FOOD CRAVING AS A CENTRAL CONSTRUCT IN THE SELF-REGULATION OF EATING BEHAVIOR

CRAVING NACH NAHRUNGSMITTELN ALS ZENTRALES KONSTRUKT BEI DER SELBST-REGULATION DES ESSVERHALTENS

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Abstract

Background: Food craving refers to an intense desire to consume a specific kind of food of which chocolate is the most often craved one. It is this intensity and specificity that differentiates food craving from feelings of hunger. Although food craving and hunger often co-occur, an energy deficit is not a prerequisite for experiencing food craving, that is, it can also occur without being hungry. Food craving often precedes and predicts over- or binge eating which makes it a reasonable target in the treatment of eating disorders or obesity. One of the arguably most extensively validated measures for the assessment of food craving are the *Food Cravings Questionnaires* (FCQs), which measure food craving on a state (FCQ-S) and trait (FCQ-T) level. Specifically, the FCQ-S measures the intensity of current food craving whereas the FCQ-T measures the frequency of food craving experiences in general. The aims of the present thesis were to provide a German measure for the assessment of food craving and to investigate cognitive, behavioral, and physiological correlates of food craving. For this purpose, a German version of the FCQs was presented and its reliability and validity was evaluated. Using self-reports, relationships between trait food craving and dieting were examined. Cognitive-behavioral correlates of food craving were investigated using food-related tasks assessing executive functions. Psychophysiological correlates of food craving were investigated using event-related potentials (ERPs) in the electroencephalogram and heart rate variability (HRV). Possible intervention approaches to reduce food craving were derived from results of those studies.

Methods: The FCQs were translated into German and their psychometric properties and correlates were investigated in a questionnaire-based study (articles #1 & #2). The relationship between state and trait food craving with executive functioning was examined with behavioral tasks measuring working memory performance and behavioral inhibition which involved highly palatable food-cues (articles #3 & #4). Electrophysiological correlates of food craving were tested with ERPs during a craving regulation task (article #5). Finally, a pilot study on the effects of HRV-biofeedback for reducing food craving was conducted (article #6).

Results: The FCQs demonstrated high internal consistency while their factorial structure could only partially be replicated. The FCQ-T also had high retest-reliability which, expectedly, was lower for the FCQ-S. Validity of the FCQ-S was shown by positive relationships with current food deprivation and negative affect. Validity of the FCQ-T was shown by positive correlations with related constructs. Importantly, scores on the subscales of the FCQ-T were able to discriminate between non-dieters and successful and unsuccessful dieters (article #1). Furthermore, scores on the FCQ-T mediated the relationship between rigid dietary control strategies and low dieting success (article #2). With regard to executive functioning, high-calorie food-cues impaired working memory performance, yet this was independent of trait food craving and rarely related to state food craving (article #3). Behavioral disinhibition in response to high-calorie food-cues was predicted by trait food craving, particularly when participants were also impulsive (article #4). Downregulation of food craving by cognitive strategies in response to high-calorie food-cues increased early, but not later, segments of the Late Positive Potential (LPP) (article #5). Few sessions of HRV-biofeedback reduced self-reported food cravings and eating and weight concerns in high trait food cravers (article #6).

Conclusions: The German FCQs represent sound measures with good psychometric properties for the assessment of state and trait food craving. Although state food craving increases during cognitive tasks involving highly palatable food-cues, impairment of task performance does not appear to be mediated by current food craving experiences. Instead, trait food craving is associated with low behavioral inhibition in response to high-calorie food-cues, but not with impaired working memory performance. Future studies need to examine if trait food craving and, subsequently, food-cue affected behavioral inhibition can be reduced by using food-related inhibition tasks as a training. Current food craving and ERPs in response to food-cues can easily be modulated by cognitive strategies, yet the LPP probably does not represent a direct index of food craving. Finally, HRV-biofeedback may be a useful add-on element in the treatment of disorders in which food cravings are elevated. To conclude, the current thesis provided measures for the assessment of food craving in German and showed differential relationships between state and trait food craving with self-reported dieting behavior, food-cue affected executive functioning, ERPs and HRV-biofeedback. These results provide promising starting points for interventions to reduce food craving based on (1) food-cue-related behavioral trainings of executive functions, (2) cognitive craving regulation strategies, and (3) physiological parameters such as HRV-biofeedback.

Zusammenfassung

Hintergrund: Craving nach Essen bezeichnet ein starkes Verlangen ein bestimmtes Nahrungsmittel zu konsumieren, welches sich meist auf Schokolade bezieht. Diese Intensität und Spezifität unterscheidet Craving nach Nahrungsmitteln von generellen Hungergefühlen. Obwohl Craving und Hunger häufig Hand in Hand gehen, ist ein Energiedefizit keine Voraussetzung dafür, Craving zu erleben; das bedeutet, es kann ebenfalls auftreten, obwohl man nicht hungrig ist. Craving geht häufig Überessen oder Essanfällen voraus, was es zu einem plausiblen Ansatzpunkt in der Therapie von Essstörungen und Adipositas macht. Eines der wohl am umfangreichsten validierten Maße zur Erfassung von Craving nach Nahrungsmitteln sind die *Food Cravings Questionnaires* (FCQs), die Craving als momentanen Zustand (engl. *state*, FCQ-S) und überdauerndes Merkmal (engl. *trait*, FCQ-T) erfassen. Genauer gesagt misst der FCQ-S die Intensität von aktuellem Craving nach Nahrungsmitteln, während der FCQ-T die Häufigkeit des Erlebens von Craving im Allgemeinen erfasst. Die Ziele der vorliegenden Arbeit waren die Bereitstellung eines deutschen Fragebogens zur Erfassung von Craving nach Nahrungsmitteln und die Untersuchung von kognitiven, behavioralen, und physiologischen Korrelaten von Craving. Hierfür wurde eine deutsche Version der FCQs präsentiert und deren Reliabilität und Validität überprüft. Zusammenhänge zwischen der Häufigkeit des Erlebens von Craving und Diätverhalten wurden mit Selbstberichtsfragebögen getestet. Kognitiv-behaviorale Korrelate von Craving wurden anhand von essensbezogenen Aufgaben zur Erfassung von exekutiven Funktionen untersucht. Psychophysiologische Korrelate von Craving wurden anhand von ereigniskorrelierten Potentialen (EKPs) im Elektroenzephalogramm und der Herzratenvariabilität (HRV) erforscht. Mögliche Interventionsansätze zur Reduktion von Craving wurden aus den Ergebnissen dieser Studien abgeleitet.

Methoden: Die FCQs wurden auf Deutsch übersetzt und deren psychometrische Eigenschaften und Korrelate wurden in einer Fragebogenstudie untersucht (Artikel #1 & #2). Der Zusammenhang zwischen momentanem und habituellem Craving mit exekutiven Funktionen wurde anhand von behavioralen Aufgaben zur Erfassung der Arbeitsgedächtnisleistung und Verhaltenshemmung, die sehr schmackhafte Essensreize enthielten, überprüft (Artikel #3 & #4). Elektrophysiologische Korrelate von Craving wurden mit Hilfe von EKPs während einer Aufgabe zur Regulation von Craving getestet (Artikel #5). Schließlich wurde eine Pilotstudie zu den Effekten von HRV-Biofeedback zur Reduktion von Craving durchgeführt (Artikel #6).

Ergebnisse: Die FCQs zeigten eine sehr hohe interne Konsistenz, wohingegen deren Faktorenstruktur nur teilweise repliziert werden konnte. Der FCQ-T hatte außerdem eine hohe Retest-Reliabilität, welche erwartungsgemäß geringer für den FCQ-S ausfiel. Validität des FCQ-S zeigte sich durch positive Zusammenhänge mit

aktueller Essensdeprivation und momentaner negativer Stimmung. Validität des FCQ-T zeigte sich durch positive Korrelationen mit verwandten Konstrukten. Zudem konnte anhand der Subskalen des FCQ-T zwischen nicht-diäthaltenden und erfolgreichen und erfolglosen diäthaltenden Personen diskriminiert werden (Artikel #1). Weiterhin zeigte sich, dass der Zusammenhang zwischen rigiden Diätstrategien und geringem Diäterfolg durch Werte des FCQ-T vermittelt wurde (Artikel #2). Bezüglich der exekutiven Funktionen ergab sich, dass die Arbeitsgedächtnisleistung durch das darbieten von hochkalorischen Essensreizen vermindert wurde, allerdings war dies unabhängig von habituellem Craving und stand kaum mit momentanem Craving in Verbindung (Artikel #3). Häufiges Erleben von Craving konnte dahingegen eine behaviorale Enthemmung als Reaktion auf hochkalorische Essensreize vorhersagen, insbesondere wenn die Teilnehmer ebenfalls eine hohe Impulsivität berichteten (Artikel #4). Die Herunterregulierung von Craving während der Präsentation hochkalorischer Essensreize mit Hilfe kognitiver Strategien führte zu einer Erhöhung von früheren, nicht jedoch von späteren, Abschnitten des *Late Positive Potential* (LPP) (Artikel #5). Bereits wenige Übungssitzungen von HRV-Biofeedback resultierten in einer Reduktion selbstberichteter Cravings sowie essens- und gewichtsbezogener Sorgen bei Menschen mit häufigem Erleben von Cravings (Artikel #6).

Schlussfolgerungen: Die deutschen FCQs stellen brauchbare Maße mit guten psychometrischen Eigenschaften zur Erfassung von Craving auf aktueller und habitueller Ebene dar. Obwohl momentanes Craving während kognitiven Aufgaben, die sehr schmackhafte Essensreize beinhalten, ansteigt, scheint eine Verminderung der Aufgabenleistung nicht durch das momentane Erleben solcher Cravings vermittelt zu sein. Habituelles Erleben von Craving ist dahingegen mit einer geringen Inhibitionsleistung auf hochkalorische Essensreize assoziiert, allerdings nicht mit einer eingeschränkten Arbeitsgedächtnisleistung. Zukünftige Studien sollten sich der Frage widmen, ob häufiges Erleben von Craving, und entsprechend auch der Einfluss von Essensreizen auf die Verhaltenshemmung, durch essensbezogene Inhibitionstrainings reduziert werden kann. Momentanes Craving und EKPs während der Präsentation von Essensreizen können leicht durch kognitive Strategien moduliert werden. Die LPP stellt hier wohl allerdings kein direktes Maß des Erlebens von Craving dar. Zu guter Letzt könnte HRV-Biofeedback ein nützliches, zusätzliches Therapieelement bei Störungen, die mit häufigem und intensivem Craving nach Nahrungsmitteln einhergehen, darstellen. Zusammenfassend lässt sich sagen, dass die vorliegende Arbeit Instrumente zur Erfassung von Craving nach Nahrungsmitteln im deutschen Sprachraum bereitgestellt hat und differenzielle Zusammenhänge zwischen momentanem und habituellem Craving mit selbstberichtetem Diätverhalten, durch Essensreize beeinträchtige exekutive Funktionen, EKPs und HRV-Biofeedback, aufgezeigt wurden. Diese Ergebnisse stellen vielversprechende Ansatzpunkte für Interventionen zur Reduktion von Craving nach Nahrungsmitteln dar, die auf (1) essensbezogenen Verhaltenstrainings der exekutiven Funktionen, (2) kognitiven Craving-Regulationsstrategien, und (3) physiologischen Parametern wie beispielsweise HRV-Biofeedback, basieren.

Contents

1. Introduction

1.1 Food craving

1.1.1 Definition and phenomenology of food craving. Craving refers to an intense desire or urge to use a substance and frequent experiences of craving are a core feature of substance use disorders (Tiffany & Wray, 2012). However, the term craving does not only refer to drug-related, but also to other substances like food or non-alcoholic beverages (Hormes & Rozin, 2010). Accordingly, food craving refers to an intense desire or urge to eat specific foods of which chocolate is the most often craved one among other highly palatable foods (Weingarten & Elston, 1990, 1991). Cultural differences have also been noted, for example, a preference for savory over sweet foods in Arabian countries or the presence of rice cravings in Asian countries (Hill, 2007; Komatsu, 2008). It is the intensity and specificity that differentiates food craving from feelings of plain hunger (Hill, 2007). Although food craving and hunger often co-occur, an energy deficit is not a prerequisite for experiencing food craving, that is, it can also occur without being hungry (Pelchat & Schaefer, 2000). Food craving experiences are common and reported by the majority of adults. That is, although more intense and more frequent experiences of food craving are associated with overeating, they do not necessarily reflect abnormal eating behavior and are not synonymous with increased food intake (Hill, 2007).

1.1.2 Assessment of food craving. The sight, smell, or taste of food and food-cues elicit so-called cephalic phase responses, which prepare the organism for food ingestion and are associated with increases in craving for those foods (Nederkoorn, Smulders, & Jansen, 2000). Physiologically, those responses involve increases in salivary secretion, cardiovascular activity (e.g., heart rate and blood pressure), body temperature, electrodermal activity, and respiration (Legenbauer, Vögele, & Rüddel, 2004; Nederkoorn et al., 2000; Vögele & Florin, 1997). Yet, attempts to measure craving objectively, for example, based on physiological data, have been criticized for being unspecific and subjective self-report seems the only viable assessment modality (Shiffman, 2000). The term craving is somewhat vague and often subjects are asked to indicate on a one-item rating scale how strong they crave or desire a specific object. Therefore, there is a need to assess craving as a multidimensional construct with standardized questionnaires instead of single questions. This is particularly important in non-English speaking countries because there is no simple equivalent expression for craving (Hormes & Rozin, 2010).

Several self-report measures for the assessment of food craving have been developed such as the *Food Cravings Questionnaires* (FCQs; Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, & Erath, 2000), the *Attitudes to Chocolate Questionnaire* (ACQ; Benton, Greenfield, & Morgan, 1998; Müller, Dettmer, & Macht, 2008), the *Orientation towards Chocolate Questionnaire* (OCQ;

Cartwright & Stritzke, 2008; Rodgers, Stritzke, Bui, Franko, & Chabrol, 2011), the *Food Craving Inventory* (FCI; Jáuregui Lobera, Bolaños, Carbonero, & Valero Blanco, 2010; Komatsu, 2008; Nicholls & Hulbert-Williams, 2013; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002), and the *Questionnaire on Craving for Sweet or Rich Foods* (QCSRF; Toll, Katulak, Williams-Piehota, & O'Malley, 2008). Each of these measures represents a different approach to the craving construct. Both the ACQ and OCQ are designed to measure cravings specifically related to chocolate and emphasize the relationship between craving and feelings of guilt (Benton et al., 1998) or the conflict between approach and avoidance inclinations during the experience of craving (ambivalence model; Cartwright & Stritzke, 2008). The FCI measures cravings related to different classes of food (high fats, sweets, carbohydrate/starches, fast-food fats; White et al., 2002). The QCSRF measures the intensity of craving for sweet or rich foods with a mixture of questions referring to momentary craving, but mainly to craving during the past week (Toll et al., 2008). Therefore, all of these instruments assess habitual cravings related to specific kinds of food and are restricted to certain dimensions of food cravings.

As opposed to these questionnaires, the FCQs were constructed to assess craving for a variety of foods, without confining them to certain categories or specific foods, for example, chocolate. Furthermore, the FCQs cover behavioral, cognitive and physiological aspects of food cravings. Finally, the FCQs combine two versions that measure current and habitual food cravings. Therefore, the FCQs are the only currently available food craving instruments that (1) do not refer specifically to chocolate or similar, (2) assess food cravings on a multidimensional level, and (3) measure food cravings as trait and state. Moreover, there is evidence that the FCQs can be used easily as a measure for specific cravings, for example, by replacing references to food with references to chocolate (Rodriguez et al., 2007).

The FCQs are arguably the most extensively validated food craving measures and are available in English (Cepeda-Benito, Gleaves, Williams, et al., 2000), Spanish (Cepeda-Benito, Gleaves, Fernández, et al., 2000), Dutch (Franken & Muris, 2005; modified version from Nijs, Franken, & Muris, 2007), and Korean (modified version from Noh et al., 2008).

The trait version of the FCQs (FCQ-T) consists of 39 items and items are scored on a 6-point scale ranging from *never* to *always*. Its original form 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 (Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, et al., 2000). However, factorial structure could only partially be replicated in a subsequent study in obese individuals and in a study using the chocolate-adapted version (Rodriguez et al., 2007; Vander Wal, Johnston, & Dhurandhar, 2007). Specifically, results yielded fewer factors in those studies, that is, eight and six subscales, respectively (Rodriguez et al., 2007; Vander Wal et al., 2007). Internal consistency of the total scale is very high (α > .90) across different versions and samples (Cepeda-Benito, Fernandez, & Moreno, 2003; Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, et al., 2000; Moreno, Rodríguez, Fernandez, Tamez, & Cepeda-Benito, 2008; Nijs et al., 2007; Rodriguez et al., 2007; Vander Wal et al., 2007).

The state version of the FCQs (FCQ-S) consists of 15 items and items are scored on a 5-point scale ranging from *strongly disagree* to *strongly agree*. Its original form comprises nine subscales measuring 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 (Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, et al., 2000). Like for the trait version, subscales could only be partially replicated in a sample of obese individuals as two subscales were merged (Vander Wal et al., 2007). Again, internal consistency for the total scale usually is α > .90 (Cepeda-Benito et al., 2003; Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, et al., 2000; Moreno et al., 2008; Nijs et al., 2007; Vander Wal et al., 2007).

1.1.3 Food craving and dieting. The relationship between dieting and experiences of food craving is a complex topic and the widely held opinion that dieting for losing weight leads to increases in food craving is challenged by null results or even contradictory findings. For example, an important moderator of this relationship is the specific type of dieting behavior and its assessment method.

For instance, dietary restraint – which does not necessarily equal current caloric restriction – has only been inconsistently associated with food craving. Polivy and colleagues (2005) found restrained eaters – as measured with the *Restraint Scale* (RS) – to experience more food cravings than unrestrained eaters. Restrained eating as measured with the *Dutch Eating Behavior Questionnaire* (DEBQ) and the *Three-Factor Eating Questionnaire* (TFEQ), however, was not correlated with craving frequency (Hill, Weaver, & Blundell, 1991). These contradictory findings could be due to the different questionnaires used, because the RS has been found to measure rather unsuccessful dietary restraint while the DEBQ and TFEQ rather identify successful restrained eaters (Heatherton, Herman, Polivy, King, & McGree, 1988; Williamson et al., 2007). Yet, another study using the RS did not find an association between restraint status and food cravings (Rodin, Mancuso, Granger, & Nelbach, 1991). Using restraint scales is critical because they do not clearly differentiate between successful and unsuccessful dietary restraint (Van Strien, 1997, 1999). Most recently, attempts have been made to distinguish more explicitly between successful and unsuccessful restrained eaters (Houben, Nederkoorn, & Jansen, 2012; Papies, Stroebe, & Aarts, 2008; Van Koningsbruggen, Stroebe, & Aarts, 2011, 2013; Van Koningsbruggen, Stroebe, Papies, & Aarts, 2011). In those studies, the subscale *concern for dieting* of the RS is used to identify dieters and non-dieters. Additionally, the *Perceived Self-Regulatory Success in Dieting*

Scale (PSRS; Fishbach, Friedman, & Kruglanski, 2003) is used to evaluate successful or unsuccessful dietary restraint. Validity of this brief 3-item measure has been shown (Meule, Papies, & Kübler, 2012) and its use will likely be beneficial for food craving research and more advantageous than using restraint scales alone.

Studies investigating the effects of caloric restriction on food craving also could not confirm that dieting increases food craving. Instead, they show that fasting or low-calorie diets can actually lead to reductions in food craving (for overviews, see Hill, 2007; Martin, McClernon, Chellino, & Correa, 2011). Furthermore, a recent study showed that weight loss during a Cognitive Behavioral Therapy based intervention was positively correlated with decreases in food cravings (Batra et al., 2013). It has also been shown that cravings for specific foods decrease as a function of diet type. That is, craving for high-fat foods particularly decreased during a low-fat diet and craving for high-sugar foods particularly decreased during a low-carbohydrate diet (Martin, Rosenbaum, et al., 2011). It appears, however, that such effects can only be observed when diets still involve a large variety of foods as monotonous diets result in increases in food craving (Pelchat & Schaefer, 2000).

1.1.4 Food craving in eating disorders and obesity. In non-clinical samples, scores on the FCQ-T are positively correlated with constructs associated with overeating, for example, higher scores on the disinhibition subscale of the TFEQ, higher scores on eating disorder questionnaires, higher self-reported sensitivity to reward, more symptoms of food addiction, lower dieting success and higher body-mass-index (BMI) (Cepeda-Benito et al., 2003; Cepeda-Benito, Gleaves, Williams, et al., 2000; Franken & Muris, 2005; Meule & Kübler, 2012; Meule, Papies, et al., 2012). Accordingly, FCQ-T scores are elevated in patients with bulimia nervosa, binge eating disorder, and obesity (Abilés et al., 2010; Van den Eynde, Koskina, et al., 2012). Furthermore, FCQ-T-subscales have been found to discriminate between anorexia and bulimia nervosa subtypes (Moreno, Warren, Rodríguez, Fernández, & Cepeda-Benito, 2009). In particular, cravings associated with a lack of control over eating, preoccupation with food, negative affect, and guilty feelings were predictive of bulimic symptomatology (Moreno et al., 2008).

1.2 Executive functions

1.2.1 Definition, measurement and relationship to self-regulation. Executive functions refer to “a collection of top-down control processes used when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible” (Diamond, 2013, p. 136). The most important and most often investigated executive functions are (1) cognitive flexibility, (2) working memory, and (3) inhibitory control (Diamond, 2013; Hofmann, Schmeichel, & Baddeley, 2012).

Cognitive flexibility involves mental set shifting, e.g. changing perspectives or approaches to a problem and flexibly adjusting to new demands, rules or priorities. Inhibitory control can refer to cognitive inhibition of, for example, irrelevant information, or to behavioral inhibition, that is, withholding pre-potent motor responses. In the current thesis, inhibitory control will be used in reference to behavioral inhibition only. Finally, working memory refers to the maintenance and updating of relevant information (Diamond, 2013; Hofmann et al., 2012).

Cognitive flexibility is often investigated with task-switching or set-shifting tasks, arguably the most popular of which is the Wisconsin Card Sorting Test (Berg, 1948). Two of the most often used tasks for measuring behavioral inhibition are go/no-go tasks and the stop-signal paradigm. Go/no-go tasks involve the instruction to respond to a certain stimulus (e.g. by pressing a button), but to inhibit this response to another stimulus. In stop-signal tasks, the go-signal is presented on every trial, but in a minority of trials a stop-signal is presented shortly after onset of the go-signal, indicating that one should not press the button on that trial. Stop-signal delay is adjusted dynamically and a stop-signal reaction time is calculated with higher values indicating lower inhibitory performance (Logan, Schachar, & Tannock, 1997). Working memory capacity or span can be measured with digit span tasks (e.g., repeat back items in the same or reverse order one had heard them) or the Corsi block-tapping test (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). A working memory task that requires on-line monitoring, updating, and manipulation of remembered information is the *n*-back paradigm, in which a series of stimuli are presented and subjects are instructed to respond whenever a stimulus is presented that is the same as the one presented *n* trials previously (usually 1-, 2-, or 3-back; Owen, McMillan, Laird, & Bullmore, 2005). Although different measures exist for each aspect of executive functions, these processes are, of course, not independent from another (Diamond, 2013). For example, it would be impossible to perform tasks on cognitive flexibility or behavioral inhibition when working memory function was heavily impaired.

Emerging evidence suggests that executive functions support important mechanisms in achieving self-regulatory goals and that temporary reductions in executive functioning may be a common mechanism contributing to self-regulatory failure (Hofmann et al., 2012). Behavioral inhibition in particular is most closely linked to and may even be a direct measure of self-regulatory ability (Diamond, 2013). Yet, recent evidence also points to the direction that higher working memory capacity and cognitive flexibility is linked to higher self-regulation in general (Delgado-Rico, Rio-Valle, Gonzalez-Jimenez, Campoy, & Verdejo-Garcia, 2012; Hofmann et al., 2012). To date, however, little is known about the exact relationships between executive functions and self-regulation. Potentially, there are many different conceptual approaches to the study of executive functions and self-regulation. For example, executive functions could be the outcome or predictor of self-regulation or could be considered both as outcome or predictor (Hofmann et al., 2012). Executive functions could also act as process moderator or mediator between another variable and self-regulation (Hofmann et al., 2012).

1.2.2 Working memory and food craving. When studying executive functions as an outcome variable, it has been proposed previously that dealing with strong cravings may consume working memory resources (Hofmann et al., 2012). Indeed, although it is not clear if findings are directly a result of experienced craving, it has been found that smokers performed worse in a working memory task when trials were preceded by smoking-cues (Wilson, Sayette, Fiez, & Brough, 2007). With regard to eating behavior, inducing food craving lead to impaired performance in a neutral working memory task in trait chocolate cravers (Kemps, Tiggemann, & Grigg, 2008) or in female students without any moderating role of trait chocolate craving (Tiggemann, Kemps, & Parnell, 2010). Vice versa, concurrent visuo-spatial information processing or mental imagery tasks reduced food cravings (Kemps & Tiggemann, 2010, 2013), which highlights the role of the visual modality in the experience of craving (Tiggemann & Kemps, 2005). Thus, it has been argued that food cravings selectively impact visuo-spatial aspects of working memory.

While the aforementioned studies used neutral working memory tasks in conjunction with prior food craving induction, there is only sparse literature on working memory tasks that directly involved food-cues. Two studies used masked subliminal food images which were presented before each trial in an *n*-back task with letters as targets and distractors (Brooks et al., 2012; Dickson et al., 2008). Yet, those studies did not find compelling evidence for an influence of food stimuli nor craving on task performance. Most recently, Svaldi and colleagues (2014) found general differences in task performance between individuals with BED and controls in a so-called *n-back task with lures*, but did not find differential effects for food words. To conclude, there is no conclusive evidence for a reduced food-cue affected working memory performance as a function of craving.

1.2.3 Behavioral inhibition and food craving. Increasing evidence suggests that low behavioral inhibition is associated with overeating. For example, lower behavioral inhibition was demonstrated in patients with bulimia nervosa (Rosval et al., 2006; Wu et al., 2013), restrained eaters (Nederkoorn, Van Eijs, & Jansen, 2004), and obese children (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Thamotharan, Lange, Zale, Huffhines, & Fields, 2013; Wirt, Hundsdörfer, Schreiber, Kesztyüs, & Steinacker, 2014) and adults (Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006), as compared to controls. In children, low behavioral inhibition has been found to prospectively predict higher BMI some years later or attenuated weight loss after a weight-loss intervention (Nederkoorn, Jansen, Mulkens, & Jansen, 2007; Reinert, Po'e, & Barkin, 2013). Furthermore, behavioral inhibition has been found to moderate food consumption in the laboratory such that particularly those restrained eaters that exhibited low inhibition showed increased food intake (Jansen et al., 2009; Meule, Lukito, Vögele, & Kübler, 2011). Finally, low inhibitory control in combination with a high implicit preference for snack foods predicted candy consumption in the laboratory (Hofmann, Friese, & Roefs, 2009) and one-year weight gain (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010) among students. To summarize, lower behavioral inhibition is associated with lower eating-related self-regulation, as operationalized by higher laboratory food intake, higher BMI, or binge eating. These findings, however, could not be confirmed by a number of studies failing to show decreased behavioral inhibition in patients with bulimia, binge eating disorder or obesity compared with controls (Claes, Mitchell, & Vandereycken, 2012; Claes, Nederkoorn, Vandereycken, Guerrieri, & Vertommen, 2006; Galimberti, Martoni, Cavallini, Erzegovesi, & Bellodi, 2012; Hendrick, Luo, Zhang, & Li, 2012; Van den Eynde, Samarawickrema, et al., 2012; Wu et al., 2013).

In the same vein as above (section 1.2.2), that is, viewing executive functions as an outcome variable in conjunction with food-cue presentation and dealing with food craving, respectively, research has been conducted on the effects of food-cues on behavioral inhibition. Those studies, however, did not reveal conclusive results. For instance, no effects of food-cues on behavioral inhibition were found when food or food stimuli were presented as peripheral cues on or besides the computer screen (Meule et al., 2011; Meule, Lutz, Vögele, & Kübler, 2012b; Nederkoorn et al., 2004). Two studies which used food-related behavioral inhibition tasks did not include a neutral control condition (Batterink, Yokum, & Stice, 2010; Jasinska et al., 2012). Some studies found general differences in inhibitory performance between food and neutral cues which may simply be due to category size effects or physical stimulus features (Loeber et al., 2012; Meule et al., in revision; Mobbs, Iglesias, Golay, & Van der Linden, 2011; Mobbs, Van der Linden, d'Acremont, & Perroud, 2008). Recently, decreased behavioral inhibition particularly in response to food-cues was found in overweight children and unsuccessful dieters (Houben et al., 2012; Nederkoorn, Coelho, Guerrieri, Houben, & Jansen, 2012). Finally, a recent study by Loeber and colleagues (2013) found reduced behavioral inhibition in response to food-cues in relation to higher self-reported hunger, but no association with current blood glucose levels. To conclude, studies on the effects of food-cues on behavioral inhibition and relationships to current hunger, BMI or trait eating behaviors are inconsistent and no study has yet examined relationships between state and trait food craving and food-cue affected behavioral inhibition.

1.2.4 Heart rate variability as an index of executive functioning. Heart rate variability (HRV) refers to the variation of heart beat intervals and is influenced by sympathetic and parasympathetic input to the sino-atrial node of the heart. Increased high-frequent parasympathetically (or vagally) mediated modulations increase HRV while increased low-frequent sympathetic activation decreases HRV (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Accordingly, time domain measures of HRV are positively correlated with indices of vagal-cardiac control (high frequency power) and negatively correlated with the ratio between low frequency and high frequency power (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). A higher vagal-cardiac control or higher HRV, respectively, reflects a higher flexibility of the cardiovascular system. This enables an organism to quickly adapt to changing environmental requirements (Thayer & Lane, 2009). Although HRV is considered a stable trait when measured at rest, short-term day-to-day variations may occur due to a variety of acute circumstances and physical conditions like overall health status, age, exercise, smoking, alcohol, sleep patterns, or body weight (Britton & Hemingway, 2004; Pinna et al., 2007; Sandercock, 2007; Thayer, Yamamoto, & Brosschot, 2010).

The model of neurovisceral integration provides a theoretical framework for the empirical observation of an association between HRV and physical conditions and introduces HRV as a measure of self-regulatory strength (Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Thayer & Lane, 2009). This model is based on a link between prefrontal and subcortical brain structures and the autonomic regulation of cardiac activity (*central autonomic network*, CAN). The output of the CAN is directly linked to HRV, and particularly high-frequent, parasympathetic mediated HRV has been shown to co-vary with the activity of the prefrontal cortex among other brain strcutures (Lane et al., 2009; Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012). Accordingly, HRV is associated with processes that are involved in self-regulation, for example, emotion regulation and executive functioning (Appelhans & Luecken, 2006; Thayer & Lane, 2009). For instance, positive associations have been found between resting levels of vagally mediated HRV and performance in working memory tasks and the continuous performance test (Hansen, Johnsen, & Thayer, 2003) or longer persistence in an unsolvable anagram task (Reynard, Gevirtz, Berlow, Brown, & Boutelle, 2011; Segerstrom & Nes, 2007).

Besides those studies showing that self-regulatory capacity in general is reflected in high HRV, there have also been studies on the link between HRV and self-regulation of food intake. For instance, results of the majority of studies point towards parasympathetic dominance and decreased sympathetic modulation in anorectic patients (Mazurak, Enck, Muth, Teufel, & Zipfel, 2011) while the opposite is true for obese individuals (Karason, Molgaard, Wikstrand, & Sjostrom, 1999; Latchman, Mathur, Bartels, Axtell, & De Meersman, 2011). Nevertheless, these differences in cardiac autonomic regulation may reflect physiological changes and differences in body mass due to malnourishment and lifestyle factors rather than variations in self-regulatory capacity. Yet, few studies exist that investigated normal-weight subjects and found that HRV modulated emotion regulation processes in women with bulimic symptoms (Hilbert, Vögele, Tuschen-Caffier, & Hartmann, 2011; Rodríguez-Ruiz, Guerra, Moreno, Fernández, & Vila, 2012) and that higher tonic HRV was related to higher eating-related self-regulation such as increased dieting success or dietary restriction, and lower eating disorder psychopathology, independent of BMI (Coles, Vögele, Hilbert, & Tuschen-Caffier, 2005; Meule, Lutz, Vögele, & Kübler, 2012a; Meule, Vögele, & Kübler, 2012; Rodríguez-Ruiz et al., 2009; Vögele, Hilbert, & Tuschen-Caffier, 2009) .

HRV can be modulated by lifestyle changes, for example, nutrition (Sauder et al., 2013; Xin, Wei, & Li, 2013) and physical activity (Tulppo et al., 2003). Another way to influence HRV is HRV-biofeedback (Lehrer, Vaschillo, & Vaschillo, 2000). This technique is based on the fact that HRV is maximal during slowed breathing at approximately 5.5 breaths per minute (Lehrer, 2013). Participants receive feedback of their HRV and are instructed to increase HRV by slowing down their respiration rate, usually by following a pacing stimulus. Although studies on long-term increases in HRV are inconsistent, some studies report increased HRV after several weeks of practice, particularly in patients with cardiovascular diseases (Patron et al., 2013; Wheat & Larkin, 2010). Symptom reductions and increases in well-being have also been observed after HRV-biofeedback training in a range of mental disorders such as depression, post-traumatic stress disorder, or generalized anxiety disorder, often in the absence of physiological changes (Brown, Gerbarg, & Muench, 2013; Lehrer, 2013; Meule, Bernhardt, Kleih, & Kübler, in preparation; Wheat & Larkin, 2010). A recent study showed that HRV-biofeedback may also be helpful in increasing executive functioning in brain injury patients (Kim et al., 2013). Thus, HRV-biofeedback may also be beneficial for treating other disorders related to dysfunctional emotion regulation or poor executive functioning such as substance use disorders, obesity, or eating disorders.

1.3 Neuronal correlates of food craving and food craving regulation

1.3.1 Functional neuroimaging. Studies using functional magnetic resonance imaging or positron emission tomography have shown that presentation of visual food-cues or mental food imagery markedly activates the human brain, particularly subcortical areas associated with reward and incentive salience and that these brain activations may be related to more intense experiences of food craving (e.g., Pelchat, Johnson, Chan, Valdez, & Ragland, 2004; Wang et al., 2004). Accordingly, increased food-cue induced brain activations can be found in those brain areas, such as the insula, striatum, or orbitofrontal cortex, in individuals with BN, BED, or obesity (Carnell, Gibson, Benson, Ochner, & Geliebter, 2012; García-García et al., 2013; Grosshans et al., 2012; Kenny, 2011; Schienle, Schäfer, Hermann, & Vaitl, 2009). Accumulating evidence suggests that those food-cue induced subcortical activations can be down-regulated by cognitive strategies, probably through increased inhibitory signals from prefrontal cortices (Hollmann et al., 2012; Kober et al., 2010; Scharmüller, Übel, Ebner, & Schienle, 2012; Siep et al., 2012; Wang et al., 2009; Yokum & Stice, 2013).

1.3.2 Event-related potentials. Event-related potentials (ERPs) refer to electrophysiological brain responses that are direct results of a specific sensory, cognitive, or motor event. In affective picture viewing, early (e.g. N100, 100-200 ms) and mid-latency ERPs (e.g. early posterior negativity [EPN], 200-300 ms) reflect physical stimulus factors but may also index early selective attention (Olofsson, Nordin, Sequeira, & Polich, 2008). In the food context, Toepel and colleagues (2009) showed that pictorial low-calorie food-cues elicited a larger relative negativity as compared to high-calorie food-cues after approximately 150-200 ms at occipital electrodes. Thus, this study complements imaging studies showing that high- and low-calorie food-cues are differently processed in the brain (Frank et al., 2010; Killgore et al., 2003; Siep et al., 2009) and that this discrimination occurs automatically and rapidly. Mid-latency ERPs such as the EPN have also been investigated in response to food stimuli and it has been shown that the EPN is sensitive to food deprivation (Stockburger, Hamm, Weike, & Schupp, 2008) and eating disorder status (Blechert, Feige, Joos, Zeeck, & Tuschen-Caffier, 2011).

Long latency ERPs (> 300 ms) index maintained attention, memory storage or meaning evaluation (Hajcak, MacNamara, & Olvet, 2010; Schupp, Flaisch, Stockburger, & Junghöfer, 2006) and are subject to cognitive (top-down) modulations (Olofsson et al., 2008). A positive, centro-parietal ERP component beginning at approximately 300 ms after stimulus onset is known as the Late Positive Potential (LPP). The LPP has been found to be enhanced in response to highly arousing stimuli, e.g. positive and negative pictures (Hajcak et al., 2010; Olofsson et al., 2008). Thus, it has been proposed that the LPP indicates *motivated attention* towards stimuli that are evolutionary relevant as they automatically attract attention and appear to be dependent on motivational factors such as approach or avoidance tendencies (cf. Littel, Euser, Munafò, & Franken, 2012). The LPP is also increased in response to substance-related compared to neutral cues in substance users (Littel et al., 2012).

Likewise, the LPP seems to reflect the motivational value of food stimuli and is modulated by food deprivation and individual differences in eating behavior. Nijs and colleagues (2008) found that food pictures elicited an enlarged LPP as compared to pictures of neutral objects. Moreover, increased LPP amplitude was found in response to food pictures when participants were hungry as compared to when they were satiated (Nijs, Muris, Euser, & Franken, 2010; Stockburger, Schmälzle, Flaisch, Bublatzky, & Schupp, 2009). With regard to individual differences, elevated LPP amplitude in response to food pictures was found in external eaters (Nijs, Franken, & Muris, 2009), women with binge eating disorder (Svaldi, Tuschen-Caffier, Peyk, & Blechert, 2010), and emotional eaters (Blechert, Goltsche, Herbert, & Wilhelm, 2014). However, no differences in food-related LPP amplitude could be observed between normal-weight vs. obese participants (Nijs et al., 2008) and high chocolate cravers vs. low chocolate cravers (Asmaro et al., 2012). In another study, the LPP in response to food pictures did not differ from neutral pictures, but was attenuated in restrained eaters when foods were available for direct consumption (Blechert, Feige, Hajcak, & Tuschen-Caffier, 2010). To summarize, most studies found that the LPP is enlarged in response to food pictures as compared to neutral pictures, particularly when participants were hungry. Some studies also point out that an enhanced food-related LPP is associated with habitual overeating and related measures, but results are not yet conclusive.

Whereas the LPP appears to be transient, a later slow wave is typically enhanced for several seconds after presentation of motivationally relevant stimuli. It has been argued that the LPP and slow wave are functionally similar and, thus, the slow wave may reflect additional attentive processing or a continuation of attentive processing of motivationally relevant stimuli (Littel et al., 2012). Both the LPP and the slow wave are subject to cognitive modulation. Several affective picture viewing studies demonstrated reductions in amplitudes during cognitive emotion regulation strategies such as distraction or reappraisal (Hajcak et al., 2010). Moreover, time course of LPP/slow wave modulations to negative images depended on the specific emotion regulation strategy used: distraction led to an earlier attenuation of the LPP than reappraisal, possibly due to the more effortful processing in the latter (Thiruchselvam, Blechert, Sheppes, Rydstrom, & Gross, 2011).

However, down-regulation of arousing material does not uniformly reduce LPP amplitudes. Other studies found the LPP to be enlarged during instructions to decrease emotions as compared to passively viewing emotional pictures (Baur, Conzelmann, Wieser, & Pauli, submitted; Langeslag & Van Strien, 2010). A similar pattern was found by Littel and Franken (2011), who investigated craving regulation strategies in smokers while watching smoking and neutral pictures. Passively viewing smoking pictures elicited larger LPP amplitudes as compared to watching neutral pictures. However, unexpectedly, reappraisal strategies did not attenuate the LPP in response to smoking pictures. When distinguishing different cognitive strategies they found that distraction strategies (thinking about something different) reduced the LPP after approximately one second. This suggests that modulation of later LPP stages may depend on the specific type of reappraisal that is applied.

To conclude, studies suggest that the LPP is elevated in response to food-cues, particularly in relation to hunger and habitual overeating, although studies are inconsistent. However, little is known about modulation of food-cue elicited ERPs by cognitive strategies in general and in relation to trait or state food craving in particular.

1.4 Synthesis

The aim of the current thesis was to provide a German measure for the assessment of food craving on a trait and state level and to examine cognitive, behavioral, and physiological features associated with food craving using these questionnaires. For this purpose, the FCQs were translated into German and psychometric properties were tested in a questionnaire-based online study. Relationships between the FCQ-T and dieting behavior were examined in greater detail. Interplays between food craving and executive functioning were investigated using the German FCQs and food-cue-related tasks measuring working memory performance and behavioral inhibition. Electrophysiological correlates of food craving were tested in an EEG study involving a task during which participants were instructed to deliberately regulate their food craving in response to food-cues. Finally, associations between food craving and a physiological index of executive functioning – HRV – was investigated in a pilot study on the influence of HRV-biofeedback on trait food craving.

1.5 Studies and hypotheses of the present thesis

First, the FCQs were translated into German and their psychometric properties were tested in a questionnaire-based study conducted online (article #1). Similar to the original versions (Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, et al., 2000), a high internal consistency was expected for both the trait and the state version. For the trait version, high retest-reliability was hypothesized, which was expected to be lower for the state version. Furthermore, it was expected to replicate the factor structure of the original versions, that is, nine factors for the FCQ-T and five factors for the FCQ-S. Validity was tested with correlations between the FCQs and other questionnaires and it was expected that scores on the FCQ-T would show medium-to-high correlations with other questionnaires associated with overeating and no or small correlations with non-eating related, but relevant, questionnaires such as drug craving or impulsivity. Contrarily, scores on the FCQ-S were expected to be unrelated to those trait measures, but to be positively correlated with current food deprivation and negative affect.

Relationships between the FCQ-T and dieting behavior were examined in greater detail. Based on the finding that FCQ-T subscales were able to discriminate between specific types of eating disorders (Moreno et al., 2009), it was expected that the subscales of the FCQ-T would be able to discriminate between current non-dieters and successful and unsuccessful dieters (article #1). Subscales of the FCQ-S, instead, were expected to rarely discriminate between those groups. A further analysis of those data aimed at testing the role of specific dieting strategies in the relationship between trait food craving and dieting success (article #2). Based on the finding that rigid control of eating behavior is related to higher BMI and disinhibited eating while the reverse is true for flexible control of eating behavior (Westenhoefer, Stunkard, & Pudel, 1999), it was expected that more rigid dietary strategies would mediate the correlation between more frequent food craving experiences and lower dieting success. Flexible dietary strategies, instead, were expected to be related to fewer food craving experiences and higher dieting success.

Relationships between food craving and executive functions were examined with a working memory task (article #3) and a behavioral inhibition task (article #4) involving palatable food-cues. In both studies, it was expected that performing the tasks would elicit food craving, that is, current self-reported food craving after the task was expected to be higher as compared to before as a result of food-cue exposure. Most relevant indices of task performance were omission errors in the working memory (*n*-back) task and commission errors in the behavioral inhibition (go/no-go) task. Based on the findings that induction of food craving decreased working memory performance (Kemps et al., 2008; Tiggemann et al., 2010) and that higher BMI and lower dieting success were associated with decreased inhibitory performance specifically in response to food-cues (Houben et al., 2012; Nederkoorn et al., 2012), it was expected that decrements in task performance in response to food, but not neutral cues, would be correlated with higher current food craving and higher trait food craving.

To elucidate the nature and time course of brain responses towards food-cues, electrophysiological correlates of food craving were examined in an EEG study involving pictures of high- and low-calorie foods (article #5). Similar to prior findings (Toepel et al., 2009), differences in electrocortical processing of high- and low-calorie food-cues were expected for early- and long-latency ERP components (N1, LPP). Moreover, based on the findings that reappraisal of emotional stimuli reduces LPP amplitude (Hajcak et al., 2010) and that brain activation in response to food pictures can be altered by food craving regulation strategies (Kober et al., 2010; Yokum & Stice, 2013), it was expected that a cognitive down-regulation of food craving would reduce the LPP in response to high-calorie food-cues which should also be reflected in decreased self-reported craving.

Finally, as low eating-related self-regulation has been previously associated with lower resting HRV (Meule, Lutz, et al., 2012a; Rodríguez-Ruiz et al., 2009), higher trait food craving was expected to be associated with lower HRV at rest (article #6). As HRV-biofeedback has been shown to reduce psychopathological symptoms in mental disorders, for example, substance craving in post-traumatic stress disorder (Wheat & Larkin, 2010; Zucker, Samuelson, Muench, Greenberg, & Gevirtz, 2009), few sessions of HRV-biofeedback were expected to increase HRV as well as to reduce the frequency of food craving experiences in high trait food cravers.

2. Publications

2.1 Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters: Validation of the Food Cravings Questionnaires in German. *Appetite*, *58*, 88-97.

Abstract: Food cravings have been strongly associated with triggering food consumption. However, definitions and measurements of food cravings are heterogeneous. Therefore, Cepeda-Benito and colleagues (2000) have suggested the Food Cravings Questionnaires (FCQs) to measure food cravings as a multidimensional construct at trait- and state-level. In the current study, we validated a German version of the FCQs in an online study ($N = 616$). The factor structure of the state and trait versions could partially be replicated, but yielded fewer than the originally proposed factors. Internal consistencies of both versions were very good (Cronbach's $\alpha > .90$), whereas retest reliability of the state version was expectedly lower than that of the trait version. Construct validity of the trait version (FCQ-T) was demonstrated by high correlations with related eating behavior questionnaires and low correlations with questionnaires unrelated to eating. Most importantly, FCQ-T-subscales were able to discriminate between successful and unsuccessful dieters and non-dieters. Validity of the state version was supported by positive relations with food deprivation and current negative affect. Taken together, the German version of the FCQs has good psychometric properties. Moreover, this study provided first evidence that distinct dimensions of food cravings are differentially related to success and failure in dieting.

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Research report

Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters. Validation of the Food Cravings Questionnaires in German ☆

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ABSTRACT

Food cravings have been strongly associated with triggering food consumption. However, definitions and measurements of food cravings are heterogeneous. Therefore, Cepeda-Benito and colleagues (2000) have suggested the Food Cravings Questionnaires (FCQs) to measure food cravings as a multidimensional construct at trait- and state-level. In the current study, we validated a German version of the FCQs in an online study ($N = 616$). The factor structure of the state and trait versions could partially be replicated, but yielded fewer than the originally proposed factors. Internal consistencies of both versions were very good (Cronbach's $\alpha > .90$), whereas retest reliability of the state version was expectedly lower than that of the trait version. Construct validity of the trait version (FCQ-T) was demonstrated by high correlations with related eating behavior questionnaires and low correlations with questionnaires unrelated to eating. Most importantly, FCQ-T-subscales were able to discriminate between successful and unsuccessful dieters and non-dieters. Validity of the state version was supported by positive relations with food deprivation and current negative affect. Taken together, the German version of the FCQs has good psychometric properties. Moreover, this study provided first evidence that distinct dimensions of food cravings are differentially related to success and failure in dieting.

Introduction

Craving is an intense desire or longing for particular substances (Weingarten & Elston, 1990), for example alcohol, tobacco, and other drugs, but also food (Hormes & Rozin, 2010). Food cravings are characterized by both appetitive and aversive components (Rodríguez, Fernández, Cepeda-Benito, & Vila, 2005). Accordingly, it has been suggested that food cravings can be viewed analogous to emotions as they have motivational significance for the organism (Shiffman, 2000). In this respect, craving and hunger are closely related and indeed show many similarities (Shiffman, 2000). However, cravings differ from hunger as they tend to be more intense and specific for the kind of food desired (Hill, 2007). Furthermore, although nutritional deprivation can increase food cravings, it is not necessary to elicit them. For instance, Pelchat and Schaefer (2000) could show that a monotonous diet – and therefore sensory rather than nutritional deprivation – is sufficient to stimulate food cravings in young adults. Moreover, psychological factors like external and emotional eating are stronger related to food cravings than dietary restraint or daily caloric intake (Hill, Weaver, & Blundell, 1991).

Attempts to measure craving objectively, e.g. based on physiological data, have been criticized for being unspecific (Shiffman, 2000). Until now, "subjective self-report seems the only viable assessment modality" (Shiffman, 2000, p. S172). The term craving is somewhat vague and often subjects are asked to indicate on a one-item rating scale how strong they crave or desire a specific object (Weingarten & Elston, 1990). Therefore, there is a need to assess craving as a multidimensional construct with standardized questionnaires instead of single questions. This is particularly important in non-English speaking countries because there is no simple equivalent expression for craving (Hormes & Rozin, 2010).

To assess craving multidimensional, different measures have been developed such as the Food Cravings Questionnaires (FCQs, including a state and a trait version; Cepeda-Benito, Gleaves, Williams, & Erath, 2000; Cepeda-Benito et al., 2000), the Attitudes to Chocolate Questionnaire (ACQ; Benton, Greenfield, & Morgan, 1998), the Orientation towards Chocolate Questionnaire (OCQ; Cartwright & Stritzke, 2008), and the Food Craving Inventory (FCI; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002). Each of these measures represents different approaches to

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the craving construct. Both the ACQ and OCQ are designed to measure cravings specifically related to chocolate and emphasize the relationship between craving and feelings of guilt (Benton et al., 1998) or the conflict between approach and avoidance inclinations during the experience of craving (ambivalence model; Cartwright & Stritzke, 2008). The FCI measures cravings related to different classes of food (high fats, sweets, carbohydrates/starches, fast-food fats; White et al., 2002). Therefore, all of these instruments assess habitual cravings related to specific kinds of food and are restricted to certain dimensions of food cravings. As opposed to these questionnaires, the FCQs were constructed to assess craving for a variety of foods, without confining them to certain categories or specific foods, e.g., chocolate. Furthermore, the FCQs cover behavioral, cognitive and physiological aspects of food cravings. Finally, the FCQs combine two versions that measure current and habitual food cravings. Therefore, the FCQs are the only currently available food craving instruments that (1) do not refer specifically to chocolate or similar, (2) assess food cravings on a multidimensional level, and (3) measure food cravings as trait and state. Moreover, there is evidence that the FCQs can be used easily as a measure for specific cravings, e.g. by replacing references to food with references to chocolate (Rodríguez et al., 2007).

The FCQs are arguably the most extensively validated food craving measures and are available in Dutch (Franken & Muris, 2005; modified version from Nijs, Franken, & Muris, 2007), English (Cepeda-Benito, Gleaves, Williams et al., 2000) and Spanish (Cepeda-Benito, Gleaves, Fernández et al., 2000). Excellent psychometric properties could be demonstrated for healthy participants (Cepeda-Benito, Fernández, & Moreno, 2003; Cepeda-Benito, Gleaves, Fernández et al., 2000; Cepeda-Benito, Gleaves, Williams et al., 2000) and patients with eating disorders (Moreno, Rodríguez, Fernández, Tamez, & Cepeda-Benito, 2008). However, the factor structure could only be partially replicated in a sample of overweight and obese persons (Vander Wal, Johnston, & Dhurandhar, 2007). The trait version of the FCQs (FCQ-T) has been positively associated with disinhibited eating behavior, habitual hunger ratings, eating disorder symptoms, sensitivity to reward, and body-mass-index (BMI) in healthy participants (Cepeda-Benito, Gleaves, Williams et al., 2000; Cepeda-Benito et al., 2003; Franken & Muris, 2005). Moreover, female participants had higher FCQ-T-scores than male participants (Cepeda-Benito et al., 2003). In patients with eating disorders, FCQ-T-subscales have been found to discriminate between anorexia and bulimia nervosa subtypes (Moreno, Warren, Rodríguez, Fernández, & Cepeda-Benito, 2009). However, only cravings that were associated with a lack of control over eating, preoccupation with food, negative affect, and guilty feelings were predictive of bulimic symptomatology (Moreno et al., 2008). Morbidly obese patients consistently reported higher food cravings than controls, except for cravings associated with positive reinforcement that result from eating (Abilés et al., 2010).

Based on these findings, we expected the FCQ-T to be associated with a loss of control in eating behavior as an indicator of convergent validity. Specifically, we expected food cravings to be highly correlated with self-reported binge eating, food addiction symptoms, low perceived self-regulatory success in dieting, and dieting strategies that have been previously connected to low dieting success or high eating-related psychopathology (*rigid control*; Shearin et al., 1994; Stewart, Williamson, & White, 2002; Timko & Perone, 2005; Westenhoefer, 1991; Westenhoefer, Stunkard, & Pudel, 1999).

Relevant, but not directly eating-related constructs were used as an indicator of divergent validity. Substance craving and impulsivity have been positively, but weakly associated with BMI (Meule, Nakovics, & Kübler, submitted for publication; Meule, Vögele, & Kübler, 2011). Furthermore, impulsivity was weakly correlated with food addiction symptoms (Meule, Vögele, & Kübler, in press). Accordingly, we expected small positive correlations between food craving and both, substance craving and impulsivity. Sensitivity to reward or punishment has been inconsistently linked to dysfunctional eating behavior (see Bijttebier, Beck, Claes, & Vandereycken, 2009 for a review). For instance, while sensitivity to reward was positively correlated with the FCQ-T (Franken & Muris, 2005), the *Behavioral Inhibition System* (BIS), but not the *Behavioral Activation System* (BAS), was positively correlated with food addiction symptoms (Gearhardt, Corbin, & Brownell, 2009; Meule et al., in press). Therefore, we expected no or small positive correlations between food craving and BIS/BAS-reactivity.

We further expected an association between food craving and dietary restraint. However, evidence for such a relationship is ambiguous. For instance, Polivy and colleagues (2005) found restrained eaters – as measured with the *Restraint Scale* (RS) – to experience more food cravings than unrestrained eaters. Restrained eating as measured with the *Dutch Eating Behavior Questionnaire* (DEBQ) and the *Three-Factor Eating Questionnaire* (TFEQ), however, was not correlated with craving frequency (Hill et al., 1991). These contradictory findings could be due to the different questionnaires used, because the RS has been found to measure unsuccessful restrained eaters while the DEBQ and TFEQ identify successful restrained eaters (Heatherton, Herman, Polivy, King, & McGree, 1988; Williamson et al., 2007). Yet, another study using the RS did not find an association between restraint status and food cravings (Rodin, Mancuso, Granger, & Nelbach, 1991). Furthermore, using restraint scales is critical because the population of restrained eaters consists of unsuccessful and successful ones (Van Strien, 1997; Van Strien, 1999). Most recently, attempts have been made to distinguish more explicitly between successful and unsuccessful restrained eaters (Papies, Stroebe, & Aarts, 2008; Van Koningsbruggen, Stroebe, & Aarts, 2011; Van Koningsbruggen, Stroebe, Papies, & Aarts, 2011). In those studies, the subscale *concern for dieting* of the RS is used to identify dieters and non-dieters. Additionally, the *Perceived Self-Regulatory Success in Dieting Scale* (PSRS; Fishbach, Friedman, & Kruglanski, 2003) is used to evaluate successful or unsuccessful dietary restraint. We adapted this procedure to classify participants as non-dieters and successful and unsuccessful dieters and explored food cravings in these subpopulations. Specifically, we expected food cravings to be increased in unsuccessful dieters compared to successful ones who in turn were expected to experience more food cravings than non-dieters.

The state version of the FCQs (FCQ-S) has been found to be sensitive to meal consumption in normal-weight (Cepeda-Benito, Gleaves, Williams et al., 2000) and overweight (Vander Wal, Marth, Khosla, Jen, & Dhurandhar, 2005; Vander Wal et al., 2007) participants. State cravings decreased after breakfast and increased afterwards during the first 3 h (Cepeda-Benito, Gleaves, Williams, et al., 2000; Vander Wal et al., 2007). Accordingly, length of food deprivation uniquely and exclusively predicted state cravings (Cepeda-Benito et al., 2003).

Thus, we expected the FCQ-S to be positively correlated with the hours that have elapsed since the last meal. Furthermore, we also predicted current cravings to be associated with less positive and more negative current affect because mood has been suggested as a possible antecedent to or consequence of craving (Hill et al., 1991).

Methods

Procedure

Student councils of several German universities were contacted by e-mail. Then, the internet address of the online study was sent using the student councils' mailing lists. As an incentive, five

×50 Euro were raffled among participants who completed the entire set of questions. Questionnaire completion took approximately 25 min. Every question required a response in order to continue. Study period lasted four weeks. Participants who entered their e-mail-address and agreed to be contacted again, were asked to participate in retesting one week after closure of the website.

Participants

The study-website was visited 1615 times. The entire set of questionnaires was completed by $N = 617$ participants (38.2%). The majority of participants were women (75.8%). Data from one participant was excluded from further analyses because of implausible statements. Mean BMI was $M = 22.3$ kg/m^2 ($SD = 3.3$), mean age was $M = 24.5$ years ($SD = 4.0$). Almost all participants were students (89.0%) and had German citizenship (95.5%). The retest was completed by $n = 237$ participants. However, data of only $n = 197$ participants could be used because individual codes of some participants did not correspond to the ones specified in the primary data collection.

Food Cravings Questionnaires (FCQs)

The FCQs measure the intensity of food cravings on a multidimensional level. The trait version (FCQ-T) has 39 items and consists of the subscales *intentions and plans to consume food* (INTENTIONS), *anticipation of positive reinforcement that may result from eating* (POS REINFORCEMENT), *anticipation of relief from negative states and feelings as a result of eating* (NEG REINFORCEMENT), *lack of control over eating* (LACK OF CONTROL), *thoughts or preoccupation with food* (THOUGHTS), *craving as a physiological state* (HUNGER), *emotions that may be experienced before or during food cravings or eating* (EMOTIONS), *cues that may trigger food cravings* (CUES), and *guilt from cravings and/or giving into them* (GUILT). The 15-item state version (FCQ-S) assesses momentary food cravings on the dimensions *intense desire to eat* (DESIRE), *anticipation of positive reinforcement that may result from eating* (POS REINFORCEMENT), *anticipation of relief from negative states and feelings as a result of eating* (NEG REINFORCEMENT), *lack of control over eating* (LACK OF CONTROL), and *craving as a physiological state* (HUNGER). Both versions of the FCQs have internal consistencies of $\alpha > .90$ (Cepeda-Benito, Gleaves, Fernández et al., 2000; Cepeda-Benito, Gleaves, Williams et al., 2000).

The English version of the FCQs was translated into German by the first and second authors of the current manuscript. In case of ambiguities, the Spanish version was also taken into account. A bilingual speaker, who did not have any knowledge about the original FCQs, translated the first draft of the German version back into English. Discrepancies between the back-translation and the original form were discussed and adjusted.

Measures to establish convergent validity

Yale Food Addiction Scale (YFAS)

The YFAS measures addictive eating behavior and consists of 27 items. The questionnaire is based on the diagnostic criteria for substance dependence of the DSM-IV (American Psychiatric Association, 1994). Scoring of the YFAS enables the calculation of a symptom count as well as a diagnosis of food addiction. Internal consistencies range between $\alpha = .81$–$.86$ (Gearhardt et al., 2009; Meule et al., in press), which could be confirmed in the present study ($\alpha = .83$).

Restraint Scale-Subscale Concern for Dieting (RS-CD)

The RS (Herman & Polivy, 1980) consists of two subscales that measure *concern for dieting* (RS-CD) and *weight fluctuations* (RS-WF; Dinkel, Berth, Exner, Rief, & Balck, 2005). However, it has been suggested to disregard RS-WF due to confounding with BMI and overweight (Stroebe, 2008). Furthermore, RS-CD has been found to have higher internal consistency than RS-WF ($\alpha = .82$ vs. .69, Dinkel et al., 2005). In the present study, we thus used the RS-CD only and internal consistency was $\alpha = .79$.

Perceived Self-Regulatory Success in dieting (PSRS)

This three-item scale developed by Fishbach and colleagues (2003) asks participants to rate on 7-point scales how successful they are in watching their weight or losing extra weight and how difficult it is for them to stay in shape. The scale was translated into German from the Dutch version used by Papies and colleagues (2008). In our study, participants were able to choose *not applicable* if they were not concerned with their weight. If this option was chosen in at least one question, total PSRS scores were excluded from analysis ($n = 135$). For the remaining $n = 480$ participants, internal consistency of the PSRS was $\alpha = .74$, which is higher than previously reported ($\alpha = .66$; Van Koningsbruggen, Stroebe, & Aarts, 2011).

Flexible and rigid control of eating behavior

These scales were originally developed by Westenhoefer (1991) who found that the *cognitive restraint* subscale of the TFEQ (Stunkard & Messick, 1985) can be further divided into flexible and rigid control strategies of dietary restraint. Later, additional items were added to increase internal consistencies (Westenhoefer et al., 1999). Flexible control is now assessed with 12 items (FC12; Cronbach's $\alpha = .83$), whereas the rigid control scale consists of 16 items (RC16; Cronbach's $\alpha = .81$). Internal consistencies were also good in the present sample ($\alpha = .82$ for FC12, $\alpha = .80$ for RC16).

Eating Disorder Examination-Questionnaire (EDE-Q)

The EDE-Q (Fairburn & Beglin, 1994; Hilbert & Tuschen-Caffier, 2006) measures specific eating pathologies with 22 items. In addition, six items assess essential behavioral patterns like binge eating and compensatory behaviors. Three of these six items, which assess binge eating frequencies within the past 28 days, were chosen for this study (the first two acted as primers for the third item).

Measures to establish divergent validity

Mannheimer Craving Scale (MaCS)

The MaCS is a questionnaire for the assessment of cravings for different addictive substances (e.g. alcohol, nicotine, drugs) and consists of 12 items. It includes obsessive thoughts and compulsive behavior related to substance use. The intensity and frequency of substance-related cravings, assessed with visual analog scales, and duration of abstinence are measured with four additional items. Internal consistencies were high in a sample of patients with different substance dependencies ($\alpha = .87$–$.93$; Nakovics, Diehl, Geiselhart, & Mann, 2009) and in the present study ($\alpha = .89$).

Barratt Impulsiveness Scale (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. It consists of 15 items and subjects have to rate each item on a 4-point Likert scale. The three-factor solution with *motor*, *attentional*, and *non-planning impulsivity* could be confirmed for the German version (Meule, Vögele, 2011). Internal consistency was slightly lower in the present study ($\alpha = .78$) compared to the validation studies ($\alpha > .80$; Meule, Vögele, 2011; Spinella, 2007).

Behavioral Inhibition System/Behavioral Activation System (BIS/BAS)

The BIS/BAS scales (Carver & White, 1994; Strobel, Beauducel, Debener, & Brocke, 2001) were created to measure the behavioral inhibition and behavioral activation systems proposed by Gray (1982). The 24-item scale includes one BIS- and several BAS-subscales (*Reward Responsiveness*, *Drive*, *Fun Seeking*). Internal consistencies of the BIS- and BAS-scales are higher (BIS: $\alpha = .78$, BAS: $\alpha = .81$) than that of the subscales ($\alpha = .67–.69$; Strobel et al., 2001). In the current study, internal consistencies of the BIS- and BAS-scales were $\alpha = .80$ and $\alpha = .79$.

Positive and Negative Affect Schedule (PANAS)

The PANAS consists of two ten-item dimensions measuring momentary positive affect (PA) and negative affect (NA; Watson, Clark, & Tellegen, 1988). Here, participants have to indicate how single adjectives apply to their current mood. For this state measure, internal consistencies were $\alpha = .88$ (PA) and $\alpha = .84$ (NA) which is comparable to validation studies ($\alpha = .85$ for PA and $\alpha = .86$ for NA; Krohne, Egloff, Kohlmann, & Tausch, 1996).

Data analysis

Exploratory factor analysis with principal component analysis (PCA) was chosen to investigate the factor structure of the German FCQs because of possible cultural differences in craving (Hill, 2007; Rodríguez et al., 2007). Criterion for the number of extracted factors was an eigenvalue >1 (Kaiser, 1960). An oblique rotation (Promax; $\kappa = 4$) was chosen because factors were expected to be correlated (Cepeda-Benito, Gleaves, Williams et al., 2000). Item means and item-total-correlations were calculated for item analysis. Crohnbach's α and retest-coefficients were calculated for evaluating reliability. Construct validity was determined by correlations with the respective questionnaires. Convergent validity of the FCQ-T was evaluated by correlations with other measures of eating behavior (restrained eating, binge eating, food addiction, dietary control strategies, dieting success) while divergent validity was determined by correlations with relevant, but not eating-related constructs (substance craving, impulsivity, BIS/BAS). The FCQ-S was correlated with current affective states and hours elapsed since the last meal. Non-parametric correlation was conducted in case data were not normally distributed (Spearman's ρ). Biserial correlation coefficient was used for gender.

Specific relationships of FCQs-subscales with dietary restraint status were explored in greater detail. Participants were divided into dieters and non-dieters based on a median split of RS-CD-scores ($Mdn = 5$). Dieters were further classified as being successful or unsuccessful in their attempt to lose weight or prevent weight gain by median split of PSRS-scores. Participants whose scores matched the median were excluded from analyses. Obviously, it is inappropriate to differentiate non-dieters as being successful or unsuccessful because they are not watching their weight. Therefore, this procedure resulted in three groups: non-dieters ($n = 241$), successful dieters ($n = 90$), and unsuccessful dieters ($n = 168$). Groups did not differ in age ($F_{(2,495)} = .04$, *ns*), but differed in BMI ($F_{(2,495)} = 38.7$, $p < .001$). Post-hoc Scheffé-tests revealed that unsuccessful dieters ($M = 24.14$ kg/m^2, $SD = 4.03$) had higher BMI than successful dieters ($M = 21.4$ kg/m^2, $SD = 2.68$, $p < .001$) and non-dieters ($M = 21.51$ kg/m^2, $SD = 2.64$, $p < .001$); BMI of successful dieters and non-dieters were equal. To further elucidate if and how different dimensions of food cravings are able to discriminate between these groups, discriminant analyses were performed separately for FCQ-T- and FCQ-S-subscales. Structure coefficients were considered as meaningful when they were higher than .33 (Tabachnick & Fidell, 2007, p. 400). In a second step, we interpreted the actual contribution of each variable to the calculation of the discriminant score (standardized coefficients) only for those variables with high structure coefficients.

Results

Psychometric properties of the German FCQs

FCQ-T

PCA extracted six factors. Eigenvalues before rotation were 16.3, 3.2, 1.7, 1.6, 1.2, and 1.2. After oblique rotation, eigenvalues were 13.0, 7.9, 11.3, 8.3, 10.8, and 3.2. These six factors explained 64.6% of variance compared to 41.7% of the one-factorial solution. Although we extracted fewer factors than Cepeda-Benito and colleagues (2000), inspection of factor loadings showed that our six-factorial solution was a combination of the nine original subscales (Table 1). While the factors CUES, EMOTIONS, and HUNGER could be replicated, the subscales POS REINFORCEMENT and NEG REINFORCEMENT were combined, reforming a factor REINFORCEMENT (Table 1). Furthermore, the subscales THOUGHTS and GUILT could also be merged into one factor. Finally, the subscales INTENTIONS and LACK OF CONTROL were also combined to one factor. It has to be noted that some items had high loadings on more than one factor (Table 1), but were kept in the original factor to adhere to the theoretical foundation by Cepeda-Benito and colleagues (2000) and to maintain comparability to the original FCQs. Factors were highly correlated (Range: $r = .44–.75$, all p's < .001).

Item difficulties ranged between $M = 1.7–3.9$ (Table 1). Range of item-total-correlations was $r_{itc} = .37–.76$ (Table 1). Internal consistency was $\alpha = .96$ for the FCQ-T total score and ranged between $\alpha = .72$ (HUNGER) and $\alpha = .93$ (THOUGHTS/GUILT) for the subscales. Retest-reliability (Spearman's ρ) was $r_{tt} = .84$ for the FCQ-T total score and ranged between $r_{tt} = .69$ (HUNGER) and $r_{tt} = .84$ (EMOTIONS) for the subscales (all p's < .001).

FCQ-S

PCA yielded a three-factorial solution. Eigenvalues were 7.4, 1.9, 1.1 before, and 6.1, 4.9, 5.2 after oblique rotation. These three factors explained 70.0% of variance compared to 49.5% of the one-factorial solution. Again, factors found by Cepeda-Benito and colleagues (2000) were combined which resulted in fewer subscales. Like for the trait version, the factor HUNGER was replicated while the factors POS REINFORCEMENT and NEG REINFORCEMENT were merged (Table 2). Factors DESIRE and LACK OF CONTROL were also merged (Table 2). Again, factors were highly correlated (range: $r = .55–.75$, all p's < .001).

Item difficulties ranged between $M = 1.4–2.2$, and item-total-correlations between $r_{itc} = .47$ and .79 (Table 2). Internal consistency was $\alpha = .92$ for the FCQ-S total score and ranged between $\alpha = .87$ (REINFORCEMENT) and $\alpha = .89$ (HUNGER, DESIRE/LACK OF CONTROL) for the subscales. Retest-reliability (Spearman's ρ) was $r_{tt} = .40$ ($p < .001$) for the FCQ-S total score and $r_{tt} = .12$ (HUNGER, *ns*), $r_{tt} = .46$ (DESIRE/LACK OF CONTROL, $p < .001$) and $r_{tt} = .52$ (REINFORCEMENT, $p < .001$) for the subscales.

Construct validity

FCQ-T

Total FCQ-T scores were positively and weakly correlated with BMI ($r = .14$, $p < .001$) and gender ($r_b = .27$, $p < .001$), indicating increased FCQ-T scores in women compared to men. Medium-to-high correlations with measures of dysfunctional eating behavior supported convergent validity (Table 3). Restrained eating behavior, binge eating frequencies, food addiction symptoms, and rigid control of eating behavior were positively related to FCQ-T scores while perceived self-regulatory success in dieting was negatively correlated. No relationship was found with flexible control of eating behavior (Table 3). Confirming divergent validity, FCQ-T scores were positively, but weakly correlated with substance craving, impulsivity, and the BIS/BAS scales (Table 3).

Table 1
Factor loadings and item statistics of the Food Cravings Questionnaire-Trait.

Factor						Item	Factor	Item mean	Item-total-correlation
1	2	3	4	5	6				
.44	−.22	.53	.04	−.14	−.05	4. I hate it when I give in to cravings (Ich hasse es, wenn ich dem starken Verlangen nach bestimmten Nahrungsmitteln nachgebe)	Thoughts/guilt	2.83	.54
.87	−.03	−.04	.09	−.04	.05	6. I feel like I have food on my mind all the time (Ich habe das Gefühl, dass ich die ganze Zeit nur Essen im Kopf habe)	Thoughts/guilt	2.15	.71
.61	−.14	.44	−.02	−.16	−.07	7. I often feel guilty for craving certain foods (Ich fühle mich oft schuldig, weil ich ein starkes Verlangen nach bestimmten Nahrungsmitteln verspüre)	Thoughts/guilt	2.10	.61
.88	−.07	.03	.07	−.10	.12	8. I find myself preoccupied with food (Ich ertappe mich dabei, wie ich mich gedanklich ständig mit Essen beschäftige)	Thoughts/guilt	2.14	.72
.55	−.20	.50	−.05	−.08	−.09	17. When I eat what I am craving I feel guilty about myself (Wenn ich das esse, wonach ich ein starkes Verlangen verspüre, fühle ich mich schuldig)	Thoughts/guilt	2.10	.60
.85	−.03	.09	.00	−.03	−.02	27. I can't stop thinking about eating no matter how hard I try (Ich kann nicht aufhören, übers Essen nachzudenken, wie sehr ich mich auch bemühe)	Thoughts/guilt	1.81	.73
.86	.11	−.18	.05	−.04	.05	28. I spend a lot of time thinking about whatever it is I will eat next (Ich verbringe viel Zeit damit über das, was ich als nächstes essen werde, nachzudenken)	Thoughts/guilt	2.27	.66
.76	.25	−.22	−.04	−.05	.20	31. I daydreamaboutfood (Manchmal stelle ich fest, dass ich mit offenen Augen vor mich hin träume und an Essen denke)	Thoughts/guilt	1.76	.60
.56	.04	−.03	−.16	.45	.07	32. Whenever I have a food craving, I keep on thinking about eating until I actually eat the food (Immer wenn ich ein starkes Verlangen nach bestimmten Nahrungsmitteln verspüre, denke ich so lange weiter ans Essen, bis ich diese tatsächlich esse)	Thoughts/guilt	2.04	.72
.68	.06	−.04	−.16	.33	.06	33. If I am craving something, thoughts of eating it consume me (Wenn ich ein starkes Verlangen nach bestimmten Nahrungsmitteln verspüre, verzehren mich die Gedanken daran, diese zu essen, geradezu)	Thoughts/guilt	1.78	.73
.10	.53	.39	−.05	−.05	−.05	9. I eat to feel better (Ich esse, um mich besser zu fühlen)	Reinforcement	2.75	.63
.19	.66	.00	−.06	−.03	.05	10. Sometimes, eating makes things seem just perfect (Etwas zu essen, lässt manchmal einfach alles perfekt erscheinen)	Reinforcement	2.31	.51
−.27	.59	−.07	−.03	.42	.07	15. Eating what I crave makes me feel better (Das zu essen, wonach ich ein starkes Verlangen verspüre, führt dazu, dass ich mich besser fühle)	Reinforcement	3.40	.41
−.10	.52	.48	−.15	.07	.01	16. When I satisfy a craving I feel less depressed (Wenn ich ein starkes Verlangen nach bestimmten Nahrungsmitteln stille, in dem ich diese esse, fühle ich mich weniger deprimiert)	Reinforcement	2.33	.57
.09	.62	.30	.15	−.18	.03	19. Eating calms me down (Essen beruhigtmich)	Reinforcement	3.00	.65
.07	.62	.41	−.17	−.09	−.10	21. I feel less anxious after I eat (Ich fühle mich weniger ängstlich besorgt, nachdem ich gegessen habe)	Reinforcement	1.98	.54
−.08	.81	−.28	.06	.20	−.10	24. When I eat what I crave I feel great (Wenn ich das esse, wonach ich ein starkes Verlangen verspüre, fühle ich mich großartig)	Reinforcement	2.68	.37
−.06	.85	.05	.12	−.11	−.10	38. When I eat food, I feel comforted (Wenn ich etwas esse, fühle ich mich behaglich oder erleichtert)	Reinforcement	2.79	.47
−.07	.09	.71	.12	.06	.15	20. I crave foods when I feel bored, angry, or sad (Ich verspüre ein starkes Verlangen nach bestimmten Nahrungsmitteln, wenn ich mich gelangweilt, wütend oder traurig fühle)	Emotions	3.02	.72
−.17	.00	.79	.04	.08	.26	30. WhenI'mstressed out, I cravefood (Wenn ich total gestresst bin, verspüre ich ein starkes Verlangen nach bestimmten Nahrungsmitteln)	Emotions	2.97	.64
.08	.11	.71	.01	.05	.08	34. My emotions often make me want to eat (Meine Emotionen bringen mich oft dazu, etwas essen zu wollen)	Emotions	2.38	.76
.01	.15	.78	−.10	−.03	.13	39. I cravefoodswhenI'mupset (Ich verspüre ein starkes Verlangen nach bestimmten Nahrungsmitteln, wenn ich aufgebracht bin)	Emotions	2.07	.65
.05	.07	.00	.66	−.13	.25	1. Being with someone who is eating often makes me hungry (Mit jemandem zusammen zu sein, der gerade isst, macht mich oft hungrig)	Cues	3.34	.49
−.07	−.06	−.10	.83	.08	.13	35. Whenever I go to a buffet I end up eating more than what I needed (Immer wenn es ein Buffet gibt, esse ich am Ende mehr, als ich gebraucht hätte)	Cues	3.92	.47
−.02	−.02	.04	.64	.28	.11	36. It is hard for me to resist the temptation to eat appetizing foods that are in my reach (Wenn sich appetitliche Nahrungsmittel in meiner Reichweite befinden, fällt es mir schwer, der Versuchung zu widerstehen, sie zu essen)	Cues	3.58	.68
.07	.03	.05	.67	.04	−.05	37. When I am with someone who is overeating, I usually overeat too (Wenn ich mit jemandem zusammen bin, der sich gerade überisst, überesse ich mich gewöhnlich auch)	Cues	2.46	.56
.27	.11	.06	.32	.22	−.14	2. When I crave something, I know I won't be able to stop eating once I start (Wenn ich ein starkes Verlangen nach etwas verspüre, weiß ich, dass ich nicht mehr aufhören kann zu essen, wenn ich erst mal angefangen habe)	Lack of control/intentions	2.61	.67
.17	.02	.16	.34	.34	−.20	3. If I eat what I am craving, I often lose control and eat too much (Wenn ich das esse, wonach ich ein starkes Verlangen verspüre, verliere ich oft die Kontrolle und esse zu viel)	Lack of control/intentions	2.94	.71
.52	.00	−.05	−.14	.45	.10	5. Food cravings invariably make me think of ways to get what I want to eat (Wenn ich ein starkes Verlangen nach bestimmten Nahrungsmitteln verspüre, denke ich ausnahmslos darüber nach, wie ich das bekomme, was ich essen will)	Lack of control/intentions	2.43	.68
.26	.09	−.06	.10	.50	.11	18. Whenever I have cravings, I find myself making plans to eat (Immer wenn ich ein starkes Verlangen nach bestimmten Nahrungsmitteln verspüre, merke ich, dass ich gleich plane, etwas zu essen)	Lack of control/intentions	2.93	.71
−.08	−.04	.05	.23	.73	−.03	22. If I get what I am craving I cannot stop myself from eating it (Wenn ich das bekomme, wonach ich ein starkes Verlangen verspüre,	Lack of	3.19	.64

						kann ich mich nicht davon abhalten, es zu essen)	control/ intentions		
−.05	.06	−.07	.03	.83	.10	23. When I crave certain foods, I usually try to eat them as soon as I can (Wenn ich ein starkes Verlangen nach bestimmten Nahrungsmitteln verspüre, versuche ich gewöhnlich, diese so bald wie möglich auch zu essen)	Lack of control/ intentions	3.27	.62
.13	−.05	.28	.11	.50	−.11	25. I have no will power to resist my food crave (Ich habe nicht die Willensstärke, um meinen Essensgelüsten widerstehen zu können)	Lack of control/ intentions	2.64	.72
.31	.02	.17	.31	.27	−.20	26. Once I start eating, I have trouble stopping (Wenn ich einmal anfange, zu essen, fällt es mir schwer, wieder aufzuhören)	Lack of control/ intentions	2.54	.75
.52	.02	.21	.00	.23	−.21	29. If I give in to a food craving, all control is lost (Wenn ich dem starken Verlangen nach bestimmten Nahrungsmitteln nachgebe, verliere ich jegliche Kontrolle)	Lack of control/ intentions	1.74	.72
.12	.10	.05	.32	−.25	.64	11. Thinking about my favorite foods makes my mouth water (Wenn ich an meine Lieblingsessen denke, läuft mir das Wasser im Mund zusammen)	Hunger	3.45	.40
−.07	−.19	.21	.03	.24	.77	12. I crave foods when my stomach is empty (Ich verspüre ein starkes Verlangen nach bestimmten Nahrungsmitteln, wenn mein Magen leer ist)	Hunger	3.33	.40
.03	−.08	.31	−.13	.45	.48	13. I feel as if my body asks me for certain foods (Es fühlt sich an, als würde mein Körper nach bestimmten Nahrungsmitteln geradezu verlangen)	Hunger	2.77	.62
.22	.02	.13	.03	.08	.47	14. I get so hungry that my stomach seems like a bottomless pit (Ich werde so hungrig, dass mir mein Magen wie ein Fass ohne Boden vorkommt)	Hunger	2.28	.50

Note. Item-total-correlation was part-whole corrected.

FCQ-S

Total FCQ-S scores were unrelated to BMI (r = .003, *ns*) or gender (r_b = .02, *ns*). State cravings were positively associated with hours elapsed since the last meal (r = .25, p < .001). FCQ-S scores were moderately correlated with negative affect (r = .32, p < .001) and weakly and negatively with positive affect (r = −.09, p < .05).

FCQs-subscales in relation to dietary restraint status

FCQ-T

The first and second discriminant function discriminated significantly between non-dieters, successful and unsuccessful dieters (Wilks Λ = .57, $\chi^2_{(12)} = 278.6$, p < .001). After removing function one, the second function was still significant (Wilks Λ = .94, $\chi^2_{(5)} = 30.8$, p < .001). Function 1 had an eigenvalue of .65 and explained 91.0% of the variance while function 2 contributed further 9.0% (eigenvalue .06). Function 1 discriminated between dieters and non-dieters whereas function 2 discriminated between successful and unsuccessful dieters (Fig. 1a). Table 4 presents the structure matrix and standardized coefficients for both discriminant functions. Within the first discriminant function, factor THOUGHTS/GUILT discriminated best between groups as did factor LACK OF CONTROL/INTENTIONS for the second (Table 4). FCQ-T-subscale scores predicted restraint status. Overall hit rate was better than what would be expected by chance alone, according to Press's Q[1] ($\chi^2_{(1)} = 281.5$, p < .001). Classification results showed that 68.7% of originally grouped cases and 68.1% of cross-validated grouped cases (jackknife procedure) were correctly classified. Classifying participants by chance would have resulted in 37.9% of correct classifications.

FCQ-S

Like for the FCQ-T, the first and second discriminant functions discriminated significantly between non-dieters, successful and unsuccessful dieters (Wilks Λ = .87, $\chi^2_{(6)} = 69.0$, p < .001). However, after removing the first function the second was no longer significant (Wilks Λ = .99, $\chi^2_{(2)} = .29$, *ns*). The first function, which explained 99.6% of variance (eigenvalue = .15), discriminated between dieters and non-dieters (Fig. 1b). The subscale DESIRE/LACK OF CONTROL discriminated best (Table 4). Press's Q indicated that correct classification of participants was better than what would be expected by chance ($\chi^2_{(1)} = 124.9$, p < .001). Classification results showed that 56.9% of originally grouped cases and 56.3% of cross-validated grouped cases (jackknife procedure) were correctly classified. Classifying participants by chance would have resulted in 37.9% of correct classifications.

Discussion

The aim of the current study was to provide a German version of the FCQs and explore the role of food cravings in success or failure in dietary restraint. Good psychometric properties of the original FCQs could be replicated. Furthermore, distinct relationships between food craving dimensions and success and failure in dietary restraint were found.

Psychometric properties of the German FCQs

The factor structure of the original FCQs could only be replicated partially. While the trait version has previously been reported to consist of nine and the state version of five subscales

[1] Press's $Q = [N - (nK)]^2/N\ (K - 1)$ where N = total sample size, n = number of observations correctly classified, K = number of groups (see Chan, 2005).

Table 2
Factor loadings and item statistics of the Food Cravings Questionnaire-State.

Factor 1	Factor 2	Factor 3	Item	Factor	Item mean	Item-total-correlation
.69	.45	−.15	1. I have an intense desire to eat [one or more specific foods] (Ich verspüre den intensiven Wunsch [eines oder mehrere bestimmte Nahrungsmittel] zu essen)	Desire/lack of control	2.15	.77
.74	.38	−.11	2. I'm craving [one or more specific foods] (Ich verspüre ein starkes Verlangen nach [einem oder mehreren bestimmten Nahrungsmitteln])	Desire/lack of control	2.04	.79
.69	.40	−.09	3. I have an urge for [one or more specific foods] (Ich verspüre den Drang, [eines oder mehrere bestimmte Nahrungsmittel] zu essen)	Desire/lack of control	2.05	.78
.85	−.26	.00	10. If I had [one or more specific foods], I could not stop eating it (Wenn ich [eines oder mehrere bestimmte Nahrungsmittel] hätte, könnte ich nicht aufhören, davon zu essen)	Desire/lack of control	1.89	.47
.82	−.22	.14	11. My desire to eat [one or more specific foods] seems overpowering (Mein Verlangen, [eines oder mehrere bestimmte Nahrungsmittel] zu essen, scheint überwältigend zu sein)	Desire/lack of control	1.44	.60
.77	−.22	.20	12. I know I'm going to keep on thinking about [one or more specific foods] until I actually have it (Ich weiß, dass ich solange an [eines oder mehrere bestimmte Nahrungsmittel] denken werde, bis ich es tatsächlich habe)	Desire/lack of control	1.56	.59
−.09	.96	−.02	13. I am hungry (Ich habe Hunger)	Hunger	2.24	.59
−.13	.91	.09	14. If I ate right now, my stomach wouldn't feel as empty.(Wenn ich jetzt etwas essen würde, würde sich mein Magen nicht so leer anfühlen)	Hunger	2.24	.61
−.22	.76	.30	15. I feel weak because of not eating (Ich fühle mich schwach, weil ich nichts gegessen habe)	Hunger	1.65	.58
.47	−.08	.39	4. Eating [one or more specific foods] would make things seem just perfect ([Eines oder mehrere bestimmte Nahrungsmittel] zu essen, würde mir alles einfach perfekt erscheinen lassen)	Reinforcement	1.51	.59
.21	.06	.64	5. If I were to eat what I am craving, I am sure my mood would improve (Wenn ich das essen würde, wonach ich mich gerade sehne, würde sich sicher meine Stimmung verbessern)	Reinforcement	1.94	.68
.45	.08	.36	6. Eating [one or more specific foods] would feel wonderful ([Eines oder mehrere bestimmte Nahrungsmittel] zu essen, würde sich großartig anfühlen)	Reinforcement	2.09	.68
−.04	.21	.69	7. If I ate something, I wouldn't feel so sluggish and lethargic (Wenn ich etwas essen würde, würde ich mich nicht so träge und antriebslos fühlen)	Reinforcement	1.79	.61
.17	−.09	.81	8. Satisfying my craving would make me feel less grouchy and irritable (Wenn ich mein Verlangen stillen könnte, würde ich mich weniger schlecht gelaunt und gereizt fühlen)	Reinforcement	1.75	.67
−.05	.22	.77	9. I would feel more alert if I could satisfy my craving (Wenn ich mein Verlangen stillen könnte, würde ich mich munterer fühlen)	Reinforcement	1.86	.68

Note. Item-total-correlation was part-whole corrected.

(Cepeda-Benito, Gleaves, Williams et al., 2000), the German FCQs were composed of six (FCQ-T) and three (FCQ-S) subscales. This was achieved by merging three FCQ-T- and two FCQ-S-subscales into other factors. Similar results were presented by Vander Wal and colleagues (2007) where – both in the state and the trait version – subscales for positive and negative reinforcement through eating, could be combined into one factor. Furthermore, PCA of an adaptation of the FCQ-T to chocolate cravings also resulted in a six-factorial solution (Rodríguez et al., 2007). Contrarily, Nijs and colleagues (2007) found a four-factorial solution for their Dutch version of the FCQ-T. However, these differences could be due to methodological reasons because they modified wording of the items. Cultural differences or translational issues might also account for diverging results in factor structure as no equivalent of the term craving exists in Dutch (Nijs et al., 2007) as in other languages (Hormes & Rozin, 2010).

Although some items had also high factor loadings on other subscales, the combination of subscales in our study was supported by good internal consistencies. For instance, even the subscale with the most items with multiple high factor loadings (LACK OF CONTROL/INTENTIONS, Table 1) had a Crohnbach's α of .92. Moreover, overall internal consistency was also very good for both the state and trait version (>.90). As expected, retest-reliabilities were higher for the trait- than for the state version and comparable to the original version (Cepeda-Benito, Gleaves, Williams et al., 2000).

FCQ-T was positively associated with eating behaviors that are related to a loss of control over eating (restrained eating, binge eating, food addiction, low success in dieting, BMI) confirming convergent validity. Rigid control strategies of eating behavior were associated with increased food cravings whereas there was no such relationship between food cravings and flexible control of eating behavior. Rigid dietary control strategies have previously been associated with disinhibited eating behavior or higher BMI

Table 3
Construct validity of the Food Cravings Questionnaire-Trait (FCQ-T).

	FCQ-T	*p*-Value
Convergent validity		
Restraint Scale-Concern for Dieting	.56	< .001
Binge Eating[a]	.54	< .001
Yale Food Addiction Scale[b]	.50	< .001
Perceived Self-Regulatory Success in Dieting	-.42	< .001
Rigid Control of Eating Behavior	.41	< .001
Flexible Control of Eating Behavior	.07	*ns*
Divergent validity		
Mannheimer Craving Scale	.16	< .001
Barratt Impulsiveness Scale	.17	< .001
Behavioral Inhibition System	.31	< .001
Behavioral Activation System	.09	< .05

[a] Binge eating refers to the number of days within the last 28 days when binge eating occurred as measured with the Eating Disorder Examination-Questionnaire.
[b] Questionnaire scores represent the amount of food addiction symptoms.

(Shearin et al., 1994; Stewart et al., 2002; Timko & Perone, 2005; Westenhoefer, 1991; Westenhoefer et al., 1999). One possible mediator could be the experience of food cravings that are fostered by rigid eating behavior (Meule, Westenhöfer, & Kübler, 2011). For instance, sticking to a monotone diet has been found to lead to food cravings in the absence of hunger feelings (Pelchat & Schaefer, 2000).

Small correlations were found between the FCQ-T and substance craving. The MaCS instructs participants to think of any addictive substance when indicating their craving. Here, we speculate that participants included food as an addictive substance. Accordingly, it has been found that the terms *craving* and *addiction* are used for food and drugs alike in the general population (Hormes & Rozin, 2010). In accordance with the crucial role of cravings in impulsive behaviors like food and drug addiction, impulsivity

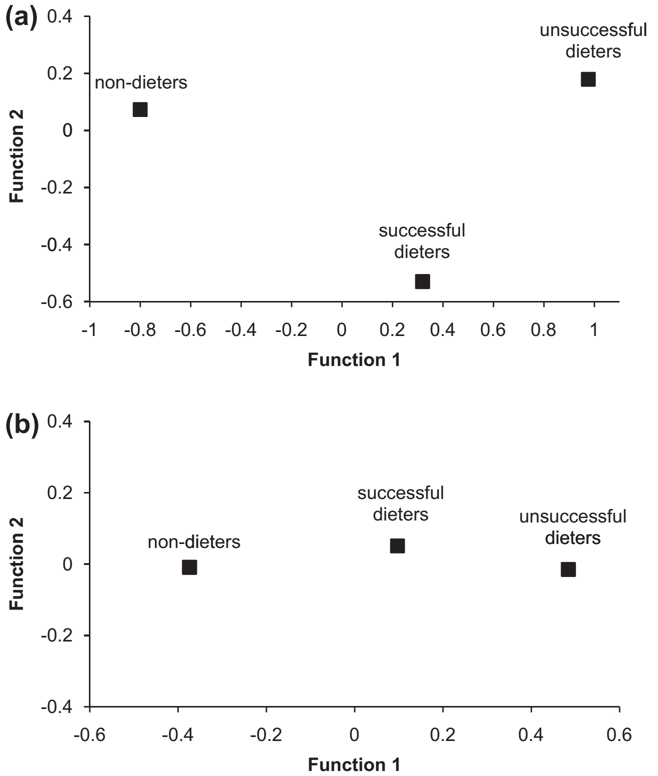

Fig. 1. Location of groups along the first and second discriminant functions according to their respective centroids for the (a) trait and (b) state version of the Food Cravings Questionnaire.

was also associated with food cravings. Additionally, BIS/BAS-reactivity was also positively correlated with food cravings which corresponds to increased BIS reactivity in food addiction (Gearhardt et al., 2009; Meule et al., in press), but also to a positive relationship between reward sensitivity and food cravings (Franken & Muris, 2005). In a similar vein, Bijttebier and colleagues (2009) have suggested BIS sensitivity to be related to withdrawal relief craving in substance abuse, while BAS sensitivity can induce reward craving. Taken together, substance craving, BIS/BAS reactivity and impulsivity were significantly, but weakly related to the FCQ-T, thereby confirming divergent validity.

Hours elapsed since the last meal were positively associated with state cravings, replicating previous findings (Cepeda-Benito, Gleaves, Williams et al., 2000; Cepeda-Benito et al., 2003). However, correlations between state cravings and affective state indicated that also factors other than hunger modulated current cravings. Negative affect was positively and positive affect negatively correlated with state cravings. While this is the first study showing that the FCQ-S is also sensitive to current mood states the causal direction between food cravings and mood states cannot be inferred from these results.

Food craving dimensions in dietary restraint

In the current study, we found a positive correlation between restrained eating and FCQ-T-scores. Nevertheless, there is an ongoing debate on the confounding of success and failure in the measurement of dietary restraint. For instance, Van Strien (1999) concluded that the total population of dieters consists of two subpopulations of successful and unsuccessful dieters who cannot be discriminated by considering the restraint score alone. Therefore, we used a measure solely of cognitive restraint combined with

Table 4
Structure matrix and standardized discriminant function coefficients.

	Structure matrix		Standardized coefficients	
	Function 1	Function 2	Function 1	Function 2
Food Cravings Questionnaire-Trait				
Thoughts/guilt	.95	−.21	.92	−1.1
Lack of control/intentions	.75	.41	.10	1.2
Emotions	.63	.26	.06	.40
Cues	.53	.29	.12	.09
Reinforcement	.41	.15	.11	−.05
Hunger	.29	−.23	−.36	−.58
Food Cravings Questionnaire-State				
Desire/lack of control	.85	–	1.09	–
Reinforcement	.50	–	.07	–
Hunger	−.07	–	−.62	–

Note. The second discriminant function was not significant for the Food Cravings Questionnaire-State.

explicit differentiation between successful and unsuccessful dieters (see Papies et al., 2008; Van Koningsbruggen, Stroebe, & Aarts, 2011; Van Koningsbruggen, Stroebe, Papies, 2011). We found that dieters – regardless of being successful or unsuccessful in their pursuit – experienced more cravings that are related to a preoccupation with food and guilt from cravings or for giving into them. Moreover, unsuccessful dieters reported more food cravings that were related to a lack of control over eating and plans to consume food than successful dieters. Therefore, this is the first study showing that (1) differences in food cravings between non-dieters and dieters depend on success or failure of these dieters and (2) that specific types of food cravings discriminate differentially between these three groups.

While the FCQ-S also discriminated between dieters and non-dieters, successful and unsuccessful dieters could not be discriminated. Specifically, the FCQ-S was not able to identify one single successful dieter. This finding corresponds to results showing that the FCQ-S is also related to dysfunctional eating behavior but the relationship is attenuated (Cepeda-Benito, Gleaves, Williams et al., 2000; Moreno et al., 2008). Furthermore, it shows that successful and unsuccessful dieters do not differ in their current experiences of craving. Successful dieters may be as susceptible as unsuccessful dieters to allurements of food, but possess mechanisms that enable them to resist those temptations.

Limitations

First, it has to be noted that the current methodology was different from other FCQs-validation studies. We conducted an online study whereas usually paper-and-pencil versions of the FCQs were used. However, there is evidence that questionnaires assessed online do not differ from traditional assessment methods (e.g. Miller et al., 2002). Furthermore, psychometric properties of the German FCQs largely corresponded to the Spanish and English version which supports comparability of studies. Second, the majority of our sample consisted of young women attending University. Therefore, results must be interpreted with caution as they may not be transferrable to the general population. Future studies using the FCQs should investigate a broader range of participants, including more men and people of higher age and with lower social status. Third, our investigation was a cross-sectional study based on self-report measures. Field or experimental designs are needed to reveal the exact role of food cravings for success or failure in dieting. For instance, factors could be examined that determine why some dieters can stick to their diet although experiencing certain food cravings.

To summarize, the German version of the FCQs is a reliable and valid measure of state and trait food cravings. Although overall food cravings are positively associated with restrained eating behavior and less dieting success, the subpopulations of successful and unsuccessful dieters show distinct experiences of specific types of cravings. These differences need to be considered when the relationship between dieting and food cravings, and particularly mechanisms leading to success or failure in dieting, are investigated.

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References

Abilés, V., Rodríguez-Ruiz, S., Abilés, J., Mellado, C., García, A., Pérez de la Cruz, A., et al. (2010). Psychological characteristics of morbidly obese candidates for bariatric surgery. *Obesity Surgery, 20*, 161–167.
American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.
Benton, D., Greenfield, K., & Morgan, M. (1998). The development of the attitudes to chocolate questionnaire. *Personality and Individual Differences, 24*, 513–520.
Bijttebier, P., Beck, I., Claes, L., & Vandereycken, W. (2009). Gray's reinforcement sensitivity theory as a framework for research on personality-psychopathology associations. *Clinical Psychology Review, 29*, 421–430.
Cartwright, F., & Stritzke, W. G. (2008). A multidimensional ambivalence model of chocolate craving. Construct validity and associations with chocolate consumption and disordered eating. *Eating Behaviors, 9*, 1–12.
Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment. The BIS/BAS scales. *Journal of Personality and Social Psychology, 67*, 319–333.
Cepeda-Benito, A., Fernández, M. C., & Moreno, S. (2003). Relationship of gender and eating disorder symptoms to reported cravings for food. Construct validation of state and trait craving questionnaires in Spanish. *Appetite, 40*, 47–54.
Cepeda-Benito, A., Gleaves, D. H., Fernández, M. C., Vila, J., Williams, T. L., & Reynoso, J. (2000). The development and validation of Spanish versions of the state and trait food cravings questionnaires. *Behaviour Research and Therapy, 38*, 1125–1138.
Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behavior Therapy, 31*, 151–173.
Chan, Y. H. (2005). Biostatistics 303. Discriminant analysis. *Singapore Medical Journal, 46*, 54–62.
Dinkel, A., Berth, H., Exner, C., Rief, W., & Balck, F. (2005). Deutsche Adaptation der Restraint Scale zur Erfassung gezügelten Essverhaltens [German version of the Restraint Scale for the assessment of restrained eating]. *Diagnostica, 51*, 67–74.
Fairburn, C. G., & Beglin, S. J. (1994). Assessment of eating disorders. Interview or self-report questionnaire? *International Journal of Eating Disorders, 16*, 363–370.
Fishbach, A., Friedman, R. S., & Kruglanski, A. W. (2003). Leading us not unto temptation. Momentary allurements elicit overriding goal activation. *Journal of Personality and Social Psychology, 84*, 296–309.
Franken, I. H. A., & Muris, P. (2005). Individual differences in reward sensitivity are related to food craving and relative body weight in healthy women. *Appetite, 45*, 198–201.
Gearhardt, A. N., Corbin, W. R., & Brownell, K. D. (2009). Preliminary validation of the Yale Food Addiction Scale. *Appetite, 52*, 430–436.
Gray, J. A. (1982). *The neuropsychology of anxiety. An inquiry into the functions of the septal-hippocampal system*. Oxford: Oxford University Press.
Heatherton, T. F., Herman, C. P., Polivy, J., King, G. A., & McGree, S. T. (1988). The (mis)measurement of restraint. An analysis of conceptual and psychometric issues. *Journal of Abnormal Psychology, 97*, 19–28.
Herman, C. P., & Polivy, J. (1980). Restrained eating. In A. J. Stunkard (Ed.), *Obesity* (pp. 208–225). Philadelphia: Saunders.
Hilbert, A., & Tuschen-Caffier, B. (2006). *Eating Disorder Examination – Questionnaire. Deutschsprachige Übersetzung*. Münster: Verlag für Psychotherapie.
Hill, A. J. (2007). The psychology of food craving. *Proceedings of the Nutrition Society, 66*, 277–285.
Hill, A. J., Weaver, C. F. L., & Blundell, J. E. (1991). Food craving, dietary restraint and mood. *Appetite, 17*, 187–197.
Hormes, J. M., & Rozin, P. (2010). Does "craving" carve nature at the joints? Absence of a synonym for craving in many languages. *Addictive Behaviors, 35*, 459–463.
Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement, 20*, 141–151.
Krohne, H. W., Egloff, B., Kohlmann, C.-W., & Tausch, A. (1996). Untersuchungen mit einer deutschen Version der "Positive and Negative Affect Schedule" (PANAS) [Investigations with a German version of the Positive and Negative Affect Schedule (PANAS)]. *Diagnostica, 42*, 139–156.
Meule, A., Nakovics, H., & Kübler. Validation of the Mannheimer Craving Scale to assess craving across substances (submitted for publication).
Meule, A., Vögele, C., & Kübler, A. Deutsche Übersetzung und Validierung der Yale Food Addiction Scale [German translation and validation of the Yale Food Addiction Scale]. *Diagnostica* (in press).
Meule, A., Vögele, C., & Kübler, A. (2011). Psychometrische Evaluation der deutschen Barratt Impulsiveness Scale - Kurzversion (BIS-15) [Psychometric evaluation of the German Barratt Impulsiveness Scale - Short Version (BIS-15)]. *Diagnostica, 57*, 126–133.
Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite, 57*, 582–584.
Miller, E. T., Neal, D. J., Roberts, L. J., Baer, J. S., Cressler, S. O., Metrik, J., et al. (2002). Test-retest reliability of alcohol measures. Is there a difference between Internet-based assessment and traditional methods? *Psychology of Addictive Behaviors, 16*, 56–63.
Moreno, S., Rodríguez, S., Fernández, M. C., Tamez, J., & Cepeda-Benito, A. (2008). Clinical validation of the trait and state versions of the food craving questionnaire. *Assessment, 15*, 375–387.
Moreno, S., Warren, C. S., Rodríguez, S., Fernández, M. C., & Cepeda-Benito, A. (2009). Food cravings discriminate between anorexia and bulimia nervosa. Implications for "success" versus "failure" in dietary restriction. *Appetite, 52*, 588–594.
Nakovics, H., Diehl, A., Geiselhart, H., & Mann, K. (2009). Entwicklung und Validierung eines Instrumentes zur substanzunabhängigen Erfassung von Craving. Die Mannheimer Craving Scale (MaCS) [Development and validation of an overall instrument to measure craving across multiple substances. The Mannheimer Craving Scale (MaCS)]. *Psychiatrische Praxis, 36*, 72–78.
Nijs, I. M. T., Franken, I. H. A., & Muris, P. (2007). The modified Trait and State Food-Cravings Questionnaires. Development and validation of a general index of food craving. *Appetite, 49*, 38–46.
Papies, E. K., Stroebe, W., & Aarts, H. (2008). Healthy cognition. Processes of self-regulatory success in restrained eating. *Personality and Social Psychology Bulletin, 34*, 1290–1300.
Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51*, 768–774.
Pelchat, M. L., & Schaefer, S. (2000). Dietary monotony and food cravings in young and elderly adults. *Physiology and Behavior, 68*, 353–359.
Polivy, J., Coleman, J., & Herman, C. P. (2005). The effect of deprivation on food cravings and eating behavior in restrained and unrestrained eaters. *International Journal of Eating Disorders, 38*, 301–309.
Rodin, J., Mancuso, J., Granger, J., & Nelbach, E. (1991). Food cravings in relation to body mass index, restraint and estradiol levels. A repeated measures study in healthy women. *Appetite, 17*, 177–185.
Rodríguez, S., Fernández, M. C., Cepeda-Benito, A., & Vila, J. (2005). Subjective and physiological reactivity to chocolate images in high and low chocolate cravers. *Biological Psychology, 70*, 9–18.
Rodríguez, S., Warren, C. S., Moreno, S., Cepeda-Benito, A., Gleaves, D. H., Fernández, M. D., et al. (2007). Adaptation of the food-craving questionnaire trait for the assessment of chocolate cravings. Validation across British and Spanish women. *Appetite, 49*, 245–250.
Shearin, E. N., Russ, M. J., Hull, J. W., Clarkin, J. F., & Smith, G. P. (1994). Construct-validity of the 3-Factor Eating Questionnaire – Flexible and rigid control subscales. *International Journal of Eating Disorders, 16*, 187–198.
Shiffman, S. (2000). Comments on craving. *Addiction, 95*(8), S171–S175.
Spinella, M. (2007). Normative data and a short form of the Barratt Impulsiveness Scale. *International Journal of Neuroscience, 117*, 359–368.
Stewart, T. M., Williamson, D. A., & White, M. A. (2002). Rigid vs. flexible dieting. Association with eating disorder symptoms in nonobese women. *Appetite, 38*, 39–44.
Strobel, A., Beauducel, A., Debener, S., & Brocke, B. (2001). Eine deutschsprachige Version des BIS/BAS-Fragebogens von Carver and White [A German Version of Carver and White's BIS/BAS Scales]. *Zeitschrift für Differentielle und Diagnostische Psychologie, 22*, 216–227.
Stroebe, W. (2008). Restrained eating and the breakdown of self-regulation. In W. Stroebe (Ed.), *Dieting, overweight, and obesity – self-regulation in a food-rich environment* (pp. 115–139). Washington, DC: American Psychological Association.
Stunkard, A. J., & Messick, S. (1985). The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *Journal of Psychosomatic Research, 29*, 71–83.
Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Boston: Allyn & Bacon.
Timko, A. C., & Perone, J. (2005). Rigid and flexible control of eating behavior in a college population. *Eating Behaviors, 6*, 119–125.
Van Koningsbruggen, G. M., Stroebe, W., & Aarts, H. (2011). Through the eyes of dieters. Biased size perception of food following tempting food primes. *Journal of Experimental Social Psychology, 47*, 293–299.
Van Koningsbruggen, G. M., Stroebe, W., Papies, E. K., & Aarts, H. (2011). Implementation intentions as goal primes. Boosting self-control in tempting environments. *European Journal of Social Psychology, 41*, 551–557.
Van Strien, T. (1997). Are most dieters unsuccessful? An alternative interpretation of confounding of success and failure in the measurement of restraint. *European Journal of Psychological Assessment, 13*, 186–194.

Van Strien, T. (1999). Success and failure in the measurement of restraint. *International Journal of Eating Disorders, 25*, 441–449.

Vander Wal, J. S., Johnston, K. A., & Dhurandhar, N. V. (2007). Psychometric properties of the State and Trait Food Cravings Questionnaires among overweight and obese persons. *Eating Behaviors, 8*, 211–223.

Vander Wal, J. S., Marth, J. M., Khosla, P., Jen, K.-L. C., & Dhurandhar, N. V. (2005). Short-term effect of eggs on satiety in overweight and obese subjects. *Journal of the American College of Nutrition, 24*, 510–515.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect. The PANAS scales. *Journal of Personality and Social Psychology, 54*, 1063–1070.

Weingarten, H. P., & Elston, D. (1990). The Phenomenology of food cravings. *Appetite, 15*, 231–246.

Westenhoefer, J. (1991). Dietary restraint and disinhibition. Is restraint a homogeneous construct? *Appetite, 16*, 45–55.

Westenhoefer, J., Stunkard, A. J., & Pudel, V. (1999). Validation of the flexible and rigid control dimensions of dietary restraint. *International Journal of Eating Disorders, 26*, 53–64.

White, M. A., Whisenhunt, B. L., Williamson, D. A., Greenway, F. L., & Netemeyer, R. G. (2002). Development and validation of the Food-Craving Inventory. *Obesity Research, 10*, 107–114.

Williamson, D. A., Martin, C. K., York-Crowe, E., Anton, S. D., Redman, L., Han, H., et al. (2007). Measurement of dietary restraint. Validity tests of four questionnaires. *Appetite, 48*, 183–192.

2.2 Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite*, *57*, 582-584.

Abstract: Both food cravings and rigid dietary control strategies have been implicated in low dieting success while flexible control often is associated with successful weight loss. An online survey was conducted (*N* = 616) to test the mediational role of food cravings between dietary control strategies and self-perceived dieting success. Food cravings fully mediated the inverse relationship between rigid control and dieting success. Contrarily, flexible control predicted dieting success independently of food cravings, which were negatively associated with dieting success. Differential mechanisms underlie the relationship between rigid and flexible control of eating behavior and dieting success.

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Short Communication

Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success

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ABSTRACT

Both food cravings and rigid dietary control strategies have been implicated in low dieting success while flexible control often is associated with successful weight loss. An online survey was conducted ($N = 616$) to test the mediational role of food cravings between dietary control strategies and self-perceived dieting success. Food cravings fully mediated the inverse relationship between rigid control and dieting success. Contrarily, flexible control predicted dieting success independently of food cravings, which were negatively associated with dieting success. Differential mechanisms underlie the relationship between rigid and flexible control of eating behavior and dieting success.

Introduction

Cravings refer to an intense desire or longing for a particular substance (Weingarten & Elston, 1990). In relation to food, this irresistible urge to eat a specific type of food has been implicated to contribute to a loss of control over eating. For instance, the experience of food cravings is related to higher body-mass-index (BMI) or binge eating behaviors (Abilés, Rodríguez-Ruiz, Abilés, Mellado, García, & Pérez de la Cruz, 2010; Franken & Muris, 2005; Gendall, Sullivan, Joyce, Fear, & Bulik, 1997; Moreno, Warren, Rodríguez, Fernández, & Cepeda-Benito, 2009). Food cravings are distinct from hunger and can even be elicited without food deprivation. For example, Pelchat and Schaefer (2000) have shown that setting people on a monotonous diet triggers food cravings without any nutritional deficit.

Eliminating "forbidden" foods from daily food intake, thereby narrowing the variety of foods, is a rigid strategy many dieters use to control their eating behavior. Westenhoefer (1991) found that such rigid control strategies as opposed to flexible strategies can be assessed by different items of the *Eating Inventory* (EI; formerly known as the Three-Factor Eating Questionnaire; Stunkard & Messick, 1985). Rigid control is marked by an "all-or-nothing" approach to dieting while flexible control reflects a more balanced approach to dietary intake that include eating slowly or taking small helpings. Higher flexible control has been found to be related to lower disinhibition and lower BMI whereas higher rigid control has been found to be related to higher disinhibition and higher BMI (Timko & Perone, 2005; Westenhoefer, 1991; Westenhoefer, Stunkard, & Pudel, 1999). Therefore, flexible control may be an adaptive dietary strategy leading to dieting success while rigid control may be associated with dieting failure.

However, there have been inconsistent findings regarding correlates of rigid and flexible control in intervention studies. In some studies, no association was found between rigid or flexible control and weight loss (Burgmer, Grigutsch, Zipfel, Wolf, de Zwaan, & Husemann, 2005; Timko, Oelrich, & Lowe, 2007). Contrarily, often both rigid and flexible control were increased after weight management interventions and were associated with weight loss (McGuire, Jeffery, French, & Hannan, 2001; Teixeira et al., 2010) or binge eating abstinence (Downe, Goldfein, & Devlin, 2009). While rigid control might lead to short-term successful weight loss, some studies point out that flexible control is especially important for long-term weight maintenance (Teixeira et al., 2010; Westenhoefer, von Falck, Stellfeldt, & Fintelmann, 2004). Besides differences in sample characteristics, inconsistent findings could be explained by different scale versions used. Often the short version of the flexible and rigid control scale is employed despite low reliability (Westenhoefer et al., 1999).

In the present study, we used the long version of the rigid and flexible control scale (Westenhoefer et al., 1999) and tested its

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relationship to dieting success in a non-clinical sample. Specifically, we expected rigid control to inversely predict dieting success while flexible control to positively predict dieting success. Moreover, we tested if these relationships were mediated by the experience of food cravings.

Methods

Participants

Data were collected as part of an online survey details of which are reported elsewhere (Meule, Lutz, Vögele, & Kübler, in revision). Student councils of several German universities were contacted via e-mail. Then, the Internet address of the online survey was sent via the student councils' mailing lists. As an incentive five × 50 Euro were raffled among participants who completed the entire set of questions. The study-website was visited 1615 times. The survey was completed by $N = 617$ participants (38.2%). Data from one participant were excluded from further analyses because of implausible statements. The majority of participants were women (75.8%, $n = 467$). Both, men and women were included in all analyses. Almost all participants were students (89.0%) and had German citizenship (95.5%). Only 4.5% reported to have other European (3.4%) or non-European (1.1%) citizenship. Mean body-mass-index (BMI) was $M = 22.3$ kg/m^2 ($SD \pm 3.3$). BMI of one participant was missing. Participants had a mean age of $M = 24.5$ years ($SD \pm 4.0$).

Measures

Rigid and flexible control of eating behavior

These scales were originally developed by Westenhoefer (1991) who found that the *cognitive restraint* subscale of the EI (Stunkard & Messick, 1985) could be further divided into flexible and rigid control strategies of dietary restraint. Later, additional items were added to increase internal consistencies (Westenhoefer et al., 1999). Flexible control is now assessed with 12 items (FC12), whereas the rigid control scale consists of 16 items (RC16). Internal consistencies in the present sample were $\alpha = .82$ for FC12 and $\alpha = .80$ for RC16. Both scales were correlated in the current study ($r = .55$, $p < .001$).

Food Cravings Questionnaires

Food cravings were assessed with the trait version of the Food Cravings Questionnaires (FCQ-T; Cepeda-Benito, Gleaves, Williams, & Erath, 2000). This 39-item instrument asks participants to indicate on a 6-point scale how frequently they experience food cravings (ranging from *never* to *always*). The FCQ-T consists of 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 and internal consistency was $\alpha = .96$.

Perceived self-regulatory success in dieting (PSRS)

This three-item scale was developed by Fishbach, Friedman, and Kruglanski (2003). Participants have to rate on 7-point scales how successful they are in watching their weight or losing weight and how difficult it is for them to stay in shape. In our study, participants were able to choose *not applicable* if they were not concerned with their weight. If this option was chosen in at least one question, participants were excluded from analysis ($n = 135$). For the remaining $n = 480$ participants, internal consistency of the PSRS was $\alpha = .74$, which is higher than previously reported ($\alpha = .66$; van Koningsbruggen, Stroebe, & Aarts, 2011).

Statistical analyses

Regression analyses were computed to reveal relationships between rigid/flexible control, food cravings, and dieting success. To test the hypothesized mediational model (i.e. rigid/flexible control → food cravings → dieting success) we followed the guidelines as described by Baron and Kenny (1986). The mediation effect was tested with the Sobel-test. The mediation analysis was also run separately for men and women, but lead to similar results. Therefore, results are only reported for the whole sample. Pearson-correlations were calculated to explore relationships between BMI and questionnaire scores.

Results

Rigid control

Rigid control was a significant predictor of food cravings ($F_{(1,478)} = 87.3$, $p < .001$, adj. $R^2 = .15$) and dieting success ($F_{(1,478)} = 24.8$, $p < .001$, adj. $R^2 = .05$). Beta-weights are depicted in Fig. 1. Food cravings also predicted dieting success ($F_{(1,478)} = 111.3$, $p < .001$, adj. $R^2 = .19$, $\beta = -.44$). The overall model including both rigid control and food cravings as predictors was also significant ($F_{(2,477)} = 56.7$, $p < .001$, adj. $R^2 = .19$). While food cravings were still a significant predictor of dieting success, the influence of rigid control was no longer significant (Fig. 1). Food cravings mediated the relationship between rigid control and dieting success (Sobel $z = -6.42$, $p < .001$).

Flexible control

Flexible control predicted dieting success ($F_{(1,478)} = 34.5$, $p < .001$, adj. $R^2 = .07$, $\beta = .26$). However, flexible control did not predict food cravings ($F_{(1,478)} = .58$, *ns*, adj. $R^2 = .00$, $\beta = -.04$).

Correlations with BMI

BMI correlations were weakly positive with rigid control ($r = .14$, $p < .01$) and food cravings ($r = .11$, $p < .05$), weakly negative with flexible control ($r = -.15$, $p < .01$), and moderately negative with dieting success ($r = -.38$, $p < .001$).

Discussion

In the current study, we found that rigid dietary control strategies were inversely related to dieting success while flexible control strategies were positively associated with dieting success.

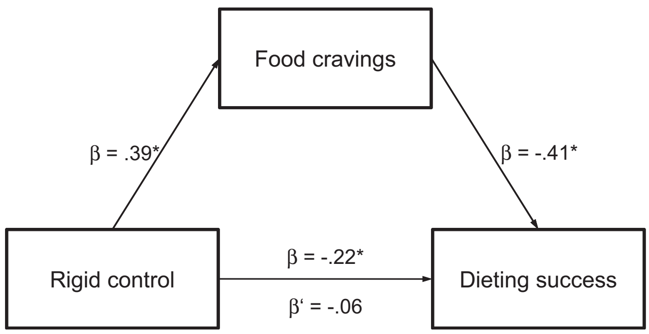

Fig. 1. Mediation model showing the mediating influence of food cravings on the relationship between rigid control of eating behavior and dieting success. Standardized β-coefficients are shown for the relation between rigid control and food cravings, food cravings and dieting success (adjusted for rigid control), and rigid control and dieting success (β' indicates the relation which is adjusted for the mediator). Asterisks indicate a p-value < .001.

We could also demonstrate that the experience of food cravings fully mediated the relationship between rigid control and dieting success. Contrarily, flexible control was not related to food cravings and predicted dieting success independent of food cravings.

Our results corroborate and extend previous findings indicating that rigid control is associated with self-regulatory failure in eating behavior (Timko & Perone, 2005; Westenhoefer, 1991; Westenhoefer et al., 1999). The mediating role of food cravings in this relationship is in line with rigid dietary strategies, such as a monotonous diet, eliciting such cravings (Pelchat & Schaefer, 2000). However, these results also contrast positive associations between rigid control and weight loss in overweight and obese women (McGuire et al., 2001; Teixeira et al., 2010). It has to be noted that we only cautiously compare our results with such studies because our cross-sectional data were based on a predominantly normal-weight sample. However, we speculate that obese patients might have low – both rigid and flexible – dietary control and therefore benefit from increases in rigid control which leads to initial weight loss. On the long run, however, rigid eating behaviors lead to food cravings thereby hampering long-term weight maintenance. Indeed, people with flexible control strategies have been found to be more successful in long-term weight maintenance (Teixeira et al., 2010; Westenhoefer et al., 2004). While flexible control was associated with dieting success in our study, this relationship was not attenuated by food cravings. Accordingly, flexible control was not related to food cravings. Dieters with flexible control strategies may also experience food cravings because they are common and experienced by most people (Hill, 2007). It is possible that even after giving in to such cravings, food intake is properly adjusted afterwards leading to successful weight loss or maintenance. Finally, flexible control in combination with less food cravings fosters dieting success even more.

A limitation of the current study is that our sample predominantly consisted of female students. Therefore, translation of results to the general population is limited. However, female participants are an appropriate target sample to investigate dieting because women are particularly concerned with their weight (Dinkel, Berth, Exner, Rief, & Balck, 2005). A second limitation is that results are based on self-report questionnaires only. Objective criteria, e.g. measuring BMI, are recommended to corroborate such findings. However, construct validity of the PSRS can be seen in negative correlations with self-reported BMI, which has also been found previously (Papies, Stroebe, & Aarts, 2008; van Koningsbruggen et al., 2011). Moreover, we excluded participants who indicated that at least one question of the PSRS was not applicable, i.e. participants who were not concerned with their weight or did not try to stay in shape. This procedure resulted in an increase in reliability and therefore improved the quality of the scale. Finally, our study was cross-sectional. Longitudinal studies investigating the predictive value of dietary control strategies and food cravings on dieting success are warranted.

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References

Abilés, V., Rodríguez-Ruiz, S., Abilés, J., Mellado, C., García, A., Pérez de la Cruz, A., et al. (2010). Psychological characteristics of morbidly obese candidates for bariatric surgery. *Obesity Surgery, 20*, 161–167.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*, 1173–1182.

Burgmer, R., Grigutsch, K., Zipfel, S., Wolf, A. M., de Zwaan, M., Husemann, B., et al. (2005). The influence of eating behavior and eating pathology on weight loss after gastric restriction operations. *Obesity Surgery, 15*, 684–691.

Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behavior Therapy, 31*, 151–173.

Dinkel, A., Berth, H., Exner, C., Rief, W., & Balck, F. (2005). German version of the Restraint Scale for the assessment of restrained eating. *Diagnostica, 51*, 67–74.

Downe, K. A., Goldfein, J. A., & Devlin, M. J. (2009). Restraint, hunger, and disinhibition following treatment for binge-eating disorder. *International Journal of Eating Disorders, 42*, 498–504.

Fishbach, A., Friedman, R. S., & Kruglanski, A. W. (2003). Leading us not unto temptation: Momentary allurements elicit overriding goal activation. *Journal of Personality and Social Psychology, 84*, 296–309.

Franken, I. H. A., & Muris, P. (2005). Individual differences in reward sensitivity are related to food craving and relative body weight in healthy women. *Appetite, 45*, 198–201.

Gendall, K. A., Sullivan, P. F., Joyce, P. R., Fear, J. L., & Bulik, C. M. (1997). Psychopathology and personality of young women who experience food cravings. *Addictive Behaviors, 22*, 545–555.

Hill, A. J. (2007). The psychology of food craving. *Proceedings of the Nutrition Society, 66*, 277–285.

McGuire, M. T., Jeffery, R. W., French, S. A., & Hannan, P. J. (2001). The relationship between restraint and weight and weight-related behaviors among individuals in a community weight gain prevention trial. *International Journal of Obesity, 25*, 574–580.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (in revision). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters: Validation of the Food Cravings Questionnaires in German.

Moreno, S., Warren, C. S., Rodríguez, S., Fernández, M. C., & Cepeda-Benito, A. (2009). Food cravings discriminate between anorexia and bulimia nervosa. Implications for "success" versus "failure" in dietary restriction. *Appetite, 52*, 588–594.

Papies, E. K., Stroebe, W., & Aarts, H. (2008). Healthy cognition: Processes of self-regulatory success in restrained eating. *Personality and Social Psychology Bulletin, 34*, 1290–1300.

Pelchat, M. L., & Schaefer, S. (2000). Dietary monotony and food cravings in young and elderly adults. *Physiology & Behavior, 68*, 353–359.

Stunkard, A. J., & Messick, S. (1985). The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *Journal of Psychosomatic Research, 29*, 71–83.

Teixeira, P. J., Silva, M. N., Coutinho, S. R., Palmeira, A. L., Mata, J., Vieira, P. N., et al. (2010). Mediators of weight loss and weight loss maintenance in middle-aged women. *Obesity, 18*, 725–735.

Timko, C. A., Oelrich, C., & Lowe, M. R. (2007). Prospective relationship of rigid and flexible control and weight loss. *Verhaltenstherapie, 17*, 84–89.

Timko, C. A., & Perone, J. (2005). Rigid and flexible control of eating behavior in a college population. *Eating Behaviors, 6*, 119–125.

van Koningsbruggen, G. M., Stroebe, W., & Aarts, H. (2011). Through the eyes of dieters: Biased size perception of food following tempting food primes. *Journal of Experimental Social Psychology, 47*, 293–299.

Weingarten, H. P., & Elston, D. (1990). The phenomenology of food cravings. *Appetite, 15*, 231–246.

Westenhoefer, J. (1991). Dietary restraint and disinhibition: Is restraint a homogeneous construct? *Appetite, 16*, 45–55.

Westenhoefer, J., Stunkard, A. J., & Pudel, V. (1999). Validation of the flexible and rigid control dimensions of dietary restraint. *International Journal of Eating Disorders, 26*, 53–64.

Westenhoefer, J., von Falck, B., Stellfeldt, A., & Fintelmann, S. (2004). Behavioural correlates of successful weight reduction over 3y. Results from the Lean Habits Study. *International Journal of Obesity, 28*, 334–335.

2.3 Meule, A., Skirde, A.K., Freund, R., Vögele, C., & Kübler, A. (2012). High-calorie food-cues impair working memory performance in high and low food cravers. *Appetite*, *59*, 264-269.

Abstract: The experience of food craving can lead to cognitive impairments. Experimentally induced chocolate craving exhausts cognitive resources and, therefore, impacts working memory, particularly in trait chocolate cravers. In the current study, we investigated the effects of exposure to food-cues on working memory task performance in a group with frequent and intense (high cravers, n = 28) and less pronounced food cravings (low cravers, n = 28). Participants performed an n-back task that contained either pictures of high-calorie sweets, high-calorie savory foods, or neutral objects. Current subjective food craving was assessed before and after the task. All participants showed slower reaction times and made more omission errors in response to food-cues, particularly savory foods. There were no differences in task performance between groups. State cravings did not differ between groups before the task, but increased more in high cravers compared to low cravers during the task. Results support findings about food cravings impairing visuo-spatial working memory performance independent of trait cravings. They further show that this influence is not restricted to chocolate, but also applies to high-calorie savory foods. Limiting working memory capacity may be especially crucial in persons who are more prone to high-calorie food-cues and experience such cravings habitually.

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Research report

High-calorie food-cues impair working memory performance in high and low food cravers

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ABSTRACT

The experience of food craving can lead to cognitive impairments. Experimentally induced chocolate craving exhausts cognitive resources and, therefore, impacts working memory, particularly in trait chocolate cravers. In the current study, we investigated the effects of exposure to food-cues on working memory task performance in a group with frequent and intense (high cravers, $n = 28$) and less pronounced food cravings (low cravers, $n = 28$). Participants performed an *n*-back task that contained either pictures of high-calorie sweets, high-calorie savory foods, or neutral objects. Current subjective food craving was assessed before and after the task. All participants showed slower reaction times and made more omission errors in response to food-cues, particularly savory foods. There were no differences in task performance between groups. State cravings did not differ between groups before the task, but increased more in high cravers compared to low cravers during the task. Results support findings about food cravings impairing visuo-spatial working memory performance independent of trait cravings. They further show that this influence is not restricted to chocolate, but also applies to high-calorie savory foods. Limiting working memory capacity may be especially crucial in persons who are more prone to high-calorie food-cues and experience such cravings habitually.

Introduction

Craving refers to an urgent desire, longing, or yearning for a particular substance, which includes alcohol, tobacco, addictive drugs, and food (Hormes & Rozin, 2010). Food cravings most often involve an intense desire to eat chocolate (Weingarten & Elston, 1991). It is this intensity and specificity that distinguishes food cravings from ordinary feelings of hunger (Hill, 2007). In both substance use and eating behavior, cravings have been associated with excessive consumption of the craved substance or food, and non-compliance to long-term goals. Drug cravings are associated with relapse in substance abuse (e.g. Allen, Bade, Hatsukami, & Center, 2008) as food cravings are associated with binge eating (Gendall, Sullivan, Joyce, Fear, & Bulik, 1997; Meule, Lutz, Vögele, & Kübler, 2012) or unsuccessful dieting (Meule, Westenhöfer, & Kübler, 2011).

The experience of craving has been found to affect cognitive performance. In simple reaction time tasks, smokers and alcohol-dependent patients displayed a slowing of reactions when craving was induced by either cue-exposure or mental imagery (Baxter & Hinson, 2001; Cepeda-Benito & Tiffany, 1996; Sayette & Hufford, 1994; Sayette et al., 1994). In Tiffany's (1990) cognitive model of drug urges, attempts to inhibit automatic drug use schemata require non-automatic processing during the experience of craving. This limits available cognitive resources, which negatively affects performance in tasks that require non-automatic processing, such as reaction time tasks.

These findings in substance use have been extended to food cravings. Using different types of cognitive tasks, chronic dieters have been found to slow down reactions after exposure to craving inducing mental imagery (Green, Rogers, & Elliman, 2000) or after consuming a preload (Meule, Lukito, Vögele, & Kübler, 2011). Similarly, trait chocolate cravers exhibited increased reaction times (Kemps, Tiggemann, & Grigg, 2008) or a slower detection of neutral targets among food-related distractors after exposure to cues eliciting chocolate craving (Smeets, Roefs, & Jansen, 2009). It has been further argued that the experience of chocolate craving in trait chocolate cravers leads to distraction by, rather than speeded detection of craving-related cues (i.e. chocolate; Smeets et al., 2009).

Craving leads not only to slowed reactions and distraction, it also affects working memory performance. For instance, smokers performed worse in a working memory task when trials were preceded by smoking-cues (Wilson, Sayette, Fiez, & Brough, 2007). Accordingly, inducing food craving lead to impaired working memory performance in trait chocolate cravers (Kemps et al., 2008) or

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in female students without any moderating role of trait chocolate craving (Tiggemann, Kemps, & Parnell, 2010). Vice versa, concurrent visuo-spatial information processing or mental imagery tasks reduced food cravings (see Kemps & Tiggemann, 2010 for a review), which highlights the role of the visual modality in the experience of craving (Tiggemann & Kemps, 2005). Thus, it has been argued that food cravings selectively impact visuo-spatial aspects of working memory (visuo-spatial sketchpad; Baddeley & Hitch, 1974) which could be confirmed recently (Tiggemann et al., 2010).

While existing studies on food cravings and working memory performance have tended to use imagery to induce craving followed by neutral working memory tasks, there is a plethora of cognitive tasks involving food stimuli that impact performance in people with disordered eating behavior (see Brooks, Prince, Stahl, Campbell, & Treasure, 2011 for a review). One of these measures is the *n-back paradigm* where participants are required to monitor a series of stimuli and to respond when a stimulus matches the one presented *n* trials previously (usually 1-, 2-, or 3-back; cf. Owen, McMillan, Laird, & Bullmore, 2005). This task requires monitoring, updating, and manipulation of information within working memory. To date, there is only one study that used an *n*-back task involving food stimuli (Dickson et al., 2008). In this study, pictorial neutral, aversive and food stimuli presented either subliminally or supraliminally preceded letters in a 1-back or 2-back condition. Although they found differential task performance between anorectic patients and controls, food stimuli did not affect task performance.

Several issues, therefore, remain unresolved in the literature. Firstly, evidence for the influence of food craving on working memory performance is restricted to chocolate craving. Little is known about other food groups that have also been shown to be craved (Hill, 2007). Secondly, the only study that used food stimuli other than chocolate did not find an effect on working memory performance (Dickson et al., 2008). This could be due to methodological reasons because food-cues only preceded targets. Instead, food-cues may have a stronger influence and, therefore, higher external validity, if they directly require a response. Thirdly, no study has investigated the influence of general food craving on working memory performance as a function of both state and trait cravings.

In the current study, we addressed these issues by using an *n*-back (2-back) task that involved pictorial food stimuli as targets and distractors. In addition and rather than restricting stimuli to chocolate, we presented separated blocks containing either pictures of savory foods, sweet foods, or neutral objects. Moreover, groups of either trait food cravers or low cravers were tested and momentary craving was assessed before and after the task. We expected food stimuli to elicit craving which in turn should lead to a decrement in task performance, i.e. prolonged reaction times and more omission and commission errors. Furthermore, we hypothesized that these effects should be particularly pronounced in trait food cravers. Therefore, the current study extends the existing literature by (1) using a newly developed variant of the *n*-back task that (2) not only involved chocolate cues, but also other sweet and savory foods, and (3) investigating effects in both trait high and low cravers with respect to general food cravings instead of specifically chocolate craving.

Methods

The reported data were part of a study investigating the effectiveness of a biofeedback training to reduce food cravings, the results of which are reported elsewhere (Meule, Freund, Skirde, Vögele, & Kübler, in press). The current data were collected at baseline, i.e. before any intervention.

Participants

An online screening was conducted to recruit high and low food cravers. A link of the screening homepage was distributed via a students' mailing list and an advertisement on a local website. The screening homepage included the subscale *lack of control over eating* of the *Food Cravings Questionnaires – Trait* (FCQ-T-LOC). This subscale represents a major feature of food cravings and was chosen to keep the screening succinct. As an incentive for participation, 3 × 10,- Euro were raffled among participants who completed the entire set of questions ($N = 603$).

FCQ-T-LOC scores ranged between the minimum and maximum possible values ($M = 16.67$, $SD = 5.90$, Range: 6–36). The majority of respondents had a body mass index (BMI) within the normal range ($M = 22.55$, $SD = 3.83$, Range: 14.15–48.19) and were in young adulthood ($M = 23.99$, $SD = 5.54$, Range: 16–62). Participants who indicated that they were interested in participating in a further study and whose FCQ-T-LOC scores were in the upper and lower third of the distribution from the initial screening were contacted by e-mail. Volunteers were only included if they had a BMI between 20 and 30 kg/m^2, and an age between 18 and 40 years, to ensure a homogenous sample without outlying body mass or age. Of all individuals who were contacted, $n = 56$ (high cravers: $n = 28$, four males; low cravers: $n = 28$, five males) met these criteria and agreed to take part in the study. Participants had a mean age of $M = 24.12$ years ($SD = 3.79$) and a mean BMI of $M = 22.65$ kg/m^2 ($SD = 3.19$). The majority of participants were students ($n = 40$).

Materials

Questionnaires

Habitual food cravings were assessed using the trait version of the Food Cravings Questionnaires (FCQ-T; Cepeda-Benito, Gleaves, Williams, & Erath, 2000; Meule et al., 2012). This 39-item instrument asks participants to indicate on a 6-point Likert scale how frequently they experience food cravings (ranging from *never* to *always*). The FCQ-T consists of 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. Subscales are highly inter-correlated and internal consistency of the total FCQ-T is $\alpha > 0.90$ (Cepeda-Benito et al., 2000; Meule et al., 2012). In the current study, we only used total FCQ-T scores in our analyses for the sake of brevity and clarity.

Current food cravings were assessed with the state version of the Food Cravings Questionnaires (FCQ-S; Cepeda-Benito et al., 2000; Meule et al., 2012). This 15-item questionnaire assesses momentary food cravings on the dimensions (1) intense desire to eat, (2) anticipation of positive reinforcement, (3) relief from negative states, (4) lack of control over eating, and (5) hunger. Subscales are highly inter-correlated and internal consistency of the total FCQ-S is $\alpha > 0.90$ (Cepeda-Benito et al., 2000; Meule et al., 2012).

Eating disorder and food addiction symptomatology was assessed with the Eating Disorder Examination – Questionnaire (EDE-Q; Fairburn & Beglin, 1994; Hilbert & Tuschen-Caffier, 2006) and the Yale Food Addiction Scale (YFAS; Gearhardt, Corbin, & Brownell, 2009; Meule, Vögele, & Kübler, in press). The YFAS is a 25-item instrument which contains different scoring options (dichotomous and frequency scoring) to indicate experience of addictive eating behavior. A food addiction symptom count can be calculated which ranges between zero and seven symptoms, according to the diagnostic criteria for substance dependence (Gearhardt et al., 2009). Internal consistency of the YFAS is

$\alpha > 0.80$ (Gearhardt et al., 2009; Meule, Vögele, et al., in press). The EDE-Q is a 28-item instrument which asks about eating disorder symptomatology during the past 28 days. Of these, 22 items assess *restraint*, *eating concern*, *weight concern*, and *shape concern* on a 7-point scale (ranging from *never* to *every day*). Subscales have an internal consistency of $\alpha = 0.85–0.93$ (Hilbert, Tuschen-Caffier, Karwautz, Niederhofer, & Munsch, 2007). The remaining six questions assess diagnostically relevant behaviors, e.g. days with binges.

Stimuli

Stimuli were selected from a set of pictures previously used (Blechert, Feige, Hajcak, & Tuschen-Caffier, 2010; Blechert, Feige, Joos, Zeeck, & Tuschen-Caffier, 2011; Meule, Lukito, et al., 2011). All pictures were edited to be homogeneous with respect to background color. In a pilot study, pictures of high-calorie savory foods, high-calorie sweets, and common household items (30 pictures each) were rated on a 5-point scale by 20 individuals with respect to brightness, recognizability, complexity, and pleasantness. For every category, 10 pictures were selected (savory foods: *pasta bake, sandwich, cheese, tortilla chips, curry sausage, fries, cheeseburger, lasagna, spaghetti, pizza*; sweets: *chocolate, waffle, cookies, crêpes, croissants, doughnut, cream gateau, strawberry pie, chocolate gateau, muffins*; neutral objects: *umbrella, shoe, piggybank, beanbags, metal can, paperclips, stapler, thumbtacks, pencil case, phone*). Those did not differ in brightness, recognizability, and complexity, but in pleasantness ($F_{(2,38)} = 16.29$, $p < 0.001$). Post-hoc t-tests showed that pictures of sweet ($M = 2.14$, $SD = 0.75$) and savory foods ($M = 2.22$, $SD = 0.58$) were equally pleasant ($t_{(19)} = -0.65$, *ns*) whereas both categories were rated as more pleasant then neutral pictures ($M = 3.01$, $SD = .67$, both p's $\leqslant 0.001$).

n-back task

An n-back task including pictures as targets and distractors was used in this study (Fig. 1). The program was compiled using E-prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA) and displayed on a LCD TFT 22″ screen. Subjects were required to press a button on a response box for every target that matched the picture two trials before (2-back task). The task was separated into three counterbalanced blocks (savory foods, sweets, or neutral objects). Each block consisted of 80 trials including 20 targets. Each picture was presented for 1500 ms or until a response was made. Inter-trial interval was 1000 ms. A practice block with numbers instead of pictures was presented prior to the experimental blocks. The whole task lasted for approximately 15 min.

Procedure

Participants were tested between 10:00 a.m. and 18:00 p.m. (median of testing time was 14:00 p.m.) and were asked to refrain from eating, smoking and caffeinated drinks at least one hour before the experiment. After providing instructions and signing informed consent, a 15 min baseline heart rate recording was conducted. The physiological data were assessed in order to evaluate the biofeedback procedure and are reported elsewhere (Meule, Freund, et al., in press). Next, participants filled out the FCQ-S and then performed the n-back task. Immediately after the task, participants filled out the FCQ-S again. Afterwards, participants completed the rest of the questionnaires and participants' weight and height was measured.

Data analysis

T-tests for independent samples were calculated to compare groups for age, BMI, hours since the last meal, trait food cravings, and food addiction and eating disorder symptomatology. A 2 (group) ×2 (time) ANOVA for repeated measures was calculated to evaluate state cravings with group (high vs. low cravers) as between-subject factor and time (before vs. after the task) as within-subject factor. Significant interactions were followed up with t-tests. In the n-back task, trials with a reaction time below 150 ms, reflecting anticipation, were excluded from analyses. Reaction times, omission errors, and commission errors were used as indexes of task performance. A 2 (group) ×3 (picture type) ANOVA for repeated measures was calculated for each of the dependent variables with group (high vs. low cravers) as between-subject factor and picture type (sweet vs. savory vs. neutral) as within-subject factor. Finally, we explored associations between task performance and change in craving with linear regression analyses. For this purpose, we calculated change scores (craving after the task minus craving before the task) for each FCQ-S subscale and used those as dependent variables. Regression analyses were calculated for each measure of interest (i.e. reaction times, omission errors, commission errors) separately.

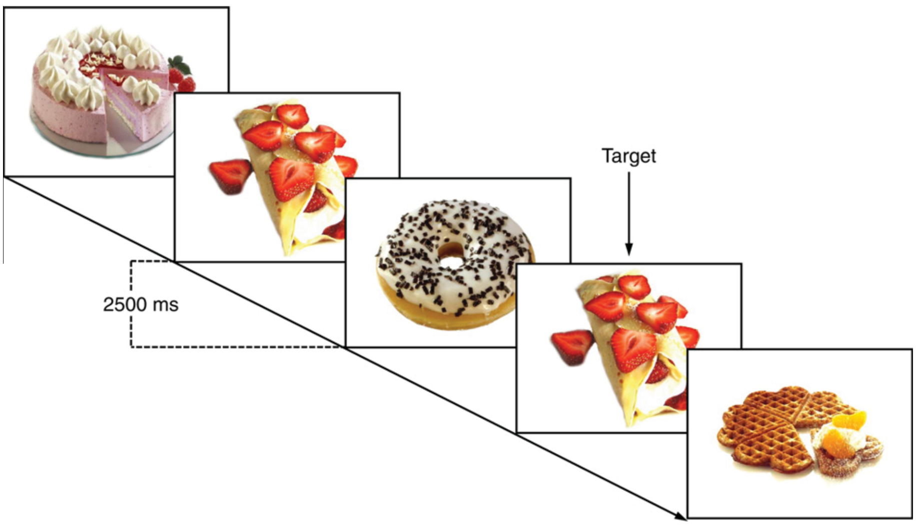

Fig. 1. n-back task with representative screen displays from a block with pictures of sweet foods. Participants had to press a button when a picture matched the one which was presented two trials before. Pictures were presented for 1500 ms or until a response was made. A blank screen was presented during the inter-trial interval for 1000 ms.

Results

Participant characteristics

Groups did not differ in age, BMI, or hours since their last meal (Table 1). As expected, high cravers had higher FCQ-T scores than low cravers (Table 1). High cravers also reported higher eating-related psychopathology as indicated by the YFAS and EDE-Q compared to low cravers (Table 1).

State cravings

There were significant main effects for group ($F_{(1,54)} = 5.61$, $p < 0.05$, $\eta^2_p = 0.09$) and time ($F_{(1,54)} = 45.63$, $p < 0.001$, $\eta^2_p = 0.46$), indicating higher state cravings in high cravers compared to low cravers and after the task compared to before. In addition, the interaction group × time was also significant ($F_{(1,54)} = 8.46$, $p < 0.01$, $\eta^2_p = 0.14$), suggesting differential responses between groups. Post-hoc *t*-tests revealed that state cravings increased in both low cravers ($t_{(27)} = -2.71$, $p < 0.05$) and high cravers ($t_{(27)} = -6.86$, $p < 0.001$). While groups did not differ before the task ($t_{(54)} = 1.65$, *ns*), high cravers ($M = 42.54$, $SD = 12.23$) reported stronger state cravings after the task compared to low cravers ($M = 33.36$, $SD = 11.15$, $t_{(54)} = 2.94$, $p < 0.01$; Fig. 2). Comparing changes in FCQ-S-subscales between groups revealed that high cravers showed a steeper increase in FCQ-S-total scores ($t_{(54)} = 2.91$, $p < 0.01$), intense desire to eat ($t_{(54)} = 1.99$, $p = 0.05$), anticipation of positive reinforcement ($t_{(54)} = 2.16$, $p < 0.05$), and lack of control over eating ($t_{(54)} = 2.80$, $p < 0.01$), but not in relief from negative states ($t_{(54)} = 0.86$, *ns*) or hunger ($t_{(54)} = 1.84$, *ns*) as compared to low cravers. Using BMI and gender as covariates did not change interpretation of results.

Task performance

Reaction times

There was a significant main effect for picture type ($F_{(2,108)} = 7.21$, $p < 0.01$, $\eta^2_p = 0.12$). Post-hoc *t*-tests indicated that participants reacted slower in response to savory foods ($M = 719.41$ ms, $SD = 120.05$) compared to sweet foods ($M = 685.29$ ms, $SD = 120.89$, $t_{(55)} = 2.37$, $p < 0.05$) and neutral objects ($M = 670.22$ ms, $SD = 124.67$, $t_{(55)} = 4.11$, $p < 0.001$). Reaction times in response to sweet foods did not differ compared to neutral objects ($t_{(55)} = 1.15$, *ns*, Fig. 3a). There was no main effect for group ($F_{(1,54)} = 1.97$, *ns*) and no interaction group × picture type ($F_{(2,108)} = 0.32$, *ns*). Using BMI and gender as covariates did not change interpretation of results.

Omission errors

There was a significant main effect for picture type ($F_{(2,108)} = 4.33$, $p < 0.05$, $\eta^2_p = 0.07$). Post-hoc *t*-tests indicated that participants made more omission errors in response to savory foods ($M = 4.84$, $SD = 2.83$) compared to neutral objects ($M = 3.86$, $SD = 2.55$, $t_{(55)} = 2.85$, $p < 0.01$). Omission errors in response to sweet foods did not differ compared to savory foods ($t_{(55)} = 1.49$, *ns*) or neutral objects ($t_{(55)} = 1.49$, *ns*, Fig. 3b). There was no main effect for group ($F_{(1,54)} = 1.77$, *ns*) and no interaction group × picture type ($F_{(2,108)} = 1.46$, *ns*). Using BMI and gender as covariates did not change interpretation of results.

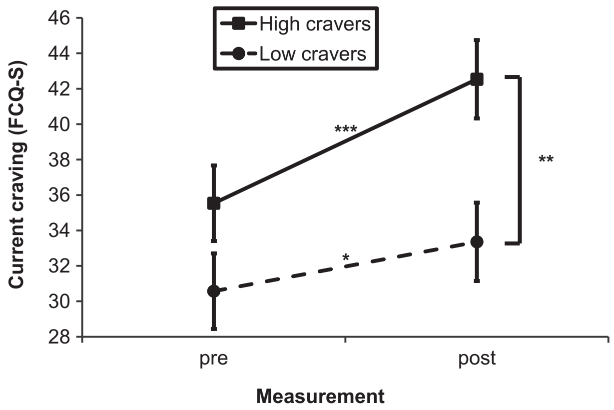

Fig. 2. Mean current food cravings as a function of group (high vs. low cravers) and time (before vs. after the task). FCQ-S = Food Cravings Questionnaires – State Version. Error bars represent the standard error of the mean. Asterisks indicate a *p*-value <0.05*, <0.01**, and <0.001***.

Commission errors

There was neither a main effect for group ($F_{(1,54)} = 1.00$, *ns*) nor a main effect for picture type ($F_{(2,108)} = 0.33$, *ns*) and no interaction group × picture type ($F_{(2,108)} = 1.55$, *ns*). Using BMI and gender as covariates did not change interpretation of results.

Relation between changes in craving and task performance

Reaction times

Neither reaction time predicted any of the change scores (all *t*'s <1.78).

Omission errors

Neither omission errors predicted any of the change scores, except for omission errors in response to savory food-cues which predicted increases in relief craving ($\beta = 0.38$, $t = 2.07$, $p < 0.05$).

Commission errors

Neither commission errors predicted any of the change scores (all *t*'s <1.56).

Table 1
Participant characteristics.

	Low cravers ($n = 28$) *M* (*SD*)	High cravers ($n = 28$) *M* (*SD*)	*t*	*p*
Age (in years)	24.46 (3.69)	23.79 (3.93)	0.67	*ns*
BMI (in kg/m^2)	22.41 (3.34)	22.90 (3.07)	−0.58	*ns*
Last meal (in hours)	5.84 (4.81)	4.10 (2.53)	1.70	*ns*
Food Cravings Questionnaire – Trait	83.11 (19.23)	131.43 (23.38)	−8.45	<0.001
Yale Food Addiction Scale (symptom count)	1.11 (0.50)	2.54 (1.35)	−5.27	<0.001
Eating Disorder Examination – Questionnaire				
Restraint	0.57 (0.77)	1.57 (1.37)	−3.36	<0.01
Eating concern	0.12 (0.16)	1.13 (1.06)	−4.99	<0.001
Weight concern	0.66 (0.79)	2.16 (1.64)	−4.37	<0.001
Shape concern	1.17 (1.00)	2.47 (1.77)	−3.39	<0.01
Days with binges	0.18 (0.48)	4.36 (8.76)	−2.52	<0.05

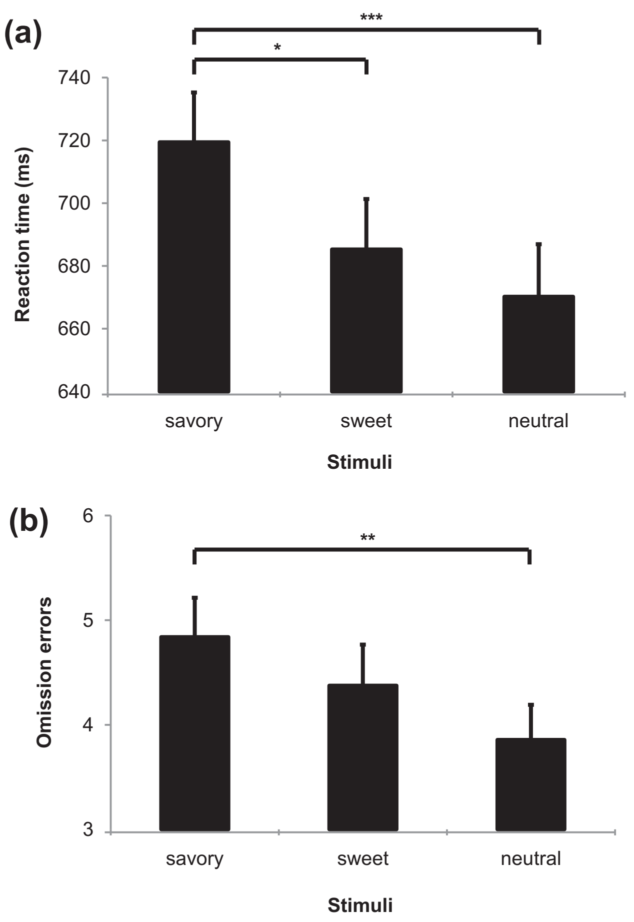

Fig. 3. Mean reaction times (a) and omission errors (b) in the *n*-back task as a function of picture type. Regardless of group, reaction time is slowest and error rate highest in trials with savory food pictures. Error bars represent the standard error of the mean. Asterisks indicate a p-value $<0.05^{*}$, $<0.01^{**}$, and $<0.001^{***}$.

Discussion

In the current study, we found that a working memory task involving high-calorie food-cues lead to slower reactions and more omission errors compared to blocks involving pictures of neutral objects. These differences were particularly pronounced for pictures of savory foods. All participants reported more intense food cravings after the task and this increase was significantly more pronounced in participants that frequently and intensely experience food cravings.

As our task required processing of pictorial stimuli in combination with performing a motor response, the current results support findings about food cravings interfering with visuo-spatial working memory task performance (Tiggemann et al., 2010). In contrast to previous studies, we used a novel paradigm where the direct influence of food stimuli on omission errors was measured as opposed to, for example, recalled digit span of neutral stimuli. The observed slowing of reactions is in line with previous findings when craving was experienced or after participants were exposed to foods (Green et al., 2000; Kemps et al., 2008; Meule, Lukito et al., 2011; Smeets et al., 2009). However, changes in craving were not correlated with reaction times in the current study. Instead, increased omission errors predicted increases in relief craving. Hence, it is possible that relief craving in particular is related to decreases in working memory performance but slowing of reaction times may be the result of mere exposure to food-cues without mediating effects of craving. It should also be noted, however, that relief craving was only one of several subscales of the FCQ-S and associations with this specific subscale might therefore be due to type I error. Nonetheless, the present results extend the current literature in that we included savory food-cues, instead of restricting cues to chocolate, as is usually the case in food craving research (e.g. Kemps & Tiggemann, 2009; Rodríguez, Fernández, Cepeda-Benito, & Vila, 2005). It is important to note that savory food-cues resulted in greater effects compared to sweets in our study. Although reaction times and omission errors in response to sweet foods were higher compared to neutral cues, these differences were not significant.

Although we did not find differences in task performance between high and low food cravers, performing the task induced stronger cravings in high cravers which substantiates that this group is particularly susceptible to experiencing food cravings that can be induced by food-cues in the environment. While Kemps and colleagues (2008) found effects of experimentally induced craving on reaction times and working memory performance only in trait chocolate cravers, they did not find an effect of trait chocolate craving when the task was restricted to visuo-spatial working memory demands (Tiggemann et al., 2010). They interpreted their findings such that most people in western cultures may have acquisition and consumption schemata related to chocolate. Accordingly, this could also apply to savory foods as food-cues like pizza or French fries are omnipresent in our environment. In persons habitually experiencing food cravings, such exposure to food-cues could even more easily elicit craving. This food-cue elicited craving could potentially affect everyday executive functions by consuming cognitive resources, e.g. driving performance in heavy traffic when food advertisements are present.

The current study has several limitations. First, food cravings where only measured subjectively. Additional parameters as e.g. skin conductance, salivary secretion and other cephalic phase responses could contribute to the validity of craving assessment. Second, we measured current food cravings only before and after the task. Therefore, specific changes after each experimental block cannot be disentangled. Third, we found an increase in subjective craving after the task, which was even more pronounced in high food cravers. It cannot be inferred if these increases were due to plain food-cue exposure or if the additional cognitive load during the task contributed to craving developing even stronger. Future studies could investigate if our paradigm triggers stronger craving when compared to similar picture presentation without using a working memory task instruction. Forth, it cannot be inferred from FCQ-S scores which types of foods (i.e. sweets or savory) participants craved after the task and, therefore, if impaired performance in response to savory foods was particularly associated with increased craving for these foods. Finally, we did not find differences in task performance between groups which maybe would have been found if a task with a higher working memory load was used, e.g. a 3-back task.

In conclusion, the paradigm used in the current study successfully induced craving and influenced working memory performance. It contained high-calorie food pictures, which have high external validity because such food-cues are all around us in modern society. Our version of the *n*-back task may be a promising tool that could easily be used in brain imaging studies to further elucidate differences and similarities between food and drug craving and addiction. By using this paradigm, further studies could address if and how the experience of food cravings impact activity of fronto-parietal cortices that have been shown to be activated during *n*-back task performance (Owen et al., 2005). Furthermore, it could be used to investigate the effects of high-calorie food-cues on working memory and the behavioral consequences resulting from this procedure. For instance, even healthy participants who are confronted with food-cues and concomitantly experience a high working memory load might develop craving and experience a loss of control over eating behavior. This process could be further facilitated in persons who are susceptible to experience craving.

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References

Allen, S. S., Bade, T., Hatsukami, D., & Center, B. (2008). Craving, withdrawal, and smoking urges on days immediately prior to smoking relapse. *Nicotine & Tobacco Research, 10*, 35–45.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. H. Bower (Ed.). *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York: Academic press.

Baxter, B. W., & Hinson, R. E. (2001). Is smoking automatic? Demands of smoking behavior on attentional resources. *Journal of Abnormal Psychology, 110*, 59–66.

Blechert, J., Feige, B., Hajcak, G., & Tuschen-Caffier, B. (2010). To eat or not to eat? Availability of food modulates the electrocortical response to food pictures in restrained eaters. *Appetite, 54*, 262–268.

Blechert, J., Feige, B., Joos, A., Zeeck, A., & Tuschen-Caffier, B. (2011). Electrocortical processing of food and emotional pictures in anorexia nervosa and bulimia nervosa. *Psychosomatic Medicine, 73*, 415–421.

Brooks, S., Prince, A., Stahl, D., Campbell, I. C., & Treasure, J. (2011). A systematic review and meta-analysis of cognitive bias to food stimuli in people with disordered eating behaviour. *Clinical Psychology Review, 31*, 37–51.

Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behavior Therapy, 31*, 151–173.

Cepeda-Benito, A., & Tiffany, S. T. (1996). The use of a dual-task procedure for the assessment of cognitive effort associated with cigarette craving. *Psychopharmacology, 127*, 155–163.

Dickson, H., Brooks, S., Uher, R., Tchanturia, K., Treasure, J., & Campbell, I. C. (2008). The inability to ignore: Distractibility in women with restricting anorexia nervosa. *Psychological Medicine, 38*, 1741–1748.

Fairburn, C. G., & Beglin, S. J. (1994). Assessment of eating disorders: interview or self-report questionnaire? *International Journal of Eating Disorders, 16*, 363–370.

Gearhardt, A. N., Corbin, W. R., & Brownell, K. D. (2009). Preliminary validation of the Yale Food Addiction Scale. *Appetite, 52*, 430–436.

Gendall, K. A., Sullivan, P. F., Joyce, P. R., Fear, J. L., & Bulik, C. M. (1997). Psychopathology and personality of young women who experience food cravings. *Addictive Behaviors, 22*, 545–555.

Green, M. W., Rogers, P. J., & Elliman, N. A. (2000). Dietary restraint and addictive behaviors: the generalizability of Tiffany's Cue Reactivity Model. *International Journal of Eating Disorders, 27*, 419–427.

Hilbert, A., & Tuschen-Caffier, B. (2006). *Eating disorder examination – questionnaire: Deutschsprachige Übersetzung*. Münster: Verlag für Psychotherapie.

Hilbert, A., Tuschen-Caffier, B., Karwautz, A., Niederhofer, H., & Munsch, S. (2007). Eating disorder examination-questionnaire: psychometric properties of the German version. *Diagnostica, 53*, 144–154.

Hill, A. J. (2007). The psychology of food craving. *Proceedings of the Nutrition Society, 66*, 277–285.

Hormes, J. M., & Rozin, P. (2010). Does "craving" carve nature at the joints? Absence of a synonym for craving in many languages. *Addictive Behaviors, 35*, 459–463.

Kemps, E., & Tiggemann, M. (2009). Attentional bias for craving-related (chocolate) food cues. *Experimental and Clinical Psychopharmacology, 17*, 425–433.

Kemps, E., & Tiggemann, M. (2010). A cognitive experimental approach to understanding and reducing food cravings. *Current Directions in Psychological Science, 19*, 86–90.

Kemps, E., Tiggemann, M., & Grigg, M. (2008). Food cravings consume limited cognitive resources. *Journal of Experimental Psychology-Applied, 14*, 247–254.

Meule, A., Freund, R., Skirde, A. K., Vögele, C., & Kübler, A. (in press). Heart rate variability biofeedback reduces food cravings in high food cravers. *Applied Psychophysiology and Biofeedback*.

Meule, A., Lukito, S., Vögele, C., & Kübler, A. (2011). Enhanced behavioral inhibition in restrained eaters. *Eating Behaviors, 12*, 152–155.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters. Validation of the Food Cravings Questionnaires in German. *Appetite, 58*, 88–97.

Meule, A., Vögele, C., & Kübler, A. (in press). [German translation and validation of the Yale Food Addiction Scale]. *Diagnostica.*

Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite, 57*, 582–584.

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: a meta-analysis of normative functional neuroimaging. *Human Brain Mapping, 25*, 46–59.

Rodríguez, S., Fernández, M. C., Cepeda-Benito, A., & Vila, J. (2005). Subjective and physiological reactivity to chocolate images in high and low chocolate cravers. *Biological Psychology, 70*, 9–18.

Sayette, M. A., & Hufford, M. R. (1994). Effects of cue exposure and deprivation on cognitive resources in smokers. *Journal of Abnormal Psychology, 103*, 812–818.

Sayette, M. A., Monti, P. M., Rohsenow, D. J., Gulliver, S. B., Colby, S. M., Sirota, A. D., et al. (1994). The effects of cue exposure on reaction-time in male alcoholics. *Journal of Studies on Alcohol, 55*, 629–633.

Smeets, E., Roefs, A., & Jansen, A. (2009). Experimentally induced chocolate craving leads to an attentional bias in increased distraction but not in speeded detection. *Appetite, 53*, 370–375.

Tiffany, S. T. (1990). A cognitive model of drug urges and drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review, 97*, 147–168.

Tiggemann, M., & Kemps, E. (2005). The phenomenology of food cravings: the role of mental imagery. *Appetite, 45*, 305–313.

Tiggemann, M., Kemps, E., & Parnell, J. (2010). The selective impact of chocolate craving on visuospatial working memory. *Appetite, 55*, 44–48.

Weingarten, H. P., & Elston, D. (1991). Food cravings in a college population. *Appetite, 17*, 167–175.

Wilson, S. J., Sayette, M. A., Fiez, J. A., & Brough, E. (2007). Carry-over effects of smoking cue exposure on working memory performance. *Nicotine & Tobacco Research, 9*, 613–619.

2.4 Meule, A. & Kübler, A. (submitted). Double trouble: Trait food craving and impulsivity interactively predict food-cue affected behavioral inhibition.

Abstract: 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 (*non-shift 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 non-planning 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 non-shift 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 HC 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 sensitive, bottom-up mechanisms may determine eating-related disinhibition, ultimately leading to increased food intake.

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

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Highlights

- Women performed a Go/No-go task with high- (HC) and low-calorie food pictures.
- In shift blocks, trait impulsivity and commission errors (CE) were positively correlated.
- In HC blocks, trait food craving and CE were positively correlated.
- In HC shift blocks, trait food craving and impulsivity interactively predicted CE.
- Top-down and bottom-up processes interactively determine food-related (dis)inhibition.

Abstract

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 (*non-shift 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 non-planning 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 non-shift 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 HC 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 sensitive, bottom-up mechanisms may determine eating-related disinhibition, ultimately leading to increased food intake.

Keywords

Behavioral inhibition; inhibitory control; go/no-go; calorie content; food-cues; food craving; impulsivity

Introduction

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, Tomasi, & Baler, 2013; Volkow, Wang, Fowler, Tomasi, & Baler, 2012). 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 overeating and obesity. 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 patients with binge eating behavior report higher reward sensitivity as opposed to patients with restrictive anorexia nervosa and healthy controls, respectively (Beck, Smits, Claes, Vandereycken, & Bijttebier, 2009; Harrison, O'Brien, Lopez, & Treasure, 2010). Higher self-reported reward sensitivity has also been associated with higher body-mass-index (BMI), more frequent experiences of food craving, and emotional and external eating behavior (Davis & Fox, 2008; Davis, Strachan, & Berkson, 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* showed that patients with bulimia nervosa

(BN) or obesity have higher scores on those measures (Abilés et al., 2010; Cappelleri et al., 2009; Schultes, Ernst, Wilms, Thurnheer, & Hallschmid, 2010; Van den Eynde et al., 2012) and that higher scores are associated with measures of overeating such as low dieting success, disinhibited eating, binge eating, emotional and externally-driven eating, and addictive-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, 2012a; Meule, Westenhöfer, & Kübler, 2011; Moreno, Rodríguez, Fernandez, Tamez, & Cepeda-Benito, 2008). In response to food stimuli patients with BN, binge eating disorder (BED), or obesity activate reward-related areas of the brain more than do controls (Frank, Kullmann, & Veit, 2013; Schienle, Schäfer, Hermann, & Vaitl, 2009).

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, patients with BN, BED, or obesity score higher on self-report measures of impulsivity (Guerrieri, Nederkoorn, & Jansen, 2008; Waxman, 2009). Likewise, self-reported impulsivity is also related to other, non-clinical constructs associated with overeating (Meule, 2013). In behavioral measures of impulsivity, patients with BN, BED, or obesity exhibit lower inhibitory control (i.e. more impulsive reactions) as compared to 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 non-clinical 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 (dorso-)lateral prefrontal hypoactivation (Chambers, Garavan, & Bellgrove, 2009), which, in turn, can also be found in relation to overeating and obesity (Batterink, Yokum, & Stice, 2010; Brooks, Cedernaes, & Schioth, 2013; Brooks, Rask-Andersen, Benedict, & Schioth, 2012).

Recent studies suggest that bottom-up and top-down processes are interdependent. Self-regulatory failure, for example overeating, can be the result of strong cue-elicited impulses that overwhelm prefrontal control, impaired prefrontal cortex function, or both (Appelhans, 2009; Heatherton & Wagner, 2011). Indeed, neuroimaging studies show that craving regulation involving food or other substances involve an interplay of prefrontal cortices and subcortical brain areas (Hollmann et al., 2012; Kober et al., 2010; Scharmüller, Übel, Ebner, & Schienle, 2012; Siep 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 and colleagues (2009) found that high automatic affective reactions to high-calorie foods were associated with increased candy consumption only when participants also had low inhibitory control. In another study, one-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 in patients with BN (Mobbs, Van der Linden, d'Acremont, & Perroud, 2008), BED or obesity (Loeber et al., 2012; Mobbs et al., 2011), or non-clinical samples (Houben, Nederkoorn, & Jansen, 2012; Meule, Lukito, et al., 2011; Meule, Lutz, Vögele, & Kübler, 2012b; Meule et al., in revision; Meule, Lutz, Vögele, & Kübler, 2014; Nederkoorn, Van Eijs, & Jansen, 2004). Yet, most of those studies failed to find differential food-cue affected inhibitory control in patients vs. controls or in relation to measures of overeating in non-clinical samples (for an overview see Meule et al., in revision). For example, in the study by Loeber and colleagues (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 and, for most individuals, "the route to obesity is generally a rather modest average daily excess of energy intake over energy expenditure" (Rogers, 2011, p. 1213). Yet, a subset of obese individuals represents a rather 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 (Loeber 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 simple be due to a category size effect (Landauer & Freedman, 1968). Thus, we used pictures of high-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 a response inhibition task including food-cues.

For this purpose, we used an *affective shifting task* (e.g., Mobbs et al., 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 (*non-shift 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 non-shift blocks.

We expected that general 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 sensitive 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 to 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/m² (*SD* = 2.39). 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 = 0.87, Range = 0.00-3.06), indicating that eating disorder psychopathology was low and comparable to other non-clinical samples (Carter, Stewart, & Fairburn, 2001; Hilbert, Tuschen-Caffier, Karwautz, Niederhofer, & Munsch, 2007; Mond, Hay, Rodgers, & Owen, 2006). Ten participants reported to be smokers. 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 α = .96 in the validation study (Meule, Lutz, et al., 2012a) and was α = .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 α = .92 in the validation study (Meule, Lutz, et al., 2012a) and was α = .91 (before the task) and α = .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) non-planning impulsivity. Only the total score was used in the current study. Internal consistency of the German version was α = .81 in the validation study (Meule, Vögele, & Kübler, 2011) and was α = .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 α = .97 in the validation study (Hilbert et al., 2007) and was α = .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 ten 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 per 100 g (*M* = 321.15 kcal/100g [*SD* = 126.43] vs. *M* = 47.25 kcal/100g [*SD* = 40.05], $t_{(18)} = 6.53$, $p < .001$) and in calories displayed per image (*M* = 1769.62 kcal/image [*SD* = 1363.04] vs. *M* = 102.23 kcal/image [*SD* = 128.89], $t_{(18)} = 3.85$, $p < .01$). Picture categories did not differ in palatability, visual complexity (jpg file size, edge detection, subjective ratings), brightness, and contrast (all $ts_{(18)} < 1.84$, *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, & Munafò, 2013; Noël et al., 2007; Noël et al., 2005), and food- or body-related stimuli (Loeber, Grosshans, Herpertz, Kiefer, & Herpertz, 2013; Loeber et al., 2012; Meule et al., in revision; Mobbs et al., 2011; Mobbs et al., 2008). In the current study, we used a modification of this task with pictures of HC and LC foods. The program was compiled using 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 inter-trial 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-HC-LC-LC-HC-HC-LC-LC or LC-LC-HC-HC-LC-LC-HC-HC-LC-LC-HC-HC-LC-LC-HC-HC (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 *non-shift* 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 was 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 ($r = .52$, $p < .001$).

A 2 (*target type*: HC vs. LC) × 2 (*block type*: shift vs. non-shift) 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-non-shift, LC-shift, and LC-non-shift 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 (Tab. 1). Trait food craving was positively correlated with BMI (Tab. 1).

Task performance

Reaction times. A significant main effect for target type ($F_{(1,54)} = 96.24$, $p < .001$, $\eta_p^2 = .64$) indicated that participants reacted slower in response to high-calorie food targets (M = 395.31 ms, $SD = 16.47$) as compared to low-calorie food targets (M = 379.74 ms, SD = 15.02). The main effect for block type ($F_{(1,54)} = 0.71$, *ns*, $\eta_p^2 = .00$) and the interaction target type × block type ($F_{(1,54)} = 0.36$, *ns*, $\eta_p^2 = .01$) were not significant (Fig. 3).

Omission errors. A significant main effect for target type ($F_{(1,54)} = 32.34$, $p < .001$, $\eta_p^2 = .38$) indicated that participants omitted more high-calorie food targets (M = 15.06 errors, SD = 6.75) than low-calorie food targets (M = 10.51 errors, SD = 5.55). A significant main effect for block type ($F_{(1,54)} = 15.80$, $p < .001$, $\eta_p^2 = .23$) indicated that participants omitted more targets in shift blocks (*M* = 14.42 errors, *SD* = 7.03) than in non-shift blocks (*M* = 11.15 errors, *SD* = 5.28). The interaction target type × block type was not significant ($F_{(1,54)}$ = 0.89, *ns*, η_p^2 = .02; Fig. 3).

Commission errors. A significant main effect for block type ($F_{(1,54)}$ = 29.47, $p < .001$, η_p^2 = .35) indicated that participants committed more errors in shift blocks (*M* = 12.26 errors, *SD* = 4.47) than in non-shift blocks (*M* = 8.73 errors, *SD* = 4.22). The main effect for target type ($F_{(1,54)}$ = 2.13, *ns*, η_p^2 = .04) and the interaction target type × block type ($F_{(1,54)}$ = 1.29, *ns*, η_p^2 = .02) were not significant (Fig. 3).

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*s < .25, *ns*). Neither predictor was significantly associated with task performance (all βs < .24, *ns*).

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

Commission errors. Trait impulsivity was positively correlated with number of commission errors in shift blocks (Tab. 2; Fig. 4a). Trait food craving was positively correlated with the total number of commission errors, particularly in HC blocks (Tab. 2; Fig. 4b). Trait food craving positively predicted number of commission errors in HC shift blocks which was further modulated by trait impulsivity (Tab. 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 ($\beta = .12$, *ns*; Fig. 5). No other variable was a significant predictor of commission errors (Tab. 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 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.

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. 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. 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.

Expectedly, participants committed more errors in shift blocks than in non-shift 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 (Loeber et al., 2013; Loeber et al., 2012; Meule et al., in revision; 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).

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 non-shift 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 & Coskunpinar, 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 cravers (Fabbricatore, Imperatori, Contardi, Tamburello, & Innamorati, 2013; Hill, 2007; Martin, McClernon, Chellino, & 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 et al., 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. 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 non-shift 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 non-shift blocks.

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. 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 motor responses have to be inhibited specifically in response to high-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, & Papies, 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.

Footnote

[1]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.

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References

Abilés, V., Rodríguez-Ruiz, S., Abilés, J., Mellado, C., García, A., Pérez de la Cruz, A., & Fernández-Santaella, M. C. (2010). Psychological characteristics of morbidly obese candidates for bariatric surgery. *Obesity Surgery, 20*, 161-167.

Adams, S., Ataya, A. F., Attwood, A. S., & Munafò, M. R. (2013). Effects of alcohol on disinhibition towards alcohol-related cues. *Drug and Alcohol Dependence, 127*, 137-142.

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions*. Thousand Oaks, CA: Sage.

Appelhans, B. M. (2009). Neurobehavioral inhibition of reward-driven feeding: Implications for dieting and obesity. *Obesity*, *17*, 640-647.

Appelhans, B. M., Woolf, K., Pagoto, S. L., Schneider, K. L., Whited, M. C., & Liebman, R. (2011). Inhibiting food reward: Delay discounting, food reward sensitivity, and palatable food intake in overweight and obese women. *Obesity, 19*, 2175-2182.

Batterink, L., Yokum, S., & Stice, E. (2010). Body mass correlates inversely with inhibitory control in response to food among adolescent girls: An fMRI study. *NeuroImage, 52*, 1696-1703.

Beck, I., Smits, D. J. M., Claes, L., Vandereycken, W., & Bijttebier, P. (2009). Psychometric evaluation of the behavioral inhibition/behavioral activation system scales and the sensitivity to punishment and sensitivity to reward questionnaire in a sample of eating disordered patients. *Personality and Individual Differences, 47*, 407-412.

Brooks, S. J., Cedernaes, J., & Schioth, H. B. (2013). Increased prefrontal and parahippocampal activation with reduced dorsolateral prefrontal and insular cortex activation to food images in obesity: A meta-analysis of fMRI studies. *Plos One, 8*(4), e60393.

Brooks, S. J., Rask-Andersen, M., Benedict, C., & Schioth, H. B. (2012). A debate on current eating disorder diagnoses in light of neurobiological findings: is it time for a spectrum model? *BMC Psychiatry, 12*(76), 1-11.

Cappelleri, J. C., Bushmakin, A. G., Gerber, R. A., Leidy, N. K., Sexton, C. C., Karlsson, J., & Lowe, M. R. (2009). Evaluating the Power of Food Scale in obese subjects and a general sample of individuals: development and measurement properties. *International Journal of Obesity, 33*, 913-922.

Carter, J. C., Stewart, D. A., & Fairburn, C. G. (2001). Eating Disorder Examination Questionnaire: Norms for young adolescent girls. *Behaviour Research and Therapy, 39*, 625-632.

Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behavior Therapy, 31*, 151-173.

Chambers, C. D., Garavan, H., & Bellgrove, M. A. (2009). Insights into the neural basis of response inhibition from cognitive and clinical neuroscience. *Neuroscience and Biobehavioral Reviews, 33*, 631-646.

Crowley, N. M., LePage, M. L., Goldman, R. L., O'Neil, P. M., Borckardt, J. J., & Byrne, T. K. (2012). The food craving questionnaire-trait in a bariatric surgery seeking population and ability to predict post-surgery weight loss at six months. *Eating Behaviors, 13*, 366-370.

Cyders, M. A., & Coskunpinar, A. (2011). Measurement of constructs using self-report and behavioral lab tasks: Is there overlap in nomothetic span and construct representation for impulsivity? *Clinical Psychology Review, 31*, 965-982.

Cyders, M. A., & Coskunpinar, A. (2012). The relationship between self-report and lab task conceptualizations of impulsivity. *Journal of Research in Personality, 46*, 121-124.

Dalton, M., Blundell, J., & Finlayson, G. S. (2013). Examination of food reward and energy intake under laboratory and free-living conditions in a trait binge eating subtype of obesity. *Frontiers in Psychology, 4*(757). doi: 10.3389/fpsyg.2013.00757

Davis, C., Curtis, C., Levitan, R. D., Carter, J. C., Kaplan, A. S., & Kennedy, J. L. (2011). Evidence that 'food addiction' is a valid phenotype of obesity. *Appetite, 57*, 711-717.

Davis, C., & Fox, J. (2008). Sensitivity to reward and body mass index (BMI): Evidence for a non-linear relationship. *Appetite, 50*, 43-49.

Davis, C., Strachan, S., & Berkson, M. (2004). Sensitivity to reward: implications for overeating and overweight. *Appetite, 42*, 131-138.

Fabbricatore, M., Imperatori, C., Contardi, A., Tamburello, A., & Innamorati, M. (2013). Food craving is associated with multiple weight loss attempts. *Mediterranean Journal of Nutrition and Metabolism, 6*, 79-83.

Fairburn, C. G., & Beglin, S. J. (1994). Assessment of eating disorders: Interview or self-report questionnaire? *International Journal of Eating Disorders, 16*, 363-370.

Frank, S., Kullmann, S., & Veit, R. (2013). Food related processes in the insular cortex. *Frontiers in Human Neuroscience, 7*(499), 1-6.

Frank, S., Laharnar, N., Kullmann, S., Veit, R., Canova, C., Hegner, Y. L., . . . Preissl, H. (2010). Processing of food pictures: Influence of hunger, gender and calorie content. *Brain Research, 1350*, 159-166.

Franken, I. H. A., & Muris, P. (2005). Individual differences in reward sensitivity are related to food craving and relative body weight in healthy women. *Appetite, 45*, 198-201.

García-García, I., Narberhaus, A., Marqués-Iturria, I., Garolera, M., Rădoi, A., Segura, B., . . . Jurado, M. A. (2013). Neural responses to visual food cues: Insights from functional magnetic resonance imaging. *European Eating Disorders Review, 21*, 89-98.

Guerrieri, R., Nederkoorn, C., & Jansen, A. (2008). The effect of an impulsive personality on overeating and obesity: Current state of affairs. *Psychological Topics, 17*, 265-286.

Harrison, A., O'Brien, N., Lopez, C., & Treasure, J. (2010). Sensitivity to reward and punishment in eating disorders. *Psychiatry Research, 177*, 1-11.

Heatherton, T. F., & Wagner, D. D. (2011). Cognitive neuroscience of self-regulation failure. *Trends in Cognitive Sciences, 15*, 132-139.

Hilbert, A., Tuschen-Caffier, B., Karwautz, A., Niederhofer, H., & Munsch, S. (2007). Eating Disorder Examination-Questionnaire: Evaluation der deutschsprachigen Übersetzung. *Diagnostica, 53*, 144-154.

Hill, A. J. (2007). The psychology of food craving. *Proceedings of the Nutrition Society, 66*, 277-285.

Hofmann, W., Friese, M., & Roefs, A. (2009). Three ways to resist temptation: The independent contributions of executive attention, inhibitory control, and affect regulation to the impulse control of eating behavior. *Journal of Experimental Social Psychology, 45*, 431-435.

Hollmann, M., Hellrung, L., Pleger, B., Schlogl, H., Kabisch, S., Stumvoll, M., . . . Horstmann, A. (2012). Neural correlates of the volitional regulation of the desire for food. *International Journal of Obesity, 36*, 648-655.

Houben, K. (2011). Overcoming the urge to splurge: Influencing eating behavior by manipulating inhibitory control. *Journal of Behavior Therapy and Experimental Psychiatry, 42*, 384-388.

Houben, K., & Jansen, A. (2011). Training inhibitory control. A recipe for resisting sweet temptations. *Appetite, 56*, 345-349.

Houben, K., Nederkoorn, C., & Jansen, A. (2012). Too tempting to resist? Past success at weight control rather than dietary restraint determines exposure-induced disinhibited eating. *Appetite, 59*, 550-555.

Jansen, A., Nederkoorn, C., van Baak, L., Keirse, C., Guerrieri, R., & Havermans, R. (2009). High-restrained eaters only overeat when they are also impulsive. *Behaviour Research and Therapy, 47*, 105-110.

Kenny, P. J. (2011). Reward mechanisms in obesity: new insights and future directions. *Neuron, 69*, 664-679.

Kober, H., Mende-Siedlecki, P., Kross, E. F., Weber, J., Mischel, W., Hart, C. L., & Ochsner, K. N. (2010). Prefrontal-striatal pathway underlies cognitive regulation of craving. *PNAS, 107*, 14811-14816.

Landauer, T. K., & Freedman, J. L. (1968). Information retrieval from long-term memory: Category size and recognition time. *Journal of Verbal Learning and Verbal Behavior, 7*, 291-295.

Lijffijt, M., Bekker, E. M., Quik, E. H., Bakker, J., Kenemans, J. L., & Verbaten, M. N. (2004). Differences between low and high trait impulsivity are not associated with differences in inhibitory motor control. *Journal of Attention Disorders, 8*, 25-32.

Loeber, S., Grosshans, M., Herpertz, S., Kiefer, F., & Herpertz, S. (2013). Hunger modulates behavioral disinhibition and attention allocation to food-associated cues in normal-weight controls. *Appetite, 71*, 32-39.

Loeber, S., Grosshans, M., Korucuoglu, O., Vollmert, C., Vollstädt-Klein, S., Schneider, S., . . . Kiefer, F. (2012). Impairment of inhibitory control in response to food-associated cues and attentional bias of obese participants and normal-weight controls. *International Journal of Obesity, 36*, 1334-1339.

Lowe, M. R., Butryn, M. L., Didie, E. R., Annunziato, R. A., Thomas, J. G., Crerand, C. E., . . . Halford, J. (2009). The Power of Food Scale. A new measure of the psychological influence of the food environment. *Appetite, 53*, 114-118.

Martin, C. K., McClernon, F. J., Chellino, A., & Correa, J. B. (2011). Food cravings: A central construct in food intake behavior, weight loss, and the neurobiology of appetitive behavior. In V. R. Preedy, R. R. Watson & C. R. Martin (Eds.), *Handbook of Behavior, Food and Nutrition* (pp. 741-755). New York: Springer.

Matton, A., Goossens, L., Braet, C., & Vervaet, M. (2013). Punishment and reward sensitivity: Are naturally occurring clusters in these traits related to eating and weight problems in adolescents? *European Eating Disorders Review, 21*, 184-194.

Meule, A. (2013). Impulsivity and overeating: a closer look at the subscales of the Barratt Impulsiveness Scale. *Frontiers in Psychology, 4*(177), 1-4.

Meule, A., & Blechert, J. (2012). food.pics: A picture database for the study of eating and appetite. *Obesity Facts, 5*(Suppl. 2), 20.

Meule, A., & Kübler, A. (2012). Food cravings in food addiction: The distinct role of positive reinforcement. *Eating Behaviors, 13*, 252-255.

Meule, A., Kübler, A., & Blechert, J. (2013). Time course of electrocortical food-cue responses during cognitive regulation of craving. *Frontiers in Psychology, 4*(669), 1-11.

Meule, A., Lukito, S., Vögele, C., & Kübler, A. (2011). Enhanced behavioral inhibition in restrained eaters. *Eating Behaviors, 12*, 152-155.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012a). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters. Validation of the Food Craving Questionnaires in German. *Appetite, 58*, 88-97.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012b). Women with elevated food addiction symptoms show accelerated reactions, but no impaired inhibitory control, in response to pictures of high-calorie food-cues. *Eating Behaviors, 13*, 423-428.

Meule, A., Lutz, A. P. C., Krawietz, V., Stützer, J., Vögele, C., & Kübler, A. (in revision). Food-cue affected motor response inhibition and self-reported dieting success: a pictorial affective shifting task.

Meule, A., Lutz, A. P. C., Vögele, C., & Kübler, A. (2014). Impulsive reactions to food-cues predict subsequent food craving. *Eating Behaviors, 15*, 99-105.

Meule, A., Skirde, A. K., Freund, R., Vögele, C., & Kübler, A. (2012). High-calorie food-cues impair working memory performance in high and low food cravers. *Appetite, 59*, 264-269.

Meule, A., Vögele, C., & Kübler, A. (2011). [Psychometric evaluation of the German Barratt Impulsiveness Scale - Short Version (BIS-15)]. *Diagnostica, 57*, 126-133.

Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite, 57*, 582-584.

Mobbs, O., Iglesias, K., Golay, A., & Van der Linden, M. (2011). Cognitive deficits in obese persons with and without binge eating disorder. Investigation using a mental flexibility task. *Appetite, 57*, 263-271.

Mobbs, O., Van der Linden, M., d'Acremont, M., & Perroud, A. (2008). Cognitive deficits and biases for food and body in bulimia: Investigation using an affective shifting task. *Eating Behaviors, 9*, 455-461.

Mond, J. M., Hay, P. J., Rodgers, B., & Owen, C. (2006). Eating Disorder Examination Questionnaire (EDE-Q): Norms for young adult women. *Behaviour Research and Therapy, 44*, 53-62.

Moreno, S., Rodríguez, S., Fernandez, M. C., Tamez, J., & Cepeda-Benito, A. (2008). Clinical validation of the trait and state versions of the food craving questionnaire. *Assessment, 15*, 375-387.

Murphy, F. C., Sahakian, B. J., Rubinsztein, J. S., Michael, A., Rogers, R. D., Robbins, T. W., & Paykel, E. S. (1999). Emotional bias and inhibitory control processes in mania and depression. *Psychological Medicine, 29*, 1307-1321.

Nederkoorn, C., Houben, K., Hofmann, W., Roefs, A., & Jansen, A. (2010). Control yourself or just eat what you like? Weight gain over a year is predicted by an interactive effect of response inhibition and implicit preference for snack foods. *Health Psychology, 29*, 389-393.

Nederkoorn, C., Smulders, F. T. Y., Havermans, R., Roefs, A., & Jansen, A. (2006). Impulsivity in obese women. *Appetite, 47*, 253-256.

Nederkoorn, C., Smulders, F. T. Y., & Jansen, A. (2000). Cephalic phase responses, craving and food intake in normal subjects. *Appetite, 35*, 45-55.

Nederkoorn, C., Van Eijs, Y., & Jansen, A. (2004). Restrained eaters act on impulse. *Personality and Individual Differences, 37*, 1651-1658.

Noël, X., Van der Linden, M., d'Acremont, M., Bechara, A., Dan, B., Hanak, C., & Verbanck, P. (2007). Alcohol cues increase cognitive impulsivity in individuals with alcoholism. *Psychopharmacology, 192*, 291-298.

Noël, X., Van der Linden, M., d'Acremont, M., Colmant, M., Hanak, C., Pelc, I., . . . Bechara, A. (2005). Cognitive biases toward alcohol-related words and executive deficits in polysubstance abusers with alcoholism. *Addiction, 100*, 1302-1309.

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51*, 768-774.

Reynolds, B., Ortengren, A., Richards, J. B., & de Wit, H. (2006). Dimensions of impulsive behavior: Personality and behavioral measures. *Personality and Individual Differences, 40*, 305-315.

Rodríguez, S., Fernandez, M. C., Cepeda-Benito, A., & Vila, J. (2005). Subjective and physiological reactivity to chocolate images in high and low chocolate cravers. *Biological Psychology, 70*, 9-18.

Rogers, P. J. (2011). Obesity - Is food addiction to blame? *Addiction, 106*, 1213-1214.

Rosval, L., Steiger, H., Bruce, K., Israël, M., Richardson, J., & Aubut, M. (2006). Impulsivity in women with eating disorders: problem of response inhibition, planning, or attention? *International Journal of Eating Disorders, 39,* 590-593.

Scharmüller, W., Übel, S., Ebner, F., & Schienle, A. (2012). Appetite regulation during food cue exposure: A comparison of normal-weight and obese women. *Neuroscience Letters*, *518*, 106-110.

Schienle, A., Schäfer, A., Hermann, A., & Vaitl, D. (2009). Binge-Eating Disorder: Reward sensitivity and brain activation to images of food. *Biological Psychiatry, 65,* 654-661.

Schultes, B., Ernst, B., Wilms, B., Thurnheer, M., & Hallschmid, M. (2010). Hedonic hunger is increased in severely obese patients and is reduced after gastric bypass surgery. *American Journal of Clinical Nutrition, 92*, 277-283.

Siep, N., Roefs, A., Roebroeck, A., Havermans, R., Bonte, M., & Jansen, A. (2012). Fighting food temptations: The modulating effects of short-term cognitive reappraisal, suppression and up-regulation on mesocorticolimbic activity related to appetitive motivation. *NeuroImage*, *60*, 213-220.

Spinella, M. (2007). Normative data and a short form of the Barratt Impulsiveness Scale. *International Journal of Neuroscience, 117*, 359-368.

Toepel, U., Knebel, J. F., Hudry, J., le Coutre, J., & Murray, M. M. (2009). The brain tracks the energetic value in food images. *NeuroImage, 44*, 967-974.

Van den Eynde, F., Koskina, A., Syrad, H., Guillaume, S., Broadbent, H., Campbell, I. C., & Schmidt, U. (2012). State and trait food craving in people with bulimic eating disorders. *Eating Behaviors, 13,* 414-417.

Van Koningsbruggen, G. M., Veling, H., Stroebe, W., & Aarts, H. (in press). Comparing two psychological interventions in reducing impulsive processes of eating behaviour: Effects on self-selected portion size. *British Journal of Health Psychology*.

Veling, H., Aarts, H., & Papies, E. K. (2011). Using stop signals to inhibit chronic dieters' responses toward palatable foods. *Behaviour Research and Therapy, 49*, 771-780.

Veling, H., Aarts, H., & Stroebe, W. (2013a). Stop signals decrease choices for palatable foods through decreased food evaluation. *Frontiers in Psychology, 4*(875). doi: 10.3389/fpsyg.2013.00875

Veling, H., Aarts, H., & Stroebe, W. (2013b). Using stop signals to reduce impulsive choices for palatable unhealthy foods. *British Journal of Health Psychology, 18*, 354-368.

Volkow, N. D., Wang, G.-J., Tomasi, D., & Baler, R. D. (2013). Obesity and addiction: neurobiological overlaps. *Obesity Reviews, 14*, 2-18.

Volkow, N. D., Wang, G. J., Fowler, J. S., Tomasi, D., & Baler, R. (2012). Food and drug reward: Overlapping circuits in human obesity and addiction. In C. S. Carter & J. W. Dalley (Eds.), *Brain Imaging in Behavioral Neuroscience* (pp. 1-24). Berlin/Heidelberg: Springer.

Waxman, S. E. (2009). A systematic review of impulsivity in eating disorders. *European Eating Disorders Review, 17*, 408-425.

Weingarten, H. P., & Elston, D. (1990). The phenomenology of food cravings. *Appetite, 15,* 231-246.

Weingarten, H. P., & Elston, D. (1991). Food cravings in a college population. *Appetite, 17,* 167-175.

Wu, M., Giel, K. E., Skunde, M., Schag, K., Rudofsky, G., de Zwaan, M., . . . Friederich, H.-C. (2013). Inhibitory control and decision making under risk in bulimia nervosa and binge-eating disorder. *International Journal of Eating Disorders, 46*, 721-728.

Yokum, S., & Stice, E. (2013). Cognitive regulation of food craving: effects of three cognitive reappraisal strategies on neural response to palatable foods. *International Journal of Obesity, 37*, 1565-1570.

Table 1

Descriptive statistics of and correlations between BMI, food deprivation, and questionnaire measures

N = 55	*M*	*SD*	1.	2.	3.	4.	5.
1. Food deprivation (hours)	4.06	4.92	-	-.07	.10	.09	.03
2. State food craving difference[a]	2.20	6.04	-.07	-	.04	-.10	.28*
3. Body-mass-index (kg/m^2)	21.90	2.39	.10	.04	-	.05	.33*
4. Barratt Impulsiveness Scale - short form (BIS-15)	32.62	6.26	.09	-.10	.05	-	.13
5. Food Cravings Questionnaire - Trait (FCQ-T)	94.18	29.07	.03	.28*	.33*	.13	-

[a]Scores on the *Food Cravings Questionnaire – State* after the task minus scores before the task.

*$p < .05$

Table 2

Correlations between BMI, food deprivation, questionnaire measures and number of commission errors

	low-calorie food blocks			high-calorie food blocks			non-shift blocks	shift blocks	total
	non-shift blocks	shift blocks	total	non-shift blocks	shift blocks	total			
Food deprivation (hours)	.27	.14	.22	.15	.14	.18	.23	.17	.24
State food craving difference[a]	.04	.10	.09	.12	-.10	.02	.10	.01	.06
Body-mass-index (kg/m^2)	.17	.06	.13	.25	-.01	.15	.25	.03	.17
Barratt Impulsiveness Scale - short form (BIS-15)	.14	.20	.20	.06	.31*	.22	.11	.31*	.25
Food Cravings Questionnaire - Trait (FCQ-T)	.19	.15	.19	.29*	.26	.34*	.29*	.25	.32*

[a]Scores on the *Food Cravings Questionnaire – State* after the task minus scores before the task.

*$p < .05$

Table 3

Regression analyses for predicting number of commission errors

	low-calorie food blocks				high-calorie food blocks			
	non-shift blocks		shift blocks		non-shift blocks		shift blocks	
	β	*p*	β	*p*	β	*p*	β	*p*
Step 1								
Food deprivation (hours)	.26	*ns*	.14	*ns*	.14	*ns*	.14	*ns*
State food craving difference[a]	.04	*ns*	.10	*ns*	.12	*ns*	-.09	*ns*
Body-mass-index (kg/m²)	.14	*ns*	.04	*ns*	.23	*ns*	-.02	*ns*
Step 2								
Food deprivation (hours)	.23	*ns*	.15	*ns*	.13	*ns*	.17	*ns*
State food craving difference[a]	.01	*ns*	.11	*ns*	.07	*ns*	-.09	*ns*
Body-mass-index (kg/m²)	.10	*ns*	.01	*ns*	.16	*ns*	-.12	*ns*
Barratt Impulsiveness Scale - short form (BIS-15)	.11	*ns*	.15	*ns*	.02	*ns*	.17	*ns*
Food Cravings Questionnaire - Trait (FCQ-T)	.09	*ns*	.11	*ns*	.22	*ns*	.41	.007
BIS-15 × FCQ-T	-.08	*ns*	.09	*ns*	.01	*ns*	.32	.03

[a]Scores on the *Food Cravings Questionnaire – State* after the task minus scores before the task.

Figure captions

Figure 1. Pictures of (a) high-calorie and (b) low-calorie foods used in the current study.

Figure 2. Snippet of an exemplary procedure of the affective shifting task. The task was separated in 16 blocks à 20 trials. Each picture was presented for 500 ms and inter-trial interval (ITI) was 1000 ms.

Figure 3. Task performance, i.e. (a) mean reaction times, (b) mean number of omission errors, and (c) mean number of commission errors, as a function of target and block type. Error bars indicate the standard error of the mean. $^{***}p < .001$.

Figure 4. Scatterplots showing associations between (a) trait impulsivity and (b) food craving with number of commission errors. Trait impulsivity is positively correlated with number of commission errors in shift blocks ($r = .31$, $p < .05$, solid line), but not in non-shift blocks ($r = .11$, *ns*, dashed line). Trait food craving is positively correlated with number of commission errors in blocks with high-calorie food targets ($r = .34$, $p < .05$, solid line), but not in blocks with low-calorie food targets ($r = .19$, *ns*, dashed line).

Figure 5. Interaction plot showing associations between trait food craving and number of commission errors in shift blocks with high-calorie food targets for individuals with high impulsivity (one standard deviation above the mean; $\beta = .73$, $p < .001$, solid line) and low impulsivity (one standard deviation below the mean; $\beta = .12$, *ns*, dashed line). All variables are *z*-standardized.

Figure 1

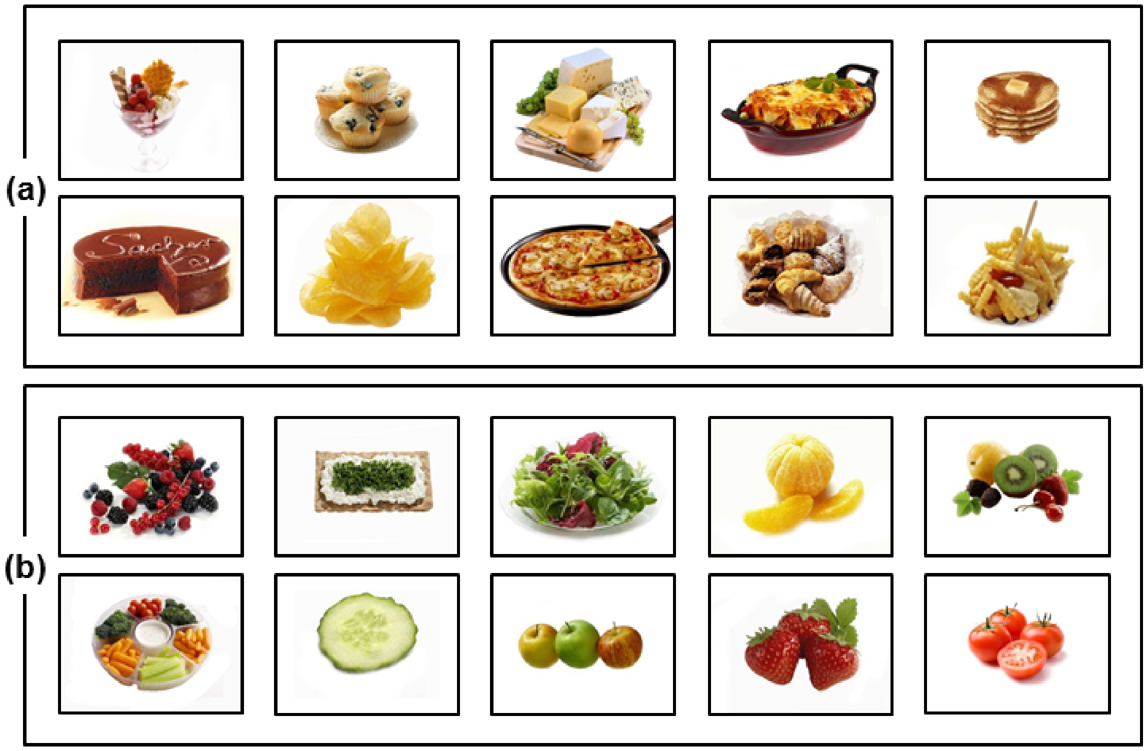


Figure 2

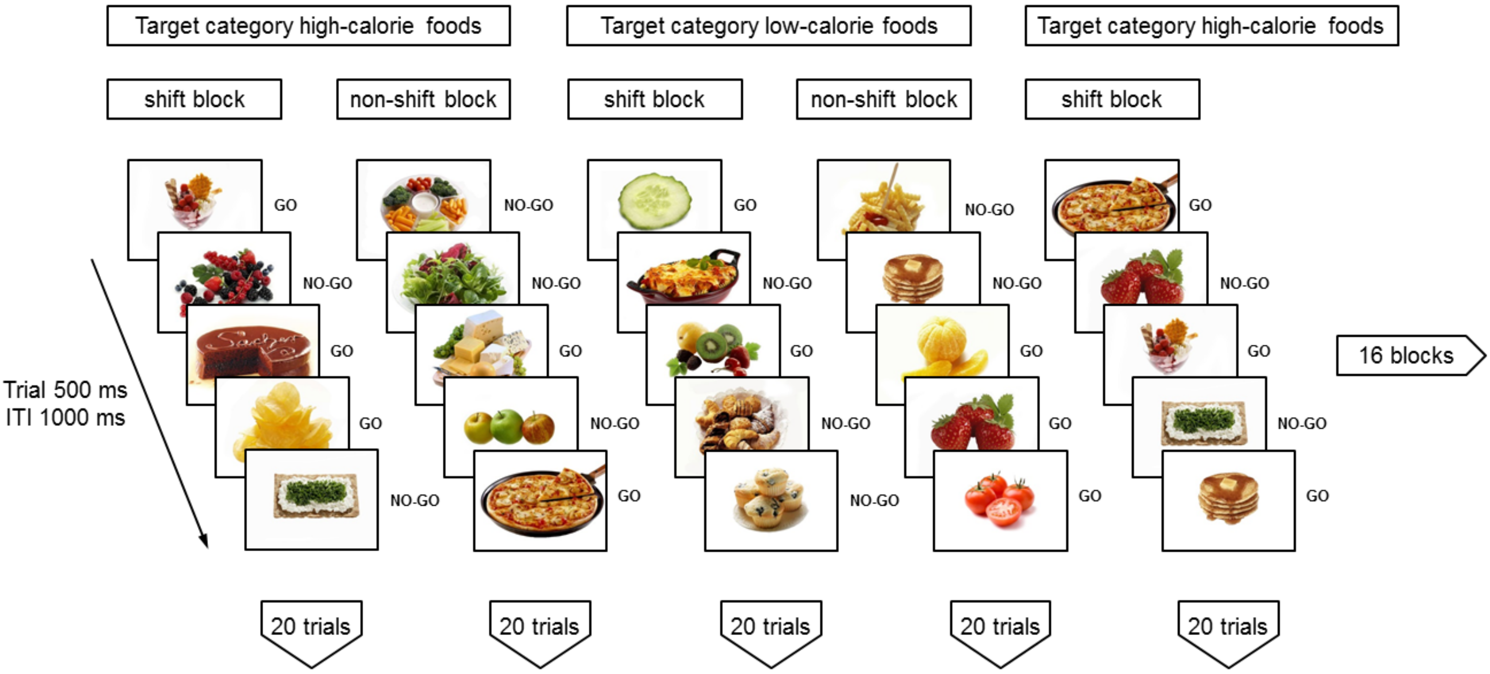

Target category high-calorie foods
Target category low-calorie foods
Target category high-calorie foods
shift block
non-shift block
shift block
non-shift block
shift block
Trial 500 ms
ITI 1000 ms
GO
NO-GO
16 blocks
20 trials

Figure 3

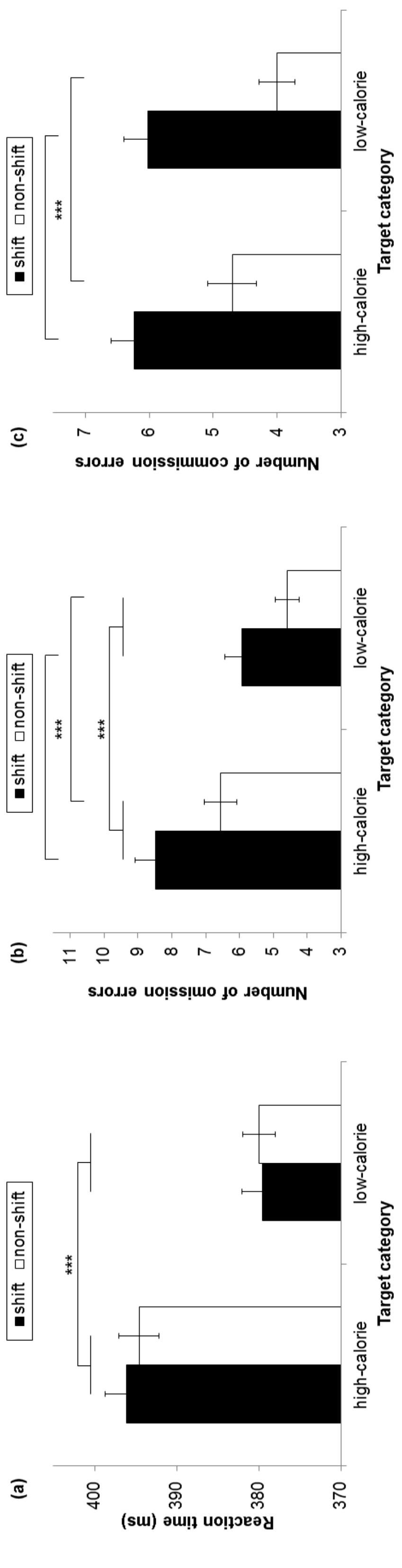

(a)
Reaction time (ms)
400
390
380
370
high-calorie
low-calorie
Target category
■shift □non-shift
***
(b)
Number of omission errors
11
10
9
8
7
6
5
4
3
high-calorie
low-calorie
Target category
■shift □non-shift
***
***
(c)
Number of commission errors
7
6
5
4
3
high-calorie
low-calorie
Target category
■shift □non-shift
***

Figure 4

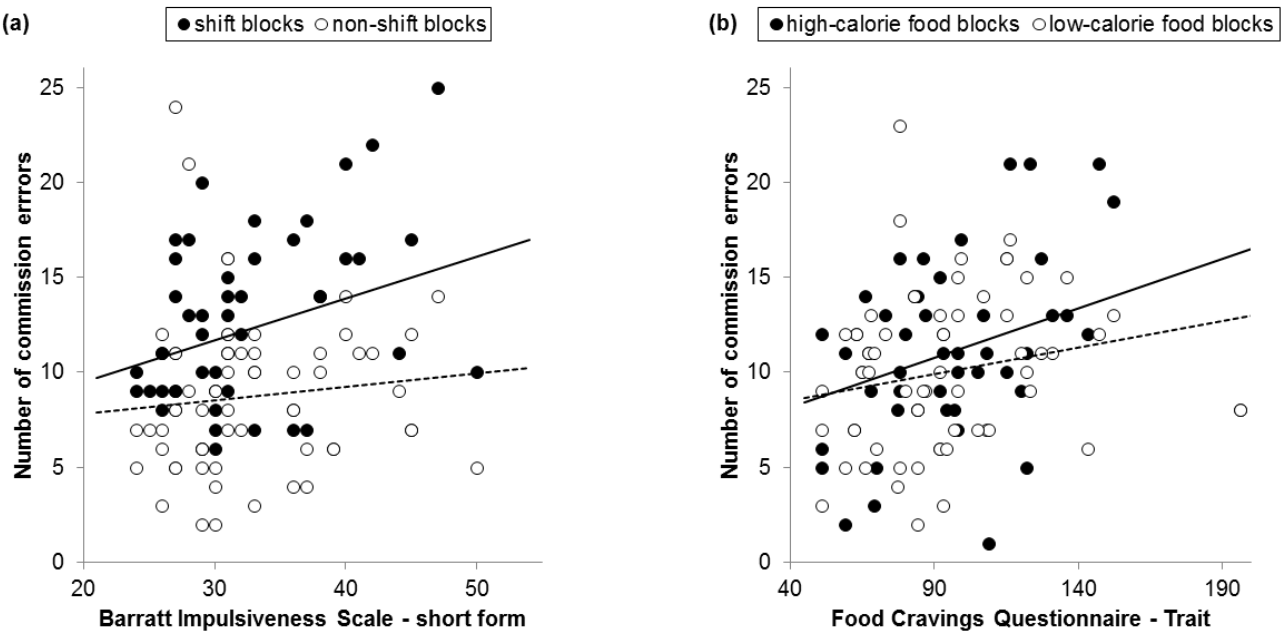
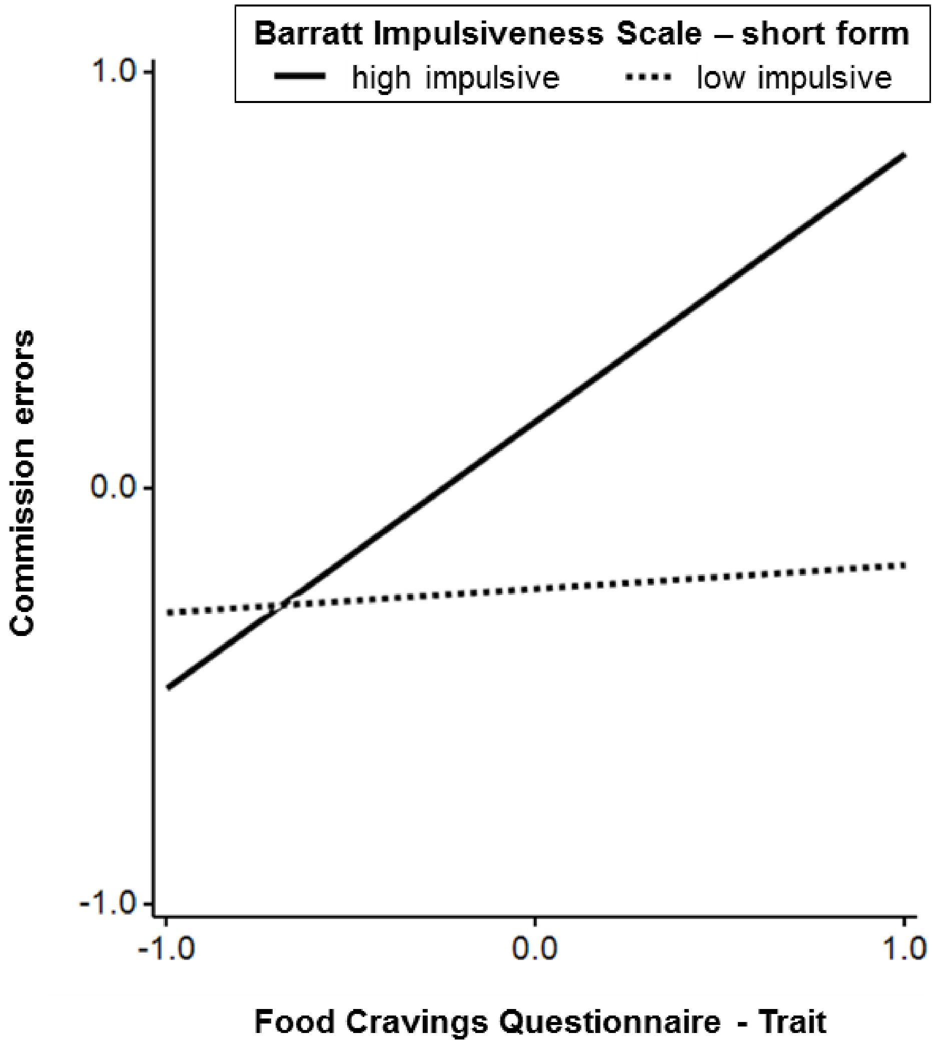

(a)
shift blocks
non-shift blocks
Number of commission errors
Barratt Impulsiveness Scale - short form
(b)
high-calorie food blocks
low-calorie food blocks
Number of commission errors
Food Cravings Questionnaire - Trait

Figure 5


Barratt Impulsiveness Scale – short form
high impulsive
low impulsive
1.0
0.0
-1.0
Commission errors
-1.0
0.0
1.0
Food Cravings Questionnaire - Trait

2.5 Meule, A., Kübler, A., & Blechert, J. (2013). Time course of electrocortical food-cue responses during cognitive regulation of craving. ***Frontiers in Psychology*, *4*, doi: 10.3389/fpsyg.2013.00669.**

Abstract: In our current obesogenic environment, exposure to visual food-cues can easily lead to craving and overeating because short-term, pleasurable effects of food intake dominate over the anticipated long-term adverse effects such as weight gain and associated health problems. Here we contrasted these two conditions during food-cue presentation while acquiring event-related potentials (ERPs) and subjective craving ratings. Female participants (n = 25) were presented with either high-calorie (HC) or low-calorie (LC) food images under instructions to imagine either immediate (NOW) or long-term effects (LATER) of consumption. On subjective ratings for HC foods, the LATER perspective reduced cravings as compared to the NOW perspective. For LC foods, by contrast, craving increased under the LATER perspective. Early ERPs (occipital N1, 150–200 ms) were sensitive to food type but not to perspective. Late ERPs (late positive potential, LPP, 350–550 ms) were larger in the HC-LATER condition than in all other conditions, possibly indicating that a cognitive focus on negative long-term consequences induced negative arousal. This enhancement for HC-LATER attenuated to the level of the LC conditions during the later slow wave (550–3000 ms), but amplitude in the HC-NOW condition was larger than in all other conditions, possibly due to a delayed appetitive response. Across all conditions, LPP amplitudes were positively correlated with self-reported emotional eating. In sum, results reveal that regulation effects are secondary to an early attentional analysis of food type and dynamically evolve over time. Adopting a long-term perspective on eating might promote a healthier food choice across a range of food types.

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Time course of electrocortical food-cue responses during cognitive regulation of craving

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In our current obesogenic environment, exposure to visual food-cues can easily lead to craving and overeating because short-term, pleasurable effects of food intake dominate over the anticipated long-term adverse effects such as weight gain and associated health problems. Here we contrasted these two conditions during food-cue presentation while acquiring event-related potentials (ERPs) and subjective craving ratings. Female participants ($n = 25$) were presented with either high-calorie (HC) or low-calorie (LC) food images under instructions to imagine either immediate (NOW) or long-term effects (LATER) of consumption. On subjective ratings for HC foods, the LATER perspective reduced cravings as compared to the NOW perspective. For LC foods, by contrast, craving increased under the LATER perspective. Early ERPs (occipital N1, 150–200 ms) were sensitive to food type but not to perspective. Late ERPs (late positive potential, LPP, 350–550 ms) were larger in the HC-LATER condition than in all other conditions, possibly indicating that a cognitive focus on negative long-term consequences induced negative arousal. This enhancement for HC-LATER attenuated to the level of the LC conditions during the later slow wave (550–3000 ms), but amplitude in the HC-NOW condition was larger than in all other conditions, possibly due to a delayed appetitive response. Across all conditions, LPP amplitudes were positively correlated with self-reported emotional eating. In sum, results reveal that regulation effects are secondary to an early attentional analysis of food type and dynamically evolve over time. Adopting a long-term perspective on eating might promote a healthier food choice across a range of food types.

Keywords: food craving, food-cues, calorie content, eating, EEG, event-related potentials, LPP, slow wave

INTRODUCTION

High-calorie (HC) foods and food-cues are ubiquitous in western or westernized societies. Those stimuli exert a strong influence on eating behavior, e.g., initiate eating or lead to an increased food intake in an automatic and implicit fashion (Cohen and Farley, 2008; Cohen and Babey, 2012). Thus, a constant self-monitoring and -regulation of eating behavior is necessary to avoid indulging in eating palatable, high caloric foods (Lowe, 2003). Food- and food-cue exposure trigger so-called cephalic phase responses that prepare the organism for the consumption of food and are associated with an increase in craving for those foods (Nederkoorn et al., 2000; Legenbauer et al., 2004; Rodríguez et al., 2005). Likewise, neuroimaging studies have shown that presentation of visual food-cues markedly activate the human brain, particularly subcortical areas associated with reward and incentive salience (Wang et al., 2004; Kenny, 2011; Carnell et al., 2012; García-García et al., 2013). Accumulating evidence suggests that those food-cue induced subcortical activations can be downregulated by the use of cognitive strategies, probably through increased inhibitory signals from prefrontal cortices (Wang et al., 2009; Kober et al., 2010b; Hollmann et al., 2012; Scharmüller et al., 2012; Siep et al., 2012; Yokum and Stice, 2013).

Yet, little is known about the time course of neural activity supporting such modulations. It would be useful to know, however, whether successful regulation extends to earlier, more implicit evaluative processes or is limited to later processing stages. Event-related potentials (ERPs) afford the temporal resolution to distinguish multiple early, mid-latency, and late components related to appetitive processing. In affective picture viewing, early (e.g., N100, 100–200 ms) and mid-latency ERPs [e.g., early posterior negativity (EPN), 200–300 ms] reflect physical stimulus factors but may also index early selective attention (Olofsson et al., 2008). In the food context, Toepel et al. (2009) showed that pictorial low-calorie (LC) food-cues elicited a larger relative negativity as compared to HC food-cues after ~150–200 ms at occipital electrodes. Thus, this study complements imaging studies showing that HC and LC food-cues are differently processed in the brain (Killgore et al., 2003; Siep et al., 2009; Frank et al., 2010) and that this discrimination occurs automatically and rapidly. Also mid-latency ERPs such as the EPN are of interest in this context as it has been shown that the EPN is sensitive to food deprivation (Stockburger et al., 2008) and eating disorder status (Blechert et al., 2011).

Long latency ERPs (>300 ms) index maintained attention, memory storage or meaning evaluation (Schupp et al., 2006;

Hajcak et al., 2010) and are subject to cognitive (top–down) modulations (Olofsson et al., 2008). A positive, centro-parietal ERP component beginning at ∼300 ms after stimulus onset is known as the P300 or Late Positive Potential (LPP). The LPP has been found to be enhanced in response to highly arousing stimuli, e.g., positive and negative pictures (Olofsson et al., 2008; Hajcak et al., 2010). Thus, it has been proposed that the LPP indicates *motivated attention* toward stimuli that are evolutionary relevant as they automatically attract attention and appear to be dependent on motivational factors such as approach or avoidance tendencies (cf. Littel et al., 2012). The LPP is also increased in response to substance-related compared to neutral cues in substance users (Littel et al., 2012).

Likewise, the LPP seems to reflect the motivational value of food stimuli and is modulated by food deprivation and individual differences in eating behavior. Nijs et al. (2008) found that food pictures elicited an enlarged LPP as compared to pictures of neutral objects. Moreover, increased LPP amplitude was found in response to food pictures when participants were hungry as compared to when they were satiated (Stockburger et al., 2009b; Nijs et al., 2010). With regard to individual differences, elevated LPP amplitude in response to food pictures was found in external eaters (Nijs et al., 2009), women with binge eating disorder (Svaldi et al., 2010), and emotional eaters (Blechert et al., in revision). However, no differences in food-related LPP amplitude could be observed between normal-weight vs. obese participants (Nijs et al., 2008) and high chocolate cravers vs. low chocolate cravers (Asmaro et al., 2012). In another study, the LPP in response to food pictures did not differ from neutral pictures, but was attenuated in restrained eaters when foods were available for direct consumption (Blechert et al., 2010). To summarize, most studies found that the LPP is enlarged in response to food pictures as compared to neutral pictures, particularly when participants were hungry. Some studies also point out that an enhanced food-related LPP is associated with habitual overeating and related measures, but results are not conclusive yet.

Whereas the LPP appears to be transient, a later slow wave is typically enhanced for several seconds after presentation of motivationally relevant stimuli. It has been argued that the LPP and slow wave are functionally similar and, thus, the slow wave may reflect additional attentive processing or a continuation of attentive processing of motivationally relevant stimuli (Littel et al., 2012). Both the LPP and the slow wave are subject to cognitive modulation. Several affective picture viewing studies demonstrated reductions in amplitudes during cognitive emotion regulation strategies such as distraction or reappraisal (cf. Hajcak et al., 2010). Moreover, time course of LPP/slow wave modulations to negative images depended on the specific emotion regulation strategy used: distraction led to an earlier attenuation of the LPP than reappraisal, possibly due to the more effortful processing in the latter (Thiruchselvam et al., 2011).

However, down-regulation of arousing material does not uniformly reduce LPP amplitudes. Other studies found the LPP to be enlarged during instructions to decrease emotions as compared to passively viewing emotional pictures (Langeslag and Van Strien, 2010; Baur et al., submitted). A similar pattern was found by Littel and Franken (2011), who investigated craving regulation strategies in smokers while watching smoking and neutral pictures. Passively viewing smoking pictures elicited larger LPP amplitudes as compared to watching neutral pictures. However, unexpectedly, reappraisal strategies did not attenuate the LPP in response to smoking pictures. Only when distinguishing different cognitive strategies they found that distraction strategies (thinking about something different) reduced the LPP after ∼1 s. This suggests that modulation of later LPP stages may depend on the specific type of reappraisal that is applied.

In the current study, we investigated if cognitive strategies for modulating food craving would alter ERPs in response to pictorial food-cues. Specifically, we adapted the paradigm used in the study by Kober et al. (2010a,b) in which participants should either focus on the long-term consequences or the immediate consequences of eating HC foods. We expected that focusing on the long-term effects would *decrease* food craving for those foods as compared to focusing on the immediate effects (Kober et al., 2010a,b). As a control condition, we presented pictures of LC food items with the very same instructions. Here, we expected that thinking about the long-term effects (e.g., health benefits) would *increase* craving for those foods as compared to focusing on immediate consumption.

With regard to ERP analyses, we aimed at replicating general, i.e., perspective independent, differences in ERP amplitudes between HC and LC food pictures. Specifically, we tested if there would be an elevated negativity in response to LC foods as compared to HC foods in an early time window (150–200 ms) at occipital sites as reported by Toepel et al. (2009). Our predictions for effects of perspective (long-term vs. short-term) focused on HC images for which we expected reduced craving and LPP amplitudes under a long-term perspective based on findings from emotion regulation research (e.g., Hajcak et al., 2010; Thiruchselvam et al., 2011). Perspective might also modulate ERP responses to LC images but predictions were less clear here. In accordance with prior studies on emotion and craving regulation (Littel and Franken, 2011; Thiruchselvam et al., 2011), we divided the LPP into an earlier (350–550 ms) and later component (550–3000 ms, slow wave) as some effects of reappraisal on LPP/slow wave amplitudes may only be observed in later stages of food-cue processing. Finally, we explored if trait measures of eating behavior (food cravings, restrained eating, external eating, emotional eating, and eating disorder symptomatology) and state food cravings would be correlated with ERP amplitudes.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-six female Psychology students of the University of Salzburg, Austria, participated in exchange for course credit or €10. Exclusion criteria were presence of cardiovascular or neurological diseases, diabetes, regular use of medication other than contraceptives, age <18 or >30 years, and underweight (BMI $< 17.50\,kg/m^2$) or obesity (BMI $\geq 30.00\,kg/m^2$). Vegetarians were also excluded because of altered attentional processing (as indicated by the LPP) of meat dishes (Stockburger

Table 1 | Descriptive statistics of participant characteristics.

N = 26	*M*	*SD*	Range
Age (years)	23.00	2.23	18.00–27.00
Body-mass-index (kg/m^2)	23.12	2.80	17.60–27.80
Food deprivation (h)	3.49	0.60	2.30–4.30
Last meal (kcal)	487.54	245.59	101.52–990.80
Food Cravings Questionnaire—Trait	108.15	21.08	74.00–147.00
Food Cravings Questionnaire—State			
Before task	27.62	8.86	15.00–51.00
After task	43.15	9.04	30.00–65.00
Eating Disorder Examination—Questionnaire	1.23	0.97	0.19–3.88
Dutch Eating Behavior Questionnaire			
Restrained eating	2.58	0.73	1.10–4.60
Emotional eating	2.28	0.57	1.50–3.70
External eating	3.42	0.68	2.00–4.80
Restraint Scale	13.77	5.93	5.00–26.00

et al., 2009a). Descriptive statistics of participant characteristics are depicted in **Table 1**. Mean scores on the eating behavior measures were comparable to scores in other non-clinical samples (e.g., Hilbert et al., 2007). Importantly, none of our participants scored above the cutoff for clinical eating disorders (i.e., a total score of at least 4 on the *Eating Disorder Examination—Questionnaire*; Carter et al., 2001; Mond et al., 2006). Half of the sample ($n = 13$) reported to be currently dieting (see section Dieting Status). Dieters did not differ from non-dieters in craving ratings [all $ts_{(24)} < 0.98$, *ns*] and ERP amplitudes [all $ts_{(23)} < 0.82$, *ns*].

QUESTIONNAIRES

Food Cravings Questionnaires (FCQ)

The trait version of the FCQ (FCQ-T; Cepeda-Benito et al., 2000) consists of 39 items and assesses the frequency of food craving experiences on nine subscales (intentions and plans to consume food, anticipation of positive reinforcement, anticipation of relief from negative states, lack of control over eating, thoughts, or preoccupation with food, hunger, emotions before or during food cravings, cue-dependent food cravings, and guilt). Only the total score was used in the current study. Internal consistency of the German version is $\alpha = 0.96$ (Meule et al., 2012a) and was $\alpha = 0.91$ in the current study.

The state version of the FCQ (FCQ-S; Cepeda-Benito et al., 2000) consists of 15 items and measures current food craving on five subscales (intense desire to eat, anticipation of positive reinforcement, anticipation of relief from negative states, lack of control over eating, and hunger). Only the total score was used in the current study. Internal consistency of the German version is $\alpha = 0.92$ (Meule et al., 2012a). Participants completed the FCQ-S at the beginning and at the end of the testing session and internal consistency was $\alpha = 0.90$ (before) and $\alpha = 0.83$ (after) in the current study.

Eating Disorder Examination – Questionnaire (EDE-Q)

The EDE-Q (Fairburn and Beglin, 1994) consists of 22 items and assesses eating disorder psychopathology on four subscales (restraint, eating concern, weight concern, and shape concern). Only the total score was used in the current study. Internal consistency of the German version is $\alpha = 0.97$ (Hilbert et al., 2007) and was $\alpha = 0.94$ in the current study.

Dutch Eating Behavior Questionnaire (DEBQ)

The DEBQ (van Strien et al., 1986) consists of 30 items and measures three aspects of eating behavior (restrained eating, external eating, and emotional eating). Internal consistencies of the German version are $\alpha > 0.80$ for all three subscales (Grunert, 1989) and ranged between $\alpha = 0.83$–0.88 in the current study.

Restraint Scale (RS)

The RS (Herman and Polivy, 1980) consists of 10 items and assesses restrained eating behavior on two subscales (concern for dieting and weight fluctuations). Only the total score was used in the current study. Internal consistency of the German version is $\alpha = 0.83$ (Dinkel et al., 2005) and was $\alpha = 0.82$ in the current study.

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)?"; cf. (Meule et al., 2012b)].

STIMULI

Stimuli were selected from a food picture database featuring food images with simple figure ground compositions for experimental research (Meule and Blechert, 2012; also see www.food-pics.sbg.ac.at) and comprised pictures of 34 HC and 34 LC foods. HC food pictures included both sweet and savory foods (**Figure 1A**, **Table 2**). LC food pictures included vegetables, fruits, salad, and crisp bread (**Figure 1B**, **Table 2**). All pictures had the same resolution and color depth (600 × 450 pixels, 96 dpi, 24 bpp) and were homogenous with regard to background color and camera distance. HC and LC food pictures did not differ in RGB brightness and contrast [all $ts_{(66)} < 0.78$, *ns*], visual complexity [jpg compression: $t_{(66)} = -0.48$, *ns*; edge detection: $t_{(66)} = -0.95$, *ns*; subjective complexity ratings: $t_{(66)} = -1.41$, *ns*]. The food picture database also includes subjective palatability ratings from a sample of young, female students (Meule and Blechert, 2012). Analyses of those ratings showed that palatability did not differ between HC and LC food pictures [$t_{(66)} = 1.36$, *ns*]. HC food pictures displayed foods with a higher calorie density ($M = 360.98$ kcal/100g, $SD = 140.87$) as compared with LC food pictures [$M = 35.44$ kcal/100g, $SD = 26.66$; $t_{(66)} = 13.24$, $p < 0.001$]. Similarly, the total amount of calories displayed in HC food pictures ($M = 625.23$ kcal/image, $SD = 680.92$) was higher than that of LC food pictures [$M = 97.95$ kcal/image, $SD = 109.81$, $t_{(66)} = 4.56$, $p < 0.001$].

REGULATION OF CRAVING (ROC) TASK

The ROC-task was adapted from the task by Kober and colleagues which involved smoking-related cues (Kober et al., 2010a,b). The

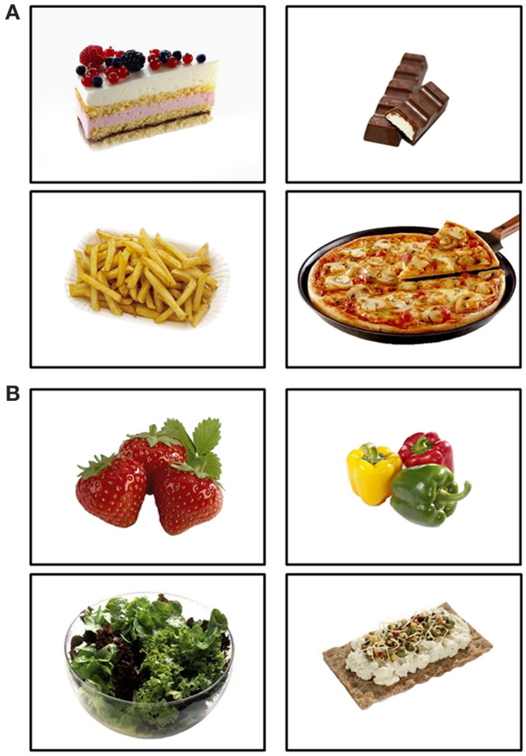

FIGURE 1 | Examples of high-calorie (A) and low-calorie (B) food pictures.

task was programmed with E-prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA) and displayed on a 23″ LCD-monitor with a resolution of 1920 × 1080 pixels at 120 Hz. One experimental trial started with a fixation cross (duration varying randomly between 2000 and 3000 ms). Then, a cue was presented for 3000 ms instructing participants to either focus on the immediate (NOW) or long-term (LATER) consequences of eating the food item presented on the following slide. Either a high-caloric (HC) or a low-caloric (LC) food item was then presented for 3000 ms (**Figure 2**). Finally, participants indicated their current craving ("I have an intense desire to eat this food.") on a 5-point scale from *not at all* to *very strong* (**Figure 2**). Participants first performed a practice block including 8 trials (2 LC-NOW, 2 HC-NOW, 2 LC-LATER, 2 HC-LATER) with 5 HC food pictures and 5 LC food pictures that were not used in the experimental task. The experimental task consisted of 136 trials with a short break after half of the trials. Each participant viewed 34 HC and 34 LC food pictures preceded by either the NOW or the LATER instruction (17 LC-NOW, 17 HC-NOW, 17 LC-LATER, 17 HC-LATER) in pseudorandomized order. The very same set was repeated after the break. Across participants, counterbalancing ensured that each picture was shown in the NOW vs. LATER conditions with equal probabilities.

APPARATUS

EEG was recorded with an actively shielded 65-channel electrode cap (sintered Ag/AgCl electrodes, manufactured for TMS

Table 2 | List of foods pictures of which were used in the current study.

	Low-calorie foods(#)	High-calorie foods(#)
Practice block	Blueberries (248)	Chips (043)
	Grapes (281)	Chocolate chips (174)
	Paprika peppers (239)	Cream cake (028)
	Pears (241)	Pizza with mushrooms (032)
	Strawberries (234)	Popsicle with chocolate and nuts (116)
Main task	Apples (238)	Bavarian doughnut (178)
	Blueberries (202)	Bundt cake (096)
	Carrots (208)	Butter (064)
	Cauliflower (249)	Candies (102)
	Celery (262)	Cashew nuts (110)
	Cherries (280)	Cheeseburger with French fries (003)
	Crisp bread with cottage cheese (205)	Cheesecake with cherries (001)
	Cucumber (267)	Cheesecake with cherries (136)
	Cucumber and carrots (215)	Cheesecake with strawberries (006)
	Fennel (277)	Chocolate bar (173)
	Figs (254)	Chocolate cookie (004)
	Grapefruit (256)	Chocolate covered nuts (160)
	Grapes (284)	Chocolate crisps (165)
	Kiwi (194)	Chocolate croissant (184)
	Lettuce (232)	Chocolate marshmallows (166)
	Limes (269)	Chocolate marshmallows (161)
	Mixed berries (203)	Chocolate muffins (048)
	Mixed berries (209)	Cream cake with raspberries (055)
	Mushrooms (263)	French fries (046)
	Nectarines (216)	Fruit gum (153)
	Oranges (200)	Ham and cheese sandwich with chips (057)
	Paprika peppers (198)	Lollipops (123)
	Pineapple (285)	Lollipops (124)
	Pomegranate (255)	Meatballs (190)
	Radishes (258)	Pancakes with syrup (016)
	Raspberries (206)	Pasta bake (143)
	Red cabbage (259)	Pizza with vegetables (131)
	Salad onions (266)	Salami (176)
	Strawberries (243)	Scoops of ice cream (038)
	Tomatoes (275)	Slice of bread with chocolate hazelnut spread (189)
	Turnip cabbage (268)	Spaghetti with tomato sauce (010)
	Vegetables with dip (212)	Spritz cookies (148)
	Water melon (199)	Strawberry cake (089)
	Zucchini (265)	Sugar-glazed doughnut (041)

[#] *Refers to the picture number in the food-pics database, see www.food-pics.sbg.ac.at*

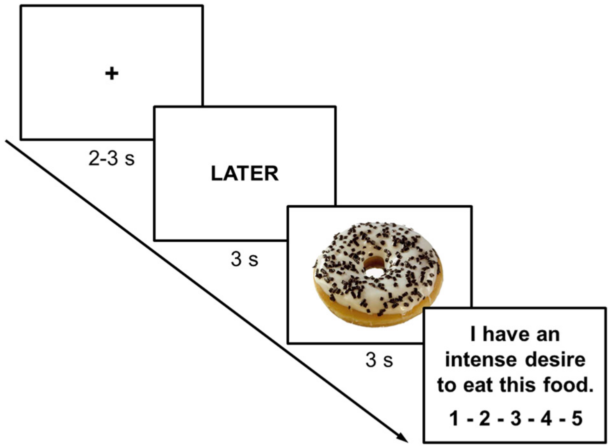

FIGURE 2 | Representative screen displays of a trial in which participants were instructed to think of the long-term consequences of eating a high-calorie food. Inter-trial interval (fixation cross) was jittered between 2000 and 3000 ms while instruction cues and food-cues were presented for 3000 ms each. At the end of each trial participants rated their current craving for the presented food on a 5-point scale from *not at all to very strong.*

International, Oldenzaal, the Netherlands). All scalp positions of the International 10–20 System were used, with additional sites 10% inferior to the standard electrodes (PO9, TP9, FT9, PO10, TP10, FT10). Data were recorded with a REFA 8–72 digital amplifier system (TMSi, Oldenzaal, the Netherlands) at a sample rate of 512 Hz and 24 bit/channel and were filtered online at 0.05–100.00 Hz. The unipolar inputs were configured as a reference amplifier: All channels were amplified against the average of all connected inputs. A wet band on the left wrist was used as patient ground. Vertical EOG was recorded with bipolar electrodes above and below the right eye. Electrode impedances were kept below 50 kOhms for all the electrodes which is appropriate for this type of high-input impedance amplifier (Ferree et al., 2001). Data acquisition was controlled through TMSi Polybench (TMSi, Oldenzaal, Netherlands).

Data were analyzed offline with Brain Vision Analyzer 2.0 (Brain Products GmbH, Gilching, Germany) and comprised the following steps: Low pass filtering at 20 Hz, semi-automatic eye-blink correction using independent component analysis, manual screening for remaining artifacts or bad channels, segmentation (200 ms baseline, 3000 ms picture), artifact correction (Exclusion of Epochs exceeding $>150\,\mu V$ amplitude change or low activity), baseline-subtraction (200 ms) und averaging of segments for each experimental condition (LC-NOW, HC-NOW, LC-LATER, HC-LATER). EEG data of one participant were excluded due to technical problems. Overall number of valid segments was high (95.91%) and did not differ by condition [$F_{(3,\,72)} = 1.30$, *ns*].

PROCEDURE

Participants completed the trait-related questionnaires online, a few days prior to the experiment in order to avoid a possible influence of performing the ROC task on questionnaire scores. On the day of the testing session, all participants ate lunch between 12 and 13 p.m. and were asked to refrain from eating until the experiment to obtain roughly comparable levels of satiety at the time of testing. All participants were tested between 3 and 4:30 p.m. On arrival at the laboratory, participants provided written informed consent and weight and height was measured. After set-up of the psychophysiological equipment, participants completed the FCQ-S. All participants were fully aware of the fact that the foods presented it the current study would not be available to eat in the laboratory during or after the experiment.

Prior to the ROC task, participants underwent a structured training session which was adapted from the instructions by Kober et al. (2010a,b). During this session, participants were trained to focus on the odor, taste, and consistency of the presented food during eating after the NOW-instruction. After the LATER-instruction, participants were instructed to think of, e.g., change in body weight that would be associated with frequent consumption of the presented food item and of other health consequences. Participants then performed a self-paced practice block under the experimenter's supervision before the main task commenced.

After the ROC-task, participants completed the FCQ-S again and were asked to rate their overall success in following instructions in percent (i.e., 100% represent a subjectively perceived success in regulating craving).

DATA ANALYSIS

Craving ratings were averaged across the 34 trials per condition. Craving ratings and ERP voltage measures were submitted to 2 (perspective) × 2 (picture type) analyses of variance (ANOVAs) for repeated measures. *Post-hoc t*-tests were calculated to follow up on interaction effects. Changes in state cravings during the task were captured in a difference score between FCQ-S before vs. after the ROC-task and submitted to correlational analyses (see below). Scores on the FCQ-S before and after the task were also compared using paired *t*-test.

Based on the findings by Toepel et al. (2009), we investigated if HC and LC food pictures elicited differential ERP amplitude at posterior sites in an early time window independent of perspective. For this purpose, we visually explored difference waveforms for HC minus LC food pictures. This difference was maximal during a relative negativity at occipital sites (PO9, PO7, PO3, POz, PO4, PO8, PO10, O1, Oz, O2) between 150 and 200 ms (N1, see below).

Due to the broad distribution and variation in amplitude maximum of the LPP in food image and affective picture viewing paradigms (e.g., Littel et al., 2012), we adopted a two-step localization approach. First, visual inspection of grand averages was used to determine the timing and location of the LPP maximum. Second, we calculated a difference waveform HC-NOW minus HC-LATER which we evaluated within this region, to determine those electrodes sites where regulation affected the LPP. Step one revealed that the LPP was maximal on bilateral centro-parieto-occipital electrodes between 350 and 550 ms (see **Figure 3A**). Time and region is thus consistent with several other reports on food image processing (Blechert et al., 2010; Nijs et al., 2010; Svaldi et al., 2010; Asmaro et al., 2012). Step two revealed that within this broad region, perspective effects were lateralized predominantly to the right hemisphere and, thus, sensors CP2, CP4, CP6, P2, P4, P6, PO4 were collapsed (**Figure 3B**) for statistical analysis. Based on the finding that differences between conditions shift over the time course in later stages of the LPP/slow wave when cognitive craving regulation strategies are used (Littel and Franken, 2011), we followed up the progression of the LPP in the very same cluster between 550 and 3000 ms (slow wave).

Differences in ERP amplitudes (μV) between conditions were tested with 2 (perspective) × 2 (picture type) ANOVAs for repeated measures. Finally, we calculated correlations between ERP amplitudes for each condition and subjective craving ratings as well as all eating behavior questionnaires. Results were considered as significant at an α level of $p = 0.05$. Results marked as *ns* refer to *p*-values > 0.05.

RESULTS

CRAVING AND PERFORMANCE RATINGS

The main effect for perspective on craving ratings was not significant [$F_{(1, 25)} = 1.74$, *ns*]. A significant main effect for picture type [$F_{(1, 25)} = 31.11$, $p < 0.001$, $\eta^2_p = 0.55$] was modulated by perspective [interaction perspective × picture type: $F_{(1,25)} = 13.85$, $p < 0.01$, $\eta^2_p = 0.36$; **Figure 4**]. As expected, craving for HC food pictures was rated higher after the NOW ($M = 2.78$, $SD = 0.67$) as compared to the LATER perspective [$M = 2.19$, $SD = 0.42$, $t_{(25)} = 4.35$, $p < 0.001$]. For LC food pictures, by contrast, craving ratings were higher after the LATER ($M = 3.43$, $SD = 0.79$) compared to the NOW perspective [$M = 3.05$, $SD = 0.76$, $t_{(25)} = 2.26$, $p < 0.05$]. Craving for HC and LC foods did not differ after the NOW perspective [$t_{(25)} = 1.33$, *ns*], but were higher for LC foods compared to HC foods after the LATER perspective [$t_{(25)} = 7.03$, $p < 0.001$].

Overall craving ratings (i.e., FCQ-S scores) were higher after the ROC-task ($M = 43.15$, $SD = 9.04$) as compared to before [$M = 27.62$, $SD = 8.86$, $t_{(25)} = 9.50$, $p < 0.001$]. Mean overall performance rating (i.e., self-perceived overall success in following instructions) was $M = 79.62\%$ ($SD = 8.82$; Range: 60–90).

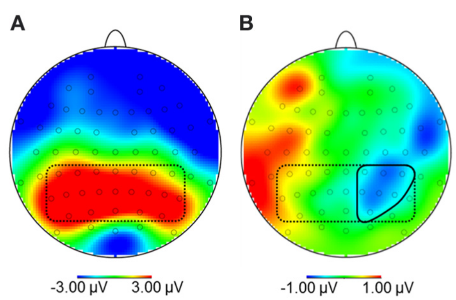

FIGURE 3 | (A) Topography of maximal amplitudes of the Late Positive Potential between 350 and 550 ms (encircled by dotted line). **(B)** Within this region, sensors where the difference for high-calorie food pictures after the NOW vs. LATER perspective was maximal were collapsed (CP2, CP4, CP6, P2, P4, P6, PO4; encircled by solid line).

ERP AMPLITUDES

N1

The ANOVA on N1 amplitudes revealed a significant main effect for picture type [$F_{(1, 24)} = 22.88$, $p < 0.001$, $\eta^2_p = 0.49$] indicating a more negative amplitude in response to LC food pictures ($M = 0.29\,\mu V$, $SD = 4.66$) as compared to HC food pictures ($M = 1.39\,\mu V$, $SD = 4.94$; **Figure 5**). There was no main effect for perspective [$F_{(1, 24)} = 3.97$, *ns*] and no interaction perspective × picture type [$F_{(1, 24)} = 1.25$, *ns*].

LPP

The main effect for picture type was not significant [$F_{(1, 24)} = 0.89$, *ns*, $\eta^2_p = 0.04$]. A main effect for perspective [$F_{(1, 24)} = 5.78$, $p < 0.05$, $\eta^2_p = 0.19$] was modulated by picture type [interaction perspective × picture type: $F_{(1, 24)} = 5.17$, $p < 0.05$, $\eta^2_p = 0.18$]. *Post-hoc t*-tests indicated that LPP amplitude was more positive in the HC-LATER condition ($M = 3.17\,\mu V$, $SD = 2.59$) than in all other conditions [HC-NOW: $M = 2.45\,\mu V$, $SD = 2.17$, $t_{(24)} = 2.99$, $p < 0.01$; LC-LATER: $M = 2.72\,\mu V$, $SD =$

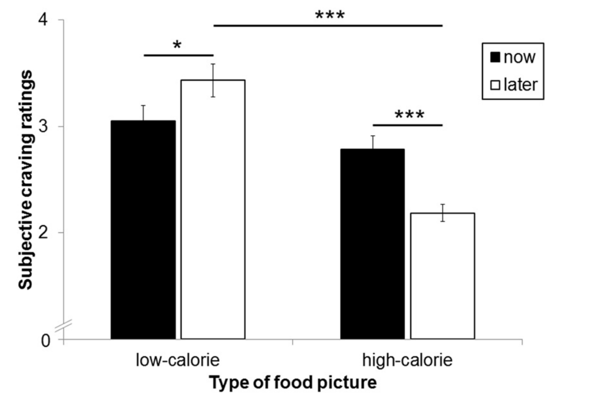

FIGURE 4 | Mean craving ratings after each food picture as a function of calorie content and perspective type. Error bars represent standard errors. Asterisks indicate *$p < 0.05$ and ***$p < 0.001$.

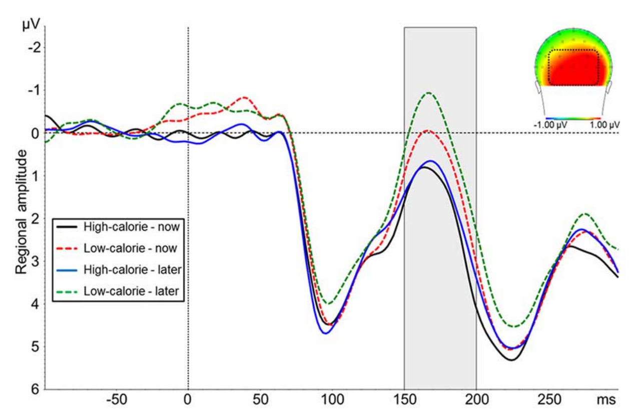

FIGURE 5 | Mean amplitude of pooled ERPs of a posterior cluster (PO9, PO7, PO3, POz, PO4, PO8, PO10, O1, Oz, O2). The headplot shows the difference between trials with high-calorie minus low-calorie food pictures in a time window between 150–200 ms.

2.20, $t_{(24)} = 2.16, p < 0.05$; LC-NOW: $M = 2.64\,\mu V, SD = 2.38, t_{(24)} = 2.40, p < 0.05$; **Figure 6**]. LPP amplitudes in the HC-NOW, LC-NOW, and LC-LATER conditions did not differ from each other [all $ts_{(24)} < 1.23$, *ns*][1].

Slow wave

The main effect for picture type was not significant [$F_{(1, 24)} = 1.14$, *ns*, $\eta_p^2 = 0.05$]. A main effect for perspective [$F_{(1, 24)} = 8.18, p < 0.01, \eta_p^2 = 0.25$] was modulated by picture type [interaction perspective × picture type: $F_{(1, 24)} = 4.26, p < 0.05, \eta_p^2 = 0.15$]. *Post-hoc t*-tests indicated that the slow wave amplitude was less positive in the HC-NOW condition ($M = -0.82\,\mu V$, $SD = 1.68$) than in all other conditions [HC-LATER: $M = -0.04\,\mu V$, $SD = 1.68$, $t_{(24)} = 3.20$, $p < 0.01$; LC-LATER: $M = -0.22\,\mu V$, $SD = 1.68$, $t_{(24)} = 3.20$, $p < 0.01$; LC-NOW: $M = -0.37\,\mu V$, $SD = 1.78$, $t_{(24)} = 2.83$, $p < 0.01$; **Figure 6**]. Slow wave amplitudes in the HC-LATER, LC-LATER, and LC-NOW conditions did not differ from each other [all $ts_{(24)} < 1.48$, *ns*][2].

CORRELATIONS BETWEEN ERP AMPLITUDES AND SELF-REPORT MEASURES

N1

Amplitudes did not correlate with any of the self-report measures.

LPP

LPP amplitudes pooled across all conditions were positively correlated with the emotional eating subscale of the DEBQ ($r = 0.42$, $p < 0.05$; **Figure 7**) and with craving ratings in the HC-LATER condition ($r = 0.57, p < 0.01$; LPP amplitudes broken down by condition: HC-LATER $r = 0.50$, $p < 0.05$, LC-NOW $r = 0.54$, $p < 0.01$, HC-NOW $r = 0.54$, $p < 0.01$, LC-LATER $r = 0.63$, $p < 0.01$). LPP amplitudes did not correlate with craving ratings in any other condition (all $rs < 0.27$, *ns*).

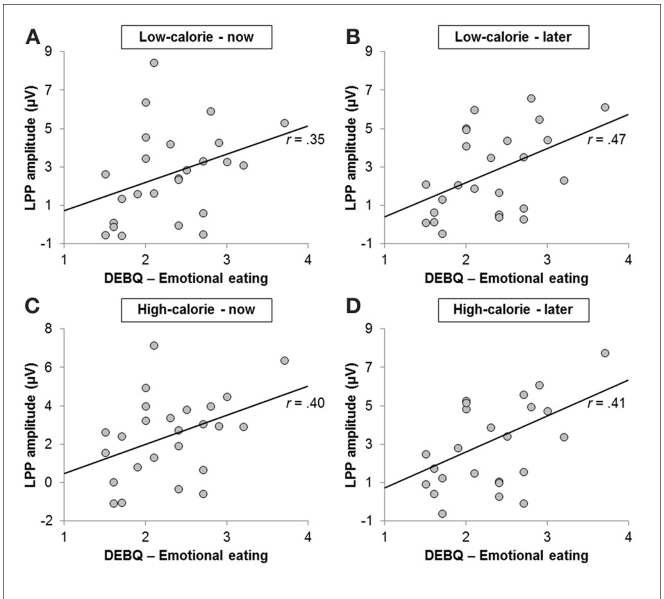

FIGURE 7 | Scatter plots showing correlations between scores on the emotional eating subscale of the Dutch Eating Behavior Questionnaire and Late Positive Potential amplitude in the (A) low-calorie—now, (B) low-calorie—later, (C) high-calorie—now, and (D) high-calorie—later condition.

[1]We also explored the corresponding cluster on the left hemisphere (CP1, CP3, CP5, P1, P3, P5, PO3) and found a significant main effect for picture type [$F(1, 24) = 8.69, p < 0.01, \eta_p^2 = 0.27$] indicating higher LPP amplitude in response to HC food pictures ($M = 4.27, SD = 2.26$) relative to LC food pictures ($M = 3.78, SD = 2.00$). There was neither a main effect for perspective [$F_{(1,24)} = 0.39$, *ns*, $\eta_p^2 = 0.03$] nor an interaction perspective × picture type [$F_{(1, 24)} = 0.81$, *ns*, $\eta_p^2 = 0.00$].

[2]We also explored the corresponding cluster on the left hemisphere (CP1, CP3, CP5, P1, P3, P5, PO3). Both main effects as well as the interaction were not significant [all $F s_{(1, 24)} < 1.81, p > 0.19, \eta_p^2 < 0.08$].

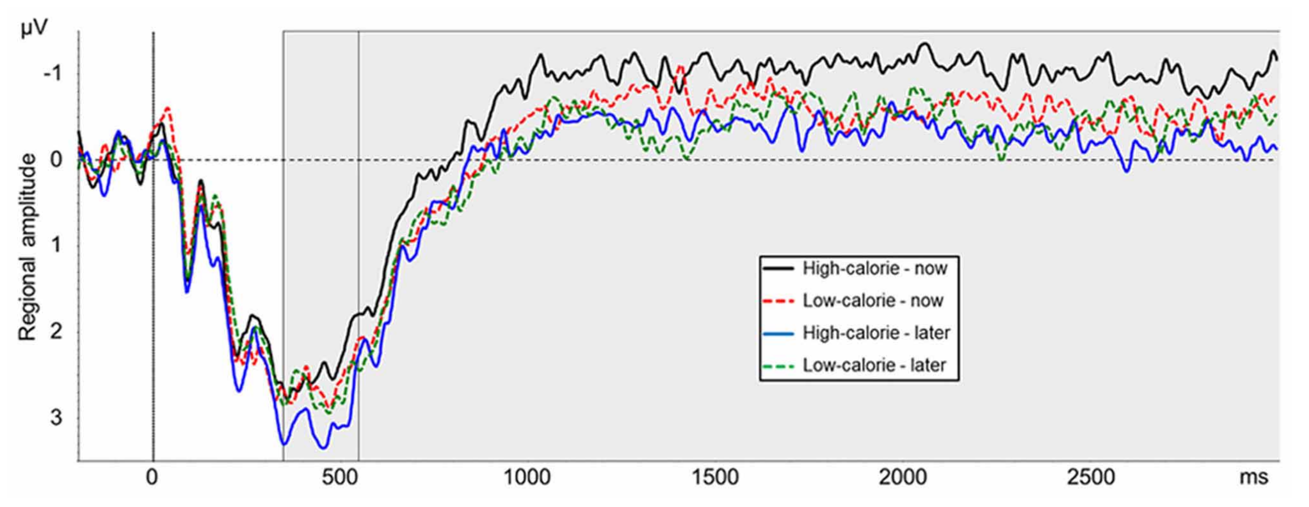

FIGURE 6 | Mean amplitude of pooled ERPs of a centro-parieto-occipital cluster (CP2, CP4, CP6, P2, P4, P6, PO4). Gray shaded boxes mark time windows between 350–550 ms and 550–3000 ms.

Slow wave

Amplitudes in the HC-NOW condition were negatively correlated with the RS ($r = -0.40$, $p < 0.05$). Craving ratings in the LC-LATER condition were positively correlated with amplitudes in the HC-NOW ($r = 0.40$, $p < 0.05$) and LC-NOW condition ($r = 0.47$, $p < 0.05$).

DISCUSSION

The current study investigated the electrophysiological correlates of food-cue processing during craving regulation. For this purpose, we used pictures of high- vs. low-calorie foods which did not differ in normative palatability ratings and physical characteristics. A first finding was that early neural processing differed between pictures of high- and low-caloric foods and was not modulated by cognitive regulation. LC food pictures elicited a larger negativity than HC food pictures at occipital sites between 150 and 200 ms after stimulus onset. This finding replicates prior studies with regard to time range, polarity and topography (Toepel et al., 2009; Frank et al., 2010) and suggests that visual areas support an early attentional discrimination of caloric content of food, possibly due to its relevance for survival. In addition, a main effect of calorie content could be observed for LPP amplitude in a left-hemispheric centro-parietal cluster (see Footnote 1), replicating that differences in the processing of HC and LC food-cues can also be found in later stages of food-cue processing and brain areas other than the occipital lobe (Toepel et al., 2009; Frank et al., 2010). It appears that the brain tracks the energetic value of food images and it is unlikely that differences emerged as a result of palatability of those foods or physical characteristics of the pictures. Yet, pictures of HC foods often display processed foods and prepared meals while pictures of LC foods often include whole foods which need to be prepared for eating. Thus, picture categories may not have differed in visual complexity but maybe in complexity with regard to content and food composition. Future studies are needed in which HC and LC food pictures are matched in this regard.

Overall, participants reported higher food craving after the task as compared to before which is a common finding when individuals are engaged in a cognitive task involving appealing food pictures (e.g., Meule et al., 2012c). Evaluations of food craving after each trial, however, revealed that perspective effects depended on caloric content. As expected, for HC foods, thinking about the long-term consequences decreased craving. For LC foods, by contrast, thinking about the long-term consequences *in*creased craving. This finding offers some interesting avenues of intervention toward inducing healthier food choices through cognitive strategies. Furthermore, the current study supports prior findings by showing that HC foods are not necessarily craved and perceived as appealing, but that contextual frames can easily influence if HC foods are associated with palatable or unhealthy (Roefs et al., 2006).

LPP amplitudes reflect the dynamic changes of attentional-motivational processing. When participants were instructed to think about the long-term effects of eating high caloric foods, craving was lowest, and LPP amplitude in a right-hemispheric centro-parietal cluster was enlarged relative to all other conditions. This finding is surprising on first sight because heightened LPP amplitude is considered to reflect motivated attention toward rewarding stimuli like drugs or food, possibly indicating increased craving for those cues (Field et al., 2009; Blechert et al., 2010; Svaldi et al., 2010; Littel et al., 2012; Nijs and Franken, 2012). Indeed, self-rated craving correlated with LPP amplitudes in all conditions. However, affective picture processing research suggests that LPP amplitude is driven by arousal regardless of valence (Olofsson et al., 2008; Hajcak et al., 2010). Thus, in the present data increased LPP amplitude in the HC-LATER condition could also reflect arousal, as it arises from negative thoughts about averse long-term effects of eating HC foods.

In accordance with ERP studies on craving regulation in substance abuse (Littel and Franken, 2011) we followed-up the development of LPP amplitudes during later processing stages. Between 550 and 3000 ms after stimulus onset, the slow wave amplitude was less positive when participants were instructed to think about the immediate, pleasurable effects of eating HC foods (i.e., in the HC-NOW condition) as compared to all other conditions, possibly due to a late motivational engagement with the appetitive value of HC foods. Amplitude in the HC-LATER condition, by contrast, which had been increased in the LPP time range was reduced to the level of the LC conditions during the slow wave time window. Although craving ratings were not systematically correlated with ERP amplitudes in this time range, we would speculate that this pattern of ERP amplitude changes may indicate successful regulation of craving. This interpretation would mirror results of the study by Littel and Franken (2011) in which the application of cognitive craving regulation strategies initially led to increased LPP amplitudes in response to smoking pictures, but to attenuated amplitudes in a late LPP (slow wave) time window.

Finally, scores on the emotional eating subscale of the DEBQ were positively correlated with LPP amplitudes across all conditions. This suggests that individuals who habitually exhibit emotional eating behavior may show a chronic vigilance and enhanced attentional processing of food in general due to its relevance for emotion regulation and behavioral control. While this interpretation is limited by the absence of a neutral control condition in the present study, it is in line with a recent study in which heightened LPP amplitudes in response to food-cues could also be observed in high emotional eaters as compared to low emotional eaters (Blechert et al., in revision).

The current study has several limitations. First, although most participants indicated after the task that they were able to effectively use the regulation strategies, it would have been beneficial to assess regulation success after each trial, as has been done in other studies (e.g., Hollmann et al., 2012). This would allow for condition-wise analyses of ERPs in relation to regulation success. Second, we did not have a neutral condition, i.e., showing pictures of neutral objects or presenting the food-cues without a craving regulation instruction. While some studies found that successful down-regulation of negative emotions or craving may reduce late LPP to the level of neutral images (e.g., Littel and Franken, 2011; Thiruchselvam et al., 2011), this effect cannot be evaluated in the current study. However, the instructional frame would not work sensibly with non-edible images. Third, HC and LC food pictures did not differ in palatability based on normative ratings. While this is an advantage because any ERP differences between categories are probably due to calorie content, future studies may use bland food items as a further control condition. Fourth, all participants were presented with the very same food pictures. Naturally, there are individual differences in food preference and, therefore, specific kinds of food pictures trigger different responses in different individuals. Likewise, a recent study emphasizes the importance of using idiosyncratic food-cues, i.e., determining individually craved foods, in craving regulation studies (Giuliani et al., 2013). Yet, an overall increase in craving across the task indicated that most participants experienced the food stimuli as appealing. Finally, participants were moderately hungry in the current study. As a result, effects of homeostatic hunger might have attenuated differential correlations of eating behavior traits like emotional or restrained eating which are reflective of the more hedonic aspects of hunger (cf. Lowe and Butryn, 2007; Lowe, 2009). Thus, future studies may benefit from including conditions in which participants are either hungry or satiated while regulating their cravings.

Several future directions appear promising. First, future studies could examine conditions that involve either compromised or pathologically enhanced craving regulation (e.g., patients with bulimia nervosa/binge eating disorder and anorexia nervosa, respectively). Second, external validity might be enhanced by incorporating actual eating into the task, for example by manipulating food availability (e.g., Werthmann et al., 2013). Some recent studies found differences in psychophysiological responses to food stimuli when foods that were immediately available to eat were contrasted to foods that were unavailable to eat (Blechert et al., 2010; Rejeski et al., 2010). For instance, available foods elicited an elevated hemodynamic response in reward-related brain areas as compared to unavailable foods (Richter et al., 2013). Thus, effects of craving regulation might interact with actual availability of the displayed foods and regulation effects observed in available conditions would probably be more representative of daily life eating situations. Finally, we investigated only one strategy for the downregulation of craving but future research might pit several strategies against each other (cf. Giuliani et al., 2013; Yokum and Stice, 2013) to inspire the development of specific and evidence based treatments. Distraction, for example, was shown to impact emotional processing earlier than reappraisal (e.g., Thiruchselvam et al., 2011) and might modulate even the early stages of attentional processing that were immune to reappraisal in the present study.

To conclude, subsequent to an early processing stage, reflecting attentional analysis of energy content, both neural and experiential food-cues responses are modulated by cognitive regulation. Mediated by a dynamic neural activation pattern that might have engaged both aversive imagery and appetitive processing, experienced cravings were influenced in an advantageous direction: low calorie foods were craved more and high calorie foods were craved less under a long-term perspective. Thus, habitually using such cognitive strategies might result in healthier food choice and eating behaviors.

AUTHOR CONTRIBUTIONS

Adrian Meule and Jens Blechert designed this study and performed data analyses. Adrian Meule wrote the first draft of the manuscript. Jens Blechert and Andrea Kübler revised the manuscript for content and approved the final version of the manuscript.

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REFERENCES

Asmaro, D., Jaspers-Fayer, F., Sramko, V., Taake, I., Carolan, P., and Liotti, M. (2012). Spatiotemporal dynamics of the hedonic processing of chocolate images in individuals with and without trait chocolate craving. *Appetite* 58, 790–799. doi: 10.1016/j.appet.2012.01.030

Blechert, J., Feige, B., Hajcak, G., and Tuschen-Caffier, B. (2010). To eat or not to eat? Availability of food modulates the electrocortical response to food pictures in restrained eaters. *Appetite* 54, 262–268. doi: 10.1016/j.appet.2009.11.007

Blechert, J., Feige, B., Joos, A., Zeeck, A., and Tuschen-Caffier, B. (2011). Electrocortical processing of food and emotional pictures in anorexia nervosa and bulimia nervosa. *Psychosom. Med.* 73, 415–421. doi: 10.1097/PSY.0b013e318211b871

Carnell, S., Gibson, C., Benson, L., Ochner, C. N., and Geliebter, A. (2012). Neuroimaging and obesity: current knowledge and future directions. *Obes. Rev.* 13, 43–56. doi: 10.1111/j.1467-789X.2011.00927.x

Carter, J. C., Stewart, D. A., and Fairburn, C. G. (2001). Eating disorder examination questionnaire: norms for young adolescent girls. *Behav. Res. Ther.* 39, 625–632. doi: 10.1016/S0005-7967(00)00033-4

Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., and Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behav. Ther.* 31, 151–173. doi: 10.1016/S0005-7894(00)80009-X

Cohen, D. A., and Babey, S. H. (2012). Contextual influences on eating behaviours: heuristic processing and dietary choices. *Obes. Rev.* 13, 766–779. doi: 10.1111/j.1467-789X.2012.01001.x

Cohen, D. A., and Farley, T. A. (2008). Eating as an automatic behavior. *Prev. Chronic Dis.* 5, 1–7.

Dinkel, A., Berth, H., Exner, C., Rief, W., and Balck, F. (2005). Deutsche adaptation der restraint scale zur erfassung gezügelten essverhaltens. *Diagnostica* 51, 67–74. doi: 10.1026/0012-1924.51.2.67

Fairburn, C. G., and Beglin, S. J. (1994). Assessment of eating disorders: interview or self-report questionnaire? *Int. J. Eat. Disord.* 16, 363–370.

Ferree, T. C., Luu, P., Russell, G. S., and Tucker, D. M. (2001). Scalp electrode impedance, infection risk, and EEG data quality. *Clin. Neurophysiol.* 112, 536–544. doi: 10.1016/S1388-2457(00)00533-2

Field, M., Munafò, M. R., and Franken, I. H. A. (2009). A meta-analytic investigation of the relationship between attentional bias and subjective craving in substance abuse. *Psychol. Bull.* 135, 589–607. doi: 10.1037/a0015843

Frank, S., Laharnar, N., Kullmann, S., Veit, R., Canova, C., Hegner, Y. L., et al. (2010). Processing of food pictures: influence of hunger, gender and calorie content. *Brain Res.* 1350, 159–166. doi: 10.1016/j.brainres.2010.04.030

García-García, I., Narberhaus, A., Marqués-Iturria, I., Garolera, M., Rădoi, A., Segura, B., et al. (2013). Neural responses to visual food cues: insights from functional magnetic resonance imaging. *Eur. Eat. Disord. Rev.* 21, 89–98. doi: 10.1002/erv.2216

Giuliani, N. R., Calcott, R. D., and Berkman, E. T. (2013). Piece of cake. Cognitive reappraisal of food craving. *Appetite* 64, 56–61. doi: 10.1016/j.appet.2012.12.020

Grunert, S. C. (1989). Ein inventar zur erfassung von selbstaussagen zum ernährungsverhalten. *Diagnostica* 35, 167–179.

Hajcak, G., Macnamara, A., and Olvet, D. M. (2010). Event-related potentials, emotion, and emotion regulation: an integrative review. *Dev. Neuropsychol*. 35, 129–155. doi: 10.1080/87565640903526504

Herman, C. P., and Polivy, J. (1980). "Restrained eating," in *Obesity*, ed A. J. Stunkard (Philadelphia, PA: Saunders), 208–225.

Hilbert, A., Tuschen-Caffier, B., Karwautz, A., Niederhofer, H., and Munsch, S. (2007). Eating disorder examination-questionnaire: evaluation der deutschsprachigen Übersetzung. *Diagnostica* 53, 144–154. doi: 10.1026/0012-1924.53.3.144

Hollmann, M., Hellrung, L., Pleger, B., Schlogl, H., Kabisch, S., Stumvoll, M., et al. (2012). Neural correlates of the volitional regulation of the desire for food. *Int. J. Obes*. 36, 648–655. doi: 10.1038/ijo.2011.125

Kenny, P. J. (2011). Reward mechanisms in obesity: new insights and future directions. *Neuron* 69, 664–679. doi: 10.1016/j.neuron.2011.02.016

Killgore, W. D. S., Young, A. D., Femia, L. A., Bogorodzki, P., Rogowska, J., and Yurgelun-Todd, D. A. (2003). Cortical and limbic activation during viewing of high- versus low-calorie foods. *Neuroimage* 19, 1381–1394. doi: 10.1016/S1053-8119(03)00191-5

Kober, H., Kross, E. F., Mischel, W., Hart, C. L., and Ochsner, K. N. (2010a). Regulation of craving by cognitive strategies in cigarette smokers. *Drug Alcohol Depend*. 106, 52–55. doi: 10.1016/j.drugalcdep.2009.07.017

Kober, H., Mende-Siedlecki, P., Kross, E. F., Weber, J., Mischel, W., Hart, C. L., et al. (2010b). Prefrontal-striatal pathway underlies cognitive regulation of craving. *Proc. Natl. Acad. Sci. U.S.A.* 107, 14811–14816. doi: 10.1073/pnas.1007779107

Langeslag, S. J. E., and Van Strien, J. W. (2010). Comparable modulation of the Late Positive Potential by emotion regulation in younger and older adults. *J. Psychophysiol*. 24, 186–197. doi: 10.1027/0269-8803/a000009

Legenbauer, T., Vögele, C., and Rüddel, H. (2004). Anticipatory effects of food exposure in women diagnosed with bulimia nervosa. *Appetite* 42, 33–40. doi: 10.1016/S0195-6663(03)00114-4

Littel, M., Euser, A. S., Munafò, M. R., and Franken, I. H. A. (2012). Electrophysiological indices of biased cognitive processing of substance-related cues: a meta-analysis. *Neurosci. Biobehav. Rev*. 36, 1803–1816. doi: 10.1016/j.neubiorev.2012.05.001

Littel, M., and Franken, I. H. A. (2011). Intentional modulation of the Late Positive Potential in response to smoking cues by cognitive strategies in smokers. *PLoS ONE* 6:e27519. doi: 10.1371/journal.pone.0027519

Lowe, M. R. (2003). Self-regulation of energy intake in the prevention and treatment of obesity: is it feasible? *Obes. Res*. 11, 44S–59S. doi: 10.1038/oby.2003.223

Lowe, M. R. (2009). Commentary on: "Neurobehavioral inhibition of reward-driven feeding: implications for dieting and obesity." *Obesity* 17, 622–624. doi: 10.1038/oby.2008.639

Lowe, M. R., and Butryn, M. L. (2007). Hedonic hunger: a new dimension of appetite? *Physiol. Behav*. 91, 432–439. doi: 10.1016/j.physbeh.2007.04.006

Meule, A., and Blechert, J. (2012). Food.pics: a picture database for the study of eating and appetite. *Obes. Facts* 5, 20.

Meule, A., Lutz, A., Vögele, C., and Kübler, A. (2012a). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters. Validation of the Food Craving Questionnaires in German. *Appetite* 58, 88–97. doi: 10.1016/j.appet.2011.09.010

Meule, A., Lutz, A., Vögele, C., and Kübler, A. (2012b). Self-reported dieting success is associated with cardiac autonomic regulation in current dieters. *Appetite* 59, 494–498. doi: 10.1016/j.appet.2012.06.013

Meule, A., Skirde, A. K., Freund, R., Vögele, C., and Kübler, A. (2012c). High-calorie food-cues impair working memory performance in high and low food cravers. *Appetite* 59, 264–269. doi: 10.1016/j.appet.2012.05.010

Mond, J., Hay, P., Rodgers, B., and Owen, C. (2006). Eating Disorder Examination Questionnaire (EDE-Q): norms for young adult women. *Behav. Res. Ther*. 44, 53–62. doi: 10.1016/j.brat.2004.12.003

Nederkoorn, C., Smulders, F. T. Y., and Jansen, A. (2000). Cephalic phase responses, craving and food intake in normal subjects. *Appetite* 35, 45–55. doi: 10.1006/appe.2000.0328

Nijs, I. M. T., and Franken, I. H. (2012). Attentional processing of food cues in overweight and obese individuals. *Curr. Obes. Rep*. 1, 106–113. doi: 10.1007/s13679-012-0011-1

Nijs, I. M. T., Franken, I. H., and Muris, P. (2008). Food cue-elicited brain potentials in obese and healthy-weight individuals. *Eat. Behav*. 9, 462–470. doi: 10.1016/j.eatbeh.2008.07.009

Nijs, I. M. T., Franken, I. H. A., and Muris, P. (2009). Enhanced processing of food-related pictures in female external eaters. *Appetite* 53, 376–383. doi: 10.1016/j.appet.2009.07.022

Nijs, I. M. T., Muris, P., Euser, A. S., and Franken, I. H. A. (2010). Differences in attention to food and food intake between overweight/obese and normal-weight females under conditions of hunger and satiety. *Appetite* 54, 243–254. doi: 10.1016/j.appet.2009.11.004

Olofsson, J. K., Nordin, S., Sequeira, H., and Polich, J. (2008). Affective picture processing: an integrative review of ERP findings. *Biol. Psychol*. 77, 247–265. doi: 10.1016/j.biopsycho.2007.11.006

Rejeski, W. J., Blumenthal, T. D., Miller, G. D., Lobe, M., Davis, C., and Brown, L. (2010). State craving, food availability, and reactivity to preferred snack foods. *Appetite* 54, 77–83. doi: 10.1016/j.appet.2009.09.009

Richter, S., Klackl, J., Wilhelm, F. H., and Blechert, J. (2013). "It is right here and waiting for you: effects of food availability on reward system activity during food picture viewing," in *Abstracts of the 55th Conference of Experimental Psychologists*, eds U. Ansorge, E. Kirchler, C. Lamm, and H. Leder (Lengerich: Pabst Science Publishers), 227.

Rodríguez, S., Fernandez, M. C., Cepeda-Benito, A., and Vila, J. (2005). Subjective and physiological reactivity to chocolate images in high and low chocolate cravers. *Biol. Psychol*. 70, 9–18. doi: 10.1016/j.biopsycho.2004.10.001

Roefs, A., Quaedackers, L., Werrij, M. Q., Wolters, G., Havermans, R., Nederkoorn, C., et al. (2006). The environment influences whether high-fat foods are associated with palatable or with unhealthy. *Behav. Res. Ther*. 44, 715–736. doi: 10.1016/j.brat.2005.05.007

Scharmüller, W., Übel, S., Ebner, F., and Schienle, A. (2012). Appetite regulation during food cue exposure: a comparison of normal-weight and obese women. *Neurosci. Lett*. 518, 106–110. doi: 10.1016/j.neulet.2012.04.063

Schupp, H. T., Flaisch, T., Stockburger, J., and Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Prog. Brain Res*. 156, 31–51. doi: 10.1016/S0079-6123(06)56002-9

Siep, N., Roefs, A., Roebroeck, A., Havermans, R., Bonte, M. L., and Jansen, A. (2009). Hunger is the best spice: an fMRI study of the effects of attention, hunger and calorie content on food reward processing in the amygdala and orbitofrontal cortex. *Behav. Brain Res*. 198, 149–158. doi: 10.1016/j.bbr.2008.10.035

Siep, N., Roefs, A., Roebroeck, A., Havermans, R., Bonte, M., and Jansen, A. (2012). Fighting food temptations: the modulating effects of short-term cognitive reappraisal, suppression and up-regulation on mesocorticolimbic activity related to appetitive motivation. *Neuroimage* 60, 213–220. doi: 10.1016/j.neuroimage.2011.12.067

Stockburger, J., Hamm, A. O., Weike, A. I., and Schupp, H. T. (2008). Deprivation selectively modulates brain potentials to food pictures. *Behav. Neurosci*. 122, 936–942. doi: 10.1037/a0012517

Stockburger, J., Renner, B., Weike, A. I., Hamm, A. O., and Schupp, H. T. (2009a). Vegetarianism and food perception. Selective visual attention to meat pictures. *Appetite* 52, 513–516. doi: 10.1016/j.appet.2008.10.001

Stockburger, J., Schmälzle, R., Flaisch, T., Bublatzky, F., and Schupp, H. T. (2009b). The impact of hunger on food cue processing: an event-related brain potential study. *Neuroimage* 47, 1819–1829. doi: 10.1016/j.neuroimage.2009.04.071

Svaldi, J., Tuschen-Caffier, B., Peyk, P., and Blechert, J. (2010). Information processing of food pictures in binge eating disorder. *Appetite* 55, 685–694. doi: 10.1016/j.appet.2010.10.002

Thiruchselvam, R., Blechert, J., Sheppes, G., Rydstrom, A., and Gross, J. J. (2011). The temporal dynamics of emotion regulation: an EEG study of distraction and reappraisal. *Biol. Psychol*. 87, 84–92. doi: 10.1016/j.biopsycho.2011.02.009

Toepel, U., Knebel, J. F., Hudry, J., Le Coutre, J., and Murray, M. M. (2009). The brain tracks the energetic value in food images. *Neuroimage* 44, 967–974. doi: 10.1016/j.neuroimage.2008.10.005

van Strien, T., Frijters, J. E. R., Bergers, G. P. A., and Defares, P. B. (1986). The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *Int. J. Eat. Disord*. 5, 295–315. doi: 10.1002/1098-108x(198602)5:2<295::AID-EAT2260050209>3.0Co;2-T

Wang, G. J., Volkow, N. D., Telang, F., Jayne, M., Ma, J., Rao, M. L., et al. (2004). Exposure to appetitive food stimuli markedly activates the human brain. *Neuroimage* 21, 1790–1797. doi: 10.1016/j.neuroimage.2003.11.026

Wang, G. J., Volkow, N. D., Telang, F., Jayne, M., Ma, Y. M., Pradhan, K., et al. (2009). Evidence of gender differences in the ability to inhibit brain activation elicited by food stimulation. *Proc. Natl. Acad. Sci. U.S.A.* 106, 1249–1254. doi: 10.1073/pnas.0807423106

Werthmann, J., Roefs, A., Nederkoorn, C., and Jansen, A. (2013). Desire lies in the eyes: attention bias for chocolate is related to craving and self-endorsed eating permission. *Appetite* 70, 81–89. doi: 10.1016/j.appet.2013.06.087

Yokum, S., and Stice, E. (2013). Cognitive regulation of food craving: effects of three cognitive reappraisal strategies on neural response to palatable foods. *Int. J. Obes*. doi: 10.1038/ijo.2013.39. [Epub ahead of print].

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Abstract: Heart rate variability (HRV) biofeedback has been reported to increase HRV while decreasing symptoms in patients with mental disorders. In addition, associations between low HRV and lowered self-regulation were found in non-clinical samples, e.g., in individuals with strong chocolate cravings or unsuccessful dieting. The current study aimed at decreasing food cravings with HRV-biofeedback in individuals frequently experiencing such cravings. Participants (N = 56) with strong or low food cravings associated with a lack of control over eating were selected from the local community. Half of the participants with strong cravings (craving-biofeedback; n = 14) performed 12 sessions of HRV-biofeedback while the other half (craving-control; n = 14) and a group with low cravings (non-craving-control; n = 28) received no intervention. Subjective food cravings related to a lack of control over eating decreased from pre- to post-measurement in the craving-biofeedback group, but remained constant in the control groups. Moreover, only the craving-biofeedback group showed a decrease in eating and weight concerns. Although HRV-biofeedback was successful in reducing food cravings, this change was not accompanied by an increase in HRV. Instead, HRV decreased in the craving-control group. This study provides preliminary evidence that HRV-biofeedback could be beneficial for attenuating dysfunctional eating behavior although specific mechanisms remain to be elucidated.

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Heart Rate Variability Biofeedback Reduces Food Cravings in High Food Cravers

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Abstract Heart rate variability (HRV) biofeedback has been reported to increase HRV while decreasing symptoms in patients with mental disorders. In addition, associations between low HRV and lowered self-regulation were found in non-clinical samples, e.g., in individuals with strong chocolate cravings or unsuccessful dieting. The current study aimed at decreasing food cravings with HRV-biofeedback in individuals frequently experiencing such cravings. Participants ($N = 56$) with strong or low food cravings associated with a lack of control over eating were selected from the local community. Half of the participants with strong cravings (craving-biofeedback; $n = 14$) performed 12 sessions of HRV-biofeedback while the other half (craving-control; $n = 14$) and a group with low cravings (non-craving-control; $n = 28$) received no intervention. Subjective food cravings related to a lack of control over eating decreased from pre- to post-measurement in the craving-biofeedback group, but remained constant in the control groups. Moreover, only the craving-biofeedback group showed a decrease in eating and weight concerns. Although HRV-biofeedback was successful in reducing food cravings, this change was not accompanied by an increase in HRV. Instead, HRV decreased in the craving-control group. This study provides preliminary evidence that HRV-biofeedback could be beneficial for attenuating dysfunctional eating behavior although specific mechanisms remain to be elucidated.

Keywords Food cravings · Eating behavior · Cardiac autonomic regulation · Heart rate variability · Biofeedback

Introduction

Heart rate variability (HRV) refers to the variation of heart beat intervals and is influenced by sympathetic and parasympathetic input to the sino-atrial node of the heart. Increased parasympathetically (or vagally) mediated modulations increase HRV while increased sympathetic activation (or sympathovagal imbalance) decreases HRV (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology 1996). HRV is associated with overall health and several physical conditions (Britton and Hemingway 2004; Thayer et al. 2010). For instance, frequent exercise positively influences HRV while unhealthy behaviors like smoking or alcohol consumption decrease HRV (Britton and Hemingway 2004; Thayer et al. 2010). Beyond indexing physical health, HRV has also been suggested as an endophenotype of self- and emotion-regulation (Appelhans and Luecken 2006; Thayer and Lane 2009). Accordingly, attenuated vagal-cardiac control has been associated with several mental disorders such as depression and anxiety (see Appelhans and Luecken 2006 for a review), posttraumatic stress disorder (PTSD; Blechert et al. 2007) or alcohol abuse (Thayer et al. 2006). In a sample of alcohol-dependent patients, reduced HRV was particularly pronounced in patients reporting strong substance cravings (Ingjaldsson et al. 2003).

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In relation to eating behavior, body weight is inversely related to HRV such that underweight patients (e.g., those with anorexia nervosa) have high HRV, while obesity is accompanied by low HRV (Karason et al. 1999; Latchman et al. 2011; Mazurak et al. 2011). Accordingly, weight loss is associated with an increase in HRV (Karason et al. 1999). Few studies have examined HRV as a marker of eating-related self-regulation that is independent of current body mass. Vögele et al. (2009) investigated a sample of patients with bulimia nervosa and classified those as individuals with current dietary restriction or without dietary restriction according to their biochemical profile. Only fasting women presented with increased vagal-cardiac control as compared to healthy controls; BMI, however was equal in both groups (Coles et al. 2005; Vögele et al. 2009). The authors speculated that current fasting status with accompanying parasympathetic dominance could be an index of successful eating-related self-regulation. Another study compared HRV between obese patients with binge eating disorder (BED) and those without BED (Friederich et al. 2006). Although there was no baseline difference between groups, an augmented reduction of vagal-cardiac control was observed in obese patients with BED when mentally challenged which was also correlated to binge eating frequency (Friederich et al. 2006).

Recent studies investigated HRV in non-clinical, normal-weight samples, particularly its relationship to food cravings. Food cravings refer to an urgent desire, longing, or yearning for a particular kind of food which most often involves chocolate (Weingarten and Elston 1990, 1991). Rodríguez-Ruiz et al. (2009) found an association between low HRV and eating disorder symptoms in trait chocolate cravers. In a subsequent study, low HRV was associated with increased eye-blink startle magnitude in women with bulimic symptoms and frequent food cravings, which is suggestive of reduced emotion regulation abilities and inhibitory control (Rodríguez-Ruiz et al. 2012). Accordingly, frequent experiences of food cravings are strongly related to reduced eating-related self-regulation such as unsuccessful dieting or binge eating (Meule et al. 2011, 2012a). HRV was also positively correlated with dieting success (Meule et al. 2012c, in revision). Taken together, these results suggest a positive association between HRV and successful self-regulation of eating behavior.

One approach to train vagal-cardiac control is HRV-biofeedback (Lehrer et al. 2000). Here, participants receive feedback of their respiratory sinus arrhythmia (RSA) amplitude. The aim is to increase RSA amplitude by breathing in resonance frequency (Lehrer et al. 2000). Individual resonance frequency depends on blood volume (Vaschillo et al. 2006), but usually is approximately .1 Hz or 6 breaths per minute (Vaschillo et al. 2002, 2004). Breathing in resonance frequency has been found to cause resonance in the cardiovascular system, thereby increasing HRV and baroreflex gain (Lehrer et al. 2003, 2006).

HRV-biofeedback has been demonstrated to successfully reduce symptoms in patients with physical conditions or mental disorders (Wheat and Larkin 2010). For instance, symptom reductions could be observed after HRV-biofeedback in patients with depression (Karavidas et al. 2007; Siepmann et al. 2008) or PTSD (Tan et al. 2011; Zucker et al. 2009). Notably, in the study by Zucker et al. (2009), there was a trend toward a decrease of drug cravings in the HRV-biofeedback group, although this was not specifically targeted. This finding may be particularly relevant for the application of HRV-biofeedback in relation to eating behavior as considerable evidence indicates common mechanisms underlying the experience of craving across addictions, e.g., food or drugs (Kühn and Gallinat 2011; Pelchat et al. 2004).

Based on these findings, the current study investigated if HRV-biofeedback is also useful to alter deregulated eating behavior. For this purpose, we trained with HRV-biofeedback a group with individuals that reported to frequently experience food cravings with concurrent lack of control over eating behavior. We compared this group to control groups with either high or low cravings, who did not receive an intervention. We expected an increase of vagal-cardiac control accompanied by a decrease of food cravings and increase of experienced control over eating behavior after the biofeedback intervention. Furthermore, we also explored whether HRV biofeedback had an influence on emotion regulation strategies and locus of control, as a positive effect has been reported by other biofeedback-assisted relaxation techniques (e.g., Sharp et al. 1997). All investigated parameters were expected to remain unchanged in the two control groups.

Methods

Participants

An online screening was conducted to recruit high and low food cravers. A link of the screening homepage was distributed via students' mailing lists of the University of Würzburg and an advertisement on a local website for inhabitants of Würzburg, Germany. The screening homepage included the subscale *lack of control over eating* of the *Food Cravings Questionnaire—Trait* (FCQ-T; see below). This subscale represents a major feature of food cravings and was chosen to keep the screening succinct. As an incentive for participation, 3 × 10,—Euro were raffled off among participants who completed the entire set of questions ($N = 603$).

Participants who indicated that they were interested in participating in a further study and whose questionnaire scores were in the upper and lower third of the distribution were contacted by e-mail. Inclusion criteria were normal- or over-weight (BMI = 18.50–29.99 kg/m^2, cf. World Health Organization 2000) and an age between 18 and 40 years. Of all individuals who were contacted, $n = 56$ (high cravers: $n = 28$, four males; low cravers: $n = 28$, five males) met these criteria and agreed to take part in the study. Participants had a mean age of M = 24.12 years (SD = 3.79) and a mean BMI of M = 22.65 kg/m^2 (SD = 3.19). None of the participants reported diagnoses of mental disorders. The majority of participants were students ($n = 40$). All participants were tested twice with an interval of 4 weeks between pre- and post-measurement. Half of the high cravers ($n = 14$, one male) were pseudo-randomly[1] assigned to the biofeedback group which performed HRV-biofeedback between the two measurements. Participants in the biofeedback group received 30 Euro for participation, and participants in the control groups received 10 Euro.

Questionnaires

Food Cravings Questionnaire—Trait

Habitual food cravings were assessed with the FCQ-T (Cepeda-Benito et al. 2000; Meule et al. 2012a). This 39-item instrument asks participants to indicate on a 6-point scale how frequently they experience food cravings (ranging from *never* to *always*). The FCQ-T consists of 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. Subscales are highly inter-correlated and internal consistency of the total FCQ-T is $\alpha > .90$ (Cepeda-Benito et al. 2000; Meule et al. 2012a) and was $\alpha = .97$ in the current sample.

Eating Disorder Examination Questionnaire

Eating disorder symptomatology was assessed with the questionnaire version of the Eating Disorder Examination (EDE-Q; Fairburn and Beglin 1994; Hilbert and Tuschen-Caffier 2006). This 28-item instrument asks about eating disorder symptomatology during the past 28 days. Of these, 22 items assess *restraint*, *eating concerns*, *weight concerns*, and *shape concerns* on a 7-point scale (ranging from *never* to *every day*). Subscales have an internal consistency of $\alpha = .85$–.93 (Hilbert et al. 2007) and was $\alpha = .82$–.93 in the current sample. The remaining 6 questions assess overeating, binge frequency, days with binges, self-induced vomiting, use of laxatives, and compulsive exercising.

Yale Food Addiction Scale

Food addiction symptoms were assessed with the Yale Food Addiction Scale (YFAS; Gearhardt et al. 2009; Meule et al. in press-a). This 25-item instrument contains different scoring options (dichotomous and frequency scoring) to indicate experience of addictive eating behavior. A food addiction symptom count can be calculated which ranges between zero and seven symptoms, according to the diagnostic criteria for substance dependence (Gearhardt et al. 2009). Internal consistency of the YFAS is $\alpha > .80$ (Gearhardt et al. 2009; Meule et al. in press-a) and was $\alpha = .81$ in the current sample.

Perceived Self-Regulatory Success in Dieting

Dieting success was assessed with the Perceived Self-Regulatory Success in Dieting Scale (PSRS; Fishbach et al. 2003; Meule et al. 2012b). This three-item scale asks participants to rate on a 7-point scale how successful they are in watching their weight or losing extra weight and how difficult it is for them to stay in shape. Internal consistency of the PSRS is $\alpha > .70$ (Meule et al. 2012b) and was $\alpha = .72$ in the current sample.

Emotion Regulation Questionnaire

Emotion regulation strategies were assessed with the Emotion Regulation Questionnaire (ERQ; Abler and Kessler 2009; Gross and John 2003). This 10-item questionnaire assesses the use of *cognitive reappraisal* and *suppression* with a 7-point scale. Internal consistencies of the subscales are $\alpha > .70$ (Abler and Kessler 2009; Gross and John 2003) and were $\alpha = .78$ (suppression) and $\alpha = .77$ (reappraisal) in the current sample.

Locus of Control

Locus of control was assessed with the IPC-scales (Krampen 1981; Levenson 1973). This 24-item questionnaire consists of a subscale for *internal locus of control* (I) and two subscales for external locus of control

[1] Initially, participants who were identified as high cravers were randomly assigned to either the biofeedback or the control group. However, when participants assigned to the biofeedback group were contacted and told that the study would require several lab visits for 4 weeks (further details were not mentioned), $n = 3$ participants indicated that they could not participate in the study because of time constraints. Those participants were then assigned to the control group.

(P: *powerful others*, C: *chance orientations*). Subjects indicate on a 6-point scale the extent to which they believe to have control over their own life, they think they are dependent on powerful others and their perceptions of chance control. Internal consistencies of the subscales are $\alpha > .90$ (Krampen 1981) and ranged between $\alpha = .67$ and .69 in the current sample.

Participant Characteristics

Subjects were asked to report their age, gender, smoking status (smoker vs. non-smoker), and hours that elapsed since their last meal. They also indicated their level of physical activity ("How often do you work out?") on an 8-point scale ranging from *never* to *everyday*.

Heart Rate Recording

Heart rate was monitored with the Polar watch RS800CX (Polar Electro Oy, Kempele, Finland), which has a sampling rate of 1000 Hz. After attaching the chest strap, participants were seated in a quiet room. Subsequently, the experimenter instructed participants to close their eyes and relax and left the room for 10 min.

HRV-Biofeedback

HRV-biofeedback was applied using the Stress Pilot version 1.3.03 (Biocomfort Diagnostics GmbH & Co.KG, Wendingen, Germany). This device measures blood volume in the earlobe and calculates heart rate and HRV-indices. Participants are instructed to breath in accordance with a pacing bar that corresponds to the resonance frequency, thereby maximizing RSA. Feedback of RSA is provided in multiple ways, e.g., by a butterfly flying high and calm when RSA is maximal. In the first session, participants were informed about the feedback procedure according to the manual from Lehrer et al. (2000). The deep breathing test (Löllgen et al. 2009) was conducted to be able to set up individual levels of difficulty as recommended in the program's manual. In every subsequent session, level of difficulty was adjusted based on performance in the previous session. Twelve HRV-biofeedback sessions were conducted, each lasting 20 min. All training sessions took place in the Department of Psychology I (University of Würzburg, Germany) in a quiet room. Performance and possible problems (e.g., hyper- or hypoventilation) were discussed with an experimenter before and after each session.

Procedure

Participants were asked to refrain from eating, drinking caffeinated drinks, and smoking at least 1 h before the first measurement. Individuals in the craving-biofeedback group were told about the health benefits of the HRV-biofeedback procedure, but not that the aim was the reduction of food cravings. After providing instructions and signing informed consent, a 10 min baseline heart rate recording was conducted. Then, participants performed a working memory task with pictures of food and neutral stimuli, which is reported elsewhere (Meule et al. in press-b). Finally, participants completed the questionnaires and height and weight were measured.

Half of the high cravers ($n = 14$) practiced HRV-biofeedback for 4 weeks, while the other half of high cravers ($n = 14$) and the non-craving control group ($n = 28$) received no intervention.

After 4 weeks, the very same routine was conducted as for the first measurement.

Data Analysis

R–R-recordings were analyzed with Kubios HRV 2.0 software (Tarvainen et al. 2009). Interbeat interval series were visually scanned by the experimenter and corrected for artifacts with the default settings of the program. Trend components were removed with the smoothness priors detrending method ($\lambda = 500$). Only the last 5 min of the 10 min heart rate recording were used for calculation of autonomic parameters to ensure that data reflected resting conditions. This time period is sufficient for calculating HRV-indices (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology 1996). Heart period (HP) was calculated as the interval [ms] between successive heart beats. Spectral power was obtained for high frequency (HF: .15–.4 Hz) and low frequency (LF: .04–.15 Hz) components by Fast Fourier Transformation. We used the HF-power to calculate with the following equation an HP-normalized index of RSA (Hayano index or RSAnorm), which has been shown to reflect vagal control independent of sympathetic influences, (cf. Blechert et al. 2007):

$$\text{RSAnorm}(\%) = 100 \times \frac{\sqrt{\text{HF power}}}{\text{mean RR interval}}$$

RSAnorm was not normally distributed and log-transformed (ln) because of skewed distribution.

Univariate ANOVAs were calculated to compare groups with regards to age, physical activity and BMI, as measured in the pre-test. Differences in gender and smoking status (smoker vs. non-smoker) between groups were tested with χ^2-tests. ANOVAs for repeated measures were calculated with group (craving-biofeedback vs. craving-control vs. non-craving-control) as between-subject factor, and time (pre- vs. post-measurement) as within-subject factor for each questionnaire and physiological parameter separately. Post hoc comparisons of significant main effects were performed with Scheffé-tests and interactions with *t*-tests. In case of the *lack of control* subscale of the FCQ-T, the within-factor included three levels, because participants already filled out this scale during the online screening.

We calculated effect sizes for all dependent variables for each group separately, the Standardized Effect Size (SES) and the Standardized Response Mean (SRM) with the following equations (cf. Hinz and Brähler 2011):

$$\mathrm{SES} = \frac{\mathrm{M_1 - M_2}}{\mathrm{SD_1}}$$

$$\mathrm{SRM} = \frac{\mathrm{M_1 - M_2}}{\mathrm{SD_{(T_1 - T_2)}}}$$

In case of the lack of control subscale of the FCQ-T, we calculated another effect size that takes into account a stable baseline phase before an intervention (Guyatt's Responsiveness Index, GRI, cf. Hinz and Brähler 2011):

$$\mathrm{GRI} = \frac{\mathrm{M_1 - M_2}}{\mathrm{SD_{(T_0 - T_1)}}}$$

Effects sizes were evaluated as small (>.2), medium (>.5) or large (>.8) based on the criteria by Cohen (1988).

Results

Means, standard deviations, and interaction effects for each questionnaire and physiological parameters are reported in Table 1. Corresponding effect sizes are reported in Table 2.

Participant Characteristics

Groups did not differ in age ($F_{(2,53)} = .24$, *ns*), BMI ($F_{(2,53)} = .16$, *ns*), physical activity ($F_{(2,53)} = .20$, *ns*), gender distribution ($\chi^2_{(2)} = 1.19$, *ns*), or smoking status ($\chi^2_{(2)} = 1.70$, *ns*).

Questionnaires

Food Cravings Questionnaire

There was a significant main effect for group ($F_{(2,53)} = 36.22$, $p < .001$), indicating higher FCQ-T total scores in the craving-biofeedback (Scheffé $p < .001$) and the craving-control group (Scheffé $p < .001$) compared to the non-craving control group while the two high craving groups did not differ. This group effect was also present in all FCQ-T subscales (all $F's_{(2,53)} > 9.50$, all $p's < .001$). There was further a main effect of time for FCQ-T-total score ($F_{(1,53)} = 12.58$, $p < .01$), and the subscales intentions to eat ($F_{(1,53)} = 24.13$, $p < .001$), positive reinforcement ($F_{(1,53)} = 4.44$, $p < .05$), feelings of hunger ($F_{(1,53)} = 8.96$, $p < .01$), negative affect ($F_{(1,53)} = 4.95$, $p < .05$), and cue-dependent eating ($F_{(1,53)} = 4.68$, $p < .05$), indicating decreases of food cravings. There were further significant interactions of group × time for the FCQ-T-total score, and the subscales lack of control, preoccupation with food, cue-dependent eating, and feelings of guilt (Table 1). For the craving-biofeedback group post hoc *t*-tests indicated reductions in FCQ-T total scores ($t_{(13)} = 2.81$, $p < .05$), and the subscales lack of control ($t_{(13)} = 2.67$, $p < .05$), preoccupation with food ($t_{(13)} = 2.90$, $p < .05$), and feelings of guilt ($t_{(13)} = 2.41$, $p < .05$). There was also a reduction of FCQ-T total scores ($t_{(27)} = 2.90$, $p < .01$) and cue-dependent eating ($t_{(27)} = 3.60$, $p < .01$) in the non-craving group. No changes occurred in the craving-control group. In case of the subscale *lack of control*, no changes were observed in any group between the online screening and the first measurement (Fig. 1). Inspection of Table 2 reveals that effect sizes were mostly medium-to-large in the craving-biofeedback group. Importantly, standardized effects sizes were consistently stronger in the craving-biofeedback group than in both control groups (Fig. 2).

Eating Disorder Examination Questionnaire

There were significant main effects for group on the scales restraint ($F_{(2,53)} = 7.71$, $p < .01$), eating concerns ($F_{(2,53)} = 11.59$, $p < .001$), weight concerns ($F_{(2,53)} = 11.45$, $p < .001$), and shape concerns ($F_{(2,53)} = 7.19$, $p < .01$), indicating higher eating pathology in the craving-biofeedback and the craving-control group compared to the non-craving control group (all Scheffé $p's < .05$). There were also significant main effects for group for self-reported overeating ($F_{(2,53)} = 5.67$, $p < .01$), binge frequency ($F_{(2,53)} = 5.54$, $p < .01$), and days with binges ($F_{(2,53)} = 5.40$, $p < .01$), indicating more frequent binge eating in both craving groups as compared to the non-craving control group (all Scheffé $p's < .01$). The craving groups did not differ from each other. Eating concerns ($F_{(1,53)} = 8.72$, $p < .01$), shape concerns ($F_{(1,53)} = 9.60$, $p < .01$), overeating ($F_{(1,53)} = 9.16$, $p < .01$), binge frequency ($F_{(1,53)} = 7.44$, $p < .01$), and days with binges ($F_{(1,53)} = 4.12$, $p < .05$) decreased with time. There were further significant group × time interactions for eating and weight concerns (Table 1). Post hoc *t* tests indicated a reduction of eating ($t_{(13)} = 2.59$, $p < .05$) and weight concerns ($t_{(13)} = 3.58$, $p < .01$) only in the craving-biofeedback group, but not in the craving-control or the non-craving control group. Effect sizes ranged between small and large (Table 2).

Yale Food Addiction Scale

There was a significant main effect for group ($F_{(2,53)} = 17.84$, $p < .001$), indicating more food addiction symptoms in the craving-control group than in the craving-

Table 1 Means, SD and interaction effects of all variables

	Online Screening			Pre-measurement			Post-measurement			Interaction effect
	CB M (SD)	CC M (SD)	NCC M (SD)	CB M (SD)	CC M (SD)	NCC M (SD)	CB M (SD)	CC M (SD)	NCC M (SD)	(Group × time)
Food cravings questionnaire—trait										
Intentions to eat	–	–	–	10.50 (1.74)	11.50 (2.79)	7.57 (2.44)	9.14 (2.25)	10.71 (2.53)	6.39 (1.66)	$F_{(2,53)} = .48$, *ns*
Positive reinforcement	–	–	–	16.29 (3.25)	16.29 (3.02)	12.07 (4.44)	14.93 (2.53)	16.29 (5.00)	10.82 (3.58)	$F_{(2,53)} = 1.02$, *ns*
Negative reinforcement	–	–	–	8.50 (2.21)	8.50 (2.88)	6.18 (2.09)	7.43 (2.03)	8.50 (3.21)	5.50 (2.05)	$F_{(2,53)} = .83$, *ns*
Lack of control	21.86 (2.28)	23.64 (4.14)	10.25 (2.59)	20.79 (4.42)	23.86 (6.16)	10.75 (3.61)	18.29 (3.27)	23.21 (5.61)	10.54 (3.55)	$F_{(4,106)} = 2.94$, $p < .05$
Preoccupation with food	–	–	–	19.64 (3.95)	19.29 (7.48)	11.21 (4.63)	15.93 (4.41)	20.71 (6.83)	10.68 (4.70)	$F_{(2,53)} = 8.33$, $p < .01$
Feelings of hunger	–	–	–	14.86 (1.96)	14.79 (3.33)	10.89 (2.86)	13.36 (2.44)	13.86 (4.56)	10.57 (2.90)	$F_{(2,53)} = 1.42$, *ns*
Negative affect	–	–	–	13.71 (3.67)	13.43 (4.15)	7.43 (2.95)	11.79 (3.83)	12.93 (4.81)	6.89 (2.57)	$F_{(2,53)} = 1.04$, *ns*
Cue-dependent eating	–	–	–	16.86 (2.98)	15.57 (4.20)	12.29 (3.83)	15.07 (2.59)	16.29 (3.56)	10.82 (3.38)	$F_{(2,53)} = 3.62$, $p < .05$
Feelings of guilt	–	–	–	9.43 (3.88)	9.07 (4.46)	4.71 (1.90)	7.64 (2.41)	9.50 (4.22)	4.79 (2.13)	$F_{(2,53)} = 4.96$, $p < .05$
Total	–	–	–	130.57 (18.00)	132.29 (28.46)	83.11 (19.23)	113.57 (15.30)	132.00 (34.89)	77.00 (18.52)	$F_{(2,53)} = 4.20$, $p < .05$
Eating disorder examination questionnaire										
Restraint	–	–	–	1.14 (1.30)	2.00 (1.35)	.57 (.77)	.99 (1.30)	1.56 (1.25)	.49 (.80)	$F_{(2,53)} = .81$, *ns*
Eating concern	–	–	–	1.03 (1.14)	1.23 (1.00)	.12 (.16)	.53 (.92)	.99 (1.02)	.12 (.18)	$F_{(2,53)} = 3.38$, $p < .05$
Weight concern	–	–	–	2.10 (1.66)	2.23 (1.67)	.66 (.79)	1.39 (1.23)	2.41 (1.70)	.61 (.61)	$F_{(2,53)} = 4.32$, $p < .05$
Shape concern	–	–	–	2.36 (1.83)	2.58 (1.76)	1.17 (1.00)	1.72 (1.44)	2.55 (1.58)	.94 (.78)	$F_{(2,53)} = 2.84$, *ns*
Overeating	–	–	–	4.00 (4.51)	8.64 (12.75)	1.11 (1.50)	2.79 (2.36)	6.14 (9.92)	.86 (1.43)	$F_{(2,53)} = 2.49$, *ns*
Binge frequency	–	–	–	1.86 (3.35)	7.50 (13.04)	.21 (.57)	1.14 (2.45)	5.21 (10.00)	.00 (.00)	$F_{(2,53)} = 2.60$, *ns*
Days with binges	–	–	–	2.00 (2.72)	6.71 (11.84)	.18 (.48)	1.14 (2.45)	5.07 (10.05)	.07 (.26)	$F_{(2,53)} = 1.22$, *ns*
Perceived self-regulatory success in dieting	–	–	–	10.14 (3.61)	10.71 (3.56)	13.96 (4.08)	11.00 (2.86)	9.64 (3.52)	13.79 (3.56)	$F_{(2,53)} = 1.21$, *ns*
Yale food addiction scale	–	–	–	2.14 (1.03)	2.93 (1.54)	1.11 (.50)	1.79 (1.19)	2.93 (1.73)	1.14 (.53)	$F_{(2,53)} = .85$, *ns*
Locus of control										
Internal locus of control	–	–	–	35.50 (3.65)	36.07 (5.37)	37.14 (4.58)	35.36 (4.73)	37.00 (4.42)	37.39 (4.64)	$F_{(2,53)} = .31$, *ns*
Powerful others	–	–	–	24.50 (4.49)	23.29 (5.43)	21.79 (5.24)	23.71 (3.83)	23.86 (5.42)	21.68 (5.91)	$F_{(2,53)} = .34$, *ns*
Chance orientations	–	–	–	23.50 (3.63)	23.93 (5.14)	23.50 (5.76)	23.79 (3.40)	25.00 (5.55)	22.36 (6.23)	$F_{(2,53)} = 2.36$, *ns*
Emotion regulation questionnaire										
Suppression	–	–	–	12.29 (4.50)	12.36 (4.07)	13.54 (6.31)	13.07 (5.69)	13.07 (4.51)	13.07 (5.47)	$F_{(2,53)} = 1.17$, *ns*
Reappraisal	–	–	–	26.14 (4.83)	25.29 (6.40)	27.03 (6.99)	27.93 (5.05)	24.14 (5.17)	27.96 (5.47)	$F_{(2,53)} = .97$, *ns*
Vagal-cardiac control										
Heart period (ms)	–	–	–	805.81 (116.20)	755.04 (105.09)	747.92 (122.34)	782.87 (175.09)	743.24 (145.00)	781.70 (124.86)	$F_{(2,53)} = 1.84$, *ns*
HF power (ms^2)	–	–	–	1268.57 (1575.20)	676.50 (783.31)	670.79 (1077.76)	911.64 (961.49)	467.43 (710.47)	999.82 (1375.41)	$F_{(2,53)} = 2.27$, *ns*
LF power (ms^2)	–	–	–	1262.93 (1232.18)	841.64 (749.40)	1310.04 (1858.09)	1828.50 (3384.30)	596.29 (474.19)	1075.68 (1186.40)	$F_{(2,53)} = 1.14$, *ns*
ln(RSAnorm)	–	–	–	1.23 (.44)	.94 (.57)	.87 (.49)	1.14 (.36)	.68 (.54)	.97 (.62)	$F_{(2,53)} = 3.27$, $p < .05$

CB craving-biofeedback group, *CC* craving-control group, *NCC* non-craving control group

Table 2 Effect sizes for all variables

	Craving-biofeedback			Craving-control			Non-craving-control		
	SES	SRM	GRI	SES	SRM	GRI	SES	SRM	GRI
Food cravings questionnaire—trait									
Intentions to eat	.78	.85	–	.28	.45	–	.48	.78	–
Positive reinforcement	.42	.51	–	.00	.00	–	.28	.43	–
Negative reinforcement	.48	.49	–	.00	.00	–	.33	.47	–
Lack of control	.57	.71	.62	.11	.17	.15	.06	.09	.06
Preoccupation with food	.94	.77	–	−.19	−.46	–	.11	.20	–
Feelings of hunger	.77	.66	–	.28	.41	–	.11	.15	–
Negative affect	.52	.42	–	.12	.18	–	.18	.23	–
Cue-dependent eating	.60	.47	–	−.17	−.27	–	.38	.68	–
Feelings of guilt	.46	.64	–	−.10	−.18	–	−.04	−.06	–
Total	.95	.75	–	.01	.02	–	.32	.55	–
Eating disorder examination questionnaire									
Restraint	.12	.13	–	.33	.42	–	.10	.14	–
Eating concern	.44	.69	–	.24	.26	–	.00	.00	–
Weight concern	.43	.95	–	−.11	−.14	–	.07	.10	–
Shape concern	.35	.84	–	.02	.05	–	.23	.42	–
Overeating	.27	.44	–	.20	.47	–	.17	.22	–
Binge frequency	.22	.52	–	.18	.42	–	.37	.37	–
Days with binges	.32	.67	–	.14	.28	–	.23	.19	–
Perceived self-regulatory success in dieting	−.24	−.29	–	.30	.27	–	.04	.06	–
Yale food addiction scale	.34	.35	–	.00	.00	–	−.06	−.04	
Locus of control									
Internal locus of control	.04	.06	–	−.17	−.23	–	−.06	−.06	–
Powerful others	.18	.22	–	−.11	−.14	–	.02	.02	–
Chance orientations	−.08	−.10	–	−.21	−.50	–	.20	.30	–
Emotion regulation questionnaire									
Suppression	−.17	−.24	–	−.17	−.26	–	.08	.16	–
Reappraisal	−.37	−.54	–	.18	.27	–	−.13	−.13	–
Vagal-cardiac control									
Heart period (ms)	.20	.20	–	.11	.12	–	−.28	−.36	–
HF power (ms^2)	.23	.23	–	.27	.53	–	−.31	−.31	–
LF power (ms^2)	−.46	−.21	–	.33	.41	–	.13	.16	–
ln(RSAnorm)	.19	.17	–	.46	.72	–	−.22	−.23	–

SES standardized effect size, *SRM* standardized response mean, *GRI* Guyatt's responsiveness index

biofeedback group (Scheffé $p < .05$) and the non-craving control group (Scheffé $p < .001$). The craving-biofeedback group also had more food addiction symptoms than the non-craving control group (Scheffé $p < .05$). There was no main effect for time ($F_{(1,53)} = .64$, *ns*) or any interactions (Table 1).

Perceived Self-Regulatory Success in Dieting

There was a significant main effect for group ($F_{(2,53)} = 8.26$, $p < .01$), indicating higher dieting success in the non-craving control group than in the craving-biofeedback group (Scheffé $p < .05$) and the craving-control group (Scheffé $p < .01$) while the high craving groups did not differ. There was no main effect for time ($F_{(1,53)} = .08$, *ns*) nor any interaction (Table 1).

Emotion Regulation Questionnaire

For both scales, there were no main effects for group (*Suppression*: $F_{(2,53)} = .09$, *ns*; *Reappraisal*: $F_{(2,53)} = 1.44$, *ns*) or time (*Suppression*: $F_{(1,53)} = .68$, *ns*; *Reappraisal*: $F_{(1,53)} = .41$, *ns*), or any interaction (Table 1).

Locus of Control

For none of the three scales, any main effects for group (*I*: $F_{(2,53)} = .89$, *ns*; *P*: $F_{(2,53)} = 1.42$, *ns*; *C*: $F_{(2,53)} = .44$, *ns*) or time (*I*: $F_{(1,53)} = .44$, *ns*; *P*: $F_{(1,53)} = .03$, *ns*; *C*: $F_{(1,53)} = .02$, *ns*) or interactions emerged (Table 1).

Vagal-Cardiac Control

Heart Period

There were no main effects for group ($F_{(2,53)} = .51$, *ns*) or time ($F_{(1,53)} = .00$, *ns*) and no interaction (Table 1).

HF Power

There were no main effects for group ($F_{(2,53)} = .91$, *ns*) or time ($F_{(1,53)} = .27$, *ns*) and no interaction (Table 1).

LF Power

There were no main effects for group ($F_{(2,53)} = 1.11$, *ns*) or time ($F_{(1,53)} = .01$, *ns*) and no interaction (Table 1).

ln(RSAnorm)

There were no main effects for group ($F_{(2,53)} = 2.39$, *ns*) or time ($F_{(1,53)} = 1.58$, *ns*), but a significant interaction (Table 1). Post hoc *t*-tests indicated that vagal-cardiac control did not change in the craving-biofeedback group ($t_{(13)} = .65$, *ns*) and the non-craving control group ($t_{(27)} = -1.20$, *ns*), but decreased from pre- to post-measurement in the craving-control group ($t_{(13)} = 2.69$, $p < .05$). Using BMI, age or hours since the last meal as covariates did not affect this result.

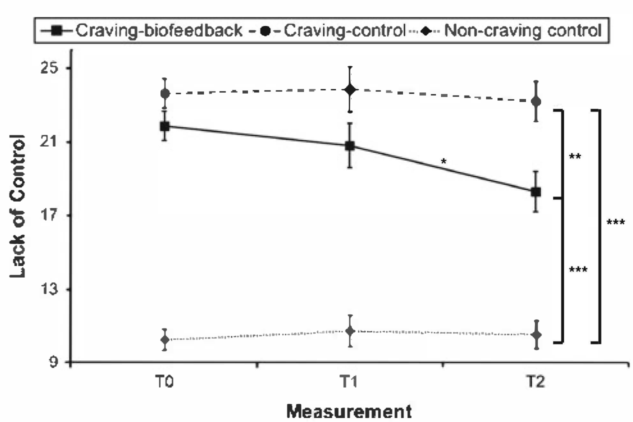

Fig. 1 Means of the food cravings questionnaire—subscale lack of control during online screening (T0), before (T1) and after intervention (T2). Error bars indicate the standard error of the mean. Asterisks indicate *p* values <.05*, <.01**, and <.001***

As high and low cravers did not differ in vagal-cardiac control, we investigated at pre-measurement the association between indexes of disordered eating behaviors and vagal-cardiac control. Here, we found that binge eating was negatively correlated with vagal-cardiac control in high cravers (*overeating*: $r = -.59$, *binge frequency*: $r = -.59$, *days with binges*: $r = -.57$, all p's $< .01$), but not in low cravers (all p's $> .05$).

Discussion

In the current study, subjective food cravings and eating- and weight-related concerns were reduced in high food cravers after HRV-biofeedback training. Particularly, food cravings related to a lack of control, preoccupation with food, and feelings of guilt were significantly decreased after the intervention in the biofeedback-group only. Although changes were not significant for some aspects of food craving, analyses of effect sizes showed medium-to-large reductions for all food craving subscales. Moreover, there was also a decrease in FCQ-T total scores, suggesting an overall effect on food cravings. Unexpectedly, reductions of food cravings elicited by external cues could also be found in the non-craving control group. However, effect sizes for FCQ-T subscales were consistently stronger in the craving-biofeedback group.

The biofeedback intervention may have altered cognitions and attitudes toward eating and weight, but did not influence behavioral aspects. Although we found reduced eating and weight concerns in high cravers, there were no significant changes in restraint, dieting success, or food addiction symptoms. In the craving-biofeedback group reduction of cravings were particularly pronounced with regards to thoughts and preoccupation with food and feelings of guilt from cravings or for giving into them. A lack of behavioral changes might be due to the short time period (1 month) between measurements.

Contrary to our hypotheses, vagal-cardiac control did not increase in the craving-biofeedback group; instead it *decreased* in the craving-control group. It is unclear why vagal-cardiac control would have decreased in the craving-control group. One could argue that HRV-biofeedback might have protected the craving-biofeedback group against this decline. However, this hypothesis remains speculative and future studies are needed addressing the long-term development of HRV in high cravers and which psychological or physical conditions are associated with possible changes in HRV.

As reductions in craving and eating and weight concerns were not associated with an increase in HRV, other mechanisms must be responsible for the observed changes. A first possibility may be that the HRV-biofeedback had a

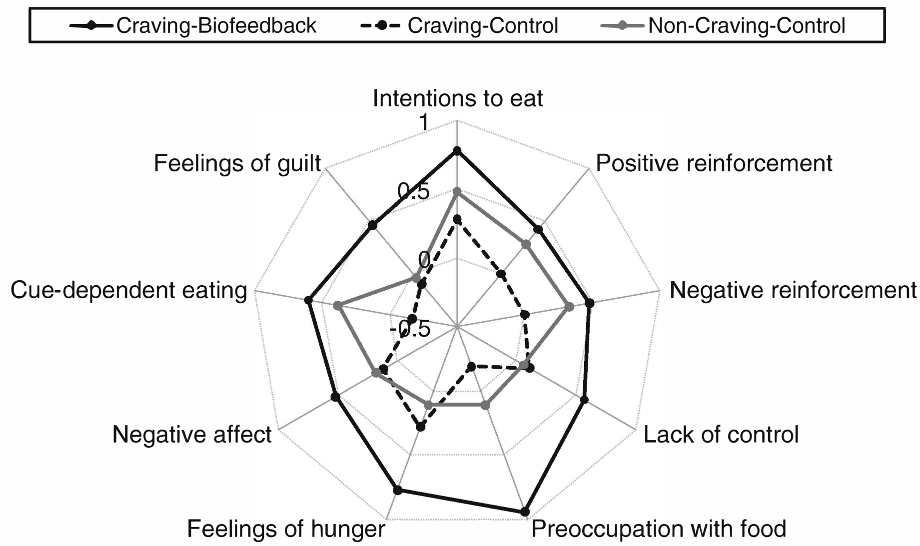

Fig. 2 Standardized effect sizes for changes between pre- and post-measurement on the subscales of the food cravings questionnaire—trait

general effect on wellbeing (e.g., relaxation) rather than the presumed specific effect on vagal-cardiac control, resulting in a more relaxed attitude to eating and weight concerns. A second explanation, which does not preclude the first, is an increased sense of mastery or perceived self-efficacy as a result of carrying out the biofeedback training. Such cognitive changes have been observed in other treatment groups (e.g., EMG-biofeedback in tension-headache patients; Holroyd et al. 1984; Lacroix et al. 1986) and may pose a mechanism underlying the effects of biofeedback, which is independent from direct physiological changes in the target variable. In line with this, most studies using HRV-biofeedback find changes in psychological variables without changes in resting HRV (Wheat and Larkin 2010). The HRV-biofeedback procedure may have immediate effects and people may strategically use the breathing technique to control symptoms. Hence, the lack of effect of HRV-biofeedback on resting HRV may be explained by the fact that resting vagal function is not affected when an individual is not experiencing craving, but that HRV will be higher during the experience of craving when they breathe in the low frequency range.

Our study has several limitations. Firstly, we did not investigate a sample of patients but recruited a non-clinical sample. This may have rendered it difficult to detect effects, especially in light of the small sample size. Our sample consisted of young and healthy individuals and, therefore, a further increase in HRV might have been difficult to achieve because of ceiling effects. Moreover, while most studies instruct participants to further practice the technique at home, we decided to restrict training to lab visits to standardize the amount of sessions for each participant. However, additional home practice and, therefore, more frequent sessions might be necessary to produce physiological changes. Secondly, our control groups did not receive a placebo or alternative treatment. The factors leading to the observed psychological changes can only be elucidated with appropriate control groups. Thirdly, with the current design demand or placebo effects cannot be ruled out. The questions asked in the online screening may have focused study participants' attention on eating, craving and food. Nevertheless, participants were not told that the aim of the study was the reduction of food cravings or alteration of eating behavior. Finally, we only assessed subjective indices of eating behavior. While we found changes in various eating-related attitudes and cognitions, further studies may investigate if HRV-biofeedback has an effect on actual, and objectively measured eating behavior.

In conclusion, the current findings demonstrate that HRV-biofeedback attenuates subjective food cravings and other eating- and weight-related concerns in a non-clinical sample. More frequent and longer HRV-biofeedback may be necessary to implement those cognitive aspects into actual eating behavior. Moreover, rather than solely practicing HRV-biofeedback, it might be more effective in producing behavioral changes when it is applied in conjunction with a cognitive-behaviorally oriented intervention. Given that cravings related to emotional eating were not influenced by the biofeedback intervention, effects of HRV-biofeedback might also be further enhanced by targeting emotional reactions to food-cues, e.g., with food exposure and response prevention. Notably, high food cravers did not have lower HRV compared to low food cravers prior to the intervention, but a subsequent analysis revealed that binge eating behaviors were negatively correlated with HRV in high food cravers. Thus, the current results lend further support to the notion that frequent and intense experiences of craving are not related to autonomic dysregulation per se, but only in combination with eating disorder symptoms (Rodríguez-Ruiz et al. 2009). Further studies should investigate whether HRV-biofeedback is also effective in altering eating behavior in clinical samples and has an effect over and above relaxation. If proven successful, HRV-biofeedback could be used as an adjunct intervention in patients with eating disorders or obesity.

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References

Abler, B., & Kessler, H. (2009). Emotion regulation questionnaire—A German version of the ERQ by Gross and John. *Diagnostica, 55*, 144–152.

Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology, 10*, 229–240.

Blechert, J., Michael, T., Grossman, P., Lajtman, M., & Wilhelm, F. H. (2007). Autonomic and respiratory characteristics of posttraumatic stress disorder and panic disorder. *Psychosomatic Medicine, 69*, 935–943.

Britton, A., & Hemingway, H. (2004). Heart rate variability in healthy populations: Correlates and consequences. In M. Malik & J. Camm (Eds.), *Dynamic electrocardiography* (pp. 90–111). Oxford: Blackwell.

Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behavior Therapy, 31*, 151–173.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Coles, J., Vögele, C., Hilbert, A., & Tuschen-Caffier, B. (2005). Fasting and (over)eating: Effects of yoyo diets on measures of cardiac sympathovagal balance. *Zeitschrift für Klinische Psychologie und Psychotherapie, 34*, 95–103.

Fairburn, C. G., & Beglin, S. J. (1994). Assessment of eating disorders: Interview or self-report questionnaire? *International Journal of Eating Disorders, 16*, 363–370.

Fishbach, A., Friedman, R. S., & Kruglanski, A. W. (2003). Leading us not unto temptation: Momentary allurements elicit overriding goal activation. *Journal of Personality and Social Psychology, 84*, 296–309.

Friederich, H. C., Schild, S., Schellberg, D., Quenter, A., Bode, C., Herzog, W., et al. (2006). Cardiac parasympathetic regulation in obese women with binge eating disorder. *International Journal of Obesity, 30*, 534–542.

Gearhardt, A. N., Corbin, W. R., & Brownell, K. D. (2009). Preliminary validation of the Yale Food Addiction Scale. *Appetite, 52*, 430–436.

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology, 85*(2), 348–362.

Hilbert, A., & Tuschen-Caffier, B. (2006). *Eating disorder examination—questionnaire: Deutschsprachige Übersetzung*. Münster: Verlag für Psychotherapie.

Hilbert, A., Tuschen-Caffier, B., Karwautz, A., Niederhofer, H., & Munsch, S. (2007). Eating disorder examination-questionnaire: Psychometric properties of the German version. *Diagnostica, 53*, 144–154.

Hinz, A., & Brähler, E. (2011). Measurement changes in clinical psychological questionnaires. *Psychotherapie, Psychosomatik, Medizinische Psychologie, 61*, 333–334.

Holroyd, K. A., Penzien, D. B., Hursey, K. G., Tobin, D. L., Rogers, L., Holm, J. E., et al. (1984). Change mechanisms in EMG biofeedback training: Cognitive changes underlying improvements in tension headache. *Journal of Consulting and Clinical Psychology, 52*, 1039–1053.

Ingjaldsson, J. T., Thayer, J. F., & Laberg, J. C. (2003). Craving for alcohol and pre-attentive processing of alcohol stimuli. *International Journal of Psychophysiology, 49*, 29–39.

Karason, K., Molgaard, H., Wikstrand, J., & Sjostrom, L. (1999). Heart rate variability in obesity and the effect of weight loss. *American Journal of Cardiology, 83*, 1242–1247.

Karavidas, M. K., Lehrer, P. M., Vaschillo, E., Vaschillo, B., Marin, H., Buyske, S., et al. (2007). Preliminary results of an open label study of heart rate variability biofeedback for the treatment of major depression. *Applied Psychophysiology and Biofeedback, 32*(1), 19–30.

Krampen, G. (1981). *IPC-Fragebogen zu Kontrollüberzeugungen*. Göttingen: Hogrefe.

Kühn, S., & Gallinat, J. (2011). Common biology of craving across legal and illegal drugs—a quantitative meta-analysis of cue-reactivity brain response. *European Journal of Neuroscience, 33*, 1318–1326.

Lacroix, J. M., Clarke, M. A., Bock, J. C., & Doxey, N. C. (1986). Physiological changes after biofeedback and relaxation training for multiple-pain tension-headache patients. *Perceptual and Motor Skills, 63*, 139–153.

Latchman, P. L., Mathur, M., Bartels, M. N., Axtell, R. S., & De Meersman, R. F. (2011). Impaired autonomic function in normotensive obese children. *Clinical Autonomic Research, 21*, 319–323.

Lehrer, P. M., Vaschillo, E., Lu, S. E., Eckberg, D., Vaschillo, B., Scardella, A., et al. (2006). Heart rate variability biofeedback—Effects of age on heart rate variability, baroreflex gain, and asthma. *Chest, 129*, 278–284.

Lehrer, P. M., Vaschillo, E., & Vaschillo, B. (2000). Resonant frequency biofeedback training to increase cardiac variability: Rationale and manual for training. *Applied Psychophysiology and Biofeedback, 25*, 177–191.

Lehrer, P. M., Vaschillo, E., Vaschillo, B., Lu, S. E., Eckberg, D. L., Edelberg, R., et al. (2003). Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. *Psychosomatic Medicine, 65*, 796–805.

Levenson, H. (1973). *Reliability and validity of the I, P, and C scales—A multidimensional view of locus of control*. Paper presented at the American Psychologcial Association Convention, Montreal, Canada.

Löllgen, D., Mück-Weymann, M., & Beise, R. (2009). The deep breathing test: Median-based expiration-inspiration difference is the measure of choice. *Muscle and Nerve, 39*, 536–544.

Mazurak, N., Enck, P., Muth, E., Teufel, M., & Zipfel, S. (2011). Heart rate variability as a measure of cardiac autonomic function in anorexia nervosa: A review of the literature. *European Eating Disorders Review, 19*, 87–99.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (in revision). Self-reported dieting success is associated with cardiac autonomic regulation in current dieters.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012a). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters. Validation of the Food Craving Questionnaires in German. *Appetite, 58*, 88–97.

Meule, A., Papies, E. K., & Kübler, A. (2012b). Differentiating between successful and unsuccessful dieters: Validity and reliability of the

perceived self-regulatory success in dieting scale. *Appetite, 58*, 822–826.
Meule, A., Skirde, A. K., Freund, R., Vögele, C., & Kübler, A. (in press-b). High-calorie food-cues impair working memory performance in high and low food cravers. *Appetite*.
Meule, A., Vögele, C., & Kübler, A. (2012c). Restrained eating is related to accelerated reaction to high caloric foods and cardiac autonomic dysregulation. *Appetite, 58*, 638–644.
Meule, A., Vögele, C., & Kübler, A. (in press-a). German translation and validation of the Yale Food Addiction Scale. *Diagnostica*.
Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite, 57*, 582–584.
Pelchat, M. L., Johnson, A., Chan, R., Valdez, J., & Ragland, J. D. (2004). Images of desire: Food-craving activation during fMRI. *NeuroImage, 23*, 1486–1493.
Rodríguez-Ruiz, S., Guerra, P. M., Moreno, S., Fernández, M. C., & Vila, J. (2012). Heart rate variability modulates eye-blink startle in women with bulimic symptoms. *Journal of Psychophysiology, 26*, 10–19.
Rodríguez-Ruiz, S., Ruiz-Padial, E., Vera, N., Fernández, C., Anllo-Vento, L., & Vila, J. (2009). Effect of heart rate variability on defensive reaction and eating disorder symptomatology in chocolate cravers. *Journal of Psychophysiology, 23*, 95–103.
Sharp, C., Hurford, D. P., Allison, J., Sparks, R., & Cameron, B. P. (1997). Facilitation of internal locus of control in adolescent alcoholics through a brief biofeedback-assisted autogenic relaxation training procedure. *Journal of Substance Abuse Treatment, 14*, 55–60.
Siepmann, M., Aykac, V., Unterdörfer, J., Petrowski, K., & Mueck-Weymann, M. (2008). A pilot study on the effects of heart rate variability biofeedback in patients with depression and in healthy subjects. *Applied Psychophysiology and Biofeedback, 33*, 195–201.
Tan, G., Dao, T. K., Farmer, L., Sutherland, R. J., & Gevirtz, R. (2011). Heart rate variability (HRV) and posttraumatic stress disorder (PTSD): A pilot study. *Applied Psychophysiology and Biofeedback, 36*, 27–35.
Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalainen, P. A. (2009). Kubios HRV—a software for advanced heart rate variability analysis. In J. Vander Sloten, P. Verdonck, M. Nyssen, & J. Haueisen (Eds.), *ECIFMBE 2008, IFMBE proceedings 22* (pp. 1022–1025). Berlin, Heidelberg: Springer.
Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal, 17*, 354–381.
Thayer, J. F., Hall, M., Sollers, J. J., & Fischer, J. E. (2006). Alcohol use, urinary cortisol, and heart rate variability in apparently healthy men: Evidence for impaired inhibitory control of the HPA axis in heavy drinkers. *International Journal of Psychophysiology, 59*, 244–250.
Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience and Biobehavioral Reviews, 33*, 81–88.
Thayer, J. F., Yamamoto, S. S., & Brosschot, J. F. (2010). The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *International Journal of Cardiology, 141*, 122–131.
Vaschillo, E., Lehrer, P., Rishe, N., & Konstantinov, M. (2002). Heart rate variability biofeedback as a method for assessing baroreflex function: A preliminary study of resonance in the cardiovascular system. *Applied Psychophysiology and Biofeedback, 27*, 1–27.
Vaschillo, E., Vaschillo, B., & Lehrer, P. (2004). Heartbeat synchronizes with respiratory rhythm only under specific circumstances. *Chest, 126*, 1385–1386.
Vaschillo, E., Vaschillo, B., & Lehrer, P. M. (2006). Characteristics of resonance in heart rate variability stimulated by biofeedback. *Applied Psychophysiology and Biofeedback, 31*, 129–142.
Vögele, C., Hilbert, A., & Tuschen-Caffier, B. (2009). Dietary restriction, cardiac autonomic regulation and stress reactivity in bulimic women. *Physiology & Behavior, 98*, 229–234.
Weingarten, H. P., & Elston, D. (1990). The phenomenology of food cravings. *Appetite, 15*, 231–246.
Weingarten, H. P., & Elston, D. (1991). Food cravings in a college population. *Appetite, 17*, 167–175.
Wheat, A. L., & Larkin, K. T. (2010). Biofeedback of heart rate variability and related physiology: A critical review. *Applied Psychophysiology and Biofeedback, 35*, 229–242.
World Health Organization. (2000). *Obesity: Preventing and managing the global epidemic*. Geneva: World Health Organization.
Zucker, T. L., Samuelson, K. W., Muench, F., Greenberg, M. A., & Gevirtz, R. N. (2009). The effects of respiratory sinus arrhythmia biofeedback on heart rate variability and posttraumatic stress disorder symptoms: A pilot study. *Applied Psychophysiology and Biofeedback, 34*, 135–143.

3. Discussion

The current thesis aimed at providing a measure in German for the assessment of food craving as a stable trait and transient state. For this purpose, one of the most widely used food craving measures – the FCQs – was translated and its psychometric properties were evaluated. Using these questionnaires, correlates of both trait and state food craving were further examined using self-report, cognitive-behavioral, and psychophysiological methods. Specifically, self-report measures were used to test the relationships between food craving and dieting behavior. Behavioral tasks were used to study the relationships between food craving and food-cue affected executive functions. With regard to physiological measures, ERPs were used to examine the electrocortical correlates during food craving regulation and HRV-biofeedback was evaluated as a possible intervention approach to reduce food craving. Main results of each goal will be briefly discussed in the following.

3.1 Assessment of food craving: German version of the Food Cravings Questionnaires

The German FCQs showed good psychometric properties. Specifically, both the FCQ-T and FCQ-S had high internal consistency and, expectedly, only the FCQ-T had high retest-reliability. Yet, factor structures found in the original versions (Cepeda-Benito, Gleaves, Fernández, et al., 2000; Cepeda-Benito, Gleaves, Williams, et al., 2000) could only be partially be replicated. In line with other studies (Rodriguez et al., 2007; Vander Wal et al., 2007), factor analysis yielded fewer factors for both the trait and the state version. Validity of the FCQ-T could be shown in medium-to-high correlations with other questionnaires associated with overeating and no or small correlations with non-eating-related, but relevant constructs such as drug craving and impulsivity. Validity of the FCQ-S could be shown in small positive correlations with current food deprivation and negative affect, that is, current food craving was higher when participants were longer food deprived and were in a negative mood.

3.2 Food cravings and dieting

Subscales of the FCQs were able to discriminate between dieters and successful and unsuccessful dieters. Specifically, it was found that dieters – regardless of being successful or unsuccessful in their pursuit – experienced more cravings that are related to a preoccupation with food and guilt from cravings or for giving into them. Moreover, unsuccessful dieters reported more food cravings, that were related to a lack of control over eating and plans to consume food than successful dieters. Therefore, this was the first study showing that (1) differences in food cravings between non-dieters and dieters depend on success or failure of these dieters in achieving their dieting goals and (2) that specific types of food cravings discriminate differentially between these three groups.

While the FCQ-S also discriminated between dieters and non-dieters, successful and unsuccessful dieters could not be discriminated. This finding corresponds to results showing that the FCQ-S is also related to dysfunctional eating behavior, but the relationship is attenuated (Cepeda-Benito, Gleaves, Williams, et al., 2000; Moreno et al., 2008). Furthermore, it shows that successful and unsuccessful dieters do not differ in their current experiences of craving. Successful dieters may be as susceptible as unsuccessful dieters to be tempted by food, but possess mechanisms that enable them to resist those temptations (Stroebe, Van Koningsbruggen, Papies, & Aarts, 2013).

In another analysis of those data, it could be shown that rigid dietary control strategies mediated the relationship between trait food craving and lower dieting success while this was not the case for flexible dietary control strategies. Those results corroborate and extend previous findings indicating that rigid control is associated with self-regulatory failure in eating behavior (Timko & Perone, 2005) and that rigid dietary strategies, such as a monotonous diet, elicit such cravings (Pelchat & Schaefer, 2000). While flexible control was associated with dieting success, it was not related to trait food craving. Dieters with flexible control strategies may also experience food cravings because they are common and experienced by most people (Hill, 2007). It is possible that even after giving in to such cravings, food intake is properly adjusted afterwards leading to successful weight loss or -maintenance. Finally, flexible control in combination with less food cravings fosters dieting success even more.

3.3 Food cravings and executive functions

Although food-cues did affect working memory task performance and state food craving increased during the task, no differential task performance could be found between trait high food cravers and low cravers. Moreover, food-cue affected task performance was related rarely to current food craving. In the behavioral inhibition task, state food craving was also elevated after the task as compared to before. Reaction times differed between blocks with high- and low-calorie food pictures, but there were no differences in commission errors. However, the number of commission errors in blocks with high-calorie food targets was predicted by an interaction of trait food craving and 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, however, no relationship between trait food craving and commission errors could be observed. That is, low trait impulsivity implicating high top-down control, could compensate for high levels of trait food craving. 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 such cues.

In sum, the hypotheses that food-cues impair executive functioning as a function of trait and state food craving could only be partially confirmed. That is, although state food craving increases during performing such tasks, task performance is rarely related to current food craving. Instead, general differences in working memory task performance can be found in response to food vs. neutral stimuli, independent of trait food craving. Moreover, trait food craving is associated with decreased behavioral inhibition in response to high-calorie food targets, particularly in combination with high trait impulsivity.

3.4 Electrocortical responses during food craving regulation

When presented with pictures of high- and low-calorie foods, early electrocortical processing differed and was not modulated by cognitive regulation. Low-calorie food pictures elicited a larger negativity 150-200 ms after stimulus onset than high-calorie food pictures at occipital sites. This finding replicates previous studies with regard to time range, polarity and topography (Frank et al., 2010; Toepel et al., 2009) and suggests that visual areas support an early attentional discrimination of caloric content of food, possibly due to its relevance for survival. In addition, a main effect of calorie content could be observed for LPP amplitude in a left-hemispheric centro-parietal cluster, replicating that differences in the processing of high- and low-calorie food-cues can also be found in later stages of food-cue processing and brain areas other than the occipital lobe (Frank et al., 2010; Toepel et al., 2009).

As expected, for high-calorie foods, thinking about the long-term consequences of eating them decreased craving. For low-calorie foods, by contrast, thinking about the long-term consequences increased craving. This finding offers some interesting avenues of intervention toward inducing healthier food choices through cognitive strategies.

When participants were instructed to think about the long-term effects of eating high caloric foods, craving was lowest, and LPP amplitude in a right-hemispheric centro-parietal cluster was enlarged relative to all other conditions. This finding is surprising on first sight because heightened LPP amplitude is considered to reflect motivated attention towards rewarding stimuli like drugs or food, possibly indicating increased craving for those cues (Blechert et al., 2010; Field, Munafò, & Franken, 2009; Littel et al., 2012; Nijs & Franken, 2012; Svaldi et al., 2010). Indeed, self-rated craving correlated with LPP amplitudes in all conditions. However, affective picture processing research suggests that LPP amplitude is driven by arousal regardless of valence (Hajcak et al., 2010; Olofsson et al., 2008). Thus, in the present data increased LPP amplitude when thinking about the adverse long-term effects of eating high-calorie foods could also reflect arousal, as it arises from negative thoughts about aversive bodily states.

In accordance with ERP studies on craving regulation in substance abuse (Littel & Franken, 2011) we followed-up the development of LPP amplitudes during later processing stages. Between 550 – 3000 ms after stimulus onset, the slow wave amplitude was less positive when participants were instructed to think about the immediate, pleasurable effects of eating high-calorie foods as compared to all other conditions, possibly due to a late motivational engagement with the appetitive value of high-calorie foods. Amplitude when thinking about the long-term effects of eating high-calorie foods, by contrast, was reduced to the level of the low-calorie food conditions during the slow wave time window. Although craving ratings were not systematically correlated with ERP amplitudes in this time range, we would speculate that this pattern of ERP amplitude changes may indicate successful regulation of craving. This interpretation would mirror results of the study by Littel and Franken (2011) in which the application of cognitive craving regulation strategies initially led to increased LPP amplitudes in response to smoking pictures, but to attenuated amplitudes in a late LPP (slow wave) time window.

3.5 Heart rate variability biofeedback for reducing food craving

Contrary to expectations, resting HRV did not differ between high and low trait food cravers. However, HRV was negatively correlated with binge eating behavior in high, but not low cravers which is in line with findings showing that frequent chocolate cravings only in combination with high eating pathology are associated with low HRV (Rodríguez-Ruiz et al., 2009).

Self-reported frequency of food cravings and magnitude of eating- and weight-related concerns were reduced in high food cravers after few sessions of HRV-biofeedback training. Particularly, food cravings related to a lack of control, preoccupation with food, and feelings of guilt were significantly decreased after the intervention in the biofeedback-group only.

The biofeedback intervention may have altered cognitions and attitudes towards eating and weight, but did not influence behavioral aspects. Although we found reduced eating and weight concerns in high cravers, there were no significant changes in BMI, restraint, dieting success, or food addiction symptoms. This lack of behavioral changes might be due to the short time period between measurements.

Contrary to our hypotheses, resting HRV did not increase in the biofeedback group. However, symptom reductions in patients with mental disorders can often be observed after HRV-biofeedback in absence of physiological changes (Lehrer, 2013; Wheat & Larkin, 2010). To date, the physiological mechanisms of HRV-biofeedback are poorly understood and more so the mechanisms that lead to improved psychological well-being (Lehrer, 2013). Thus, further studies with appropriate control conditions that examine the acute and long-term effects of HRV-biofeedback on physiological (e.g., HRV), cognitive (e.g., food craving), and behavioral (e.g., actual eating behavior) variables in individuals with eating disorders or obesity are desperately needed.

3.6 Conclusions and future directions

In the current thesis, a German version of the FCQs was presented which, to date, are the only food craving measures available in German. Although good psychometric properties could be shown in student samples, future studies are needed with clinical samples such as patients with eating disorders and obesity. Importantly, factor structures of both the trait and state version could only be partially replicated which was also found in studies using other versions (Rodriguez et al., 2007; Vander Wal et al., 2007). This instability in factor structure and the very high internal consistency of both versions challenge the plausibility of calculating subscale scores. Indeed, it could be found recently that results comparable to the 39-item version can be obtained when a reduced form of the FCQ-T consisting of 15 items only is used (Meule, Hermann, & Kübler, submitted). Thus, it may be recommended for future studies to preferably use the total scores of the FCQs and a short version of the FCQ-T may be an efficient alternative to assess trait food craving.

With regard to dieting behavior, the present thesis showed that simply investigating the relationship between food craving and dietary restraint oversimplifies the complex relationship between dieting and food craving. Specifically, the current studies suggest that the distinction between success and failure in dietary restraint and flexible vs. rigid dieting is crucial when examining relationships between food craving and dieting. Those distinctions are, of course, not exhaustive and future research needs to consider a large array of other diet-related variables when studying food craving such as an individual's history of dieting, motivation behind dieting (e.g., to lose weight or to avoid gaining weight), or weight suppression (i.e., the difference between an individual's current weight and highest previous weight) (Lowe, 1993; Witt, Katterman, & Lowe, 2013).

The study on food-cue affected working memory performance was the first which (1) used a newly developed variant of the *n*-back task that (2) not only involved chocolate cues, but also other sweet and savory foods, and (3) investigating effects in both trait high and low cravers with respect to general food cravings instead of specifically chocolate craving. In the meantime, the effects of food-cues on working memory performance were partially replicated in a subsequent study (Meule & Kübler, in preparation). However, such effects heavily depend on task design such as sequence of target- and distractor trials (Svaldi et al., 2014) or the specific type of stimuli used. For instance, great care needs to be taken that food and neutral stimuli are matched with regard to physical stimulus features and other characteristics such as category size. These issues could be solved by using control conditions other than neutral stimuli, for example, comparing effects of high- vs. low-calorie foods or the like.

Similar methodological issues apply to food-cue-related behavioral inhibition tasks. For example, differences in task performance between food and neutral stimuli may simply be due to category size effects or physical stimulus features (Loeber et al., 2012; Meule et al., in revision). In the current thesis, a behavioral inhibition task was presented in which high-calorie food stimuli were contrasted with low-calorie food stimuli rather than neutral stimuli and, indeed, no difference in inhibitory performance between stimulus types were observed. Instead, individual differences in trait food craving and impulsivity predicted low inhibitory control specifically in high-calorie food blocks. Although results were obtained in healthy, primarily normal-weight female students, they likely have implications for interventions aiming at the control of food intake. In line with existing models of self-regulation (Appelhans, 2009; Heatherton & Wagner, 2011), results suggest that such interventions possibly can address (1) attenuating automatic, bottom-up reactions or (2) increasing top-down control to enhance eating-related self-regulation. Addressing the former, recent studies used food-related inhibition tasks in which motor responses have to be inhibited specifically in response to high-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, & Papies, 2011; Veling, Aarts, & Stroebe, 2013). Future research is needed to extend those findings to individuals with eating disorders or obesity and investigate if interventions which both strengthen top-down control and attenuate reward-related processes are particularly useful for controlling food intake or altering food choice in such patients.

Some studies exist in which ERP responses during passive viewing of food stimuli were recorded. In the current thesis, the first ERP study was presented which investigated the time course of electrocortical food-cue responses during food craving regulation. In the meantime, another ERP study has been published which corroborates the finding that cognitive regulation of food craving does not reduce the LPP in response to food pictures (Sarlo, Übel, Leutgeb, & Schienle, 2013). Future studies may benefit from methodological modulations such as using idiosyncratically craved food-cues (Giuliani, Calcott, & Berkman, 2013) or contrasting different craving regulation strategies against one another (Yokum & Stice, 2013).

Finally, a study was presented which applied HRV-biofeedback for modulation of eating behavior. Only one other published study had examined a biofeedback procedure for altering eating behavior (Pop-Jordanova, 2000). Thus, this study was one of the first studies in a field that will likely receive more attention in the future (cf. Bartholdy, Musiat, Campbell, & Schmidt, 2013). For instance, exciting new approaches include the use of real- time fMRI neurofeedback in obesity (Frank et al., 2012). Yet, the application of bio- and neurofeedback for treating disordered eating behavior or obesity is in its infancy and, to date, literature is scarce (Bartholdy et al., 2013; Teufel et al., 2013). Results of the current study suggest that HRV-biofeedback may be beneficial for reducing the frequency of food craving experiences. Yet, the exact mechanisms remain unclear. For example, it could be that HRV-biofeedback only has unspecific relaxing effects leading to increased well-being in general and reductions in eating pathology such as reduced preoccupation with food may only be a side benefit. However, it is also possible that the breathing technique acquired during HRV-biofeedback may be used as an acute craving regulation strategy in tempting situations – provided individuals are aware of their craving, that is, do not engage in mindless eating. Thus, future studies need to examine acute effects of slowed paced breathing on current food craving and studies evaluating the long-term effects of regular HRV-biofeedback training on food craving compared to appropriate control conditions.

To conclude, the current thesis provided measures for the assessment of food craving in German and showed differential relationships between state and trait food craving with self-reported dieting behavior, food-cue affected executive functioning, ERPs and HRV-biofeedback. These results provide promising starting points for interventions to reduce food craving based on (1) food-cue-related behavioral trainings of executive functions, (2) cognitive craving regulation strategies, and (3) physiological parameters such as HRV-biofeedback.

4. References

Abilés, V., Rodríguez-Ruiz, S., Abilés, J., Mellado, C., García, A., Pérez de la Cruz, A., & Fernández-Santaella, M. C. (2010). Psychological characteristics of morbidly obese candidates for bariatric surgery. *Obesity Surgery, 20*, 161-167.

Appelhans, B. M. (2009). Neurobehavioral inhibition of reward-driven feeding: Implications for dieting and obesity. *Obesity, 17*, 640-647.

Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology, 10*, 229-240.

Asmaro, D., Jaspers-Fayer, F., Sramko, V., Taake, I., Carolan, P., & Liotti, M. (2012). Spatiotemporal dynamics of the hedonic processing of chocolate images in individuals with and without trait chocolate craving. *Appetite, 58*, 790-799.

Bartholdy, S., Musiat, P., Campbell, I. C., & Schmidt, U. (2013). The potential of neurofeedback in the treatment of eating disorders: a review of the literature. *European Eating Disorders Review, 21*, 456-463.

Batra, P., Das, S. K., Salinardi, T., Robinson, L., Saltzman, E., Scott, T., . . . Roberts, S. B. (2013). Relationship of cravings with weight loss and hunger. Results from a 6 month worksite weight loss intervention. *Appetite, 69*, 1-7.

Batterink, L., Yokum, S., & Stice, E. (2010). Body mass correlates inversely with inhibitory control in response to food among adolescent girls: An fMRI study. *NeuroImage, 52*, 1696-1703.

Baur, R., Conzelmann, A., Wieser, M. J., & Pauli, P. (submitted). Free-choice emotion regulation: An analysis of late positive potentials and muscular face activity.

Benton, D., Greenfield, K., & Morgan, M. (1998). The development of the attitudes to chocolate questionnaire. *Personality and Individual Differences, 24*, 513-520.

Berg, E. A. (1948). A simple objective technique for measuring flexibility in thinking. *The Journal of General Psychology, 39*, 15-22.

Blechert, J., Feige, B., Hajcak, G., & Tuschen-Caffier, B. (2010). To eat or not to eat? Availability of food modulates the electrocortical response to food pictures in restrained eaters. *Appetite, 54*, 262-268.

Blechert, J., Feige, B., Joos, A., Zeeck, A., & Tuschen-Caffier, B. (2011). Electrocortical processing of food and emotional pictures in anorexia nervosa and bulimia nervosa. *Psychosomatic Medicine, 73*, 415-421.

Blechert, J., Goltsche, J. E., Herbert, B. M., & Wilhelm, F. H. (2014). Eat your troubles away: Electrocortical and experiential correlates of food image processing are related to emotional eating style and emotional state. *Biological Psychology, 96*, 94-101.

Britton, A., & Hemingway, H. (2004). Heart rate variability in healthy populations: correlates and consequences. In M. Malik & J. Camm (Eds.), *Dynamic Electrocardiography* (pp. 90-111). Oxford: Blackwell.

Brooks, S. J., O'Daly, O. G., Uher, R., Schioth, H. B., Treasure, J., & Campbell, I. C. (2012). Subliminal food images compromise superior working memory performance in women with restricting anorexia nervosa. *Consciousness and Cognition, 21*, 751-763.

Brown, R. P., Gerbarg, P. L., & Muench, F. (2013). Breathing practices for treatment of psychiatric and stress-related medical conditions. *Psychiatric Clinics of North America, 36*, 121-140. doi: 10.1016/j.psc.2013.01.001

Carnell, S., Gibson, C., Benson, L., Ochner, C. N., & Geliebter, A. (2012). Neuroimaging and obesity: current knowledge and future directions. *Obesity Reviews, 13*, 43-56.

Cartwright, F., & Stritzke, W. G. (2008). A multidimensional ambivalence model of chocolate craving: construct validity and associations with chocolate consumption and disordered eating. *Eating Behaviors, 9*, 1-12.

Cepeda-Benito, A., Fernandez, M. C., & Moreno, S. (2003). Relationship of gender and eating disorder symptoms to reported cravings for food: construct validation of state and trait craving questionnaires in Spanish. *Appetite, 40*, 47-54.

Cepeda-Benito, A., Gleaves, D. H., Fernández, M. C., Vila, J., Williams, T. L., & Reynoso, J. (2000). The development and validation of Spanish versions of the state and trait food cravings questionnaires. *Behaviour Research and Therapy, 38*, 1125-1138.

Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait Food-Cravings Questionnaires. *Behavior Therapy, 31*, 151-173.

Claes, L., Mitchell, J. E., & Vandereycken, W. (2012). Out of control? Inhibition processes in eating disorders from a personality and cognitive perspective. *International Journal of Eating Disorders, 45*, 407-414.

Claes, L., Nederkoorn, C., Vandereycken, W., Guerrieri, R., & Vertommen, H. (2006). Impulsiveness and lack of inhibitory control in eating disorders. *Eating Behaviors, 7*, 196-203.

Coles, J., Vögele, C., Hilbert, A., & Tuschen-Caffier, B. (2005). [Fasting and (over)eating: Effects of yoyo diets on measures of cardiac sympathovagal balance]. *Zeitschrift für Klinische Psychologie und Psychotherapie, 34*, 95-103.

Delgado-Rico, E., Rio-Valle, J. S., Gonzalez-Jimenez, E., Campoy, C., & Verdejo-Garcia, A. (2012). BMI predicts emotion-driven impulsivity and cognitive inflexibility in adolescents with excess weight. *Obesity, 20*, 1604-1610.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168.

Dickson, H., Brooks, S., Uher, R., Tchanturia, K., Treasure, J., & Campbell, I. C. (2008). The inability to ignore: Distractibility in women with restricting anorexia nervosa. *Psychological Medicine, 38*, 1741-1748.

Field, M., Munafò, M. R., & Franken, I. H. A. (2009). A meta-analytic investigation of the relationship between attentional bias and subjective craving in substance abuse. *Psychological Bulletin, 135*, 589-607.

Fishbach, A., Friedman, R. S., & Kruglanski, A. W. (2003). Leading us not unto temptation: Momentary allurements elicit overriding goal activation. *Journal of Personality and Social Psychology, 84*, 296-309.

Frank, S., Laharnar, N., Kullmann, S., Veit, R., Canova, C., Hegner, Y. L., . . . Preissl, H. (2010). Processing of food pictures: Influence of hunger, gender and calorie content. *Brain Research, 1350*, 159-166.

Frank, S., Lee, S., Preissl, H., Schultes, B., Birbaumer, N., & Veit, R. (2012). The obese brain athlete: Self-regulation of the anterior insula in adiposity. *Plos One, 7*. doi: 10.1371/journal.pone.0042570

Franken, I. H. A., & Muris, P. (2005). Individual differences in reward sensitivity are related to food craving and relative body weight in healthy women. *Appetite, 45*, 198-201.

Galimberti, E., Martoni, R. M., Cavallini, M. C., Erzegovesi, S., & Bellodi, L. (2012). Motor inhibition and cognitive flexibility in eating disorder subtypes. *Progress in Neuro-Psychopharmacology & Biological Psychiatry, 36*, 307-312.

García-García, I., Narberhaus, A., Marqués-Iturria, I., Garolera, M., Rădoi, A., Segura, B., . . . Jurado, M. A. (2013). Neural responses to visual food cues: Insights from functional magnetic resonance imaging. *European Eating Disorders Review, 21*, 89-98.

Giuliani, N. R., Calcott, R. D., & Berkman, E. T. (2013). Piece of cake. Cognitive reappraisal of food craving. *Appetite, 64*, 56-61.

Grosshans, M., Vollmert, C., Vollstädt-Klein, S., Tost, H., Leber, S., Bach, P., . . . Kiefer, F. (2012). Association of leptin with food-cue induced activation in human reward pathways. *Archives of General Psychiatry, 69*, 529-537.

Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-related potentials, emotion, and emotion regulation: An integrative review. *Developmental Neuropsychology, 35*, 129-155.

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology, 48*, 263-274.

Heatherton, T. F., Herman, C. P., Polivy, J., King, G. A., & McGree, S. T. (1988). The (mis)measurement of restraint: An analysis of conceptual and psychometric issues. *Journal of Abnormal Psychology, 97*, 19-28.

Heatherton, T. F., & Wagner, D. D. (2011). Cognitive neuroscience of self-regulation failure. *Trends in Cognitive Sciences, 15*, 132-139.

Hendrick, O. M., Luo, X., Zhang, S., & Li, C. S. R. (2012). Saliency processing and obesity: A preliminary imaging study of the Stop Signal Task. *Obesity, 20*, 1796-1802.

Hilbert, A., Vögele, C., Tuschen-Caffier, B., & Hartmann, A. S. (2011). Psychophysiological responses to idiosyncratic stress in bulimia nervosa and binge eating disorder. *Physiology & Behavior, 104*, 770-777.

Hill, A. J. (2007). The psychology of food craving. *Proceedings of the Nutrition Society, 66*, 277-285.

Hill, A. J., Weaver, C. F. L., & Blundell, J. E. (1991). Food craving, dietary restraint and mood. *Appetite, 17*, 187-197.

Hofmann, W., Friese, M., & Roefs, A. (2009). Three ways to resist temptation: The independent contributions of executive attention, inhibitory control, and affect regulation to the impulse control of eating behavior. *Journal of Experimental Social Psychology, 45*, 431-435.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences, 16*, 174-180.

Hollmann, M., Hellrung, L., Pleger, B., Schlogl, H., Kabisch, S., Stumvoll, M., . . . Horstmann, A. (2012). Neural correlates of the volitional regulation of the desire for food. *International Journal of Obesity, 36*, 648-655.

Hormes, J. M., & Rozin, P. (2010). Does "craving" carve nature at the joints? Absence of a synonym for craving in many languages. *Addictive Behaviors, 35*, 459-463.

Houben, K. (2011). Overcoming the urge to splurge: Influencing eating behavior by manipulating inhibitory control. *Journal of Behavior Therapy and Experimental Psychiatry, 42*, 384-388.

Houben, K., & Jansen, A. (2011). Training inhibitory control. A recipe for resisting sweet temptations. *Appetite, 56*, 345-349.

Houben, K., Nederkoorn, C., & Jansen, A. (2012). Too tempting to resist? Past success at weight control rather than dietary restraint determines exposure-induced disinhibited eating. *Appetite, 59*, 550-555.

Jansen, A., Nederkoorn, C., van Baak, L., Keirse, C., Guerrieri, R., & Havermans, R. (2009). High-restrained eaters only overeat when they are also impulsive. *Behaviour Research and Therapy, 47*, 105-110.

Jasinska, A. J., Yasuda, M., Burant, C. F., Gregor, N., Khatri, S., Sweet, M., & Falk, E. B. (2012). Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults. *Appetite, 59*, 738-747.

Jáuregui Lobera, I., Bolaños, P., Carbonero, R., & Valero Blanco, E. (2010). Psychometric properties of the Spanish version of the Food Craving Inventory (FCI-SP). *Nutrición Hospitalaria, 25*, 984-992.

Karason, K., Molgaard, H., Wikstrand, J., & Sjostrom, L. (1999). Heart rate variability in obesity and the effect of weight loss. *American Journal of Cardiology, 83*, 1242-1247.

Kemps, E., & Tiggemann, M. (2010). A cognitive experimental approach to understanding and reducing food cravings. *Current Directions in Psychological Science, 19*, 86-90.

Kemps, E., & Tiggemann, M. (2013). Hand-held dynamic visual noise reduces naturally occurring food cravings and craving-related consumption. *Appetite, 68*, 152-157.

Kemps, E., Tiggemann, M., & Grigg, M. (2008). Food cravings consume limited cognitive resources. *Journal of Experimental Psychology: Applied, 14*, 247-254.

Kenny, P. J. (2011). Reward mechanisms in obesity: new insights and future directions. *Neuron, 69*, 664-679.

Kessels, R. P., van Zandvoort, M. J., Postma, A., Kappelle, L. J., & de Haan, E. H. (2000). The Corsi Block-Tapping Task: standardization and normative data. *Applied Neuropsychology, 7*, 252-258.

Killgore, W. D. S., Young, A. D., Femia, L. A., Bogorodzki, P., Rogowska, J., & Yurgelun-Todd, D. A. (2003). Cortical and limbic activation during viewing of high- versus low-calorie foods. *NeuroImage, 19*, 1381-1394.

Kim, S., Zemon, V., Cavallo, M. M., Rath, J. F., McCraty, R., & Foley, F. W. (2013). Heart rate variability biofeedback, executive functioning and chronic brain injury. *Brain Injury, 27*, 209-222.

Kober, H., Mende-Siedlecki, P., Kross, E. F., Weber, J., Mischel, W., Hart, C. L., & Ochsner, K. N. (2010). Prefrontal-striatal pathway underlies cognitive regulation of craving. *PNAS, 107*, 14811-14816.

Komatsu, S. (2008). Rice and sushi cravings: A preliminary study of food craving among Japanese females. *Appetite, 50*, 353-358.

Lane, R. D., Mcrae, K., Reiman, E. M., Chen, K. W., Ahern, G. L., & Thayer, J. F. (2009). Neural correlates of heart rate variability during emotion. *NeuroImage, 44*, 213-222.

Langeslag, S. J. E., & Van Strien, J. W. (2010). Comparable modulation of the Late Positive Potential by emotion regulation in younger and older adults. *Journal of Psychophysiology, 24*, 186-197.

Latchman, P. L., Mathur, M., Bartels, M. N., Axtell, R. S., & De Meersman, R. F. (2011). Impaired autonomic function in normotensive obese children. *Clinical Autonomic Research, 21*, 319-323.

Legenbauer, T., Vögele, C., & Rüddel, H. (2004). Anticipatory effects of food exposure in women diagnosed with bulimia nervosa. *Appetite, 42*, 33-40.

Lehrer, P. (2013). How does heart rate variability biofeedback work? Resonance, the baroreflex, and other mechanisms. *Biofeedback, 41*, 26-31.

Lehrer, P., Vaschillo, E., & Vaschillo, B. (2000). Resonant frequency biofeedback training to increase cardiac variability: Rationale and manual for training. *Applied Psychophysiology and Biofeedback, 25*, 177-191.

Littel, M., Euser, A. S., Munafò, M. R., & Franken, I. H. A. (2012). Electrophysiological indices of biased cognitive processing of substance-related cues: A meta-analysis. *Neuroscience and Biobehavioral Reviews, 36*, 1803-1816.

Littel, M., & Franken, I. H. A. (2011). Intentional modulation of the Late Positive Potential in response to smoking cues by cognitive strategies in smokers. *Plos One, 6*(11), e27519.

Loeber, S., Grosshans, M., Herpertz, S., Kiefer, F., & Herpertz, S. (2013). Hunger modulates behavioral disinhibition and attention allocation to food-associated cues in normal-weight controls. *Appetite, 71*, 32-39.

Loeber, S., Grosshans, M., Korucuoglu, O., Vollmert, C., Vollstädt-Klein, S., Schneider, S., . . . Kiefer, F. (2012). Impairment of inhibitory control in response to food-associated cues and attentional bias of obese participants and normal-weight controls. *International Journal of Obesity, 36*, 1334-1339.

Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science, 8*, 60-64.

Lowe, M. R. (1993). The effects of dieting on eating behavior: A three-factor model. *Psychological Bulletin, 114*, 100-121.

Martin, C. K., McClernon, F. J., Chellino, A., & Correa, J. B. (2011). Food cravings: A central construct in food intake behavior, weight loss, and the neurobiology of appetitive behavior. In V. R. Preedy, R. R. Watson & C. R. Martin (Eds.), *Handbook of Behavior, Food and Nutrition* (pp. 741-755). New York: Springer.

Martin, C. K., Rosenbaum, D., Han, H. M., Geiselman, P. J., Wyatt, H. R., Hill, J. O., . . . Foster, G. D. (2011). Change in food cravings, food preferences, and appetite during a low-carbohydrate and low-fat diet. *Obesity, 19*, 1963-1970.

Mazurak, N., Enck, P., Muth, E., Teufel, M., & Zipfel, S. (2011). Heart rate variability as a measure of cardiac autonomic function in anorexia nervosa: A review of the literature. *European Eating Disorders Review, 19*, 87-99.

Meule, A., Bernhardt, K., Kleih, S., & Kübler, A. (in preparation). Heart rate variability biofeedback in patients with generalized anxiety disorder: a pilot study.

Meule, A., Hermann, T., & Kübler, A. (submitted). A short version of the *Food Cravings Questionnaire - Trait*: The FCQ-T-reduced.

Meule, A., & Kübler, A. (2012). Food cravings in food addiction: The distinct role of positive reinforcement. *Eating Behaviors, 13*, 252-255.

Meule, A., & Kübler, A. (in preparation). Self-reported dieting success is associated with food-cue affected working memory performance in current dieters.

Meule, A., Lukito, S., Vögele, C., & Kübler, A. (2011). Enhanced behavioral inhibition in restrained eaters. *Eating Behaviors, 12*, 152-155.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012a). Self-reported dieting success is associated with cardiac autonomic regulation in current dieters. *Appetite, 59*, 494-498.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012b). Women with elevated food addiction symptoms show accelerated reactions, but no impaired inhibitory control, in response to pictures of high-calorie food-cues. *Eating Behaviors, 13*, 423-428.

Meule, A., Lutz, A. P. C., Krawietz, V., Stützer, J., Vögele, C., & Kübler, A. (in revision). Food-cue affected motor response inhibition and self-reported dieting success: a pictorial affective shifting task.

Meule, A., Papies, E. K., & Kübler, A. (2012). Differentiating between successful and unsuccessful dieters: Validity and reliability of the Perceived Self-Regulatory Success in Dieting Scale. *Appetite, 58*, 822-826.

Meule, A., Vögele, C., & Kübler, A. (2012). Restrained eating is related to accelerated reaction to high caloric foods and cardiac autonomic dysregulation. *Appetite, 58*, 638-644.

Mobbs, O., Iglesias, K., Golay, A., & Van der Linden, M. (2011). Cognitive deficits in obese persons with and without binge eating disorder. Investigation using a mental flexibility task. *Appetite, 57*, 263-271.

Mobbs, O., Van der Linden, M., d'Acremont, M., & Perroud, A. (2008). Cognitive deficits and biases for food and body in bulimia: Investigation using an affective shifting task. *Eating Behaviors, 9*, 455-461.

Moreno, S., Rodríguez, S., Fernandez, M. C., Tamez, J., & Cepeda-Benito, A. (2008). Clinical validation of the trait and state versions of the food craving questionnaire. *Assessment, 15*, 375-387.

Moreno, S., Warren, C. S., Rodríguez, S., Fernández, M. C., & Cepeda-Benito, A. (2009). Food cravings discriminate between anorexia and bulimia nervosa. Implications for "success" versus "failure" in dietary restriction. *Appetite, 52*, 588-594.

Müller, J., Dettmer, D., & Macht, M. (2008). The Attitudes to Chocolate Questionnaire: Psychometric properties and relationship to dimensions of eating. *Appetite, 50*, 499-505.

Nederkoorn, C., Braet, C., Van Eijs, Y., Tanghe, A., & Jansen, A. (2006). Why obese children cannot resist food: The role of impulsivity. *Eating Behaviors, 7*, 315-322.

Nederkoorn, C., Coelho, J. S., Guerrieri, R., Houben, K., & Jansen, A. (2012). Specificity of the failure to inhibit responses in overweight children. *Appetite, 59*, 409-413.

Nederkoorn, C., Houben, K., Hofmann, W., Roefs, A., & Jansen, A. (2010). Control yourself or just eat what you like? Weight gain over a year is predicted by an interactive effect of response inhibition and implicit preference for snack foods. *Health Psychology, 29*, 389-393.

Nederkoorn, C., Jansen, E., Mulkens, S., & Jansen, A. (2007). Impulsivity predicts treatment outcome in obese children. *Behaviour Research and Therapy, 45*, 1071-1075.

Nederkoorn, C., Smulders, F. T. Y., Havermans, R., Roefs, A., & Jansen, A. (2006). Impulsivity in obese women. *Appetite, 47*, 253-256.

Nederkoorn, C., Smulders, F. T. Y., & Jansen, A. (2000). Cephalic phase responses, craving and food intake in normal subjects. *Appetite, 35*, 45-55.

Nederkoorn, C., Van Eijs, Y., & Jansen, A. (2004). Restrained eaters act on impulse. *Personality and Individual Differences, 37*, 1651-1658.

Nicholls, W., & Hulbert-Williams, L. (2013). British English translation of the Food Craving Inventory (FCI-UK). *Appetite, 67*, 37-43.

Nijs, I. M. T., & Franken, I. H. (2012). Attentional processing of food cues in overweight and obese individuals. *Current Obesity Reports, 1*, 106-113.

Nijs, I. M. T., Franken, I. H., & Muris, P. (2008). Food cue-elicited brain potentials in obese and healthy-weight individuals. *Eating Behaviors, 9*, 462-470.

Nijs, I. M. T., Franken, I. H. A., & Muris, P. (2007). The modified Trait and State Food-Cravings Questionnaires: Development and validation of a general index of food craving. *Appetite, 49*, 38-46.

Nijs, I. M. T., Franken, I. H. A., & Muris, P. (2009). Enhanced processing of food-related pictures in female external eaters. *Appetite, 53*, 376-383.

Nijs, I. M. T., Muris, P., Euser, A. S., & Franken, I. H. A. (2010). Differences in attention to food and food intake between overweight/obese and normal-weight females under conditions of hunger and satiety. *Appetite, 54*, 243-254.

Noh, J., Kim, J. H., Nam, H., Lim, M., Lee, D., & Hong, K. (2008). Validation of the Korean version of the General Food Cravings Questionnaire-Trait (G-FCQ-T). *Korean Journal of Clinical Psychology, 27*, 1039-1051.

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology, 77*, 247-265.

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging. *Human Brain Mapping, 25*, 46-59.

Papies, E. K., Stroebe, W., & Aarts, H. (2008). Healthy cognition: Processes of self-regulatory success in restrained eating. *Personality and Social Psychology Bulletin, 34*, 1290-1300.

Patron, E., Benvenuti, S. M., Favretto, G., Valfre, C., Bonfa, C., Gasparotto, R., & Palomba, D. (2013). Biofeedback assisted control of respiratory sinus arrhythmia as a biobehavioral intervention for depressive symptoms in patients after cardiac surgery: a preliminary study. *Applied Psychophysiology and Biofeedback, 38*, 1-9.

Pelchat, M. L., Johnson, A., Chan, R., Valdez, J., & Ragland, J. D. (2004). Images of desire: Food-craving activation during fMRI. *NeuroImage, 23*, 1486–1493.

Pelchat, M. L., & Schaefer, S. (2000). Dietary monotony and food cravings in young and elderly adults. *Physiology & Behavior, 68*, 353-359.

Pinna, G. D., Maestri, R., Torunski, A., Danilowicz-Szymanowicz, L., Szwoch, M., La Rovere, M. T., & Raczak, G. (2007). Heart rate variability measures: a fresh look a reliability. *Clinical Science, 113*, 131-140.

Polivy, J., Coleman, J., & Herman, C. P. (2005). The effect of deprivation on food cravings and eating behavior in restrained and unrestrained eaters. *International Journal of Eating Disorders, 38*, 301-309.

Pop-Jordanova, N. (2000). Psychological characteristics and biofeedback mitigation in preadolescents with eating disorders. *Pediatrics International, 42*, 76-81.

Reinert, K. R. S., Po'e, E. K., & Barkin, S. L. (2013). The relationship between executive function and obesity in children and adolescents: A systematic literature review. *Journal of Obesity*. doi: 10.1155/2013/820956

Reynard, A., Gevirtz, R., Berlow, R., Brown, M., & Boutelle, K. (2011). Heart rate variability as a marker of self-regulation. *Applied Psychophysiology and Biofeedback, 36*, 209-215.

Rodgers, R. F., Stritzke, W. G. K., Bui, E., Franko, D. L., & Chabrol, H. (2011). Evaluation of the French version of the orientation towards chocolate questionnaire: Chocolate-related guilt and ambivalence are associated with overweight and disordered eating. *Eating Behaviors, 12*, 254-260.

Rodin, J., Mancuso, J., Granger, J., & Nelbach, E. (1991). Food cravings in relation to body mass index, restraint and estradiol levels: A repeated measures study in healthy women. *Appetite, 17*, 177-185.

Rodríguez-Ruiz, S., Guerra, P. M., Moreno, S., Fernández, M. C., & Vila, J. (2012). Heart rate variability modulates eye-blink startle in women with bulimic symptoms. *Journal of Psychophysiology, 26*, 10-19.

Rodríguez-Ruiz, S., Ruiz-Padial, E., Vera, N., Fernández, C., Anllo-Vento, L., & Vila, J. (2009). Effect of heart rate variability on defensive reaction and eating disorder symptomatology in chocolate cravers. *Journal of Psychophysiology, 23*, 95-103.

Rodriguez, S., Warren, C. S., Moreno, S., Cepeda-Benito, A., Gleaves, D. H., Fernandez, M. D., & Vila, J. (2007). Adaptation of the food-craving questionnaire trait for the assessment of chocolate cravings: Validation across British and Spanish Women. *Appetite, 49*, 245-250.

Rosval, L., Steiger, H., Bruce, K., Israël, M., Richardson, J., & Aubut, M. (2006). Impulsivity in women with eating disorders: problem of response inhibition, planning, or attention? *International Journal of Eating Disorders, 39*, 590-593.

Sandercock, G. (2007). Normative values, reliability and sample size estimates in heart rate variability. *Clinical Science, 113*, 129-130.

Sarlo, M., Übel, S., Leutgeb, V., & Schienle, A. (2013). Cognitive reappraisal fails when attempting to reduce the appetitive value of food: An ERP study. *Biological Psychology, 94*, 507-512.

Sauder, K. A., Skulas-Ray, A. C., Campbell, T. S., Johnson, J. A., Kris-Etherton, P. M., & West, S. G. (2013). Effects of omega-3 fatty acid supplementation on heart rate variability at rest and during acute stress in adults with moderate hypertriglyceridemia. *Psychosomatic Medicine, 75*, 382-389.

Scharmüller, W., Übel, S., Ebner, F., & Schienle, A. (2012). Appetite regulation during food cue exposure: A comparison of normal-weight and obese women. *Neuroscience Letters, 518*, 106-110.

Schienle, A., Schäfer, A., Hermann, A., & Vaitl, D. (2009). Binge-Eating Disorder: Reward sensitivity and brain activation to images of food. *Biological Psychiatry, 65*, 654-661.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in Brain Research, 156*, 31-51.

Segerstrom, S. C., & Nes, L. S. (2007). Heart rate variability reflects self-regulatory strength, effort, and fatigue. *Psychological Science, 18*, 275-281.

Shiffman, S. (2000). Comments on craving. *Addiction, 95*, S171-S175.

Siep, N., Roefs, A., Roebroeck, A., Havermans, R., Bonte, M., & Jansen, A. (2012). Fighting food temptations: The modulating effects of short-term cognitive reappraisal, suppression and up-regulation on mesocorticolimbic activity related to appetitive motivation. *NeuroImage, 60*, 213-220.

Siep, N., Roefs, A., Roebroeck, A., Havermans, R., Bonte, M. L., & Jansen, A. (2009). Hunger is the best spice: An fMRI study of the effects of attention, hunger and calorie content on food reward processing in the amygdala and orbitofrontal cortex. *Behavioural Brain Research, 198*, 149-158.

Stockburger, J., Hamm, A. O., Weike, A. I., & Schupp, H. T. (2008). Deprivation selectively modulates brain potentials to food pictures. *Behavioral Neuroscience, 122*, 936-942.

Stockburger, J., Schmälzle, R., Flaisch, T., Bublatzky, F., & Schupp, H. T. (2009). The impact of hunger on food cue processing: An event-related brain potential study. *NeuroImage, 47*, 1819-1829.

Stroebe, W., Van Koningsbruggen, G. M., Papies, E. K., & Aarts, H. (2013). Why most dieters fail but some succeed: A goal conflict model of eating behavior. *Psychological Review, 120*, 110-138.

Svaldi, J., Schmitz, F., Trentowska, M., Tuschen-Caffier, B., Berking, M., & Naumann, E. (2014). Cognitive interference and a food-related memory bias in binge eating disorder. *Appetite, 72*, 28-36.

Svaldi, J., Tuschen-Caffier, B., Peyk, P., & Blechert, J. (2010). Information processing of food pictures in binge eating disorder. *Appetite, 55*, 685-694.

Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal, 17*, 354-381.

Teufel, M., Stephan, K., Kowalski, A., Käsberger, S., Enck, P., Zipfel, S., & Giel, K. E. (2013). Impact of biofeedback on self-efficacy and stress reduction in obesity: A randomized controlled pilot study. *Applied Psychophysiology and Biofeedback, 38*, 177-184.

Thamotharan, S., Lange, K., Zale, E. L., Huffhines, L., & Fields, S. (2013). The role of impulsivity in pediatric obesity and weight status: A meta-analytic review. *Clinical Psychology Review, 33*, 253-262.

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews, 36*, 747-756.

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine, 37*, 141-153.

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience & Biobehavioral Reviews, 33*, 81-88.

Thayer, J. F., Yamamoto, S. S., & Brosschot, J. F. (2010). The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *International Journal of Cardiology, 141*, 122-131.

Thiruchselvam, R., Blechert, J., Sheppes, G., Rydstrom, A., & Gross, J. J. (2011). The temporal dynamics of emotion regulation: An EEG study of distraction and reappraisal. *Biological Psychology, 87*, 84-92.

Tiffany, S. T., & Wray, J. M. (2012). The clinical significance of drug craving. *Annals of the New York Academy of Sciences, 1248*, 1-17.

Tiggemann, M., & Kemps, E. (2005). The phenomenology of food cravings: The role of mental imagery. *Appetite, 45*, 305-313.

Tiggemann, M., Kemps, E., & Parnell, J. (2010). The selective impact of chocolate craving on visuospatial working memory. *Appetite, 55*, 44-48.

Timko, C. A., & Perone, J. (2005). Rigid and flexible control of eating behavior in a college population. *Eating Behaviors, 6*, 119-125.

Toepel, U., Knebel, J. F., Hudry, J., le Coutre, J., & Murray, M. M. (2009). The brain tracks the energetic value in food images. *NeuroImage, 44*, 967-974.

Toll, B. A., Katulak, N. A., Williams-Piehota, P., & O'Malley, S. (2008). Validation of a scale for the assessment of food cravings among smokers. *Appetite, 50*, 25-32.

Tulppo, M. P., Hautala, A. J., Makikallio, T. H., Laukkanen, R. T., Nissila, S., Hughson, R. L., & Huikuri, H. V. (2003). Effects of aerobic training on heart rate dynamics in sedentary subjects. *Journal of Applied Physiology, 95*, 364-372.

Van den Eynde, F., Koskina, A., Syrad, H., Guillaume, S., Broadbent, H., Campbell, I. C., & Schmidt, U. (2012). State and trait food craving in people with bulimic eating disorders. *Eating Behaviors, 13*, 414-417.

Van den Eynde, F., Samarawickrema, N., Kenyon, M., DeJong, H., Lavender, A., Startup, H., & Schmidt, U. (2012). A study of neurocognition in bulimia nervosa and eating disorder not otherwise specified-bulimia type. *Journal of Clinical and Experimental Neuropsychology, 34*, 67-77.

Van Koningsbruggen, G. M., Stroebe, W., & Aarts, H. (2011). Through the eyes of dieters: Biased size perception of food following tempting food primes. *Journal of Experimental Social Psychology, 47*, 293-299.

van Koningsbruggen, G. M., Stroebe, W., & Aarts, H. (2013). Successful restrained eating and trait impulsiveness. *Appetite, 60*, 81-84.

Van Koningsbruggen, G. M., Stroebe, W., Papies, E. K., & Aarts, H. (2011). Implementation intentions as goal primes: Boosting self-control in tempting environments. *European Journal of Social Psychology, 41*, 551-557.

Van Strien, T. (1997). Are most dieters unsuccessful? An alternative interpretation of confounding of success and failure in the measurement of restraint. *European Journal of Psychological Assessment, 13*, 186-194.

Van Strien, T. (1999). Success and Failure in the Measurement of Restraint. *International Journal of Eating Disorders, 25*, 441-449.

Vander Wal, J. S., Johnston, K. A., & Dhurandhar, N. V. (2007). Psychometric properties of the State and Trait Food Cravings Questionnaires among overweight and obese persons. *Eating Behaviors, 8*, 211-223.

Veling, H., Aarts, H., & Papies, E. K. (2011). Using stop signals to inhibit chronic dieters' responses toward palatable foods. *Behaviour Research and Therapy, 49*, 771-780.

Veling, H., Aarts, H., & Stroebe, W. (2013). Using stop signals to reduce impulsive choices for palatable unhealthy foods. *British Journal of Health Psychology, 18*, 354-368.

Vögele, C., & Florin, I. (1997). Psychophysiological responses to food exposure: An experimental study in binge eaters. *International Journal of Eating Disorders, 21*, 147-157.

Vögele, C., Hilbert, A., & Tuschen-Caffier, B. (2009). Dietary restriction, cardiac autonomic regulation and stress reactivity in bulimic women. *Physiology & Behavior, 98*, 229-234.

Wang, G. J., Volkow, N. D., Telang, F., Jayne, M., Ma, J., Rao, M. L., . . . Fowler, J. S. (2004). Exposure to appetitive food stimuli markedly activates the human brain. *NeuroImage, 21*, 1790-1797.

Wang, G. J., Volkow, N. D., Telang, F., Jayne, M., Ma, Y. M., Pradhan, K., . . . Fowler, J. S. (2009). Evidence of gender differences in the ability to inhibit brain activation elicited by food stimulation. *PNAS, 106*, 1249-1254.

Weingarten, H. P., & Elston, D. (1990). The phenomenology of food cravings. *Appetite, 15*, 231-246.

Weingarten, H. P., & Elston, D. (1991). Food cravings in a college population. *Appetite, 17*, 167-175.

Westenhoefer, J., Stunkard, A. J., & Pudel, V. (1999). Validation of the flexible and rigid control dimensions of dietary restraint. *International Journal of Eating Disorders, 26*, 53-64.

Wheat, A. L., & Larkin, K. T. (2010). Biofeedback of heart rate variability and related physiology: A critical review. *Applied Psychophysiology and Biofeedback, 35*, 229-242.

White, M. A., Whisenhunt, B. L., Williamson, D. A., Greenway, F. L., & Netemeyer, R. G. (2002). Development and validation of the Food-Craving Inventory. *Obesity Research, 10*, 107-114.

Williamson, D. A., Martin, C. K., York-Crowe, E., Anton, S. D., Redman, L., Han, H., & Ravussin, E. (2007). Measurement of dietary restraint: Validity tests of four questionnaires. *Appetite, 48*, 183-192.

Wilson, S. J., Sayette, M. A., Fiez, J. A., & Brough, E. (2007). Carry-over effects of smoking cue exposure on working memory performance. *Nicotine & Tobacco Research, 9*, 613-619.

Wirt, T., Hundsdörfer, V., Schreiber, A., Kesztyüs, D., & Steinacker, J. M. (2014). Associations between inhibitory control and body weight in German primary school children. *Eating Behaviors, 15*, 9-12.

Witt, A. A., Katterman, S. N., & Lowe, M. R. (2013). Assessing the three types of dieting in the Three-Factor Model of dieting. The Dieting and Weight History Questionnaire. *Appetite, 63*, 24-30.

Wu, M., Giel, K. E., Skunde, M., Schag, K., Rudofsky, G., de Zwaan, M., . . . Friederich, H.-C. (2013). Inhibitory control and decision making under risk in bulimia nervosa and binge-eating disorder. *International Journal of Eating Disorders, 46*, 721-728.

Xin, W., Wei, W., & Li, X. Y. (2013). Short-term effects of fish-oil supplementation on heart rate variability in humans: a meta-analysis of randomized controlled trials. *American Journal of Clinical Nutrition, 97*, 926-935.

Yokum, S., & Stice, E. (2013). Cognitive regulation of food craving: effects of three cognitive reappraisal strategies on neural response to palatable foods. *International Journal of Obesity, 37*, 1565-1570.

Zucker, T. L., Samuelson, K. W., Muench, F., Greenberg, M. A., & Gevirtz, R. N. (2009). The effects of respiratory sinus arrhythmia biofeedback on heart rate variability and posttraumatic stress disorder symptoms: A pilot study. *Applied Psychophysiology and Biofeedback, 34*, 135-143.

Appendix A: Affidavit

Affidavit

I hereby confirm that my thesis entitled *Food craving as a central construct in the self-regulation of eating behavior* is the result of my own work. I did not receive any help or support from commercial consultants. All sources and/or materials applied are listed and specified in the thesis.
Furthermore, I confirm that this thesis has not yet been submitted as part of another examination process neither in identical nor in similar form.

Würzburg,

___________________________ ___________________________

Place, Date Signature

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, die Dissertation *Food craving as a central construct in the self-regulation of eating behavior* eigenständig, d.h. insbesondere selbstständig und ohne Hilfe eines kommerziellen Promotionsberaters, angefertigt und keine anderen als die von mir angegebenen Quellen und Hilfsmittel verwendet zu haben.
Ich erkläre außerdem, dass die Dissertation weder in gleicher noch in ähnlicher Form bereits in einem anderen Prüfungsverfahren vorgelegen hat.

Würzburg,

___________________________ ___________________________

Place, Date Signature

Appendix B: Approval of a dissertation based on several published manuscripts

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Graduate School
Life Sciences

Approval of a "Dissertation Based on Several Published Manuscripts"

for the doctoral researcher

Adrian Meule

(Name)

who has accomplished a publication record significantly above average as documented in the attachment.

The **Section Speakers and the Thesis Committee** therefore approve a "Dissertation Based on Several Published Manuscripts".

The **Thesis Committee** additionally confirms that the doctoral researcher has fulfilled all requirements of the GSLS program "life science".

Thesis Committee

Supervisor	Name	Date	Signature
1	Prof. Dr. A. Kübler	29.2.12	[signature]
2	Prof. Dr. P. Pauli	3.5.12	[signature]
3	Prof. Dr. C. Sommer	10.5.12	[signature]
4 (if applicable)	Prof. Dr. C. Vögele	25/2/2012	[signature]

Section Speakers

Speaker	Name	Date	Signature
1	Prof. Dr. M. Sendtner	29.5.2012	[signature]
2	Prof. Dr. P. Pauli	3.5.12	[signature]
3 (if applicable)	Prof. Dr. E. Asan	14.05.12	[signature]

Appendix C: Statement of individual author contributions and of legal second publication rights

Publication: Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite*, *57*, 582-584.

Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design	AM	AK			
Data Collection	AM				
Data Analysis and Interpretation	AM				
Manuscript Writing	AM	AK	JW		

Publication: Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters: Validation of the Food Cravings Questionnaires in German. *Appetite*, *58*, 88-97.

Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design	AM	AL	AK	CV	
Data Collection	AM	AL			
Data Analysis and Interpretation	AM				
Manuscript Writing	AM	AK	CV		

Publication: Meule, A., Skirde, A.K., Freund, R., Vögele, C., & Kübler, A. (2012). High-calorie food-cues impair working memory performance in high and low food cravers. *Appetite*, *59*, 264-269.

Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design	AM	AK	CV		
Data Collection	AKS	RF	AM		
Data Analysis and Interpretation	AM				
Manuscript Writing	AM	AK	CV		

Publication: Meule, A., Freund, R., Skirde, A.K., Vögele, C., & Kübler, A. (2012). Heart rate variability biofeedback reduces food cravings in high food cravers. *Applied Psychophysiology and Biofeedback*, *37*, 241-251.

Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design	AM	AK	CV		
Data Collection	AKS	RF	AM		
Data Analysis and Interpretation	AM				
Manuscript Writing	AM	AK	CV		

Publication: Meule, A., Kübler, A., & Blechert, J. (2013). Time course of electrocortical food-cue responses during cognitive regulation of craving. *Frontiers in Psychology, 4*(669), 1-11.

Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design	AM	JB	AK		
Data Collection	JB	AM			
Data Analysis and Interpretation	AM	JB			
Manuscript Writing	AM	JB	AK		

Publication: Meule, A., & Kübler, A. (submitted). Double trouble: Trait food craving and impulsivity interactively predict food-cue affected behavioral inhibition.

Participated in	**Author Initials,** Responsibility decreasing from left to right				
Study Design	AM				
Data Collection	AM				
Data Analysis and Interpretation	AM				
Manuscript Writing	AM	AK			

I confirm that I have obtained permission from both the publishers and the co-authors for legal second publication.

I also confirm my primary supervisor's acceptance.

Adrian Meule Würzburg

Doctoral Researcher's Name Date Place Signature

Appendix D: Curriculum vitae

Adrian Meule, Dipl.-Psych.
Department of Psychology I
University of Würzburg
Marcusstr. 9-11
97070 Würzburg, Germany
Phone: +49 931 31 808 34
Email: adrian.meule@uni-wuerzburg.de

Education and research experience

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since 11/2009	PhD student at the Department of Psychology I, University of Würzburg (Workgroup Prof. Dr. A. Kübler)
10/2004 – 10/2009	Studies of Psychology at the University of Würzburg Thesis: *Inhibitory control in women with restrained and disordered eating*
08/2007 – 08/2009	Miscellaneous workings as a student assistant at the Department of Psychology I, University of Würzburg
08/2008 – 10/2008	Internship at the clinic for neurological rehabilitation, Rotenburg a.d.F., Germany
02/2007 – 03/2007	Internship at the rehabilitation clinic *Taubertal*, Bad Mergentheim, Germany
07/2003 – 04/2004	Alternative service at the rehabilitation clinic *Taubertal*, Bad Mergentheim, Germany
06/2003	High-school diploma (“Abitur”) at the commercial high school (“Wirtschaftsgymnasium”), Bad Mergentheim, Germany

Teaching and supervision of students

Practical course on behavior analysis and –regulation

Summer term 2010, winter term 2010/11, winter term 2012/13, summer term 2013, winter term 2013/14

Seminar on self- and emotion regulation

Summer term 2011, winter term 2011/12, summer term 2012, winter term 2012/13, summer term 2013, winter term 2013/14

Supervised master's theses

Désirée Baumbusch, Maja Englert, Rebecca Freund, Tilman Gründel, Daniela Heckel, Vera Krawietz, Annika Lutz, Sabine Meininger, Ann Kathrin Skirde, Judith Stützer

Supervised bachelor's theses

Tina Hermann, Martina Mayerhofer, Nadine Weber

Co-supervised master's theses

Kristina Bernhardt, Carolin Ernst, Katharina Fath (née Eichhorn), Friederike Obergfell, Alice Ranger

Co-supervised bachelor's theses

Carina Beck Teran, Jasmin Berker, Dominik Gall

Professional activities

Editorship	Specialty Chief Editor of Frontiers in Eating Behavior
Ad-hoc reviewer	Alcohol and Alcoholism; American Journal of Clinical Nutrition; Appetite; Clinical Obesity; Eating Behaviors; European Addiction Research; European Eating Disorders Review; Fortschritte der Neurologie – Psychiatrie; General Hospital Psychiatry; International Journal of Women's Health; Journal of Addictive Behaviors, Therapy & Rehabilitation; Journal of Behavioral Addictions; Journal of Experimental Social Psychology; Medical Hypotheses; Obesity; Physiology & Behavior; Psychiatry Research; Psychotherapie – Psychosomatik – Medizinische

	Psychologie; SpringerPlus; Substance Abuse and Rehabilitation; Zeitschrift für Kinder- und Jugendpsychiatrie und Psychotherapie
Chaired symposia	*Regulation of eating behavior II: Effects of food-cues and new intervention approaches on the cognitive and behavioral level,* symposium at the 11th congress of the Health Psychology section of the German Psychological Society, Luxembourg, 2013
	Psychophysiological aspects of disordered eating behavior, symposium at the 13th congress of the German Society of Behavioral Medicine & Behavior Modification, Luxembourg, 2011

Membership in professional societies

European Health Psychology Society (EHPS)

German Psychological Society (Deutsche Gesellschaft für Psychologie, DGPs)
Sections: Clinical Psychology and Psychotherapy, *Health Psychology*

German Society of Behavioral Medicine & Behavior Modification (Deutsche Gesellschaft für Verhaltensmedizin und Verhaltensmodifikation, DGVM)

German Society on Eating Disorders (Deutsche Gesellschaft für Essstörungen, DGESS)

Society for the Study of Ingestive Behavior (SSIB)

Honors and awards

2013	Travel grant from the German Society of Behavioral Medicine & Behavior Modification (Deutsche Gesellschaft für Verhaltensmedizin und Verhaltensmodifikation, DGVM) for attending the 14th congress of the DGVM in Prien, Germany (250 €)

2013	Travel grant from the German Academic Exchange Service (Deutscher Akademischer Austausch Dienst, DAAD) for attending the 11th congress of the DGPs section health psychology in Luxembourg (513 €)
2012	Best publication award of the Research Training Group 1253 (500 €)
2011	Best publication award of the Research Training Group 1253 (400 €)
11/2009 – 12/2012	Scholarship of the Research Training Group 1253 "Processing of affective stimuli: from the molecular basis to the emotional experience" (funded by the German Research Foundation)

Journal articles

Forthcoming

Meule, A. (submitted). The relation between body-mass-index and substance use: A true can of worms.

Meule, A. (in press). Süchtiges Essverhalten. *neuro aktuell*.

Meule, A., Allison, K.C., & Platte, P. (in press). Emotional eating moderates the relationship of night eating with binge eating and body mass. *European Eating Disorders Review*.

Meule, A., Heckel, D., Jurowich, C., Vögele, C., & Kübler, A. (submitted). Correlates of food addiction in obese individuals seeking bariatric surgery.

Meule, A., Hermann, T., & Kübler, A. (submitted). A short version of the *Food Cravings Questionnaire - Trait*: The FCQ-T-reduced.

Meule, A. & Kübler, A. (submitted). Double trouble: Trait food craving and impulsivity interactively predict food-cue affected behavioral inhibition.

Meule, A., Lutz, A.P.C., Vögele, C., & Kübler, A. (in revision). Food-cue affected motor response inhibition and self-reported dieting success: a pictorial affective shifting task.

Platte, P., Vögele, C., & **Meule, A.** (in revision). Adipositas im Kindes- und Jugendalter [Obesity in childhood and adolescence].

2014

Meule, A., Lutz, A.P.C., Vögele, C., & Kübler, A. (2014). Impulsive reactions to food-cues predict subsequent food craving. *Eating Behaviors*, *15*, 99-105.

2013

Meule, A. (2013). Impulsivity and overeating: a closer look at the subscales of the Barratt Impulsiveness Scale. *Frontiers in Psychology, 4*(177), 1-4.

Meule, A.*, Fath, K.*, Real, R.G.L., Sütterlin, S., Vögele, C., & Kübler, A. (2013). Quality of life, emotion regulation, and heart rate variability in individuals with intellectual disabilities and concomitant impaired vision. *Psychology of Well-Being: Theory, Research and Practice*, *3*, 1-14. *shared first authorship

Meule, A., Kübler, A., & Blechert, J. (2013). Time course of electrocortical food-cue responses during cognitive regulation of craving. *Frontiers in Psychology, 4*(669), 1-11.

Meule, A. & Vögele, C. (2013). The psychology of eating. *Frontiers in Psychology, 4*(215), 1-2.

2012

Meule, A. (2012). Food addiction and body-mass-index: A non-linear relationship. *Medical Hypotheses, 79*, 508-511.

Meule, A., Freund, R., Skirde, A.K., Vögele, C., & Kübler, A. (2012). Heart rate variability biofeedback reduces food cravings in high food cravers. *Applied Psychophysiology and Biofeedback*, *37*, 241-251.

Meule, A., Heckel, D., & Kübler, A. (2012). Factor structure and item analysis of the Yale Food Addiction Scale in obese candidates for bariatric surgery. *European Eating Disorders Review, 20*, 419-422.

Meule, A. & Kübler, A. (2012). The translation of substance dependence criteria to food-related behaviors: Different views and interpretations. *Frontiers in Psychiatry*, *3*(64), 1-2.

Meule, A. & Kübler, A. (2012). Corrigendum to "Food cravings in food addiction: The distinct role of positive reinforcement" [Eat Behav 13 (3) (2012) 252-255]. *Eating Behaviors, 13*, 433.

Meule, A. & Kübler, A. (2012). Food cravings in food addiction: the distinct role of positive reinforcement. *Eating Behaviors*, *13*, 252-255.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012). Women with elevated food addiction symptoms show accelerated reactions, but no impaired inhibitory control, in response to pictures of high-calorie food-cues. *Eating Behaviors, 13,* 423-428.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012). Self-reported dieting success is associated with cardiac autonomic regulation in current dieters. *Appetite*, *59*, 494-498.

Meule, A., Lutz, A., Vögele, C., & Kübler, A. (2012). Food cravings discriminate differentially between successful and unsuccessful dieters and non-dieters: Validation of the Food Cravings Questionnaires in German. *Appetite*, *58*, 88-97.

Meule, A., Papies, E.K., & Kübler, A. (2012). Differentiating between successful and unsuccessful dieters: Validity and reliability of the Perceived Self-Regulatory Success in Dieting Scale. *Appetite*, *58*, 822-826.

Meule, A., Roeser, K., Randler, C., & Kübler, A. (2012). Skipping breakfast: Morningness-eveningness preference is differentially related to state and trait food cravings. *Eating and Weight Disorders*, *17*, 304-308.

Meule, A., Skirde, A.K., Freund, R., Vögele, C., & Kübler, A. (2012). High-calorie food-cues impair working memory performance in high and low food cravers. *Appetite*, *59*, 264-269.

Meule, A., Vögele, C., & Kübler, A. (2012). Restrained eating is related to accelerated reaction to high caloric foods and cardiac autonomic dysregulation. *Appetite*, *58*, 638-644.

Meule, A., Vögele, C., & Kübler, A. (2012). Deutsche Übersetzung und Validierung der Yale Food Addiction Scale [German translation and validation of the Yale Food Addiction Scale]. *Diagnostica*, *58*, 115-126.

Roeser, K.*, **Meule, A.***, Schwerdtle, B., Kübler, A., & Schlarb, A.A. (2012). Subjective sleep quality exclusively mediates the relationship between morningness-eveningness preference and self-perceived stress response. *Chronobiology International*, *29*, 955-960. *shared first authorship

Roeser, K., Obergfell, F., **Meule, A.**, Vögele, C., Schlarb, A., & Kübler, A. (2012). Of larks and hearts – morningness/eveningness, heart rate variability and cardiovascular stress response at different times of day. *Physiology & Behavior*, *106*, 151-157.

2011

Meule, A. (2011). How prevalent is 'food addiction'?. *Frontiers in Psychiatry*, *2*(61), 1-4.

Meule, A., Lukito, S., Vögele, C., & Kübler, A. (2011). Enhanced behavioral inhibition in restrained eaters. *Eating Behaviors, 12*, 152-155.

Meule, A., Vögele, C., & Kübler, A. (2011). Psychometrische Evaluation der deutschen Barratt Impulsiveness Scale – Kurzversion (BIS-15) [Psychometric evaluation of the German Barratt Impulsiveness Scale - Short Version (BIS-15)]. *Diagnostica*, *57*, 126-133.

Meule, A., Westenhöfer, J., & Kübler, A. (2011). Food cravings mediate the relationship between rigid, but not flexible control of eating behavior and dieting success. *Appetite*, *57*, 582-584.

Conference contributions and invited talks

2014

Meule, A. (2014, January). *[Addicted to food: media hype or scientifically supported?]*. Invited talk at the Hannover Medical School, Hannover, Germany.

2013

Meule, A. (2013). Back by popular demand: On the history and state of the art of food addiction research. *Verhaltenstherapie & Verhaltensmedizin, 34*(Suppl. 1), 35-36.

Meule, A. (2013, June). *[Self-regulation of eating behavior: Influence of high caloric food-cues on executive control and individual differences]*. Invited talk at the Central Institute for Mental Health, Mannheim, Germany.

Meule, A. (2013, November). *[Heart rate variability and heart rate variability biofeedback]*. Invited talk at the LWL University Clinic, Hamm, Germany.

Meule, A., Englert, M., Kübler, A., & Kohlmann, S. (2013, October). *[Emotion regulation and eating behavior in bariatric patients]*. Paper presented at the 29th annual meeting of the German Obesity Society, Hannover, Germany.

Meule, A., Hermann, T., & Kübler, A. (2013). Food addiction in overweight and obese adolescents seeking weight-loss treatment. *Adipositas*, *7*, A48.

Meule, A., Hermann, T., & Kübler, A. (2013). Food addiction in overweight and obese adolescents seeking weight-loss treatment. *Verhaltenstherapie & Verhaltensmedizin, 34*(Suppl. 1), 97-98.

Meule, A., & Kübler, A. (2013). Interactive effects of food craving and impulsivity on food-cue affected response inhibition. *Verhaltenstherapie & Verhaltensmedizin, 34*(Suppl. 1), 33.

Meule, A., & Kübler, A. (2013). Interactive effects of food craving and impulsivity on food-cue affected response inhibition. In C. Vögele (Ed.), *11. Kongress der Fachgruppe Gesundheitspsychologie – Selbstregulation und Gesundheit – Abstractband des Kongresses* (pp. 18-19). Luxembourg: Inside Research Reports.

Meule, A., Kübler, A., & Blechert, J. (2013). Cognitive regulation of food craving modulates electrocortical processing of food-cues. In U. Ansorge, E. Kirchler, C. Lamm, & H. Leder (Eds.), *Abstracts of the 55th Conference of Experimental Psychologists* (p. 185). Lengerich: Pabst Science Publishers.

2012

Meule, A. (2012, April). *Food addiction in obese individuals seeking bariatric surgery and its relation to impulsivity and alcohol use*. Paper presented at the Springschool of the GK-Emotions, Marktbreit, Germany.

Meule, A. (2012, October). *Cognitive regulation of food craving modulates electrocortical processing of food-cues*. Paper presented at the Summerschool of the GK-Emotions, Lohr a.M., Germany.

Meule, A., Baumbusch, D., Allison, K.C., Stunkard, A.J., & Platte, P. (2012). A German version of the Night Eating Questionnaire (NEQ): Prevalence and correlates of night eating syndrome. *Obesity Facts*, *5*(Suppl. 2), 21.

Meule, A. & Blechert, J. (2012). food.pics: A picture database for the study of eating and appetite. *Obesity Facts*, *5*(Suppl. 2), 20.

Meule, A., Ernst, C., Kübler, A., & Blechert, J. (2012, June). *Cognitive regulation of food craving modulates electrocortical processing of food-cues*. Poster presented at the 38th annual meeting of the German Society for Psychophysiology and its Application (DGPA) and the DGPs section Biological Psychology and Neuropsychology, Jena, Germany.

Meule, A., Heckel, D., & Kübler, A. (2012). Food addiction in obese candidates for bariatric surgery. *German Medical Science,* doi: 10.3205/12dgess084.

Meule, A., Heckel, D., Vögele, C., & Kübler, A. (2012). Food addiction in obese candidates for bariatric surgery. In C. Vögele (Ed.), *Abstracts of the 30th Symposium Clinical Psychology and Psychotherapy of the DGPs Section Clinical Psychology and Psychotherapy* (p. 61). Luxembourg: University of Luxembourg.

Meule, A., Vögele, C., & Kübler, A. (2012, November). *Prävalenz und Korrelate süchtigen Essverhaltens*. Paper presented at the annual meeting of the German Association of Psychiatry, Psychotherapy, and Psychosomatics, Berlin, Germany.

Meule, A., Vögele, C., & Kübler, A. (2012). Biofeedback of heart rate variability reduces food cravings in high food cravers. *German Medical Science,* doi: 10.3205/12dgess028.

Roeser, K., **Meule, A.**, Schwerdtle, B., Kübler, A., & Schlarb, A.A. (2012). Chronotypen, Schlafprobleme und Stress. *Somnologie, 16*(Suppl. 1), 24-25.

2011

Lutz, A.P.C., **Meule, A.**, Kübler, A., & Vögele, C. (2011). Selbstregulation und Inhibition von 'Food Cravings'. *Verhaltenstherapie*, *21*(Suppl. 1), 21-22.

Lutz, A.P.C., **Meule, A.**, Kübler, A., & Vögele, C. (2011, May). *The allure of the cream gateau: Attentional and response bias towards high calorie foods*. Paper presented at the 2nd Luxembourgish Nutrition Conference NULUX 2011, Bad Mondorf, Luxembourg.

Meule, A. (2011, April). *Emotion regulation, eating behavior, and cardiac autonomic activity*. Poster presented at the Springschool of the GK-Emotions, Schwanberg, Germany.

Meule, A. (2011, October). *Cardiac autonomic activity and the self-regulation of eating behavior*. Paper presented at the Summerschool of the GK-Emotions, Marktbreit, Germany.

Meule, A. (2011, November). *Food Cravings und Food Addiction*. Paper presented at the 12th meeting of the Interdisciplinary Center for Addiction Research at the University of Wuerzburg, Wuerzburg, Germany.

Meule, A., Skirde, A.K., Freund, R., Vögele, C., & Kübler, A. (2011). Biofeedback of heart rate variability reduces food cravings in high food cravers. *Psychophysiology*, *48*, S81.

Meule, A., Vögele, C., & Kübler, A. (2011). Herzratenvariabilitäts-Biofeedback zur Normalisierung des Essverhaltens – Ergebnisse einer Pilotstudie und Ausblick. *Verhaltenstherapie*, *21*(Suppl. 1), 22.

2010

Meule, A. & Kübler, A. (2010, April). *Restrained eating, impulsivity, and its modulation through food-cues*. Paper presented at the Springschool of the GK-Emotions, Schweinfurt, Germany.

Meule, A., Lukito, S., Vögele, C., & Kübler, A. (2010, February). *Enhanced behavioral inhibition in restrained eaters*. Poster presented at the 2nd Congress of the German Society for Eating Disorders, Aachen, Germany.

Meule, A., Vögele, C., & Kübler, A. (2010). Deutsche Übersetzung und Validierung der Yale Food Addiction Scale. *Sucht*, *56*(3-4), 286-287.

Meule, A., Vögele, C., & Kübler, A. (2010, October). *Food cravings and dietary control strategies disriminate between non-dieters and successful and unsuccessful dieters*. Poster presented at the Summerschool of the GK-Emotions, Retzbach, Germany.

2009

Meule, A. & Kübler, A. (2009, December). *Essstörungen – Parallelen zu anderen Suchterkrankungen auf der Verhaltensebene*. Paper presented at the 10th meeting of the Interdisciplinary Center for Addiction Research at the University of Wuerzburg, Wuerzburg, Germany.

Würzburg,

Place, Date　　　　　　　　　　　　　　　　Signature