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Research report

Subtypes of trait impulsivity differentially correlate with neural responses to food choices

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HIGHLIGHTS

- Twenty females performed an fMRI food choice task.
- Delay discounting correlates with number of high energy food choices.
- Impulsivity correlates with food choice-related brain activation in striatum.

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ABSTRACT

Impulsivity is a personality trait that is linked to unhealthy eating and overweight. A few studies assessed how impulsivity relates to neural responses to anticipating and tasting food, but it is unknown how impulsivity relates to neural responses during food choice. Although impulsivity is a multi-faceted construct, it is unknown whether impulsivity subtypes have different underlying neural mechanisms. We investigated how impulsivity correlates with brain responses during food choice and in how far different impulsivity subtypes modulate brain responses during food choice differently. Twenty weight-concerned females performed an fMRI task in which they indicated for high and low energy snacks whether or not they wanted to eat them. Impulsivity subtypes were measured by the monetary delay discounting task and the Barratt Impulsiveness Scale (total BIS-11 and subscales). Only temporal subtypes of impulsivity, namely delay discounting and the BIS-11 non-planning subscale, modulated responses to food choice; both measures correlated positively with striatum activation during high versus low energy choices. However, only delay discounting predicted high energy choices, whereas BIS-11 non-planning independently related to a striatum region that reflects subjective stimulus value. To conclude, the brain mechanisms underlying subtypes of impulsivity have a common ground but differ in specific aspects of food-related decision-making. The findings advance our understanding of the neural correlates of different impulsivity subtypes in the food domain.

1. Introduction

In the current Western environment, palatable high energy foods are omnipresent and this is thought to be an important contributor to unhealthy eating and the epidemic of overweight [1]. However, not every individual is equally susceptible to the presence of these immediately rewarding foods: there are large individual differences in personality that relate to the ability to regulate food choices [2,3]. A personality trait that has been repeatedly linked to unhealthy food choices and overweight/obesity is impulsivity [2,4–7]. Impulsivity is a complex and multifaceted construct, comprising of impaired behavioral inhibition, increased reward sensitivity, acting without thinking, and favoring immediate rewards over long-term goals [8–10]. Accordingly, a wide range of measures are employed to measure subtypes of impulsive behavior, including questionnaires that rely on an individuals' self-perception of behavior, and computer-based behavioral tasks that measure overt behavior related to impulsivity [9].

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The link between impulsivity and BMI has been shown in many studies, in many different populations, and with a wide range of impulsivity measures (for reviews, see [2,11]). On average obese individuals are more impulsive than normal weight individuals [12–14]. In line with this, several studies have reported positive correlations between impulsivity and BMI [15,16]. Furthermore, Sutin et al. [17] found that their top 10% most impulsive participants weighed on average 11 kg more than the bottom 10%. Moreover, Ryden et al. [18], who investigated a group of obese individuals, showed that more severely obese men were more impulsive than less severely obese men.

Also, in normal weight individuals, impulsivity is related to eating behavior. More impulsive individuals have a higher preference for high energy foods [19] and eat more in experimental settings [5,20,21]. Furthermore, high impulsivity is related to increased snacking [22] and non-obese individuals (BMI < 30) high in impulsivity have higher total energy intake in an experimental setting [23]. A large longitudinal study showed that high impulsivity scores are related to weight gain [17]. Furthermore, they found that individuals higher in impulsivity had more weight fluctuations, an effect that remained significant when controlling for baseline BMI.

An explanation for this link between impulsivity, overeating and excess weight is that more impulsive individuals are more tempted by immediately rewarding foods, which are generally higher in sugar and fat than bland foods. Also it has been proposed that impulsive individuals have more difficulty in sticking to longer term goals and controlling their direct impulses. Lastly, it has been proposed that highly impulsive individuals might be less good at planning meals, which might promote snack food consumption [11].

Despite the robust link between impulsivity and unhealthy eating behavior, only a few neuroimaging studies have analyzed how impulsivity and its subtypes modulate brain responses to foods [24–27]. To our knowledge, only one single study investigated how individual differences in impulsivity modulate neural responses to food cues [25]. In this study, higher impulsivity was related to increased activation in the anterior cingulate cortex and amygdala during anticipation of a pleasant taste and increased activation in the caudate during taste receipt. For reward sensitivity it has been shown that individuals high on this construct have stronger activation in reward areas like the medial orbitofrontal cortex (OFC), ventral striatum, amygdala and ventral tegmental area (VTA) in response to images of pleasant foods [24], although null-findings have also emerged [26,27].

There appear to be at least two gaps in our knowledge of the neural mechanisms underlying impulsivity in the food domain. First, it is unknown how impulsivity modulates neural responses during the behavior that actually initiates intake, i.e., during food choice. Earlier studies used taste stimuli or food image paradigms which measure responses related to anticipation and consumption [24–27]. Food choice constitutes more than anticipation alone: for many individuals, for example those who have the long-term goal to eat healthy or to lose weight, food choices require a trade-off between the immediate reward of eating a palatable food and their longer term health or dieting goal [28]. The outcome of this trade-off, that is, which food is chosen, is influenced by impulsivity [29]. Since eating behavior is ultimately determined by a series of food choices, it is crucial to know how impulsivity impacts on the underlying neural mechanisms of food choice.

The second knowledge gap concerns the multifaceted nature of impulsivity. The term impulsivity is regarded as an umbrella term for different subtypes and personality facets that relate to impulsive behavior. There are several theoretical models that explain impulsive behavior, which all have their own set of self-report and/or behavioral measurements. For example, Gray's biopsychological theory of personality led to the development of the BIS/BAS scales [30], the Five Factor model of personality led to the development of the UPPS [31], and Eysenk's personality theory [32] led to the development of the I7 (for reviews see [2,11,33]). Though the different models of impulsivity emphasize different aspects, researchers generally agree that there are three subtypes that have their approximate equivalent in the majority of the operationalizations of impulsivity [2,11,34]. The first broad subtype refers to the responsivity/sensitivity to reward, and the behavioral preference of short term gains over long term ones, which is sometimes denoted temporal impulsivity [11,35]. This subtype is measured by delay gratification paradigms (Metcalfe & Mischel, 1991, Psychol. Rev.) [83], delay discounting tasks [36] and several self-reports (non-planning subscale of the BIS-11 [37], Lack of premeditation subscale of the UPPS [31] and the BAS-scales of the BIS/BAS [30]. The second subtype refers to insufficient response inhibition, i.e., responding immediately without thinking. This subtype is operationalized by behavioral tasks (e.g., Stop signal task [38]) and self-report scales (e.g., Motor impulsivity subscale of the BIS-11 [37], Urgency subscale of UPPS [31], functional and dysfunctional impulsivity subscales of Dickman Impulsivity Inventory [39]). The third subtype refers to the inability to concentrate (Attentional impulsivity subscale of BIS-11 [37], Lack of perseverance subscale of UPPS [31]). In addition to these three, there are several subtypes which are less often noted as independent factors, like the tendency to pursue novel exciting activities (Sensation-seeking subscale of UPPS [31], BAS fun-seeking subscale of BIS/BAS scales [30]). In the behavioral field, several attempts have been made to confirm these independent subtypes by performing factor analyses on multiple impulsivity constructs [9,35,40]. Despite differences in exact mapping and labeling of impulsivity subtypes, there is general consensus that impulsivity is not a unitary construct, and represents multiple independent subtypes [9,35,40]. However, neuroimaging studies linking impulsivity with food-induced brain responses typically acquire a single measure and denote it as 'impulsivity', disregarding the wide array of processes and subtypes contributing to impulsive behavior [24–27]. Also, only self-report measures of impulsivity have been employed in the study of food-induced brain responses.

Although several single subtypes of impulsivity and self-report as well as behavioral measures of impulsivity have been linked to unhealthy eating and overweight [2,11], it has been suggested that these different subtypes tap into different underlying (neural) processes [9,40–42]. Temporal impulsivity and sensitivity to reward are thought to relate to a ventral striatal related circuit [24,34] while insufficient response inhibition has been linked to prefrontal structures like the dorsolateral prefrontal cortex [43,44]. Furthermore, it has been shown that behavioral and self-reported measures of impulsivity often do not correlate [9,35]. Therefore, it has been suggested that they may have different underlying (neural) mechanisms [9,35]. To date, it has not been tested how different impulsivity subtypes modulate the neural processes underlying food choice.

The present study intended to fill these gaps. The first aim was to determine how impulsivity modulates neural responses during food choice. The second aim was to investigate whether differ-

Table 1
Means and standard deviations ($n = 20$) of the scores on the delay discounting task and the BIS-11.

	Mean	Standard deviation
Delay discounting score	0.011	0.016
BIS-11 total score	57.35	6.64
BIS-11 motor subscale[a]	1.84	0.28
BIS-11 attentional subscale[a]	1.96	0.24
BIS-11 non-planning subscale[a]	1.95	0.32

[a] Score divided by the number of questions in the subscale.

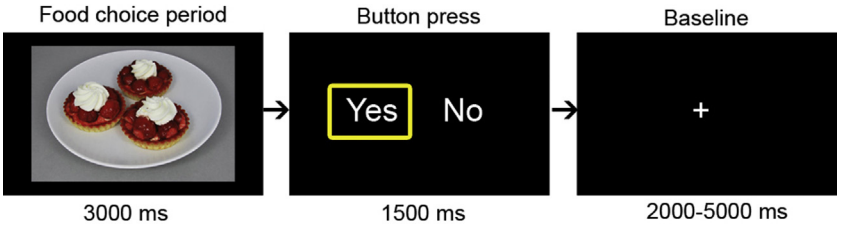

Fig. 1. fMRI food choice task trial structure.

ent subtypes of impulsivity modulate brain responses during food choice differently. Earlier studies showed that energy rich – more rewarding – foods elicit stronger ventral striatum responses than foods with less energy [45] during passive viewing. Furthermore, it has been shown that highly impulsive individuals differ from controlled individuals in functional connectivity between the ventral striatum and vmPFC during nonfood choices [46]. Therefore, we expected that impulsivity would correlate with brain responses to food in ventral striatum and vmPFC.

2. Materials and methods

2.1. Participants

Part of these data have been published in a previous paper [47], an extensive description of methods can be found there. Here, extra data on impulsivity measures is presented. Twenty normal-weight women (age: $M = 21.2$ years, SD = 2.8; BMI: $M = 21.3$, SD = 1.7) who were all weight-concerned and occupied with being slim, participated in the study. Weight-concern was defined as having an above average or higher restraint score on the Dutch Eating Behaviour Questionnaire (reference table for female students; [48]) as well as a rating of six or higher on the following two questions: 'To what extent are you weight-concerned?' and 'To what extent are you occupied with being slim?' (on a scale from one to nine, adapted from 28). Only weight-concerned women were recruited because earlier research had shown that individuals high in dietary restraint/weight concerns only overeat when they are also impulsive [29]. Only women were included, because of known gender differences in levels of weight-concern and differences in brain anatomy and functional responses to food [49–53]. Additional inclusion criteria were having an age between 18 and 30 years, having a normal weight (BMI between 18.5 and 25 kg/m^2), being right-handed. Exclusion criteria consisted of standard MRI exclusion criteria (no irremovable metal in the body or claustrophobia), having a food allergy, being vegetarian, having an eating disorder, and having a history of medical or surgical events that might affect the study outcome, such as metabolic or endocrine disease, or a gastro-intestinal disorder. Smokers and individuals having a current alcohol consumption of >28 units per week were also excluded. We excluded women that followed a medically prescribed diet in the past 6 months or that had weight fluctuations of more than five kg in the past six months.

Participants were recruited with posters and flyers at the University Medical Center Utrecht and the adjacent university campus. The poster mentioned that normal-weight female subjects between the ages of 18 and 30, non-vegetarians, without food allergies and irremovable metal in the body were wanted for a study on brain responses to food. Potential subjects received an information brochure and a screening questionnaire on inclusion/exclusion criteria. Fifty-six potential subjects returned their screening questionnaire. Of these, 20 were excluded because of low dietary restraint or weight-concerns, three were vegetarian, three were current or past smokers, two had a too high BMI, two reported a current or past eating disorder, two had a gastrointestinal disorder, two had a food allergy, one was left-handed, and one had irremovable metal in the body.

All participants provided informed consent in accordance with the Declaration of Helsinki, and the Medical Ethical Committee of the University Medical Center Utrecht approved all procedures.

2.2. Procedure

The study consisted of two sessions. During the first session participants completed several questionnaires and computer tasks, including the impulsivity measures described below. One to eight days later participants completed the second session, at approximately the same time of the day as the first session. In advance they were instructed to refrain from eating and drinking (except water) for two hours before the start of the session, so that they would be craving for a snack. Participants were scanned with fMRI (3T) while they performed two food choice tasks (of which the first is analyzed in this study, as described below). Before and after scanning they rated their hunger, thirst and satiety on a visual analog scale. Finally, participants received a snack of their choice, were thanked and reimbursed.

Table 2
Brain regions with a significant correlation between delay discounting score and activation during HE food choice periods compared with LE food choice periods.

Brain region	Side	x	*y*	*z*	k***	*Z*-value	$p_{FWE\text{-corrected}}$	Effect size[a]
ROIs*								
Striatum (putamen)	*L*	−22	4	−10	11	3.62	0.028	0.81
Striatum (caudate)	*R*	14	4	18	69	3.62	0.029	0.81
Whole brain**								
Middle frontal gyrus	*L*	−22	8	38	41	4.16	N.A.	1.0
Supplementary motor area	*L*	−2	4	46	41	3.50	N.A.	0.78
Caudate	*R*	14	4	18	12	3.62	N.A.	0.81
Caudate	*R*	18	12	6	12	3.23	N.A.	0.72

* Peaks significant at $p < .05$ FWE-corrected on ROI level are reported.
** Peaks significant at $p < .001$ uncorrected, $k > 12$ voxels are reported.
*** Extent of the cluster to which the peak belongs (at uncorrected threshold, i.e. $p < .005$ an $k > 3$ for ROIs or $p < .001$ and $k > 12$ for whole brain results).
[a] Effect size = Z-score/$\sqrt{n}$.

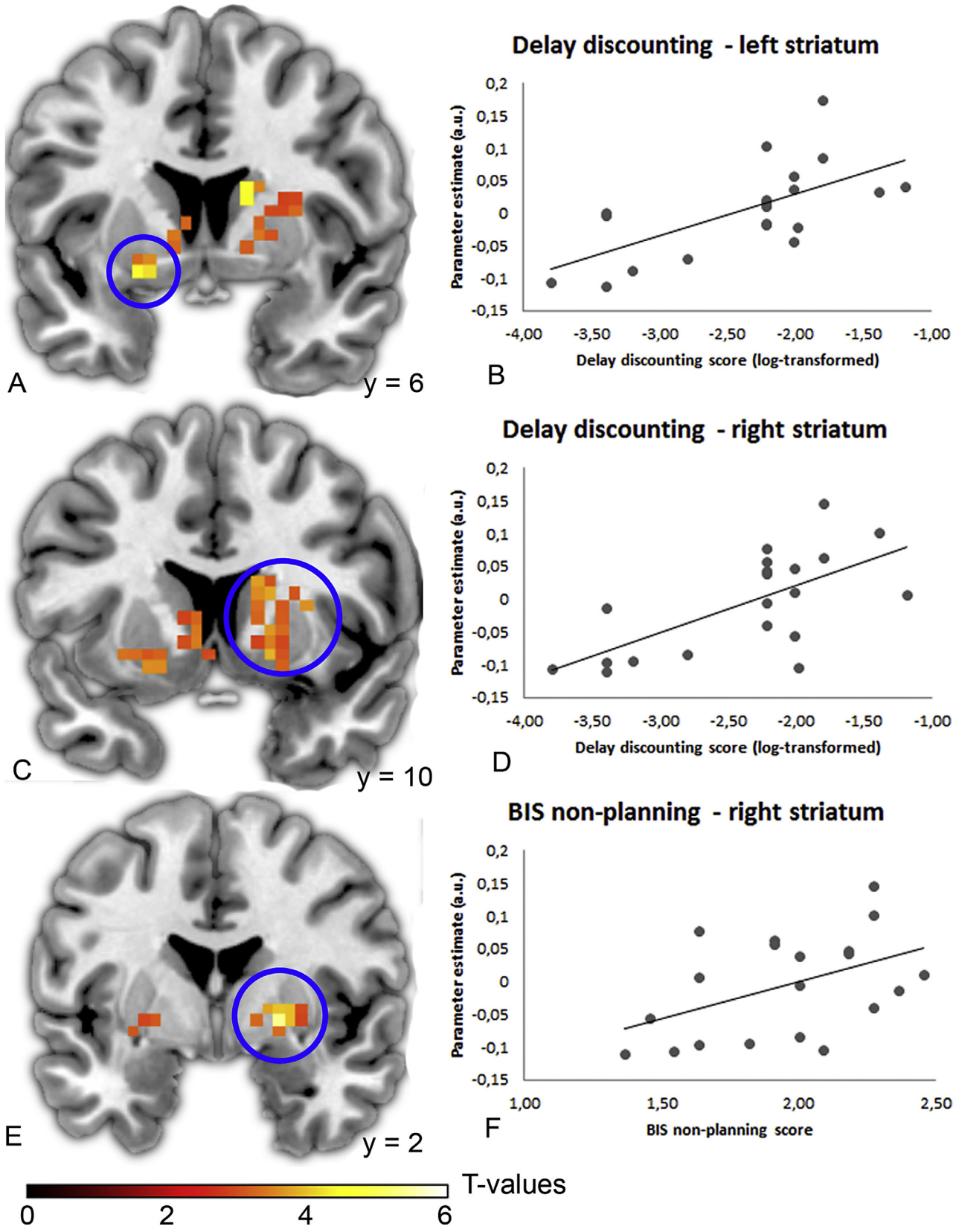

Fig. 2. Brain regions in which activation correlates with impulsivity during high energy versus low energy food choices: (A–B) correlation with delay discounting in left striatum, (C–D) correlation with delay discounting in right striatum, (E–F) correlation with BIS-11 non-planning in right striatum. For visualization purposes, activation maps are thresholded at $T > 2.8$ and masked for ROIs. The scatter plots show the impulsivity score on the *x*-axis and the mean parameter estimate of the respective significant cluster for the contrast high energy versus low energy food choices on the *y*-axis; each dot represents a subject.

2.3. Measures of impulsivity

To tap into the different subtypes of impulsivity, the two most widely used self-reported and behavioral measures of impulsivity were obtained: the Barratt Impulsiveness Scale [BIS-11; 37] and the monetary delay discounting task [36]. The BIS-11 has good psychometric properties [54] and assesses impulsivity on three subscales, namely 'motor impulsivity' (acting without thinking), 'attentional impulsivity' (inability to focus attention or concentrate), and 'non-planning impulsivity' (lack of future orientation or forethought) [42,54]. The monetary delay discounting task provides a measure of the value of delayed relative to immediate rewards. In the monetary delay discounting task, participants chose between large delayed monetary rewards and smaller more immediate monetary rewards. A higher discount rate indicates a relatively strong valuation of the immediate reward and a relatively low willingness to withstand the delay [36]. The higher the discount rate, the more impulsive the person is considered to be [36,55]. We used a computerized version of the monetary delay discounting questionnaire of Kirby et al. [36]. The 27 questions were presented one at a time and subjects had to indicate their choices with a button press. The questions were identical to those of Kirby et al. [36] except that dollar signs were replaced by euro signs. An estimate of a participant's discounting rate (k) was calculated from the participant's pattern of choices with the estimation procedure described in the article of Kirby et al. [36].

2.4. Food choice fMRI task

During the functional MRI scan, participants indicated whether or not they wanted to eat each of 100 snacks that were either high (HE, energy content in kcal/100 g: $M = 419$, SD = 103) or low (LE, $M = 56$, SD = 37) in energy. In each trial, the food picture was presented for 3 s (food choice period), after which the words 'yes' and 'no' appeared left/right (randomized) on the screen for 1.5 s (button press period, Fig. 1). During the button press period participants could indicate whether they wanted to eat the snack or not. To ensure that their choices were actually made in direct response to the food pictures, participants were instructed to make their choice already during the period that the image was shown (food choice period). The button press period was so short that it only allowed them to locate whether they had to push the left or right button. At the beginning, halfway and at the end an additional baseline period of 30 s was included. In order to make the choices realistic, participants actually received one portion of one of the snacks they chose at the end of the study session.

2.5. Behavioral data analyses

Correlations between impulsivity scores and the number of HE and LE food choices were calculated with SPSS Statistics 20. Delay discounting scores were log-transformed to correct the skewed distribution.

2.6. fMRI analyses

2.6.1. Image acquisition and preprocessing

MRI scanning was performed on a 3 tesla scanner (Philips Achieva, Philips Healthcare, Best, The Netherlands). An anatomical image was acquired at a resolution of $1 \times 1 \times 1$ mm. Functional scans were acquired with a 2D-EPI sequence (resolution: $4 \times 4 \times 4$ mm; TR: 1400 ms). The total number of volumes acquired differed between participants because of the random inter-trial interval (range: 540–580).

Preprocessing and analysis was conducted with SPM8 (Wellcome Department of Imaging Neuroscience, London, United Kingdom) ran with MATLAB R2013B (The Mathworks Inc., Natick, MA). Functional images were realigned to the first image of the time series. Functional and anatomical images were co-registered and normalized (retaining $4 \times 4 \times 4$ mm voxels) to MNI space [56]. The data were smoothed with an isotropic Gaussian kernel of 8 mm full width at half maximum. Further details about acquisition and preprocessing can be found elsewhere [47].

2.6.2. Subject 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. Four conditions were modeled: the choice periods of HE trials, those of LE trials, the button press periods, and the practice trial and missed trials. A contrast image was calculated for every participant by subtracting the mean response during LE choice periods from that of HE choice periods.

2.6.3. Group level analyses

To test where impulsivity correlates with neural responses during HE vs LE food choices, the contrast images were entered into one-sample t-tests with the delay discounting score or one of the BIS-11 (subscale) scores as covariate of interest. To examine the overlap in variability in brain activation explained by delay discounting impulsivity and BIS-11 impulsivity, both covariates were entered in a one-sample t-test simultaneously to examine the effect of either of the variables controlled for the other.

Statistical significance was determined according to a two-step procedure. First, the whole-brain results were thresholded at a threshold of $p < 0.005$ uncorrected with an extent threshold of $k > 3$. In the next step, small volume correction (SVC) was applied to clusters within a priori ROIs, with a threshold for peaks at $p < .05$ family-wise error (FWE) corrected. SVC is a widely used ROI approach in fMRI studies [24,57,58,59]. A priori ROIs were brain regions known to activate in response to food and shown to respond differently during choice in impulsive individuals in non-food domains [45,46,60]: the left and right striatum and left and right ventromedial PFC (vmPFC). We constructed a mask for each a priori ROI. ROI masks were generated using the AAL atlas as implemented in the WFU pickatlas toolbox [61,62]. The left striatum ROI was constructed by combining the following AAL labels: the left pallidum, putamen and caudate. The left vmPFC ROI was constructed by combining the following AAL labels: left orbital part of the medial frontal gyrus and left orbital part of the superior frontal gyrus. The right vmFPC and striatum ROIs were defined in the same fashion with the right-sided structures.

To facilitate future meta-analyses, we also provide whole brain results thresholded at $p < 0.001$ uncorrected with a cluster extent of $k > 12$ voxels.

3. Results

3.1. Behavioral results

The means and standard deviations of the impulsivity measures can be found in Table 1. There was no significant correlation between delay discounting score and BIS-11 score (total nor subscales). Participants accepted 62% of the LE snacks and 48% of the HE snacks. There was a positive correlation between delay discounting score and the percentage of trials in which participants accepted the HE snack ($r = .50$, $p < .05$). There was no significant correlation between the BIS-11 impulsivity score (total nor subscales) and the percentage of accepted HE or LE snacks.

Table 3
Brain regions with a significant correlation between BIS non-planning scale and activation during HE food choice periods compared with LE food choice periods.

Brain region	Side	*x*	*y*	*z*	*k*[***]	*Z*-value	$p_{FWE\text{-}corrected}$	Effect size[a]
ROIs[*]								
Striatum (pallidum)	*R*	22	0	−2	22	4.10	0.005	0.92
Whole brain[**]								
Pallidum	*R*	22	0	−2	12	4.10	N.A.	0.92

[*] Peaks significant at $p < .05$ FWE-corrected on ROI level are reported.
[**] Peaks significant at $p < .001$ uncorrected, $k > 12$ voxels are reported.
[***] Extent of the cluster to which the peak belongs (at uncorrected threshold, i.e. $p < .005$ an $k > 3$ for ROIs or $p < .001$ and $k > 12$ for whole brain results).
[a] Effect size = *Z*-score/$\sqrt{n}$.

3.2. Modulation of the neural response during food choice by impulsivity

In the HE vs LE contrast a positive correlation was found between impulsivity as measured with the delay discounting task and activation in the bilateral striatum (left hemisphere: $z = 3.62$; right hemisphere: $z = 3.62$; Table 2; Fig. 2). Thus, more impulsive women showed more activation in the bilateral striatum during HE compared with LE food choices.

No significant correlation was found between BIS-11 total score and activation in any of the ROIs. The BIS-11 non-planning score, however, correlated positively with activation in the right striatum during HE vs LE food choices ($z = 4.10$; Table 3; Fig. 2). There was a trend in the left striatum (putamen) (MNI: −30, 8, 2; $z = 3.29$, $p_{FWE\text{-}corrected} = 0.065$).

3.3. Overlap and differences between subtypes of impulsivity

Fig. 3 shows the overlap of clusters for the impulsivity measures as single covariates. As a final step, we examined if the variability in brain activation during food choice explained by delay discounting impulsivity and BIS non-planning impulsivity overlap, by combining both covariates in one model. When controlled for BIS-11 non-planning impulsivity, there were no significant correlations of delay discounting score with activation in any of the ROIs. Controlled for delay discounting score, the peak in the right pallidum correlating with BIS-11 non-planning score remained significant (MNI: 22, 0, −2; $z = 3.73$, $p_{FWE\text{-}corrected} = 0.021$).

4. Discussion

We investigated how impulsivity correlates with neural responses during food choice. Earlier studies showed that during passive viewing or tasting of experimental food stimuli, a wide network of brain regions correlates with impulsivity and related concepts, such as reward sensitivity [24,25]. Our study extends these findings by being the first to correlate impulsivity with brain response during an activity that more closely resembles real eating behavior, namely during deciding what to eat. We found that impulsive individuals had stronger activation in the striatum during HE vs. LE food choices, which is in line with the key role of the striatum in reward processing [63]. Earlier studies showed that more impulsive individuals have a stronger nucleus accumbens response to predictors of nonfood rewards [64,65] and that highly impulsive individuals differ from controlled individuals in functional connectivity between the ventral striatum and vmPFC during nonfood choices [46]. Likewise, it has been shown that highly impulsive human subjects show increased D2/3 receptor availability in the nucleus accumbens [66]. In rat models it has been shown that high impulsivity is related to increased transcription of ΔFosB, a protein that is implicated as a critical factor in developing addictions, in the nucleus accumbens shell, following exposure to a rewarding food [67]. Together with these earlier findings, our results suggest that individual differences in the functioning of the striatum affect impulsivity and therefore underlie important personality-related differences in behavior.

As stated earlier, there is strong evidence that impulsivity is related to overweight and obesity [2,11]. Also, in normal weight subjects and in mixed populations, impulsivity has been linked to stronger preferences for energy rich foods and higher food intake [2,20,21]. Moreover, higher impulsivity is related to weight gain [17] and high impulsivity may hinder the treatment of obesity [68]. Our finding, that more impulsive individuals have a stronger striatal response to food choice, provides a neurobiological explanation for the abovementioned behavioral finding that they are more likely to eat unhealthy and be overweight/obese [2,4–7]. There is over-

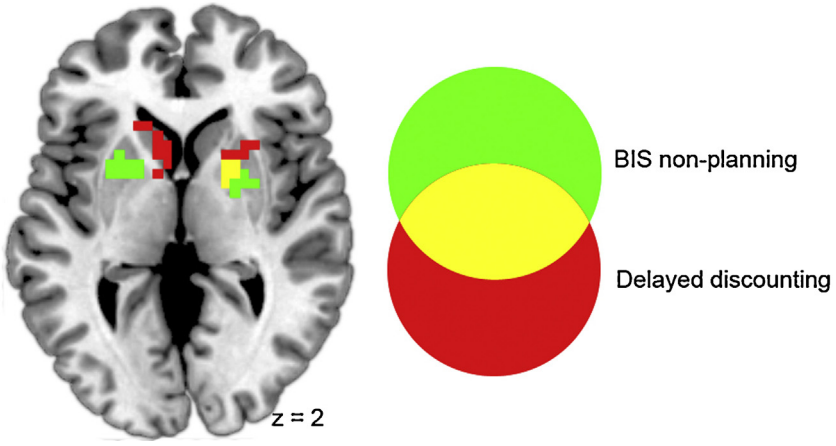

Fig. 3. Behavioural (delayed discounting, green) and self-reported temporal impulsivity (BIS-11 non-planning, red) modulate food choice-related activation in partially overlapping regions (yellow) of the right striatum. For visualization purposes, clusters are thresholded at $T > 2.8$ and masked for ROIs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

whelming evidence that a stronger striatum response (i.e., caudate, putamen and nucleus accumbens) to food (tasting, viewing pictures, food commercials) predicts future weight gain [69–73]. Thus, our findings suggest that the stronger striatal responsivity during food choice of more impulsive individuals might be a causal risk factor which increases the vulnerability of impulsive individuals to overeating.

This study also examined the overlap and differences in how distinct measures of impulsivity modulate brain activation during food choice. This distinction in underlying neural mechanisms is important, because not all aspects of impulsivity relate similarly to eating behavior [2]. To characterize which aspects of impulsivity are important for food choice, we assessed how multiple impulsivity subtypes relate to food choice-related brain activation. We found that only delay discounting and BIS-11 non-planning correlated positively with food choice-related activation. The other aspects of impulsivity, motor impulsivity and attentional impulsivity did not correlate with food choice-related activation. Both delay discounting and BIS non-planning are regarded as measures of the temporal aspect of impulsivity [35]. Thus, our findings suggests that in particular the temporal aspect of impulsivity plays a role in HE vs LE food choices rather than motor or attentional aspects of impulsivity. This finding is in line with the notion that food choices pose a temporal dilemma between the immediate eating enjoyment (eating palatable HE foods) and future health or dieting goals [28] [e.g.,28]. That HE food choices trigger a stronger striatal response in impulsive individuals compared to LE food choices is also in line with the notion that impulsive individuals have a stronger preference for HE foods [19].

Different aspects of impulsivity have not robustly been found to correlate with one another [9,40,74–78], but at least two studies did report a correlation between delay discounting and BIS-11 non-planning [35,41]. Our finding, that there is overlap in regions where delay discounting and BIS non-planning modulate food choice-related activation, supports the notion that these two aspects of temporal impulsivity may have an – at least partial – common underlying neural basis. The finding is especially interesting because BIS-11 non-planning measures impulsivity in a broad range of behavioral domains (i.e., measuring generalized impulsivity) and delay discounting measures impulsivity solely in the monetary domain. Though the peaks for delay discounting and BIS-11 were at somewhat different locations within the striatum, this is in line with the notion that impulsivity is a general personality trait, which is expressed in several different behavioral domains. Interestingly, one earlier study also showed that impulsivity (as measured with BAS-drive), was related to striatal responses to passively viewing food pictures [24]. Though the peak of the activation within the striatum was not at exactly the same location, this does suggests that BAS-drive maps to the temporal impulsivity subtype. Also, since similar results were found for passive viewing of food pictures, this suggests that impulsivity modulates brain responses to food irrespective of whether the subject has to choose.

Previously, it was suggested that self-reports of impulsivity and behavioral tasks measure different underlying constructs [9], which would suggests that neural correlates would be in different areas of the brain. In contrast with this notion, our findings for self-reported and behaviorally measured temporal subtype of impulsivity showed that the neural correlates underlying the trait are partly overlapping. Though this has to be confirmed for the other subtypes (e.g., self-reported response inhibition vs behavioral tasks measuring response inhibition) in future research, it does imply that self-reports and behavioral tasks of impulsivity might be more similar than previously suggested.

By testing a model with both delay discounting and BIS-11 non-planning as factors modulating brain response to food choices, we found that BIS-11 non-planning explained unique variance in a part of the striatum (pallidum) that has been related to subjective valence of rewarding outcomes in a meta-analysis on a wide range of fMRI choice paradigms [79]. The finding that mainly self-reported BIS-11 non-planning explains variation in this area might indicate that individuals who perceive their own behaviour as more impulsive also perceive HE foods as having a higher value. We speculate that this subjective experience of value of HE foods might be better reflected by a self-reported measure than by a behavioural measure of impulsivity.

A reason why temporal impulsivity measured by delay discounting correlates significantly with HE food choices whereas self-reported temporal impulsivity (BIS-11 non-planning) does not, could be that the monetary delay discounting and food choice task both assess actual choices, while BIS-11 non-planning measures individuals' self-perception of behaviour. This finding adds to the growing body of evidence that self-perceptions of behaviour might not be accurate for describing actual behaviour, because self-reports only reflect motives and behaviours that individuals are conscious of and because individuals are prone to socially desirable answering [80]. Thus, these observations suggest that, while self-reports of impulsivity might relate very well to subjective experience, their relation with actual behaviour is less robust.

It should be noted that our study population consisted of young females who had the explicit goal to watch their weight. Therefore, caution should be taken to generalize the findings from our current study to other populations. We used the Dutch version of the BIS-11 as self-report of impulsivity. The internal consistency of the BIS-11 in this study was acceptable.

Our results provide insights into the neurobiological mechanisms underlying impulsivity in relation to unhealthy food choices. It could be speculated that in natural environments where food was scarce, impulsivity may have played an adaptive role by enhancing reward-related responsiveness (striatum response) and shifting decision-making towards the selection of HE foods. However, in today's environment of food abundance, the same neurobiological mechanisms could instead promote overeating and predispose impulsive individuals to weight gain. By linking personality characteristics to food-induced brain responses, this study contributes to the establishment of simple measures, such as questionnaires and behavioral tasks, to screen individuals on their neurobiological predisposition for unhealthy eating and weight gain. Since earlier reviews and meta-analyses indicated that many personality characteristics are interrelated [2,3], future studies should include a wide range of general and food-specific personality characteristics as well as proxies for eating behavior, such as weight-change. In this way, personality-related differences in brain responses to food may be linked to the risk of becoming overweight.

Identifying the neural and trait profile associated with overweight and weight gain may help to inform future intervention research. Although personality traits are considered stable traits, the expression of these traits is thought to be amenable. As such, interventions that aim to modify characteristic impulsive eating behaviours may be the most effective. We found the temporal subtype of impulsivity was related to the number of HE food choices and correlated with striatal activation during choice. Since this subtype is related to having a preference for immediate rewards and a lack of future orientation, this suggests that interventions that stress menu planning and regular meal schedules might be helpful [11]. In addition, since we found that impulsive individuals have a higher reward-related response in the ventral striatum during choices concerning energy rich foods, they might benefit from avoiding eating situations in which they are confronted with particularly tempting high energy foods. Intervention approaches that could decrease the reward-related response in the striatum to high energy foods might also be helpful for highly impulsive individuals. It has been shown that suppression (supressing thoughts

about hunger and eating), which is a short-term cognitive control strategy, is successful in decreasing striatal responses to food and reducing food craving [81,82]. It should however be noted that the participants in the study of Siep et al. [81] scored within the normative population range of impulsivity and that the effect of Wang et al. [82] was only significant in males. Therefore, future research should assess whether these cognitive strategies are also effective in decreasing striatal response to food in more impulsive individuals of both genders.

5. Conclusions

To conclude, impulsivity correlates with striatum activation during high versus low energy food choices, which is consistent with its key role in reward-driven behavior. The neural mechanisms underlying temporal impulsivity measured behaviorally and by self-reports have a common neural ground but differ in an area of the striatum related to value evaluation.

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References

[1] M. Ng, T. Fleming, M. Robinson, et al., Global, regional, and national prevalence of overweight and obesity in children and adults during a systematic analysis for the global burden of disease study 2013, Lancet (2014) 1980–2013.
[2] U. Vainik, A. Dagher, L. Dube, L.K. Fellows, Neurobehavioural correlates of body mass index and eating behaviours in adults: a systematic review, Neurosci. Biobehav. Rev. 37 (2013) 279–299.
[3] L.N. van der Laan, P.A. Smeets, You are what you eat: a neuroscience perspective on consumers' personality characteristics as determinants of eating behavior, Curr. Opin. Food Sci. 3 (2015) 11–18.
[4] R. Guerrieri, C. Nederkoorn, K. Stankiewicz, et al., The influence of trait and induced state impulsivity on food intake in normal-weight healthy women, Appetite 49 (2007) 66–73.
[5] R. Guerrieri, C. Nederkoorn, A. Jansen, The interaction between impulsivity and a varied food environment: its influence on food intake and overweight, Int. J. Obes. (Lond.) 32 (2008) 708–714.
[6] A.J. Jasinska, M. Yasuda, C.F. Burant, et al., Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults, Appetite 59 (2012) 738–747.
[7] I.H. Franken, P. Muris, Individual differences in reward sensitivity are related to food craving and relative body weight in healthy women, Appetite 45 (2005) 198–201.
[8] S. Dawe, M.J. Gullo, N.J. Loxton, Reward drive and rash impulsiveness as dimensions of impulsivity: implications for substance misuse, Addict. Behav. 29 (2004) 1389–1405.
[9] B. Reynolds, A. Ortengren, J.B. Richards, H. de Wit, Dimensions of impulsive behavior: personality and behavioral measures, Pers. Individ. Difer. 40 (2006) 305–315.
[10] F.G. Moeller, E.S. Barratt, D.M. Dougherty, J.M. Schmitz, A.C. Swann, Psychiatric aspects of impulsivity, Am. J. Psychiatry 158 (2001) 1783–1793.
[11] R. Guerrieri, C. Nederkoorn, A. Jansen, The effect of an impulsive personality on overeating and obesity: current state of affairs, Psychol. Top. 17 (2008) 265–286.
[12] D.K. Chalmers, C.A. Bowyer, N.L. Olenick, Problem drinking and obesity: a comparison in personality patterns and life-style, Int. J. Addict. 25 (1990) 803–817.
[13] C. Davis, K. Patte, C. Curtis, C. Reid, Immediate pleasures and future consequences. A neuropsychological study of binge eating and obesity, Appetite 54 (2010) 208–213.
[14] R.E. Weller, E.W. Cook III, K.B. Avsar, J.E. Cox, Obese women show greater delay discounting than healthy-weight women, Appetite 51 (2008) 563–569.
[15] E.B. Rasmussen, S.R. Lawyer, W. Reilly, Percent body fat is related to delay and probability discounting for food in humans, Behav. Process. 83 (2010) 23–30.
[16] S. Reimers, E.A. Maylor, N. Stewart, N. Chater, Associations between a oneshot delay discounting measure and age, income, education and real-world impulsive behavior, Pers. Individ. Differ. 47 (2009) 973–978.
[17] A.R. Sutin, L. Ferrucci, A.B. Zonderman, A. Terracciano, Personality and obesity across the life span, Pers. Soc. Psychol. 101 (2011) 579–592.
[18] A. Ryden, M. Sullivan, J.S. Torgerson, J. Karlsson, A.K. Lindroos, C. Taft, Severe obesity and personality: a comparative controlled study of personality traits, Int. J. Obes. Relat. Metab. Disord. 27 (2003) 1534–1540.
[19] C. Davis, S. Strachan, M. Berkson, Sensitivity to reward: implications for overeating and overweight, Appetite 42 (2004) 131–138.
[20] R. Guerrieri, C. Nederkoorn, K. Stankiewicz, et al., The influence of trait and induced state impulsivity on food intake in normal-weight healthy women, Appetite 49 (2007) 66–73.
[21] R. Guerrieri, C. Nederkoorn, A. Jansen, How impulsiveness and variety influence food intake in a sample of healthy women, Appetite 48 (2007) 119–122.
[22] S. Churchill, D.C. Jessop, Reflective and non-reflective antecedents of health-related behaviour: exploring the relative contributions of impulsivity and implicit self-control to the prediction of dietary behaviour, Br. J. Health Psychol. 16 (2011) 257–272.
[23] B.Y. Rollins, K.K. Dearing, L.H. Epstein, Delay discounting moderates the effect of food reinforcement on energy intake among non-obese women, Appetite 55 (2010) 420–425.
[24] J.D. Beaver, A.D. Lawrence, D.J. van, M.H. Davis, A. Woods, A.J. Calder, Individual differences in reward drive predict neural responses to images of food, J. Neurosci. 26 (2006) 5160–5166.
[25] K.L. Kerr, J.A. Avery, J.C. Barcalow, et al., Trait impulsivity is related to ventral ACC and amygdala activity during primary reward anticipation, Soc. Cogn. Affect Neurosci. 10 (January (1)) (2014) 36–42, http://dx.doi.org/10.1093/scan/nsu023.
[26] A. Schienle, A. Schafer, A. Hermann, D. Vaitl, Binge-eating disorder: reward sensitivity and brain activation to images of food, Biol. Psychiatry 65 (2009) 654–661.
[27] T.D. Watson, K.T. Garvey, Neurocognitive correlates of processing food-related stimuli in a Go/No-go paradigm, Appetite 71 (2013) 40–47.
[28] A. Fishbach, R.S. Friedman, A.W. Kruglanski, Leading us not unto temptation: momentary allurements elicit overriding goal activation, J. Pers. Soc. Psychol. 84 (2003) 296–309.
[29] A. Jansen, C. Nederkoorn, B.L. van, C. Keirse, R. Guerrieri, R. Havermans, High-restrained eaters only overeat when they are also impulsive, Behav. Res. Ther. 47 (2009) 105–110.
[30] C.S. Carver, T.L. White, Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales, J. Pers. Soc. Psychol. 67 (1994) 319–333.
[31] S.P. Whiteside, D.R. Lynam, The five factor model and impulsivity: using a structural model of personality to understand impulsivity, Pers. Individ. Differ. 30 (2001) 669–689.
[32] S.B.G. Eysenck, P.R. Pearson, G. Easting, J.F. Allsop, Age norms for impulsiveness, venturesomeness and empathy in adults, Pers. Individ. Differ. 6 (1985) 613–619.
[33] J.L. Evenden, Varieties of impulsivity, Psychopharmacology (Berl.) 146 (1999) 348–361.
[34] M.R. Lowe, J. van Steenburgh, C. Ochner, M. Coletta, Neural correlates of individual differences relating to appetite, Physiol. Behav. 97 (2009) 561–571.
[35] A.J. Caswell, R. Bond, T. Duka, M.J. Morgan, Further evidence of the heterogenous nature of impulsivity, Pers. Individ. Differ. 76 (2015) 68–74.
[36] K.N. Kirby, N.M. Petry, W.K. Bickel, Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls, J. Exp. Psychol. Gen. 128 (1999) 78–87.
[37] J.H. Patton, M.S. Stanford, E.S. Barratt, Factor structure of the Barratt impulsiveness scale, J. Clin. Psychol. 51 (1995) 768–774.
[38] G.D. Logan, R.J. Schachar, R. Tannock, Impulsivity and inhibitory control, Psychol. Sci. 8 (1997) 60–64.
[39] S.J. Dickman, Functional and dysfunctional impulsivity: personality and cognitive correlates, J. Pers. Soc. Psychol. 58 (1990) 95–102.
[40] S.A. Meda, M.C. Stevens, M.N. Potenza, et al., Investigating the behavioral and self-report constructs of impulsivity domains using principal component analysis, Behav. Pharmacol. 20 (2009) 390–399.
[41] H. de Wit, J.D. Flory, A. Acheson, M. McCloskey, S.B. Manuck, IQ and nonplanning impulsivity are independently associated with delay discounting in middle-aged adults, Pers. Individ. Differ. 42 (2007) 111–121.
[42] A. Meule, Impulsivity and overeating: a closer look at the subscales of the Barratt Impulsiveness Scale, Front. Psychol. 4 (2013) 177.
[43] A.R. Aron, T.W. Robbins, R.A. Poldrack, Inhibition and the right inferior frontal cortex: one decade on, Trends Cogn. Sci. 18 (April (4)) (2014) 177–185, http://dx.doi.org/10.1016/j.tics.2013.12.003.
[44] C.S. Ray Li, C. Huang, T. Constable, R. Sinha, Imaging response inhibition in a stop-signal task: neural correlates independent of signal monitoring and post-response processing, J. Neurosci. 26 (2006) 186–192.
[45] L.N. van der Laan, D.T. De Ridder, M.A. Viergever, P.A. Smeets, The first taste is always with the eyes: a meta-analysis on the neural correlates of processing visual food cues, Neuroimage 55 (2011) 296–303.
[46] E.K. Diekhof, L. Nerenberg, P. Falkai, P. Dechent, J. Baudewig, O. Gruber, Impulsive personality and the ability to resist immediate reward: an fMRI study examining interindividual differences in the neural mechanisms underlying self-control, Hum. Brain Mapp. 33 (2012) 2768–2784.

[47] L.N. van der Laan, D.T. De Ridder, M.A. Viergever, P.A. Smeets, Activation in inhibitory brain regions during food choice correlates with temptation strength and self-regulatory success in weight-concerned women, Front. Neurosci. 8 (2014) 308.
[48] T. Van Strien, J.E.R. Frijters, G.P.A. Bergers, P.B. Defares, The Dutch eating behavior questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior, Int. J. Eat. Disord. 5 (1986) 195–215.
[49] L. Haase, E. Green, C. Murphy, Males and females show differential brain activation to taste when hungry and sated in gustatory and reward areas, Appetite 57 (2011) 421–434.
[50] E. Luders, C. Gaser, K.L. Narr, A.W. Toga, Why sex matters: brain size independent differences in gray matter distributions between men and women, J. Neurosci. 29 (2009) 14265–14270.
[51] D. Neumark-Sztainer, N.E. Sherwood, S.A. French, R.W. Jeffery, Weight control behaviors among adult men and women: cause for concern, Obes. Res. 7 (1999) 179–188.
[52] R. Pingitore, B. Spring, D. Garfield, Gender differences in body satisfaction, Obes. Res. 5 (1997) 402–409.
[53] P.A. Smeets, G.C. de, A. Stafleu, M.J. van Osch, R.A. Nievelstein, G.J. van der, Effect of satiety on brain activation during chocolate tasting in men and women, Am. J. Clin. Nutr. 83 (2006) 1297–1305.
[54] M.S. Stanford, C.J. Mathias, D.M. Dougherty, S.L. Lake, N.E. Anderson, J.H. Patton, Fifty years of the Barratt Impulsiveness Scale: an update and review, Pers. Individ. Differ. 47 (2009) 395.
[55] G. Ainslie, Specious reward: a behavioral theory of impulsiveness and impulse control, Psychol. Bull. 82 (1975) 463–496.
[56] A.C. Evans, D.L. Collins, D.R. Mills, E.D. Brown, R.L. Kelly, T.M. Peters, 3D statistical neuroanatomical models from 305 MRI volumes, Proc. IEEE Nucl. Sci. Symp. Med. Imaging 3 (1993) 1813–1817.
[57] J. Ng, E. Stice, S. Yokum, C. Bohon, An fMRI study of obesity, food reward, and perceived caloric density. Does a low-fat label make food less appealing? Appetite 57 (2011) 65–72.
[58] P.A. Smeets, F.M. Kroese, C. Evers, D.T. De Ridder, Allured or alarmed: counteractive control responses to food temptations in the brain, Behav. Brain Res. 248 (2013) 41–45.
[59] E. Stice, S. Yokum, C. Bohon, N. Marti, A. Smolen, Reward circuitry responsivity to food predicts future increases in body mass: moderating effects of DRD2 and DRD4, Neuroimage 50 (2010) 1618–1625.
[60] F. Van Meer, L.N. van der Laan, R.A. Adan, M.A. Viergever, P.A. Smeets, What you see is what you eat: an ALE meta-analysis of the neural correlates of food viewing in children and adolescents, Neuroimage 104 (2015) 35–43.
[61] J.A. Maldjian, P.J. Laurienti, R.A. Kraft, J.H. Burdette, An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets, Neuroimage 19 (2003) 1233–1239.
[62] N. Tzourio-Mazoyer, B. Landeau, D. Papathanassiou, et al., Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain, Neuroimage 15 (2002) 273–289.
[63] W.A. Carlezon Jr., M.J. Thomas, Biological substrates of reward and aversion: a nucleus accumbens activity hypothesis, Neuropharmacology 56 (Suppl. 1) (2009) 122–132.
[64] T. Hahn, T. Dresler, A.C. Ehlis, et al., Neural response to reward anticipation is modulated by gray's impulsivity, Neuroimage 46 (2009) 1148–1153.
[65] A.R. Hariri, S.M. Brown, D.E. Williamson, J.D. Flory, H. de Wit, S.B. Manuck, Preference for immediate over delayed rewards is asociated with magnitude of ventral striatal activity, J. Neurosci. 26 (2006) 13213–13217.
[66] S.J. Reeves, C. Polling, P.R. Stokes, et al., Limbic striatal dopamine D2/3 receptor availability is associated with non-planning impulsivity in healthy adults after exclusion of potential dissimulators, Psychiatry Res. 202 (2012) 60–64.
[67] C. Velazquez-Sanchez, A. Ferragud, C.F. Moore, B.J. Everitt, V. Sabino, P. Cottone, High trait impulsivity predicts food addiction-like behavior in the rat, Neuropsychopharmacology 39 (2014) 2463–2472.
[68] C. Nederkoorn, E.L.G.M. Jansen, A.A.N. Mulkens, A.T.M. Jansen, Impulsivity predicts treatment outcome in obese children, Behav. Res. Ther. 45 (2007) 1071–1075.
[69] K.S. Burger, E. Stice, Greater striatopallidal adaptive coding during cue-reward learning and food reward habituation predict future weight gain, Neuroimage 99 (2014) 122–128.
[70] K.E. Demos, T.F. Heatherton, W.M. Kelley, Individual differences in nucleus accumbens activity to food and sexual images predict weight gain and sexual behavior, J. Neurosci. 32 (2012) 5549–5552.
[71] P.Y. Geha, K. Aschenbrenner, J. Felsted, S.S. O'Malley, D.M. Small, Altered hypothalamic response to food in smokers, Am. J. Clin. Nutr. 97 (2013) 15–22.
[72] E. Stice, S. Spoor, C. Bohon, D.M. Small, Relation between obesity and blunted striatal response to food is moderated by TaqIA A1 allele, Science 322 (2008) 449–452.
[73] S. Yokum, A.N. Gearhardt, J.L. Harris, K.D. Brownell, E. Stice, Individual differences in striatum activity to food commercials predict weight gain in adolescents, Obesity (Silver Spring) 22 (2014) 2544–2551.
[74] L. Hogarth, D.J. Stillwell, R.J. Tunney, BIS impulsivity and acute nicotine exposure are associated with discounting global consequences in the Harvard game, Hum. Psychopharmacol. 28 (2013) 72–79.
[75] S. Krishnan-Sarin, B. Reynolds, A.M. Duhig, et al., Behavioral impulsivity predicts treatment outcome in a smoking cessation program for adolescent smokers, Drug Alcohol Depen. 88 (2007) 79–82.
[76] S. Lane, D.R. Cherek, H.M. Rhodes, C.J. Pietras, O.V. Techeremissine, Relationships among laboratory and psychometric measures of impulsivity: implications in substance abuse and dependence, Addict. Disord. Treat. 2 (2003) 33–40.
[77] K.M. Lempert, A.J. Porcelli, M.R. Delgado, E. Tricomi, Individual differences in delay discounting under acute stress: the role of trait perceived stress, Front. Psychol. 3 (2012) 251.
[78] B. Reynolds, J.B. Richards, K. Horn, K. Karraker, Delay discounting and probability discounting as related to cigarette smoking status in adults, Behav. Proc. 65 (2004) 35–42.
[79] O. Bartra, J.T. McGuire, J.W. Kable, The valuation system: a coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value, Neuroimage 76 (2013) 412–427.
[80] R.H. Fazio, M.A. Olson, Implicit measures in social cognition: research: their meaning and use, Annu. Rev. Psychol. 54 (2003) 297–327.
[81] N. Siep, A. Roefs, A. Roebroeck, R. Havermans, M. Bonte, A. Jansen, Fighting food temptations: the modulating effects of short-term cognitive reappraisal, suppression and up-regulation on mesocorticolimbic activity related to appetitive motivation, Neuroimage 60 (2012) 213–220.
[82] G.J. Wang, N.D. Volkow, F. Telang, et al., Evidence of gender differences in the ability to inhibit brain activation elicited by food stimulation, Proc. Natl. Acad. Sci. U. S. A. 106 (2008) 1249–1254.
[83] J. Metcalfe, W. Mischel, A hot/cool-system analysis of delay of gratification: dynamics of willpower, Psychol. Rev. 106 (1) (1999) 3–19.