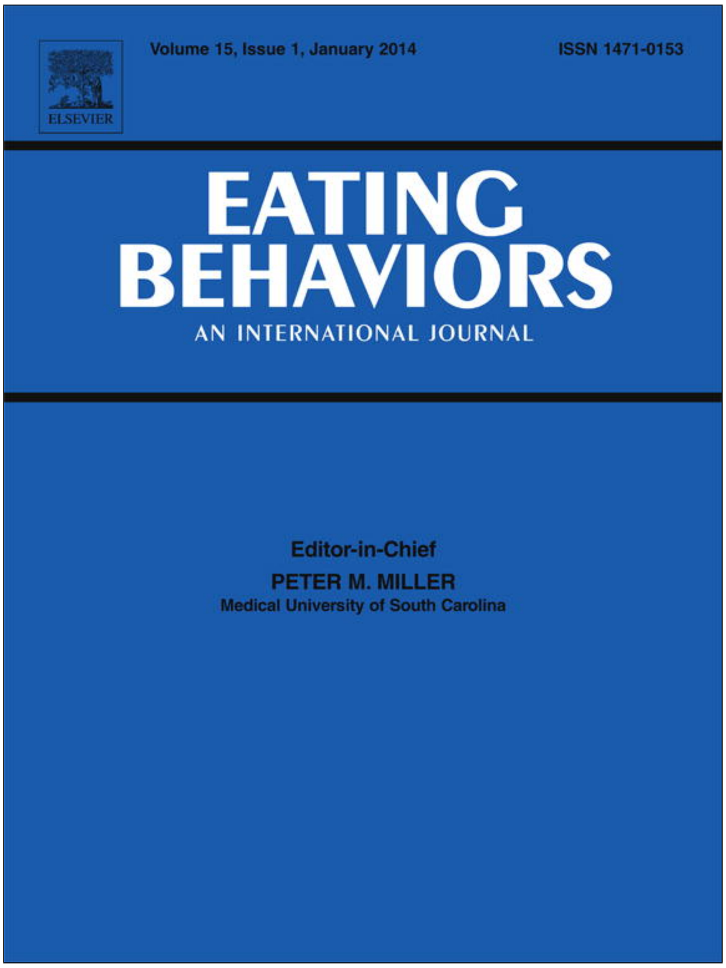
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Impulsive reactions to food-cues predict subsequent food craving

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A B S T R A C T

Low inhibitory control has been associated with overeating and addictive behaviors. Inhibitory control can modulate cue-elicited craving in social or alcohol-dependent drinkers, and trait impulsivity may also play a role in food-cue reactivity. The current study investigated food-cue affected response inhibition and its relationship to food craving using a stop-signal task with pictures of food and neutral stimuli. Participants responded slower to food pictures as compared to neutral pictures. Reaction times in response to food pictures positively predicted scores on the *Food Cravings Questionnaire — State* (FCQ-S) after the task and particularly scores on its hunger subscale. Lower inhibitory performance in response to food pictures predicted higher FCQ-S scores and particularly those related to a desire for food and lack of control over consumption. Task performance was unrelated to current dieting or other measures of habitual eating behaviors. Results support models on interactive effects of top-down inhibitory control processes and bottom-up hedonic signals in the self-regulation of eating behavior, such that low inhibitory control specifically in response to appetitive stimuli is associated with increased craving, which may ultimately result in overeating.

1. Introduction

Animal research and studies in humans have shown that food-cue exposure elicits pre-digestive hormonal reflexes, which include secretion of saliva, insulin, and gastric juices, etc. (Rodin, 1985). These cephalic phase responses prepare the organism for the consumption of food and are associated with an increase in craving (Legenbauer, Vögele, & Rüddel, 2004; Nederkoorn, Smulders, & Jansen, 2000). This cue-reactivity can also be observed when food pictures are presented instead of real food (e.g. Rodríguez, Fernandez, Cepeda-Benito, & Vila, 2005).

Previous studies on inter-individual differences in food-cue reactivity have mostly focused on dietary restraint, eating disorders, overweight/obesity, and trait levels of food craving. Results from these studies suggest elevated levels of food-cue reactivity in restrained eaters (e.g. Fedoroff, Polivy, & Herman, 1997, 2003), patients with binge eating disorder (e.g. Vögele & Florin, 1997) or bulimia nervosa (Legenbauer et al., 2004), overweight children (e.g. Jansen et al., 2003) and trait food/chocolate cravers (e.g. Kemps, Tiggemann, & Grigg, 2008; Meule, Skirde, Freund, Vögele, & Kübler, 2012; Moreno-Domínguez, Rodríguez-Ruiz, Martín, & Warren, 2012; Rodríguez et al., 2005) when compared to control participants.

Impulsivity is another possible source of individual variation in food-cue elicited craving. It can be defined as a predisposition toward rapid, unplanned reactions to internal or external stimuli without taking into account the negative consequences of these reactions (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Impulsivity represents a multifaceted construct and there are several measures that assess its different aspects. Two of the most widely used methods are self-report instruments and motor response inhibition tasks (e.g. go/no-go tasks or the stop-signal task (SST); Guerrieri, Nederkoorn, & Jansen, 2008). In such tasks, impulsive behavior is reflected in low inhibitory control as indicated by, e.g., more commission errors or higher stop-signal reaction time (SSRT, see below). Self-report measures of impulsivity and impulsive reactions in response inhibition tasks are positively, but weakly, correlated (Cyders & Coskunpinar, 2011, 2012; Lijffijt et al., 2004; Reynolds, Ortengren, Richards, & de Wit, 2006).

Both self-reported impulsivity and low response inhibition have been found to be positively associated with restrained eating or unsuccessful dieting (Meule, Papies, & Kübler, 2012; Nederkoorn, Van Eijs, & Jansen, 2004; van Koningsbruggen, Stroebe, & Aarts, 2013), binge eating (Nasser, Gluck, & Geliebter, 2004; Rosval et al., 2006), bulimia nervosa (Wu et al., 2013), overweight and obesity (Mobbs, Iglesias, Golay, & Van der Linden, 2011; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Jansen, Mulkens, & Jansen, 2007; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006), and trait food craving (Meule, Lutz, Vögele, & Kübler, 2012a). Response inhibition has also been found to moderate food consumption such that only those restrained eaters with low inhibitory control showed increased food intake in a laboratory environment (Jansen et al., 2009; Meule, Lukito, Vögele, & Kübler, 2011).

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Besides those studies that related general response inhibition as assessed with neutral tasks to eating behavior, there are also some studies that investigated response inhibition directly in response to palatable, high-calorie food-cues. For example, low dieting success and higher body-mass-index (BMI) were associated with behavioral disinhibition, particularly in response to food pictures (Houben, Nederkoorn, & Jansen, 2012; Meule et al., in revision; Nederkoorn, Coelho, Guerrieri, Houben, & Jansen, 2012). In a recent study, food-cue affected response inhibition was related to participants' self-reported current hunger levels (Loeber, Grosshans, Herpertz, Kiefer, & Herpertz, 2013). In other studies, however, inhibitory control in response to food-cues was unrelated to BMI, trait eating behaviors, or current hunger (Loeber et al., 2012; Meule, Lutz, Vögele, & Kübler, 2012c; Mobbs et al., 2011). To summarize, some studies suggest that impulsive reactions, i.e. low inhibitory control, when exposed to food-cues are associated with higher BMI, low dieting success, and current hunger levels, but results are inconclusive.

Investigations on the relationship between self-reported impulsivity or response inhibition, and food-cue elicited craving are rare. Recent evidence from the addiction literature suggests that response inhibition may modulate cue-reactivity. Specifically, Papachristou et al. found that heavy social drinkers with low response inhibition had elevated levels of craving during alcohol cue-exposure as compared to those with high response inhibition (Papachristou, Nederkoorn, Havermans, van der Horst, & Jansen, 2012). Furthermore, low response inhibition was related to higher craving after alcohol cue-exposure when alcohol was perceived as available (Papachristou, Nederkoorn, Corstjens, & Jansen, 2012). Most recently, it was shown that both self-reported impulsivity and low response inhibition predicted alcohol craving in alcohol-dependent patients during cue-exposure in a real bar (Papachristou et al., 2013). In a series of studies by Doran and colleagues, self-reported impulsivity was related to higher smoking-cue induced craving in smokers (Doran, Cook, McChargue, & Spring, 2009; Doran, McChargue, & Spring, 2008; Doran, Spring, & McChargue, 2007). With regard to eating behavior, self-reported impulsivity was associated with increases in food craving after food exposure (Tetley, Brunstrom, & Griffiths, 2010). However, there have also been contradicting findings such that food-cue exposure did not affect food intake in high impulsive individuals (Larsen, Hermans, & Engels, 2012). Yet, it is important to note that food intake does not necessarily reflect levels of food craving (cf. Hill, 2007).

In the current study, we investigated impulsivity by means of self-report and the SST. Importantly, this task involved pictures of food and non-food related objects allowing for the direct assessment of impulsive reactions to food stimuli as compared to a neutral control condition. We hypothesized that inhibitory control in response to food stimuli would predict subsequent food craving. Specifically, as a higher SSRT in the SST indicates less inhibitory control (i.e. more impulsive reactions), we expected that higher SSRT in response to food-cues would be related to stronger food craving. Based on the finding that SSRT was positively correlated with self-reported impulsivity and that low food-cue affected response inhibition was associated with higher BMI, lower dieting success and current hunger (Houben et al., 2012; Loeber et al., 2013; Nederkoorn et al., 2012), we also explored if task performance was associated with self-reported impulsivity, current food deprivation, BMI, and self-report measures related to overeating (i.e., low dieting success and food addiction symptoms).

2. Method

2.1. Participants

Female participants were recruited among students at the University of Würzburg, Germany. Advertisements were posted on campus and additionally distributed via a mailing list of a student association. Women who responded to the advertisements were contacted by phone ($N = 82$) and screened for exclusion criteria which included mental disorders, psychoactive medication, under- or overweight (BMI < 17.5 or >25 kg/m^2), and age > 40 years. We decided to restrict the sample to women with normal-weight because only few participants of the screened sample were in the overweight range and, therefore, BMI distribution would have been skewed. A total of $n = 50$ participants took part in the study. Descriptive statistics of participant characteristics are reported in Table 1. Eighteen participants indicated that they were currently trying to control their weight (i.e. were dieters). Five participants reported to be smokers.

2.2. Measures and materials

2.2.1. BMI

Height (cm) was measured with a double meter stick and weight (kg) was measured with a digital personal scale (BG 22, Beurer GmbH, Ulm, Germany). BMI was calculated as weight in kg divided by height in meters squared.

2.2.2. Dieting status

Current dieting status (yes/no) was assessed with a single question ["Are you currently restricting your food intake to control your weight (e.g. by eating less or avoiding certain foods)?"].

2.2.3. Perceived Self-Regulatory Success in Dieting Scale (PSRS)

The PSRS (Fishbach, Friedman, & Kruglanski, 2003) was used to assess dieting success. In this three-item questionnaire, participants have to rate on 7-point scales how successful they are in watching their weight, in losing weight, and how difficult it is for them to stay in shape. Validity of the PSRS has been shown by negative associations with BMI, rigid dieting strategies and other correlates of disinhibited eating while it is positively related to flexible dieting strategies (Meule et al., 2012a; Meule, Papies, et al., 2012; Meule, Westenhöfer, & Kübler, 2011). Internal consistency of the German version is $\alpha > .70$ (Meule, Papies, et al., 2012) and was $\alpha = .79$ in the current study.

2.2.4. Yale Food Addiction Scale (YFAS)

The YFAS (Gearhardt, Corbin, & Brownell, 2009) measures addictive eating behavior and consists of 25 items. Validity of the YFAS has been indicated by positive associations with BMI, eating disorder symptomatology, emotional eating, food cravings, binge eating, difficulties in emotion regulation, and impulsivity in non-clinical samples and obese patients (Davis et al., 2011; Gearhardt et al., 2009, 2012; Meule, Heckel, & Kübler, 2012; Meule & Kübler, 2012; Meule, Vögele, & Kübler, 2012). Internal consistency of the German version is $\alpha = .81$ (Meule, Vögele, et al., 2012) and was $\alpha = .83$ in the current study.

2.2.5. Barratt Impulsiveness Scale — Short Version (BIS-15)

The BIS-15 was proposed by Spinella (2007) as short version of the BIS-11 (Patton, Stanford, & Barratt, 1995) for the measurement of impulsivity on the dimensions *motor*, *attentional*, and *non-planning impulsivity*. Instead of 30 items as in the long version, it consists of 15 items only. Moderate to strong relationships between the BIS-15 and the Frontal Systems Behavior Scale and the UPPS Impulsive Behavior Scale support convergent validity, while weak correlations with sensation seeking indicate discriminant validity (Meule, Vögele, & Kübler, 2011; Spinella, 2007). Internal consistency of the German version is $\alpha = .81$ and ranges between $\alpha = .68$–.82 for the subscales (Meule, Vögele, et al., 2011). In the current study, internal consistency of the total scale was $\alpha = .79$ and ranged between $\alpha = .68$–.82 for the subscales.

2.2.6. Food Cravings Questionnaires — State Version (FCQ-S)

Current food craving was measured with the FCQ-S (Cepeda-Benito, Gleaves, Williams, & Erath, 2000). This 15-item questionnaire assesses momentary food craving on the dimensions *intense desire to eat*, *anticipation of positive reinforcement that may result from eating*, *anticipation of relief from negative states and feelings as a result of eating*,

Table 1
Descriptive statistics of and correlations between participant characteristics and questionnaire measures.

$N = 50$	*M*	*SD*	1.	2.	3.	4.	5.	6.	7.
1. Age (years)	22.32	3.03	–	.04	.03	−.19	−.33*	−.23	.21
2. Body-mass-index (kg/m^2)	21.45	2.67	.04	–	−.67***	.42**	.15	−.03	.23
3. Perceived Self-Regulatory Success in Dieting Scale	12.18	4.09	.03	−.67***	–	−.35*	−.12	.02	.01
4. Yale Food Addiction Scale (symptom count)	1.56	1.05	−.19	.42**	−.35*	–	.26#	−.09	.09
5. Barratt Impulsiveness Scale — short form	31.28	5.43	−.33*	.15	−.12	.26#	–	.14	−.01
6. Food Cravings Questionnaire — State	44.78	10.56	−.23	−.03	.02	−.09	.14	–	.16
7. Food deprivation (h)	5.66	3.99	.21	.23	.01	.09	−.01	.16	–

# $p < .10$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

lack of control over eating, and *hunger* (Cepeda-Benito et al., 2000). In the German version, those factors can be reduced to three subscales (*desire/lack of control*, *reinforcement*, and *hunger*; Meule et al., 2012a). Positive associations with length of food deprivation and current negative affect support validity of the FCQ-S (Cepeda-Benito, Fernandez, & Moreno, 2003; Meule et al., 2012a). Moreover, the FCQ-S has been found to be sensitive to meal consumption and food-cue exposure such that state cravings decreased after breakfast (Cepeda-Benito et al., 2000; Vander Wal, Johnston, & Dhurandhar, 2007) and increased after performing a cognitive task involving food pictures (Meule, Skirde, et al., 2012). Subscales are highly inter-correlated and internal consistency of the total scale is $\alpha = .92$ and ranges between $\alpha = .87$–$.89$ for the subscales (Meule et al., 2012a). In the current study, internal consistency of the total scale was $\alpha = .92$ and ranged between $\alpha = .81$–$.85$ for the subscales.

2.2.7. Stop-signal task (SST)

The SST was originally developed by Logan and colleagues (Logan & Cowan, 1984; Logan, Cowan, & Davis, 1984). In this task, participants are required to respond by pressing a left or right response button which is assigned to two stimuli (e.g., the letters X and O; Logan, Schachar, & Tannock, 1997). In some trials, however, a tone is presented shortly after stimulus onset which indicates that the response has to be withheld. In the current study, we used a modification of this task which included 13 pictures of palatable, high-calorie, sweet or savory foods and 13 pictures of neutral objects (Fig. 1). All pictures were edited to be homogeneous with respect to background color. The task was compiled with E-prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA) and displayed on a LCD TFT 22″ screen. Participants were instructed to either press a left or right response button when either a food or neutral picture was presented in the center of the screen (assignment of pictures to response buttons was counterbalanced across subjects). Each stimulus was presented for 500 ms, followed by an inter-trial interval of 800 ms. In 25% of the trials, a 1000-Hz tone (i.e. stop-signal) was presented for 500 ms via headphones. Stop-signal delay (SSD) was set at 200 ms initially and then adjusted dynamically depending on the participant's behavior. The delay was increased by 50 ms in the next stop-trial after successful inhibition of response and decreased by 50 ms after failed inhibition of response. As a result, approximately 50% of stop-trials are successfully inhibited (53.79% in the current study; see Table 2). Minimal SSD was 150 ms and maximal 250 ms, i.e. SSD was either 150 ms, 200 ms, or 250 ms. The whole task comprised 416 trials divided into four blocks of 104 trials each. In each block, each picture was presented four times and was paired with a stop-signal once. Pictures were displayed randomly. After each block, participants received feedback of their reaction time and instruction to

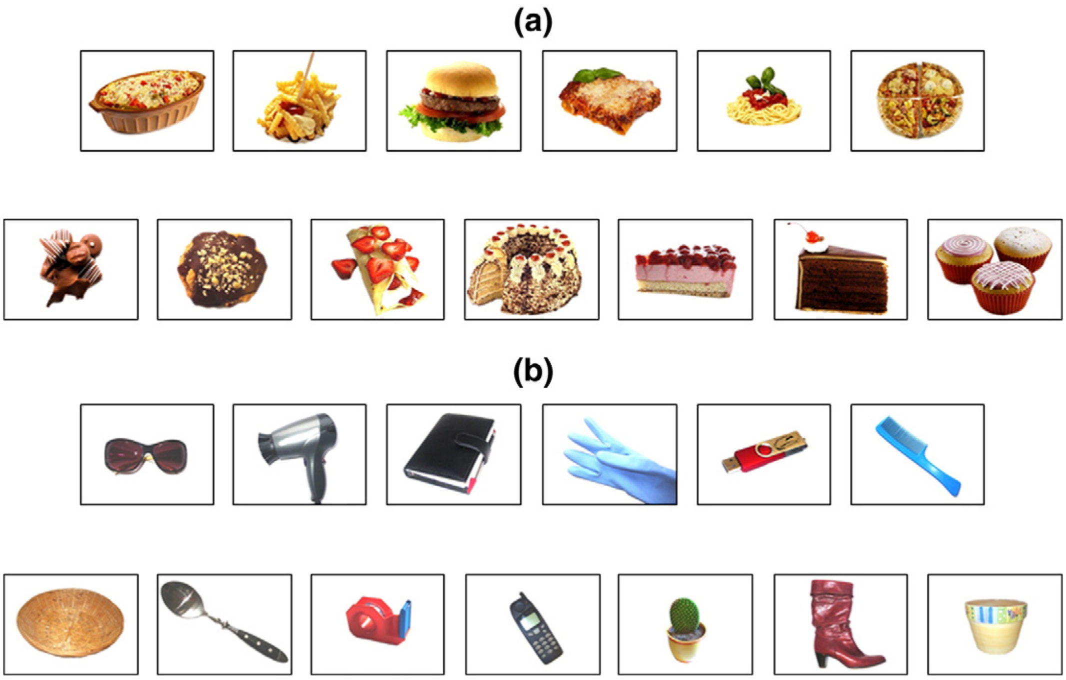

Fig. 1. Stimulus set of (a) food pictures and (b) neutral pictures.

Table 2
Descriptive statistics of and correlations between the different task performance indices.

$N = 50$	M	SD	1.	2.	3.	4.
1. Reaction time (ms) in go-trials	476.83	40.24	–	−.46**	−.47**	.30*
2. Errors	16.04	9.40	−.46**	–	.56***	.13
3. $P_{(RIS)}$	.46	.13	−.47**	.56***	–	.64***
4. Stop-signal reaction time	253.06	39.00	.30*	.13	.64***	–

Notes. Errors = number of wrong button presses in go-trials, $P_{(RIS)}$ = probability of responding in stop-trials.
* p < .05.
** p < .01.
*** p < .001.

react even faster during the next block to sustain motivation and prevent waiting for the stop-signal (cf. Sylwan, 2004). The whole task lasted approximately 20 min.

2.3. Procedure

Participants were tested between 9:00 a.m. and 5:30 p.m. (median of testing time was 12:00 noon). All participants were asked not to consume food, caffeine, nicotine, or alcohol at least 3 h before the experiment. Mean time since the last meal was $M = 5.66$ h ($SD = 3.99$). After participants had performed the SST, they immediately filled out the FCQ-S and reported the hours that had elapsed since their last meal. Completion of the other questionnaires and measurement of participants' height and weight was conducted either on the same day or within 1–2 weeks after the experiment, depending on individual assignment to experimental conditions[1]. Participants either received course credits or € 20 for participation.

2.4. Data analysis

Trials with a reaction time of less than 150 ms, reflecting anticipation, were excluded from analyses. Measures of interest were reaction times (ms) in go-trials, number of errors in go-trials (i.e., pressing the wrong button), the probability of responding in stop-trials ($P_{(RIS)}$), and SSRT. Stop signal reaction time was calculated for each SSD and picture type separately using the method described by Logan and Cowan (1984). Firstly, reaction times in go-trials were ranked and the mth reaction time was determined, where m is the product of the probability P of responding given a stop signal at a specific SSD and the number n of responses in the go-signal reaction time distribution ($m = n \times P_{(respond|signal)}$). Secondly, the respective SSD was subtracted from the mth reaction time ($SSRT = RT_{(m)} - SSD$). Note, that we did not use the apparently simpler method for calculating SSRT by subtracting mean SSD from reaction times in go-trials (Logan et al., 1997) because adjustment of SSD in a stop-trial with a neutral picture could be due to a response in a previous stop-trial with a food picture and vice versa. Descriptive statistics of and correlations between the different task performance indices are presented in Table 2. Although all indices are interrelated, only SSRT is considered as a pure measure of response inhibition and, thus, is related to self-reported impulsivity (Logan et al., 1997). Yet, we decided to present results for the other indices also for the sake of comprehensiveness.

Differences in task performance between food and neutral pictures were investigated with paired t-tests. For SSRT, a 2 (*picture type*: food vs. neutral) × 3 (*SSD*: 150 ms vs. 200 ms vs. 250 ms) ANOVA for repeated measures was calculated because differences in SSRT between food and neutral stimuli may depend on SSD (cf. findings with emotional stimuli; Herbert & Sütterlin, 2011). Associations between task performance and food craving were investigated with linear regression analyses. For each parameter, performances in response to neutral and food pictures were entered as predictors and FCQ-S scores as dependent variable. Finally, associations between task performance and FCQ-S scores, respectively, and control variables (self-reported impulsivity, BMI, dieting success, food addiction symptoms, and food deprivation) were tested with Pearson-correlations or independent t-tests (dieting status).

3. Results

3.1. Differences in task performance between food and neutral pictures

Reaction time in food trials ($M = 483.16$ ms, $SD = 48.34$) was slower as compared to neutral trials ($M = 470.90$ ms, $SD = 40.84$, $t_{(49)} = 2.25$, $p < .05$). Errors, $P_{(RIS)}$ and SSRT did not differ between food and neutral trials (errors: $M = 8.34$ ($SD = 5.84$) vs. $M = 7.7$ ($SD = 4.94$), $t_{(49)} = 0.85$, *ns*; $P_{(RIS)}$: $M = .47$ ($SD = .16$) vs. $M = .45$ ($SD = .15$), $t_{(49)} = 1.01$, *ns*; SSRT: M = 261.54 (SD = 49.94) vs. M = 253.19 (SD = 63.82), $F_{(1,49)} = 0.81$, *ns*, $\eta_p^2 = .02$). There was no interaction of picture type × SSD ($F_{(2,98)} = 0.74$, *ns*, $\eta_p^2 = .02$). As expected, the main effect of SSD was significant ($F_{(2,98)} = 7.52$, $p < .01$, $\eta_p^2 = .13$) indicating decreasing SSRTs with increasing SSD ($M_{(SSD\ 150ms)} = 277.30$ ($SD = 60.21$) > $M_{(SSD\ 200ms)} = 250.36$ ($SD = 32.42$) > $M_{(SSD\ 250ms)} = 231.52$ ($SD = 44.52$), all $t_{(49)}$'s > 4.00, $p < .001$).

3.2. Associations between task performance and current food craving

3.2.1. Reaction times

The model for the prediction of FCQ-S total scores from reaction times was significant ($F_{(2,47)} = 4.91$, $p < .05$, adj. $R^2 = .14$). Reaction time in food trials, but not in neutral trials, positively predicted FCQ-S total scores (Table 3). The model was also significant for each FCQ-S subscale (desire/lack of control: $F_{(2,47)} = 3.24$, $p < .05$, adj. $R^2 = .08$; reinforcement: $F_{(2,47)} = 3.72$, $p < .05$, adj. $R^2 = .10$; hunger: $F_{(2,47)} = 5.00$, $p < .05$, adj. $R^2 = .14$). Reaction times in food trials positively predicted desire/lack of control and hunger, but not anticipated reinforcement (Table 3).

3.2.2. Errors

The model for the prediction of FCQ-S scores from errors was neither significant for the total score ($F_{(2,47)} = 0.05$, *ns*, adj. $R^2 = -.04$) nor for any subscale (all $F_{(2,47)}$'s < 0.90, *ns*, adj. $R^2 < .00$).

3.2.3. $P_{(RIS)}$

The model for the prediction of FCQ-S scores from $P_{(RIS)}$ was neither significant for the total score ($F_{(2,47)} = 0.12$, *ns*, adj. $R^2 = -.04$) nor for any subscale (all $F_{(2,47)}$'s < 0.80, *ns*, adj. $R^2 < .00$).

3.2.4. SSRT

The model for the prediction of FCQ-S total scores from SSRT was significant ($F_{(2,47)} = 3.41$, $p < .05$, adj. $R^2 = .09$). SSRT in food trials, but not in neutral trials, positively predicted FCQ-S total scores (Table 3). The model was also significant for the desire/lack of control subscale ($F_{(2,47)} = 3.99$, $p < .05$, adj. $R^2 = .11$) and the reinforcement subscale

[1] The reported data were part of a study that also included other tasks and physiological recordings on three occasions, which are reported elsewhere (Meule, Lutz, Vögele, & Kübler, 2012b; Meule et al., 2012c; Meule et al., in revision). The order of tasks was counterbalanced, i.e. subjects performed the SST either on the first, second, or third session. None of the stimuli used in the SST were used in the other tasks.

Table 3
Beta-weights of regression analyses predicting self-reported food craving after the stop-signal task from task performance.

	Food Cravings Questionnaire — State											
	Desire/lack of control			Reinforcement			Hunger			Total		
	β	*t*	*p*	*β*	*t*	*p*	*β*	*t*	*p*	*β*	*t*	*p*
Reaction time in go-trials (ms)												
Food	.34	1.91	.06	.29	1.65	*ns*	.39	2.28	<.05	.37	2.15	<.05
Neutral	.02	0.08	*ns*	.11	0.63	*ns*	.04	0.23	*ns*	.07	0.38	*ns*
Number of errors in go-trials												
Food	−.11	−0.64	*ns*	.11	0.67	*ns*	−.22	−1.29	*ns*	−.05	−0.30	*ns*
Neutral	.03	0.15	*ns*	.02	0.09	*ns*	.06	0.36	*ns*	.03	0.19	*ns*
Probability of responding in stop-trials ($P_{(RIS)}$)												
Food	.18	1.11	*ns*	−.02	−0.13	*ns*	−.05	−0.32	*ns*	.05	0.32	*ns*
Neutral	−.17	−1.05	*ns*	.04	0.23	*ns*	−.09	−0.54	*ns*	−.08	−0.47	*ns*
Stop-signal reaction time (SSRT)												
Food	.39	2.68	<.05	.19	1.31	*ns*	.22	1.43	*ns*	.30	2.08	<.05
Neutral	−.02	−0.12	*ns*	.23	1.56	*ns*	.06	0.40	*ns*	.11	0.75	*ns*

($F_{(2,47)} = 3.18$, $p = .05$, adj. $R^2 = .08$), but not for the hunger subscale ($F_{(2,47)} = 1.49$, *ns*, adj. $R^2 = .02$). SSRT in food trials positively predicted desire/lack of control, but not anticipated reinforcement (Table 3).

3.3. Associations between task performance, BMI, and questionnaire measures

Self-reported impulsivity was not associated with task performance except for motor impulsivity which was positively correlated with overall SSRT ($r = .35$, $p < .05$). BMI, dieting success, food addiction symptoms, and food deprivation were not correlated with any parameter and task performance did not differ between dieters and non-dieters (all $ts_{(48)} < 1.43$, *ns*).

3.4. Associations between current food craving, BMI, and questionnaire measures

Self-reported impulsivity, BMI, dieting success, food addiction symptoms, and food deprivation were not correlated with the FCQ-S (Table 1) and scores did not differ between dieters and non-dieters (all $ts_{(48)} < 1.28$, *ns*).

4. Discussion

In the current study, we examined the relationship between task performance in a food-related response inhibition task and current food craving in young women. We found that all participants responded slower in food trials as compared to neutral trials. This result seems to contrast findings of previous studies in which participants responded faster to food-cues compared to neutral cues in a go/no-go task (Loeber et al., 2012; Meule et al., 2012c; Meule et al., in revision; Mobbs et al., 2011; Mobbs, Van der Linden, d'Acremont, & Perroud, 2008). These discrepant findings may be explained by differences in the tasks employed: while the tasks used in previous studies required only a simple reaction (i.e. either press or not press one button), the task in the current study involved a two-choice reaction. While it cannot be concluded from the current results if slower reactions in food-trials were due to the required categorization (stimulus dependent button press with left or right hand), we found that increased reaction times in response to food-cues were associated with increased self-reported craving after the task and increased self-reported hunger in particular, supporting an effect of food-cues beyond categorization. Likewise, some studies have found that inducing craving via mental imagery or cue-exposure can result in a slowing of responses both in relation to food (e.g. Green, Rogers, & Elliman, 2000; Kemps et al., 2008; Meule, Lukito, et al., 2011; Smeets, Roefs, & Jansen, 2009) or drug craving (e.g. Baxter & Hinson, 2001; Cepeda-Benito & Tiffany, 1996; Sayette & Hufford, 1994; Sayette et al., 1994). Furthermore, attentional bias to food- or drug-related cues has been found to be positively associated with current craving (Field, Munafò, & Franken, 2009; Smeets et al., 2009; Werthmann et al., 2011). Hence, the present results lend further support for associations between food craving and attention allocation processes to food-cues which may be reflected in a slowing of responses in motor response inhibition tasks.

A second finding of the present study was that lowered inhibitory control in response to food-cues was related to an increased self-reported food craving after the task, particularly an increased desire to eat and lack of control over eating. Self-reported motor impulsivity was correlated with lower inhibitory performance during the task, but was unrelated to current cravings. It has been noted previously that although self-reported impulsivity is associated with SSRT (Logan et al., 1997), the two are only weakly correlated and, therefore, may represent different facets of impulsivity (Cyders & Coskunpinar, 2011). Accordingly, Papachristou et al. found that — although heavy drinkers reported higher trait impulsivity than light drinkers — only motor response inhibition, but not self-reported impulsivity, modulated alcohol-cue elicited craving (Papachristou, Nederkoorn, Corstjens, et al., 2012). Thus, our study provides further evidence for the crucial role of motor response inhibition in cue-induced craving. Furthermore, it extends recent findings by showing that low inhibitory control particularly when confronted with food-cues, and not inhibitory ability in general, is predictive for experiencing food craving. Therefore, the current results concur with contemporary conceptualizations of self-regulatory failure in eating behavior, which argue that interactive effects of food-cue induced bottom-up processes and reduced inhibitory control mechanisms determine food intake (Appelhans, 2009; Heatherton & Wagner, 2011), which may be mediated by food craving experiences.

Neither task performance nor current craving was associated with food deprivation, BMI, dieting, or food addiction. This might be explained by the fact that all participants were instructed not to eat for at least 3 h, i.e. all participants were hungry. It has been found that individuals show an attentional bias towards food-cues when food deprived regardless of habitual eating behaviors (Gearhardt, Treat, Hollingworth, & Corbin, 2012; Mogg, Bradley, Hyare, & Lee, 1998). Although total scores on the FCQ-S were predicted by both reaction time and SSRT in response to food pictures, it appears that there was a dissociation between FCQ-S subscales. While reaction time was primarily related with increased hunger ratings, SSRT predicted increased desire to eat and lack of control over eating. We argue that reaction times in the SST reflect attentional processes rather than impulsive reactions. Thus, our study confirms results which show that hunger is related to an attentional bias to food-cues (Gearhardt, Treat, et al., 2012; Mogg et al., 1998). Additionally, low motor response inhibition in the presence of food-cues may be a behavioral index of a strong desire to consume foods in particular.

Some limitations have to be considered when interpreting the current results. Firstly, we did not match food and neutral stimuli for physical features like visual complexity, brightness, colors, etc. Thus, different reaction times between stimulus types may not be due to content, but to other characteristics. However, relationships between task performance and current craving are sound because they were specifically observed for food trials and this may unlikely be due to physical features. Secondly, we did not assess state cravings prior to the task. Although this may also be an advantage as priming effects of such an assessment were prevented, it cannot be evaluated if food cravings increased during the task (but they did most likely, cf. Meule, Skirde, et al., 2012) and whether they were already elevated prior to the task thereby limiting cognitive resources and diminishing task performance in food trials (cf. Kemps et al., 2008). Thirdly, we did not measure actual food intake after the task. Although individuals with low inhibitory control in food trials reported to experience elevated food craving related to a lack of control over eating, food cravings do not necessarily result in overeating (Hill, 2007). A recent study by Houben et al. found that low inhibition in response to food-cues after food exposure was associated with increased laboratory food intake in unsuccessful dieters (Houben et al., 2012). Hence, we would argue that heightened levels of food craving might have mediated this relationship between task performance and food intake. Finally, interpretation of results is restricted to young women only. Such samples are usually investigated when food-related issues are examined and, thus, our sample was comparable to other studies investigating food-related response inhibition (Houben et al., 2012; Meule, Lukito, et al., 2011; Meule et al., 2012c; Nederkoorn et al., 2004). However, results may differ in other types of samples, e.g. men. Moreover, clinical samples, e.g. patients with binge eating disorder or bulimia nervosa, need to be investigated as those in particular have been associated with high impulsivity and low inhibitory control, respectively (Waxman, 2009; Wu et al., 2013), and with high susceptibility to experience food-cue induced craving (Moreno, Rodríguez, Fernandez, Tamez, & Cepeda-Benito, 2008; Van den Eynde et al., 2012). Thus, both food-cue affected response inhibition and subsequent food craving may be even more pronounced in those samples.

To conclude, the current study showed that reduced inhibitory control when confronted with food, but not with neutral cues, was predictive of increased food craving. Future studies may examine the underlying neuronal mechanisms. For example, it may be that reduced task performance is associated with increased activation of reward-related subcortical structures with concurrent hypoactivation of prefrontal areas associated with inhibitory control (Appelhans, 2009; Heatherton & Wagner, 2011). Furthermore, it has to be determined if low food-cue affected inhibition is the result of strong craving experiences (or dealing with those cravings) or if elevated cravings are the result of performing the task, i.e. through self-regulatory depletion. To date, the study of the relationship between executive functions and self-regulation is in its infancy, and it is possible that executive functions are the outcome, predictor, moderator or mediator of self-regulation (Hofmann, Schmeichel, & Baddeley, 2012). Finally, recent approaches show that a training of food-related inhibition can affect subsequent food intake or food choice (Houben, 2011; Houben & Jansen, 2011; Veling, Aarts, & Stroebe, 2013). Future research should investigate if such training can effectively and lastingly reduce food intake of unhealthy, highly caloric foods and if this effect is mediated by an attenuation of food cravings. As a result, such trainings may not only be effective for enhancing dieting success in current dieters, but also for attenuating binge eating symptomatology in eating disorders.

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Contributors

All authors contributed to the design of the study. Annika Lutz collected the data. Data analyses were performed by Annika Lutz and Adrian Meule who also wrote the first draft of the manuscript. Claus Vögele and Andrea Kübler contributed to interpretation of the data and manuscript preparation. All authors have approved the final manuscript.

Conflict of interest

Neither of the authors has any conflicts of interest.

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