wordt van deze redenen.

Gezien de nadelen van expliciete markers, is het noodzakelijk om markers van voedselkeuze te vinden die niet afhankelijk zijn van het expliciet vragen naar de reden van de keuze, de zogenaamde impliciete markers. In dit proefschrift hebben we de potentie van cognitieve (reactietijden), visuele attentie (oogbewegingen) en centrale (hersenactiviteit) markers, geëvalueerd.

De eerste potentiele marker die we gebruiken is de reactietijd. De reactietijd is de tijd tussen de presentatie van een bepaalde stimulus en de daaropvolgende reactie. Reactietijden worden in psychologisch onderzoek vaak gebruikt als indicator van cognitieve processen. Voorgaand onderzoek heeft aangetoond dat reactietijden hoger zijn tijdens het maken van moeilijke vergeleken met makkelijke keuzes. Een tweede marker die veel potentie heeft om inzicht te geven in voedselkeuze zijn oogbewegingen. Oogbewegingen kunnen worden gemeten met een eye-tracker. Het product waar iemand als eerste naar kijkt en hoe lang iemand ergens naar kijkt, geeft aan welke aspecten direct de aandacht trekken en waaraan aandacht wordt besteed tijdens het maken van een keuze. De derde marker die we bekeken hebben is hersenactivatie. Omdat alle aspecten van het keuzeproces worden geïntegreerd in het brein, is het aannemelijk dat hersenactivatie een zeer hoge potentie heeft om de keuze te voorspellen en inzicht te geven in de beweegredenen die ten grondslag liggen aan de voedsel keuze. Hersenactivatie hebben wij gemeten met functionele MRI.

In **Hoofdstuk 1** zijn deze markers in meer detail beschreven, alsmede de belangrijkste eigenschappen waar een marker voor voedselkeuze aan moet voldoen. Daarnaast geeft het eerste hoofdstuk een overzicht van de factoren die van invloed zijn op de voedselkeuze.

We hadden twee verwachtingen over de toegevoegde waarde van impliciete markers in het onderzoek naar voedselkeuze. Ten eerste verwachtten we dat impliciete markers accuraat de voedselkeuze kunnen voorspellen. Ten tweede verwachtten we dat de impliciete markers gebruikt kunnen worden om meer inzicht te krijgen in de onbewuste processen die ten grondslag liggen aan de voedselkeuze.

Bevindingen en interpretatie

De eerste stap in het evalueren van de potentie van hersenactiviteit als impliciete marker voor voedselkeuze, was het samenvoegen van de resultaten van eerdere studies. In **Hoofdstuk 2** hebben we een meta-analyse uitgevoerd om te bepalen welke hersengebieden activeren tijdens het kijken naar afbeeldingen van voedsel. Een meta-analyse is een onderzoek waarin onderzoeken van een bepaald fenomeen worden samengevoegd om één secuurdere uitkomst te krijgen. Omdat gedragsmatige studies hebben laten zien dat producten met veel suiker en vet over het algemeen lekkerder worden gevonden en voedsel meer belonend is als iemand veel honger heeft, hebben we ook gekeken in welke hersengebieden de activiteit wordt beïnvloed door de calorische inhoud (de hoeveelheid kilocalorieën) van het voedsel en de mate waarin iemand honger heeft. Hoewel de voorgaande onderzoeken een uitgebreide set van hersengebieden hebben gerapporteerd die activeren tijdens het bekijken van afbeeldingen van voedsel, liet onze meta-analyse zien dat slechts een aantal gebieden door meerdere studies gevonden werden. De overlap tussen studies was op zijn hoogst 41%. Dat wil zeggen dat de vaakst gevonden hersengebieden in reactie op het bekijken van afbeeldingen van voeding slechts door 41% van de studies gevonden werden. We vonden dat de fusiforme gyrus, de linker laterale orbitofrontale cortex en de linker insula het meest robuust sterker activeerden in reactie op afbeeldingen van voedsel, vergeleken met andere afbeeldingen (van gebouwen, natuur, dieren, gebruiksvoorwerpen, etcetera). Activiteit in de rechter amygdala en linker orbitofrontale cortex in reactie op afbeeldingen van voedsel was sterker wanneer iemand honger had. Activiteit in de hypothalamus/ventrale striatum (betrokken bij beloningsprocessen) en de middelste occipitale gyrus (visuele verwerking) was sterker tijdens het bekijken van afbeeldingen van hoog- vergeleken met laagcalorisch voedsel.

In **Hoofdstuk 3** hebben we onderzocht hoe accuraat functionele MRI, in combinatie met de nieuwe analyse techniek multivariate patroon analyse (MVPA), voedselkeuzes kon voorspellen. Eerdere studies hebben laten zien dat het mogelijk is om keuzes te voorspellen voor producten waarbij een hoge betrokkenheid is, bijvoorbeeld voor auto's en gadgets. Het was echter nog onbekend hoe accuraat voedselkeuzes voorspeld kunnen worden met fMRI in combinatie met MVPA. Voedsel wordt doorgaans verpakt verkocht in de supermarkt. De verpakking kan van grote invloed zijn op de keuze. Voor dit onderzoek werden de hersenen van 20 vrouwelijke deelnemers gescand terwijl ze kozen uit twee alternatieven van hetzelfde product, in verschillende verpakkingen. Voedselkeuzes konden met 61.2% accuraatheid worden voorspeld met activatiepatronen in hersengebieden betrokken bij het maken van gezonde keuzes (de bovenste frontale gyrus) en visuele verwerking (de middelste occipitale gyrus). We vonden dat de traditionele analyse techniek gevoelig genoeg was om kleine door de verpakking veroorzaakte verschillen in voorkeur te detecteren en dat MVPA succesvol toegepast kon worden om keuzes te voorspellen. Daarnaast lieten de gedragsmatige resultaten van de studie zien dat de aantrekkelijkheid van de verpakking de belangrijkste voorspeller van de keuze was. Hieruit kan worden gespeculeerd dat gezonde voedselkeuzes kunnen worden gestimuleerd door gezonde producten in aantrekkelijke verpakkingen te verkopen.

In **Hoofdstuk 4** hebben we twee belangrijke vragen omtrent de relatie tussen visuele attentie en de consumentenkeuze onderzocht. Ten eerste, voorgaand onderzoek heeft laten zien dat keuzes beïnvloed kunnen worden door de visuele aspecten (bijvoorbeeld contrast, helderheid) van de verpakking zo te manipuleren dat het product direct in het oog springt. Het was echter onbekend of dit effect verklaard kon worden doordat het product als eerste bekeken werd (eerste fixatie), of omdat er langer naar gekeken werd (langere fixatieduur). Daarom was het eerste doel om te onderzoeken of de keuze kan worden beïnvloed door te sturen waar iemand als eerste naar kijkt. Ten tweede, de huidige modellen van visuele attentie schrijven fixatieduur volledig toe aan het opbouwen van voorkeur voor het product waarnaar gekeken wordt. Het is echter niet specifiek voor voorkeurskeuzetaken dat het langst gekeken wordt naar de uiteindelijk gekozen optie. Dit effect treedt ook op bij objectieve keuzetaken. Als je iemand bijvoorbeeld vraagt om de meest gezonde optie uit een verzameling producten te selecteren, kijkt iemand het langst naar de meest gezonde. Omdat fixatieduur in objectieve keuzes niet toegeschreven kan worden aan het opbouwen van voorkeur, is het de vraag of dit voor voorkeurskeuzes wel geldt. Daarom was het tweede doel om te onderzoeken of de fixatieduur bepaald wordt door de taakinstructie, of door de voorkeur. Om dit te onderzoeken hebben we 23 vrouwelijke deelnemers keuzes laten maken uit twee producten terwijl hun oogbewegingen werden geregistreerd door middel van eye-tracking. De resultaten lieten zien dat de keuze niet beïnvloed kon worden door de eerste blik naar een van de producten te sturen. Daarnaast vonden we dat de fixatieduur met name gedreven werd door de taakinstructie, maar ook beïnvloed werd door voorkeur. Implicaties van dit onderzoek zijn dat het niet nodig is om verpakkingen te ontwerpen die direct in het oog springen (als eerste bekeken worden), maar dat het mogelijk effectiever is om verpakkingen te ontwerpen die langer de aandacht vasthouden. Daarnaast onderstrepen onze resultaten het belang van de taakinstructie in eye-tracking onderzoek.

In de laatste twee hoofdstukken verschoof de focus van het onderzoek meer naar de toepassing van impliciete markers om meer inzicht te krijgen in de processen die ten grondslag liggen aan de voedselkeuze. Meer specifiek richtte het onderzoek zich op zelfcontrole. Voorgaand onderzoek heeft aangetoond dat vrouwen die op de lijn letten, over het algemeen niet succesvol zijn in het beperken van hun calorie inname. Voor mensen die hun calorie inname willen beperken, wordt de keuze tussen gezonde en (lekkerdere) ongezonde snacks gezien als een klassiek zelfcontrole dilemma waarbij een afweging moet worden gemaakt tussen de directe beloning van het eten van de ongezonde snack en het toekomstige 'gewin' van een slank en gezond lichaam. Om dit dilemma te overwinnen, en dus een keuze te maken die congruent is met hun intentie om de calorie inname te beperken, moet er zelfcontrole worden toegepast (bijvoorbeeld de cognitieve herwaardering en onderdrukking van gedachten). De basis aanname van psychologische theorieën over zelfcontrole is dat als iemand geconfronteerd wordt met een product dat niet congruent is met hun lange termijn doel om op de lijn te letten (als de persoon dus voor een zelfcontrole dilemma wordt gesteld), er een innerlijk conflict ontstaat. Deze aanname is echter nog nooit getest. Daarom is het dus nog onduidelijk of het falen om hun calorie inname te beperken kan worden toegeschreven aan dat er geen intern conflict wordt ervaren tijdens confrontatie met een zelfcontrole dilemma, of dat ze er niet in slagen zelfcontrole toe te passen om daarmee het dilemma te overwinnen.

In **Hoofdstuk 5** hebben we reactietijden, eye-tracking en fMRI gebruikt om te onderzoeken of vrouwen die op de lijn letten een intern conflict hebben wanneer ze geconfronteerd worden met een zelfcontrole dilemma. Hiertoe werden de hersenen van 20 vrouwelijke deelnemers gescand terwijl ze keuzes maakten die ze of voor een dilemma stelden (keuze tussen een zeer lekkere hoogcalorische snack en een minder lekkere laagcalorische snack), of niet (keuze tussen een hoog- en een laagcalorische snack die ze even lekker vonden). Oogbewegingen en reactietijden tijdens de keuzes werden gemeten. In tegenstelling tot de basis aanname dat confrontatie met een zelfcontrole dilemma een intern conflict zou moeten oproepen, vonden wij het tegenovergestelde: de keuzes waarbij de deelnemers voor een zelfcontrole dilemma werden gesteld, riepen geen conflict op, zoals aangetoond door lagere reactietijden, lagere fixatieduraties en minder vaak heen en weer kijken tussen de opties. Daarnaast was er tijdens de keuzes met een zelfcontrole dilemma lagere activatie van de anteriore cingulaire cortex, een gebied dat bekend staat om zijn rol in het waarnemen van intern conflict. Het is dus meer waarschijnlijk dat het falen om de calorie inname te beperken wordt veroorzaakt doordat er geen intern conflict is in reactie op een zelfcontrole dilemma, dan doordat ze er niet in slagen om dit dilemma te overwinnen. Uit deze resultaten kan worden opgemaakt dat het mogelijk effectief is als gewichtsbeheersingsinterventies zich richten op de detectie van het zelfcontrole dilemma.

Hoewel **Hoofdstuk 5** liet zien dat vrouwen die op de lijn letten er niet in slagen om laagcalorische snacks te kiezen, hebben we in het laatste onderzoek (**Hoofdstuk 6**) onderzocht of ze daar wel in slagen wanneer ze voor elke snack apart moesten kiezen of ze het wilden eten of niet. Voorgaand onderzoek heeft laten zien dat de aanwezigheid van alternatieven de keuze sterk kan beïnvloeden. Onderzoeken naar de ‘vicareous goal fulfillment’ theorie hebben bijvoorbeeld laten zien dat alleen al de aanwezigheid van een gezond alternatief in de keuzeset, het lange termijn doel vervult, ongeacht of het gekozen wordt. Hierdoor maakt de aanwezigheid van een gezond alternatief het juist meer waarschijnlijk dat iemand voor een ongezond product gaat. Daarom was het eerste doel van het onderzoek beschreven in **Hoofdstuk 6** om te bepalen in hoeverre vrouwen die op de lijn letten er in slagen om gezonde voedselkeuzes te maken wanneer ze voor elke snack apart moesten kiezen of ze het wilden eten. Omdat hoogcalorische snacks met name moeilijk te weerstaan zijn als ze heel erg lekker zijn, was het tweede doel om te onderzoeken in welke hersengebieden de hersenactiviteit tijdens de keuze samen hing met hoe lekker het product is. Voorgaand onderzoek liet zien dat niet iedereen even succesvol is in het uitoefenen van zelfcontrole. Daarom was het laatste doel om te onderzoeken of vrouwen die meer succesvol zijn in het weerstaan van hoogcalorische snacks andere hersenactivatie hebben tijdens de keuze dan vrouwen die daarin minder succesvol zijn. Dit hebben we onderzocht door de hersenen van 20 vrouwen te scannen terwijl ze voor hoog- en laagcalorische snacks moesten kiezen of ze die wilden eten of niet. Onze resultaten lieten zien dat ook in dit onderzoek de vrouwen over het algemeen maar betrekkelijk succesvol waren in het weerstaan van hoogcalorische snacks. Tijdens het kiezen of ze een hoogcalorische snack wilden eten was er een sterkere activiteit in gebieden die betrokken zijn bij beloning (mediale orbitofrontale cortex en het striatum) dan tijdens keuzes met laagcalorische snacks. Zeer lekkere hoogcalorische snacks waren moeilijker om te weerstaan en overeenkomstig vonden we dat activatie in hersengebieden betrokken bij inhibitie (het remmen of blokkeren van gedrag) negatief samenhingen met hoe lekker de snack was. Vrouwen die meer hoogcalorische snacks afwezen, hadden sterkere activiteit in het supplementaire motor gebied. Dit suggereert dat verschillen in activatie in dit hersengebied tijdens de keuze de variatie in zelfcontrole succes zouden kunnen verklaren.

Conclusie

De onderzoeken beschreven in dit proefschrift hebben laten zien dat fMRI en eye-tracking waardevolle markers zijn die kunnen differentië ren tussen meer en minder geprefereerde producten, en dat fMRI in combinatie met MVPA gebruikt kan worden om voedselkeuzes te voorspellen. Dit is met name relevant voor 'neuromarketing' doeleinden. Daarnaast hebben we laten zien dat het meten van reactietijden, eye-tracking en fMRI tijdens voedselkeuzes meer inzicht geeft in de processen die hierbij betrokken zijn. Met name wanneer deze technieken met elkaar worden gecombineerd.

Daarnaast hebben de onderzoeken belangrijke inzichten opgeleverd in de oorzaken van zelfcontrole falen. Zo kan de bevinding dat beloningsgebieden (striatum, orbitofrontale cortex) activeren in reactie op het bekijken van hoogcalorisch voedsel verklaren waarom het zo moeilijk is te weerstaan. Ook duiden onze resultaten aan dat het falen om de calorie inname te beperken mogelijk wordt veroorzaakt doordat er geen intern conflict is in reactie op een zelfcontrole dilemma.

Daarnaast kan uit de resultaten opgemaakt worden dat er twee aanpakken zijn (uitgebreider beschreven in **Hoofdstuk 7**) die mogelijk effectief zijn om mensen te stimuleren om gezonde producten te kiezen, waar toekomstig onderzoek zich op zou moeten richten, namelijk: (1) het meer aantrekkelijk maken van gezonde producten en (2) interventies die er voor zorgen dat een zelfcontrole dilemma beter opgemerkt wordt door het ervaren van een intern conflict.

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Scientific achievements

Publications

- **Van der Laan, L.N.**, De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. One at a time: temptation strength and self-regulatory success modulate activation in inhibitory brain regions during food choice in weight-concerned women *(submitted for review)*.

- **Van der Laan, L.N.**, De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. Sweet Lies: neural, visual and behavioral measures reveal a lack of self-control conflict during food choice in weight-concerned women *(submitted for review)*.

- **Van der Laan, L.N.**, Hooge, I.T.C., De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. Do you like what you see? Associations between first gaze, gaze duration and consumer choice *(submitted for review)*.

- **Van der Laan, L.N.**, De Ridder, D.T.D., Viergever, M.A., Smeets, P.A. (2012). Appearance matters: the neural correlates of food choice and packaging attractiveness. *PLoS ONE*, 7(7), art. no. e41738.

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Conference presentations

- **Van der Laan, L.N.**, De Ridder, D.T.D., Viergever, M.A., Smeets, P.A.M. Sweet lies: Neural, visual and behavioral measures reveal a lack of self-control conflict during food choice in weight-concerned women (oral presentation). The 37th annual meeting of the British feeding & drinking group 2013 (Loughborough, United Kingdom).
- **Van der Laan, L.N.**, de Ridder, D.T.D., Viergever, M.A., Smeets, P.A.M. On resisting forbidden fruits: neural correlates of food choice (poster presentation). The 10th Dutch Endo-Neuro-Psycho meeting 2012 (Lunteren, The Netherlands).
- **Van der Laan, L.N.**, de Ridder, D.T.D., Viergever, M.A., Smeets, P.A.M. On resisting forbidden fruits: neural correlates of food choice (poster presentation). The 12th annual meeting for the organisation for Human Brain Mapping 2012 (Beijing, China).
- **Van der Laan, L.N.**, de Ridder, D.T.D., Viergever, M.A., Smeets, P.A.M. On resisting forbidden fruits: neural correlates of food choice (oral presentation). The 5th European conference on sensory and consumer research 2012(Bern, Switzerland).
- **Van der Laan, L.N.**, Hooge, I.T.C, de Ridder, D.T.D., Viergever, M.A, Smeets, P.A.M. Love at first sight or a deliberate decision? Associations between first gaze, gaze duration and consumer choice (oral presentation). The 9th Pangborn sensory science symposium 2011 (Toronto, Canada).
- **Van der Laan, L.N.**, de Ridder, D.T.D., Viergever, M.A., Smeets, P.A.M. Appearance matters: neural correlates of packaging aesthetics predict consumer choices (poster presentation). The 17th annual meeting of the organization for Human Brain Mapping 2011 (Quebec city, Canada).
- **Van der Laan, L.N.**, Smeets, P.A.M., de Ridder, D.T.D., Viergever, M.A. The neuroscience of food reward (oral presentation in symposium). The 8th conference on Psychology & Health 2010 (Lunteren, The Netherlands).
- **Van der Laan, L.N.**, Smeets, P.A.M., de Ridder, D.T.D., Viergever, M.A. The neural correlates of processing visual food cues: an ALE meta-analysis (poster presentation). The 16th annual meeting of the organization for Human Brain Mapping 2010 (Barcelona, Spain).
- **Van der Laan, L.N.**, Smeets, P.A.M., de Ridder, D.T.D., Viergever, M.A. The neural correlates of processing visual food cues: an ALE meta-analysis (oral presentation). The 34th annual meeting of the British feeding and drinking group 2010 (Maastricht, The Netherlands).

National and international invited presentations

- Guest college ‘The role of neuroscience in packaging design’. Rotterdam school of management, Erasmus University, February 2013 (Rotterdam, The Netherlands).
- Guest college ‘Eye-tracking en neuromarketing’. Hogeschool van Arnhem en Nijmegen, September 2012 (Nijmegen, The Netherlands).
- Guest college ‘Van het oog naar het brein’. Hogeschool van Arnhem en Nijmegen, March 2012 (Nijmegen, The Netherlands).
- Seminar ‘Biomarkers of food reward and decision-making’. MAPP - center for research on costumer relations in the food sector, Aarhus University, November 2011 (Aarhus, Denmark)

Awards and bursaries

- Student bursary of The 37th annual meeting of the British feeding & drinking group 2013.
- Student bursary award of the 5th European conference on sensory and consumer research 2012.
- Student bursary award of the 9th Pangborn sensory science symposium 2011.
- Student bursary of the 34th annual meeting of the British feeding and drinking group 2010

Curriculum Vitae

Nynke van der Laan was born on May 30th 1984 in Groningen, the Netherlands. In 2002, she graduated from secondary school (VWO) at the Rölingcollege Belcampo in Groningen. In the same year she started her bachelor study on Nutrition & Health at Wageningen University, which she finished in 2005 with a BSc thesis on the difference in satiating effects between solid and liquid foods. Subsequently, she enrolled in the MSc study Nutrition & Health and specialized in the two directions Nutrition in Health and Disease and Nutritional and Public Health Epidemiology. Her first MSc-research, which was under the supervision of the department of Human Nutrition and Communication Science at Wageningen University, was on the association between parental child-feeding strategies and the vegetable intake and preference of school-aged children. The second MSc-research, carried out at the National Institute for public health and the environment (RIVM), was on the association between early (breast- and complementary) feeding and the development of atopic eczema in children. She did an internship at the Municipal Health Services in Nijmegen and was involved in an epidemiological study on prevalence and treatment of overweight and underweight children. During her MSc study she was part of the board of the study association Di-Et-Tri (chair and commissary of education) and she worked one year full time as a board member of the Wageningen Student Union WSO. During her MSc study she also worked as tutor in statistical courses for nutritionists and as a research assistant on a sensory study on the influence of food aromas on satiety. In January 2009 she graduated and a month later (February 2009) Nynke started her PhD at the Image Sciences Institute, University Medical Center Utrecht. This PhD-project was part of a collaborative AgentschapNL project entitled 'Onbewust gezonder' which involved Friesland Campina and the department of packaging design and management of the University of Twente. The aim of the PhD-project was to establish the potential of implicit markers (1) to predict food choice and (2) to gain insight into the decision-making processes underlying food choice. The results of the studies conducted as part of the PhD-project are described in this thesis.