Research report

Double trouble. Trait food craving and impulsivity interactively predict food-cue affected behavioral inhibition ☆

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Impulsivity and food craving have both been implicated in overeating. Recent results suggest that both processes may interactively predict increased food intake. In the present study, female participants performed a Go/No-go task with pictures of high- and low-calorie foods. They were instructed to press a button in response to the respective target category, but withhold responses to the other category. Target category was switched after every other block, thereby creating blocks in which stimulus–response mapping was the same as in the previous block (nonshift blocks) and blocks in which it was reversed (shift blocks). The Food Cravings Questionnaires and the Barratt Impulsiveness Scale were used to assess trait and state food craving and attentional, motor, and nonplanning impulsivity. Participants had slower reaction times and more omission errors (OE) in high-calorie than in low-calorie blocks. Number of commission errors (CE) and OE was higher in shift blocks than in nonshift blocks. Trait impulsivity was positively correlated with CE in shift blocks while trait food craving was positively correlated with CE in high-calorie blocks. Importantly, CE in high-calorie-shift blocks were predicted by an interaction of food craving × impulsivity such that the relationship between food craving and CE was particularly strong at high levels of impulsivity, but vanished at low levels of impulsivity. Thus, impulsive reactions to high-calorie food-cues are particularly pronounced when both trait impulsivity and food craving is high, but low levels of impulsivity can compensate for high levels of trait food craving. Results support models of self-regulation which assume that interactive effects of low top-down control and strong reward sensitivity, bottom-up mechanisms may determine eating-related disinhibition, ultimately leading to increased food intake.

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I n t r o d u c t i o n

Food craving refers to a strong desire to consume specific foods of which chocolate is the most often craved one (Weingarten & Elston, 1990, 1991). The sight, smell, and taste of high-calorie foods and other food-cues elicit cephalic phase responses, which prepare the organism for digestion and are associated with increased craving (Nederkoorn, Smulders, & Jansen, 2000; Rodríguez, Fernandez, Cepeda-Benito, & Vila, 2005). On a neuronal level, those processes are accompanied by strong activation of limbic and paralimbic brain structures associated with reward and incentive salience such as the insula, amygdala, striatum, and orbitofrontal cortex (García-García et al., 2013; Kenny, 2011; Volkow, Wang, Fowler, Tomasi, & Baler, 2012; Volkow, Wang, Tomasi, & Baler, 2013). Thus, food-cue elicited craving along with reward-related hyperactivation is considered a bottom-up mechanism leading to increased food intake (Heatherton & Wagner, 2011).

Accordingly, individual differences in reward sensitivity and susceptibility to food-cue elicited craving have been related to various measures of overeating. For example, studies using self-report measures for the assessment of a general sensitivity to reward such as the BIS/BAS scales or the Sensitivity to Punishment and Sensitivity to Reward Questionnaire showed that higher reward sensitivity is associated with higher body mass index (BMI), more frequent experiences of food craving, and emotional or external eating behavior (Davis & Fox, 2008; Davis, Strachan, & Berksen, 2004; Franken & Muris, 2005; Matton, Goossens, Braet, & Vervaet, 2013). Similarly, studies using self-report measures specifically assessing food reward sensitivity or frequent experiences of food craving such as the Power of Food Scale or the Food Cravings Questionnaire – Trait show that higher scores are associated with measures of overeating such as low dieting success, disinhibited eating, binge eating, emotional or external eating, and addiction-like eating (Cepeda-Benito, Gleaves, Williams, & Erath, 2000; Crowley et al., 2012; Davis et al., 2011; Lowe et al., 2009; Meule & Kübler, 2012; Meule, Lutz, Vögele, & Kübler, 2012; Meule, Westenböker, & Kübler, 2011; Moreno, Rodriguez, Fernandez, Tamez, & Cepeda-Benito, 2008).

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Overeating is not only determined by strong reward sensitivity, that is, bottom-up impulses, but also by a lack of sufficient top-down control. For example, self-reported impulsivity is positively related to various measures associated with overeating such as frequent experiences of food craving, emotional eating, or low dieting success (Meule, 2013). In behavioral measures of impulsivity, individuals with binge eating behaviors or obesity exhibit lower inhibitory control (i.e. more impulsive reactions) as compared with controls (Mobbs, Iglesias, Golay, & Van der Linden, 2011; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006; Rosval et al., 2006; Wu et al., 2013). Low inhibitory control has also been found to modulate food intake in nonclinical samples such that restrained eaters with low inhibitory performance ate more in a laboratory setting (Jansen et al., 2009; Meule, Lukito, Vögele, & Kübler, 2011). Impulsivity and low inhibitory control are associated with (dorsolateral) frontal hyperactivity (Chambers, Garavan, & Bellgrove, 2009), which, in turn, can also be found in relation to overeating and obesity (Batterink, Yokum, & Stice, 2010; Brooks, Cederneäs, & Schiöth, 2013; Brooks, Rask-Andersen, Benedict, & Schiöth, 2012).

Recent studies suggest that bottom-up and top-down processes are interdependent. Self-regulatory failure, resulting for example in overeating, can occur due to strong cue-elicited impulses that overwhelm frontal control, impaired frontal cortex function, or both (Appelhans, 2009; Heatherton & Wagner, 2011). Indeed, neuroimaging studies show that craving regulation involves an interplay of frontal cortices and subcortical brain areas (Hollmann et al., 2012; Rober et al., 2010; Scharmüller, Übel, Ebner, & Schienele, 2012; Sip et al., 2012; Yokum & Stice, 2013). Similarly, studies using behavioral and self-report measures of top-down, inhibitory control and bottom-up, reward sensitive processes found interactive effects when predicting laboratory food intake or weight gain. Hofmann, Friese, and Roefs (2009) found that high automatically reactive reactions to high-calorie foods were associated with increased candy consumption only when participants also had low inhibitory control. In another study, 1-year weight gain in students was predicted by low inhibitory control only when participants also showed a high implicit preference for high-calorie foods (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Finally, in a sample of obese individuals, high food reward sensitivity predicted intake of palatable foods only when inhibitory control was low (Appelhans et al., 2011).

Based on those findings, individuals prone to overeating may show impaired inhibitory control specifically when confronted with highly palatable, high-calorie food stimuli because of their lower inhibitory control and higher reward responsiveness. Indeed, some studies investigated inhibitory control in response to such food-cues, but most of these studies failed to find differential food-cue affected inhibitory control in relation to habitual overeating (for an overview see Meule et al., 2014). For example, in a study by Loeb et al. (2012), commission errors differed between food and neutral blocks, but did not differ between obese and normal-weight participants. One possible explanation for the lack of differences between obese and normal-weight participants is that obesity is a heterogeneous condition. That is, only a subset of obese individuals represents rather an impulsive, reward-sensitive subtype with binge eating behavior (Dalton, Blundell, & Finlayson, 2013) and, thus, particularly those individuals would be expected to show impaired food-cue affected inhibitory control. Thus, taking such individual differences into account may indeed show differential task performance in food-cue related response inhibition tasks as a function of impulsivity and reward sensitivity.

The aims of the current study were twofold: Firstly, to overcome issues in previous studies regarding stimulus selection. Specifically, studies using an affective shifting task (see below) contrasted food and neutral stimuli and found differences in commission errors between those categories (Loeb et al., 2012; Mobbs et al., 2011). However, the nature of general differences in commission errors between food and neutral blocks are hard to interpret as they may simply be due to a category size effect (Landauer & Freedman, 1968). Thus, we used pictures of high- and low-calorie foods and contrasted them with low-calorie foods in the present study in order to avoid possible effects of category size. Second, we examined the relationship of individual differences in top-down control (i.e. trait impulsivity) and bottom-up processes (i.e. trait food craving) with food-cue affected response inhibition.

For this purpose, we used an affective shifting task (e.g., Mobbs, Van der Linden, d’Acremont, & Perroud, 2008; Murphy et al., 1999) with pictures of high- and low-calorie foods in which participants are instructed to press a button in response to the respective target category, but withhold responses to the other category. Target category is switched after every other block, thereby creating blocks in which stimulus–response mapping is the same as in the previous block (nonshift blocks) and blocks in which it is reversed (shift blocks). As a result, task performance usually is decreased in shift blocks (e.g., higher number of commission errors) as compared with nonshift blocks.

We expected that task performance (reaction times, omission errors, commission errors) would not differ between blocks with high-calorie and blocks with low-calorie food targets as both stimulus types belong to the same broad category (i.e., food). As low inhibitory control (i.e. high number of commission errors) is regarded as one facet of impulsivity, we expected that the number of commission errors would be positively correlated with self-reported trait impulsivity, particularly in the more challenging shift blocks. As individuals high in reward sensitivity react sensitively in response to and have problems controlling the intake of high-calorie foods, we expected that the number of commission errors would be positively correlated with self-reported trait food craving, particularly in blocks with high-calorie food targets. Finally, we examined if commission errors can also be predicted by an interaction of trait food craving and impulsivity, comparable with studies that assessed actual food intake (e.g., Appelhans et al., 2011). Although our hypotheses referred to commission errors only, we also explored associations with reaction times and omission errors to determine if results were specific for inhibitory control or related to overall task performance.

Methods

Participants

Female participants were recruited among students at the University of Würzburg, Germany, via advertisements posted on campus. A total of N = 55 women participated in the study. Mean age was M = 24.35 years (SD = 4.21) and mean BMI M = 21.90 kg/m^2 (SD = 2.39). Most participants had normal weight (BM = 18.50–24.99 kg/m^2, n = 46, 83.64%) and few participants were overweight (BM > 18.50 kg/m^2, n = 4, 7.27%) or underweight (BM > 24.99 kg/m^2, n = 5; 9.09%). Sixteen participants indicated that they were currently trying to control their weight (i.e. were dieters). Mean score on the Eating Disorder Examination – Questionnaire (EDE-Q, see below) was M = 1.05 (SD = .87, Range = .00–3.06), indicating that eating disorder psychopathology was low and comparable with other nonclinical samples (Carver, Stewart, & Fairburn, 2001; Hilbert, Tuschen-Caffier, Kowatz, Niederhofer, & Munsch, 2007; Mond, Hay, Rodgers, & Owen, 2006). Ten participants reported to be smokers.1

1 Smokers had higher BIS-15 total and subscale scores than nonsmokers (all t[53]>2.22, P<.05). Controlling for smoking status in the subsequent analyses did not affect results. Smokers did not differ from nonsmokers on any other study variable (all t[53]<1.74, ns).
Mean food deprivation (i.e. hours since the last meal) was $M = 4.06$ hours ($SD = 4.92$). Participants received course credits for participation.

**Self-report measures**

**Food Cravings Questionnaire – Trait (FCQ-T)**

The FCQ-T (Cepeda-Benito et al., 2000) consists of 39 items and measures the frequency of food craving experiences on a 6-point scale ranging from never to always. It comprises nine subscales measuring food cravings in relation to (1) intentions to consume food, (2) anticipation of positive reinforcement, (3) relief from negative states, (4) lack of control over eating, (5) preoccupation with food, (6) hunger, (7) emotions, (8) cues that trigger cravings, and (9) guilt. Only the total score was used in the current study. Internal consistency of the German version was $\alpha = .96$ in the validation study (Meule et al., 2012) and was $\alpha = .97$ in the current study.

**Food Cravings Questionnaire – State (FCQ-S)**

The FCQ-S (Cepeda-Benito et al., 2000) consists of 15 items and measures the intensity of current food craving on a 5-point scale ranging from strongly disagree to strongly agree. It comprises five subscales referring to current food craving in relation to (1) an intense desire to eat, (2) anticipation of positive reinforcement, (3) relief from negative states, (4) lack of control over eating, and (5) hunger. Only the total score was used in the current study. Internal consistency of the German version was $\alpha = .92$ in the validation study (Meule et al., 2012) and was $\alpha = .91$ (before the task) and $\alpha = .93$ (after the task) in the current study.

**Barratt Impulsiveness Scale – short form (BIS-15)**

The BIS-15 (Spinella, 2007) is a 15-item short form of the 11th version of the Barratt Impulsiveness Scale (Patton, Stanford, & Barratt, 1995) and measures trait impulsivity on a 4-point scale ranging from rarely/never to almost always/always. It comprises three subscales assessing (1) attentional, (2) motor, and (3) nonplanning impulsivity. Only the total score was used in the current study. Internal consistency of the German version was $\alpha = .81$ in the validation study (Meule, Vögele, & Kübler, 2011) and was $\alpha = .84$ in the current study.

**Eating Disorder Examination – Questionnaire (EDE-Q)**

The EDE-Q (Fairburn & Beglin, 1994) was used to evaluate participants’ eating disorder psychopathology in the past 28 days. It consists of 22 items and items are scored on a 7-point scale ranging from never to every day. It comprises four subscales assessing (1) restraint, (2) eating concern, (3) weight concern and (4) shape concern. Only the total score was used in the current study. Internal consistency of the German version was $\alpha = .97$ in the validation study (Hilbert et al., 2007) and was $\alpha = .94$ in the current study.

**Stimuli**

Twenty pictures were selected from the food.pics database (see www.food-pics.sbg.ac.at) which contains information on calorie content, subjectively rated palatability, and physical features of the food pictures (Meule & Blechert, 2012). Ten pictures of high-calorie (HC) and 10 pictures of low-calorie (LC) foods were selected which were homogeneous with respect to background color (Fig. 1). Food items of the two categories differed both in calories and palatability, visual complexity (jpg file size, edge detection, subjective ratings), brightness, and contrast (all $t_{(18)} < 1.84$, ns).

**Affective Shifting Task (AST)**

The AST is a Go/No-go task which has been previously employed using emotional (Murphy et al., 1999), alcohol-related (Adams, Ataya, Attwood, & Munafo, 2013; Noël et al., 2005, 2007), and food-related stimuli (Loeber, Grosshans, Herpertz, Kiefer, & Herpertz, 2013; Loeber et al., 2012; Meule et al., 2014; Mobbs et al., 2008, 2011). In the current study, we used a modification of this task with pictures of HC and LC foods. The program was compiled using

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2 Picture number in the food.pics database: 16, 26, 32, 40, 60, 82, 90, 106, 115, 143, 195, 201, 212, 217, 221, 224, 225, 234, 238, 275.
E-prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA) and displayed on a LCD TFT 22” screen. Participants were instructed to press a response button as quickly as possible when a target was presented, but withhold responses to distractors. The task was separated into 16 blocks consisting of 20 trials each (=320 trials in total). Within each block, every picture was shown once, i.e. half of the pictures were targets and half were distractors. Pictures were presented one by one for 500 ms in a randomized order. A blank screen was presented during intertrial interval for 1000 ms or participants received a feedback in case of a false reaction or omission. Before each block, either HC or LC foods were specified as target category. The order of blocks was either HC-HC-LC-LC-HC-HC-LC-LC-HC-LC-HC-LC-HC-LC-LC-HC-LC (counterbalanced across subjects). Due to this arrangement, four blocks of each target category were shift blocks in which participants had to reverse stimulus–response associations of the previous block, and four blocks were nonshift blocks in which stimulus–response associations were the same as in the previous block (Fig. 2). To ensure that the first block could be analyzed as a shift block, a practice block (20 trials) with the opposite target category was run prior to the test blocks. The whole task lasted for approximately 10 min.

Procedure

Participants were tested between 8:30 a.m. and 5:00 p.m. (median of testing time was 11:00 a.m.). There was no instruction regarding food intake prior to testing. After arrival, participants signed informed consent, completed the FCQ-S and then performed the AST. Afterwards, they immediately filled out the FCQ-S again and completed the other questionnaires (data of which are only reported for the BIS-15 and FCQ-T in the current manuscript). Finally, height and weight were measured.

Data analysis

Trials with a reaction time of less than 150 ms, reflecting anticipation, were excluded from analyses. Dependent variables were reaction times (ms) in go-trials (i.e. time taken to respond to each target), number of commission errors (i.e. responses to distractors), and omission errors (i.e. failure to respond to targets). Reaction times and omission errors are thought to reflect attentional processes while commission errors reflect behavioral disinhibition. Reaction times were positively correlated with omission errors ($r = .52$, $P < .001$). Reaction times, commission errors and omission errors were normally distributed (all $K-S Z_{(55)} < .11$, $P > .20$).

A 2 (target type: HC vs. LC) × 2 (block type: shift vs. nonshift) ANOVA for repeated measures was calculated for each dependent variable. State food craving (i.e. scores on the FCQ-S before and after the task) was compared with dependent t-test. For correlational analyses (Pearson’s correlation coefficient), a difference score was calculated (FCQ-S scores after the task minus FCQ-S scores before the task) with higher scores indicating a higher increase in food craving during the task. Hierarchical linear regression analyses were used to investigate the relationships between impulsivity, trait food craving, and task performance. Specifically, control variables (food deprivation [i.e. hours since last meal], FCQ-S difference score [i.e. craving increase during the task] and BMI) were entered in step 1 for predicting reaction times, omission errors, and commission errors separately for HC-shift, HC-nonshift, LC-shift, and LC-nonshift blocks. In step 2, trait impulsivity (scores on the BIS-15), trait food craving (scores on the FCQ-T) and the interaction impulsivity × food craving were entered as additional predictor variables. Significant interactions were examined by simple slopes for the regression of trait food craving on task performance for individuals with low impulsivity (one SD below the mean) and those with high impulsivity (one SD above the mean; Aiken & West, 1991). All $P$-values are reported two-tailed and ns refers to a $P$-value > .05.

Results

Current food craving and correlations between BMI, food deprivation, and questionnaire measures

Participants reported higher food craving after the task ($M = 32.44$, $SD = 11.87$) than before ($M = 30.24$, $SD = 10.63$, $t_{(54)} = 2.70$, $P = .009$).
Increases in food craving during the task were positively correlated with trait food craving (Table 1). Trait food craving was positively correlated with BMI (Table 1).

**Task performance**

**Reaction times**

A significant main effect for target type \(F(1,54) = 96.24, P < .001\), \(\eta^2_\text{p} = .64\) indicated that participants reacted slower in response to high-calorie food targets \((M = 395.31 \text{ ms}, \text{SD} = 16.47)\) as compared with low-calorie food targets \((M = 379.74 \text{ ms}, \text{SD} = 15.02)\). The main effect for block type \(F(1,54) = 12.97, \text{ns}, \eta^2_\text{p} = .21\) and the interaction target type \(\times\) block type \(F(1,54) = .36, \text{ns}, \eta^2_\text{p} = .01\) were not significant (Fig. 3a).

**Omission errors**

A significant main effect for target type \(F(1,54) = 32.34, P < .001\), \(\eta^2_\text{p} = .38\) indicated that participants omitted more high-calorie food targets \((M = 15.06 \text{ errors}, \text{SD} = 6.75)\) than low-calorie food targets \((M = 10.51 \text{ errors}, \text{SD} = 5.55)\). A significant main effect for block type \(F(1,54) = 15.80, P < .001, \eta^2_\text{p} = .23\) indicated that participants omitted more targets in shift blocks \((M = 14.42 \text{ errors}, \text{SD} = 7.03)\) than in nonshift blocks \((M = 11.15 \text{ errors}, \text{SD} = 5.28)\). The interaction target type \(\times\) block type was not significant \((F(1,54) = .89, \text{ns}, \eta^2_\text{p} = .02\) (Fig. 3b).

**Commission errors**

A significant main effect for block type \(F(1,54) = 29.47, P < .001, \eta^2_\text{p} = .35\) indicated that participants committed more errors in shift blocks \((M = 12.26 \text{ errors}, \text{SD} = 4.47)\) than in nonshift blocks \((M = 8.73 \text{ errors}, \text{SD} = 4.22)\). The main effect for target type \(F(1,54) = 2.13, \text{ns}, \eta^2_\text{p} = .04\) and the interaction target type \(\times\) block type \(F(1,54) = 1.29, \text{ns}, \eta^2_\text{p} = .02\) were not significant (Fig. 3c).

**Task performance as a function of trait impulsivity and food craving**

**Reaction times**

Reaction times were not correlated with BMI, food deprivation, or questionnaire measures (all \(r < .25, \text{ns}\)). Neither predictor was significantly associated with task performance (all \(\beta < .24, \text{ns}\)).

**Omission errors**

Omission errors were not correlated with BMI, food deprivation, or questionnaire measures (all \(r < .26, \text{ns}\)). Trait food craving predicted number of omission errors in HC-nonshift blocks \(\beta = .46, P = .004\), which was further modulated by impulsivity (interaction impulsivity \(\times\) food craving; \(\beta = .34, P = .03\)). The relationship between trait food craving and number of omission errors was particularly strong at high levels of impulsivity \((\beta = .79, P < .001)\), but vanished at low levels of impulsivity \((\beta = .15, \text{ns})\). The interaction impulsivity \(\times\) food craving also predicted number of omission errors in LC-nonshift blocks \((\beta = .33, P = .04)\). The relationship between trait food craving and number of omission errors was particularly strong at high levels of impulsivity \((\beta = .57, P = .003)\), but vanished at low levels of impulsivity \((\beta = .06, \text{ns})\). No other variable was a significant predictor of omission errors (all \(\beta < .25, \text{ns}\)).

**Commission errors**

Trait impulsivity was positively correlated with number of commission errors in shift blocks (Table 2; Fig. 4a). Trait food craving was positively correlated with the total number of commission errors, particularly in HC blocks (Table 2; Fig. 4b). Trait food craving positively predicted number of commission errors in HC shift blocks which was further modulated by trait impulsivity (Table 3). The relationship between trait food craving and commission errors was particularly strong at high levels of impulsivity \((\beta = .73, P < .001)\), but...
vanished at low levels of impulsivity ($\beta = .12, \text{ns}$; Fig. 5). No other variable was a significant predictor of commission errors (Table 3).

### Discussion

The current study aimed at investigating the influence of pictorial high- and low-calorie food-cues on inhibitory control and at revealing its associations with individual differences in trait impulsivity and trait food craving.

#### Current food craving

Current food craving increased during the task, but was unrelated to task performance. Replicating prior findings (Meule, Skirde, Freund, Vögele, & Kübler, 2012), this increase in state food craving was positively correlated with trait food craving which further supports the validity of the FCQ-T as a measure of reward sensitivity which includes the susceptibility for experiencing food-cue elicited craving.

#### Task performance

### Reaction times and omission errors

High- and low-calorie food pictures did not differ in physical features, for example visual complexity or subjective palatability ratings. Unexpectedly, differences in task performance could be found between the two food types. Participants reacted slower in response to and also omitted more high-calorie food targets than...
low-calorie food targets. In line with this, reaction times in response to high-calorie food pictures were slower than in response to low-calorie food pictures in a related task (Flanker paradigm; Forestell, Lau, Cyrilovski, Dickter, & Haque, 2012). Electrophysiological and neuroimaging studies showed that high- and low-calorie food cues are differently processed in the brain such that the brain automatically and rapidly performs an attentional analyses of calorie content thereby discriminating food pictures which differ in energy density (Frank et al., 2010; Meule, Kübler, & Blechert, 2013; Toepel, Knebel, Hudry, Le Coutre, & Murray, 2009). Thus, behavioral differences (e.g., as seen in reaction times in the present study) between picture types may be secondary to such early differences in attentional processing due to caloric content. In a study of visual attention by Castellanos et al. (2009), participants were more likely to initially look at high- than low-calorie food pictures and also looked longer at high- than low-calorie food pictures. Thus, it may be that high-calorie foods are salient cues that attract and maintain attention, thereby distracting participants from the primary task and resulting in slowed reactions. Yet, alternative explanations could be that high-calorie food pictures represented processed foods or even prepared meals while low-calorie food pictures were mainly whole foods. Although we intentionally selected low-calorie foods which represented food ready for consumption, that is, without further preparation necessary, increased reaction times (and, subsequently, more omissions) in response to high-calorie food pictures may be due to a higher semantic (rather than visual) complexity as more cognitive resources may be recruited to capture the more complex picture content.

**Commission errors**

Expectedly, participants committed more errors in shift blocks than in nonshift blocks as a result of higher level of difficulty. No differences emerged between high- and low-calorie food blocks. Previous studies using high-calorie foods and neutral stimuli found differences in commission errors between picture types (Loeb et al., 2012, 2013; Meule et al., 2014; Mobbs et al., 2011). Those differences, however, may be simply due to a category size effect, i.e., that the category of food is smaller than the broader category of neutral objects, which may result in differences in processing speed and stimulus recognition (Landauer & Freedman, 1968). Hence, the current results may indeed indicate that this is the case as no differences in commission errors could be found when both picture types belong to one category (i.e., food).

**Task performance as a function of trait impulsivity and food craving**

Beyond those general differences in task performance between picture types, individual differences in trait impulsivity and trait food craving were differentially related to task performance. Trait impulsivity was positively correlated with the number of commission errors in shift, but not in nonshift blocks. This finding is in line with previous observations that self-reported impulsivity was positively, but weakly, correlated with behavioral inhibition as assessed with stop-signal or Go/No-go tasks (Cyders & Koskumpari, 2011, 2012; Lijffijt et al., 2004; Reynolds, Ortengren, Richards, & De Wit, 2006). Trait food craving was positively correlated with the number of commission errors in high-calorie, but not low-calorie food blocks. This finding is in line with the fact that usually high-calorie foods are craved foods and their consumption is difficult to control, particularly in trait high cravings (Fabricatore, Imperatori, Contardi, Tamburro, & Innamorati, 2013; Hill, 2007; Martin, McClernon, Chelloni, & Correa, 2011; Weingarten & Elston, 1990, 1991). Although we did not assess actual food consumption in the current study, we would argue that reduced inhibitory control in high-calorie food blocks as a function of trait food craving may reflect the process underlying overeating in real life. This view is also supported by a recent study which showed that impaired food-cue affected behavioral inhibition was related to increased food intake in the laboratory (Houben, Nederkoorn, & Jansen, 2012).

In high-calorie shift blocks, the relationship between trait food craving and the number of commission errors was moderated by trait impulsivity. In high impulsive individuals, the positive association between trait food craving and commission errors was particularly strong. That is, trait food craving and impulsivity had additive effects such that inhibitory control in response to high-calorie food cues was particularly reduced when both traits were pronounced. In low impulsive individuals no relationship between trait food craving and commission errors could be observed. That is, low trait impulsivity (i.e. high top-down control) could compensate for high levels of trait food craving. Furthermore, high trait impulsivity was not associated with increased disinhibition when trait food craving was low, suggesting that trait impulsivity does not inevitably lead to a loss of control in response to high-calorie food cues unless individuals are also sensitive to food reward. Unexpectedly, omission errors in nonshift blocks were also predicted by an interaction of trait food craving and impulsivity. We would argue that this finding may likely reflect an overcompensation as high impulsive, reward sensitive individuals committed many errors in shift blocks and, as a result, might have been more cautious in the subsequent nonshift blocks.

**Limitations and future directions**

Some limitations of the current study have to be considered. Firstly, interpretation of results is limited to young, healthy women and may likely differ in other samples, for example men. Yet, we intentionally decided to recruit women to avoid a confounding effect of gender, for example, with regard to food craving experiences (Cepeda-Benito, Fernandez, & Moreno, 2003). Moreover, investigating an all-female sample ensured comparability with prior studies employing such tasks (Meule et al., 2014; Mobbs et al., 2008). Secondly, we did not measure actual food intake and, thus, cannot infer the external validity of food-cue induced behavioral disinhibition. However, we think that the present results nonetheless have implications for interventions aiming at the control of food intake. Our results, in line with existing models of self-regulation (Appelhans,
2009; Heatherton & Wagner, 2011), suggest that interventions could address (1) attenuating automatic, bottom-up reactions or (2) increasing top-down control to enhance eating-related self-regulation. Indeed, recent studies used food-related inhibition tasks in which multiple processes are involved in reaction to the inhibition of intake to control for calorie food-cues. These studies show that such a training can decrease subsequent food intake or alter food choice and that this is probably mediated by an attenuation of automatic, bottom-up processes (Houben, 2011; Houben & Jansen, 2011; Veling, Aarts, & Papiès, 2011; Veling, Aarts, & Stroebe, 2013a, 2013b). Importantly, such inhibition trainings appear to be as effective as more effortful top-down approaches (e.g., forming implementation intentions) in reducing the amount of self-selected sweets (Van Koningsbruggen, Veling, Stroebe, & Aarts, in press). To conclude, the present study demonstrated that inhibitory control in response to high-calorie, but not low-calorie food-cues depends on both impulsivity and reward sensitivity. Future research is needed to extend those findings to individuals with eating disorders or obesity and investigate if interventions which strengthen top-down control and attenuate reward-related processes are particularly useful for controlling food intake or altering food choice in such individuals.

References


