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UNSEEN FOOD IMAGES CAPTURE THE ATTENTION OF HUNGRY
VIEWERS: EVIDENCE FROM EVENT-RELATED POTENTIALS

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Abstract:

THE CURRENT STUDY INVESTIGATED THE INFLUENCE OF SUBCONSCIOUSLY PERCEIVED PICTURES OF FOOD ON THE DEPLOYMENT OF SPATIAL ATTENTION OF HEALTHY, NORMAL-WEIGHT PARTICIPANTS. DURING AN OBJECT-SUBSTITUTION MASKING TASK, VISUAL EVOKED POTENTIALS OF THE PARTICIPANTS WERE RECORDED AND THE N2PC AS A MARKER OF SPATIAL ATTENTION ALLOCATION WAS EXTRACTED. AS A RESULT, AN ENHANCED ALLOCATION OF SPATIAL ATTENTION COULD BE NOTED IN RESPONSE TO SUBCONSCIOUSLY PERCEIVED PICTURES OF FOOD, BUT ONLY WHEN THE PARTICIPANTS WERE HUNGRY. NO SUCH EFFECT WAS FOUND FOR CONSCIOUSLY PERCEIVED PICTURES OF FOOD OR FOR PICTURES OF CLOTHING ITEMS. THE LACK OF AN ATTENTIONAL CAPTURE DURING CONDITIONS OF FULL VISIBILITY COULD BE THE RESULT OF A COGNITIVE CONTROL MECHANISM THAT FAILS IN LIGHT OF SUBCONSCIOUS PERCEPTION. THESE RESULTS ARE RELEVANT FOR THE STUDY OF SUBCONSCIOUSLY PERCEIVED STIMULI AND HOW THEY INFLUENCE HUMAN PERCEPTION AND DECISION MAKING. THEY COULD CONTRIBUTE TO THE UNDERSTANDING OF THE PATHOGENESIS OF IMPORTANT DISEASES, FOR EXAMPLE EATING DISORDERS AND OBESITY.

Keywords:

CRAVING, FOOD, HUNGER, N2PC, OBJECT-SUBSTITUTION MASKING, VISUAL ATTENTION, VISUAL AWARENESS

Contents

1	Deutsche Zusammenfassung	3
2	List of abbreviations	4
3	Introduction	5
3.1	Attention and awareness	5
3.2	Experimentally dissociating attention from awareness: the object-substitution masking paradigm	6
3.3	Neurophysiological index of attention	8
3.4	The influence of reward and other motivational states on attention	9
3.5	The role of food and how it influences attention	11
3.6	The present work	12
4	Materials and Methods	14
4.1	Participants	14
4.2	Overall procedure	14
4.3	Questionnaires	15
4.4	Tasks and stimuli	15
4.4.1	General	15
4.4.2	Rating task	16
4.4.3	Object-substitution masking task	17
4.5	EEG Acquisition	18
4.6	EEG offline processing	20
4.7	Extraction of the N2pc	21
4.8	Statistical analyses and figures	22
4.8.1	Behavioral data	22
4.8.2	Electrophysiology data	24
5	Results	25
5.1	Questionnaires	25
5.2	Behavior	26
5.3	Electrophysiology	27
5.3.1	Unmasked condition	27
5.3.2	Masked condition and further analysis	31

6	Discussion	37
6.1	The automatic capture of attention by food-related stimuli	37
6.2	Behavioral strategies and response bias	40
6.3	Limitations, clinical perspective and future prospects	42
7	Summary	44
8	References	45
9	Acknowledgements	53
10	Ehrenerklärung	54
11	Darstellung des Bildungsweges	55
12	Appendix	57

1 Deutsche Zusammenfassung

Zielgerichtete räumliche Aufmerksamkeit kann auf verschiedene Arten beeinflusst werden: Durch Merkmale der Stimuli selbst oder durch willentliche oder unwillkürliche Kontrolle durch höhere kognitive Funktionen. Es ist nicht verwunderlich, dass auch das Zusammenspiel von Bildern von Essen mit dem Status, in dem sich der eigene Stoffwechsel gerade befindet, einen Einfluss auf räumliche Aufmerksamkeit ausüben kann. Es ist allerdings nicht klar, inwieweit Aufmerksamkeit durch *unterbewusst* wahrgenommene Bilder von Essen beeinflusst wird. Für die vorliegende Studie haben wir 30 Probanden eine “object-substitution masking”-Aufgabe durchführen lassen - einmal nach einer 12-stündigen Fastenperiode und einmal direkt nach einer Mahlzeit. Die Probanden mussten dann Bilder von Essen und Bilder von Kleidungsstücken der richtigen Kategorie zuordnen, oder erkennen, wenn gar kein Bild gezeigt worden war. Währenddessen zeichneten wir mittels EEG visuell evozierte Potenziale auf. Hierbei interessierte uns vor allem die N2pc-Komponente als Ausdruck der lateralen Orientierung räumlicher Aufmerksamkeit. In den Verhaltensdaten zeigte sich eine größere Genauigkeit beim Zuordnen von Kleidungsstücken, wenn die Probanden satt und wenn die Stimuli voll sichtbar, also nicht maskiert waren. Dies ließ sich durch einen “Response Bias” erklären, da die Unterscheidbarkeit der beiden Kategorien, ausgedrückt durch d' , gleich war. Weiterhin zeigte sich eine höhere N2pc-Amplitude für Bilder von Essen, aber nur wenn diese unterbewusst wahrgenommen wurden und die Probanden hungrig waren. Bei gänzlich sichtbaren Bildern waren es eher die Kleidungsstücke, die eine höhere N2pc-Amplitude bewirkten. Dies spricht dafür, dass unterbewusst wahrgenommene Bilder von Essen räumliche Aufmerksamkeit unter bestimmten Voraussetzungen automatisch auf sich ziehen. Dies legt eine Form von “Top-down”-Kontrolle in Bezug auf essensbezogene Stimuli nahe, die versagt, sobald diese Stimuli der bewussten Wahrnehmung entgehen. Die hier dargestellten Ergebnisse leisten einen wichtigen Beitrag zur Frage, inwieweit unterbewusst wahrgenommene Bilder von Essen das Verhalten beeinflussen und können insbesondere in der Erforschung der Pathogenese von Übergewichtigkeit und Adipositas Anwendung finden.

2 List of abbreviations

ANOVA = analysis of variance

BMI = body-mass index [kg/m²]

e. g. = *exempli gratia*, meaning “for example”

EEG = electroencephalography

ERP = event-related potential

et al. = *et alia*, meaning “and others”

FCQ-S = food cravings questionnaire - state

G-FCQ-S = general food cravings questionnaire - state

i. e. = *id est*, meaning “that is”

LPP = late positive potential

N1pc = first negative voltage peak of a visual evoked potential, occurring posterior and contralateral to a visually presented target

N2pc = second negative voltage peak of a visual evoked potential, occurring posterior and contralateral to a visually presented target

OSM = object-substitution masking

P3 = positive voltage deflection of an evoked potential, occurring around 300 ms post-stimulus

SE = standard error

vs. = versus

3 Introduction

3.1 Attention and awareness

Attention and awareness are central concepts in cognitive neuroscience and especially in vision science. Without the ability to focus visual attention on a target we would be overwhelmed by the many stimuli competing for processing by the visual pathways and, ultimately, competing for our awareness.

Attention in vision science has often been compared to a spotlight (e. g. Posner et al. 1980) or a zoom lens (Eriksen et al. 1986), among others, as it was thought to select and highlight a certain location for enhanced processing. These metaphors may be useful when they are not taken too literally. As we now know, attention does not only operate in a spatial manner, but can also be employed to enhance processing of certain features (feature-based attention) or objects (object-based attention) and can even be split to enhance processing of non-adjacent locations (Awh et al. 2000). With all these concepts in mind, attention can be described as a set of processes that help identify, select and prioritize relevant information and suppress other, irrelevant information.

Another aspect of attention is that it can be directed by moving the eyes (overt attention) or that it can be directed to a parafoveal target (covert attention) while the eyes remain fixated on a certain point. This finding goes back to the 19th century, when Hermann von Helmholtz published the book “*Handbuch der physiologischen Optik*”, where he described an experiment on covert attention while studying optical illusions (Helmholtz 1867). He would look into a dark box through two pinholes and direct attention to a parafoveal area while retaining fixation to another pinhole ahead. A light would then flash inside the box and he would describe having briefly seen the pattern present at the attended location.

However, processing of stimuli is not restricted to those that are attended. For example, there has been research showing that at least some degree of semantic processing of unattended words takes place (Corteen et al. 1972, 1974). Specifically, in these studies, subjects were exposed to an auditory stream of city names, which had before been associated with an unpleasant shock, and intermixed unrelated nouns. Meanwhile, their attention was engaged in a shadowing task. Although subjects reported that they did not notice any city names, the words that were previously shock associated elicited a galvanic skin response significantly more often than the unrelated nouns, pointing to a subconscious state of emotional arousal. This, as the authors argue, implies that the city names, albeit unattended, were processed to a semantic level. Moreover, it implies that processing may happen not only in the absence of attention, but also in the absence

of awareness, where in this case awareness may be described as the capacity to explicitly report relevant stimulus content. These findings speak to an automaticity of processing that happens, at least to some degree, irrespective of either attention and awareness.

Evidence for this automatic processing of stimuli comes from vision science as well. In one study, Marshall and Halligan showed a patient with hemispatial neglect vertically aligned pairs of line drawings of houses (Marshall et al. 1988). The drawings were similar, only that one of the houses had fire coming out of a left-side window. The patient failed to notice the fire due to the neglect and reported that there was no difference between the pictures. When asked, however, which house she would prefer to live in, she picked the non-burning house on a surprisingly high number of trials. This suggests that the information that one of the houses was on fire might have somehow been processed by her brain and thus influenced her decision without her noticing it consciously.

There are other studies suggesting that subconsciously processed stimuli might influence human behavior. In 1997, Moore and Egeth published a study where participants watched a computer screen and were asked to judge the length of two lines (Moore et al. 1997). These were superimposed on a random dot array, which on a critical trial changed so that it matched an illusion that let one of the lines appear longer. The subjects reliably judged the length of the lines in accordance with the optical illusion, but when asked about the array, reported to not have seen it. The authors suggested that the array was processed subconsciously at least to an extent where it could influence the subject's choice of line length on a basis of Gestalt grouping principles. This finding was recently replicated in a larger study (Wood et al. 2019).

As a summary, research suggests that stimuli can be processed automatically across different sensory modalities and that this automatic processing occurs either in the absence of attention, in the absence of awareness, or both.

3.2 Experimentally dissociating attention from awareness: the object-substitution masking paradigm

The study of attention in the absence of awareness requires an experimental paradigm that can dissociate those two concepts. Specifically, an attended object has to go unnoticed by the subject completing the task. Typically, this involves some form of masking paradigm. In this study, we worked with object-substitution masking (OSM). This form of masking was first described as a conjunction of four-dot masking (Enns et al. 1997) and common-onset masking by Enns, Di Lollo and Rensink in 2000 (Di Lollo et al. 2000).

Here, the subject is told to maintain fixation at the center of the screen and the target is then briefly presented parafoveally along with a surrounding four-dot cue and a number of distractors. When the whole display offsets simultaneously (unmasked condition), subjects can reliably report target properties they are asked about. When, however, the offset of the four-dot cue is delayed (masked condition), the cue serves as a mask and the accuracy for the task at hand decreases (figure 1).

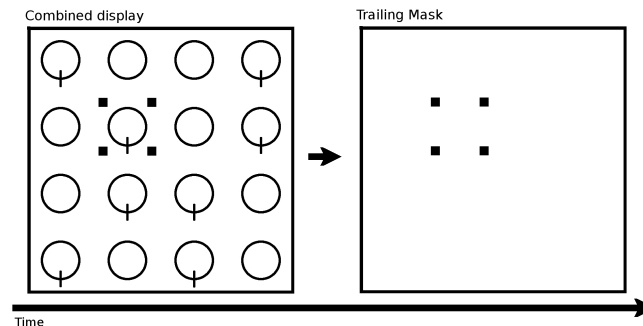


Figure 1: **Setup of the classical object-substitution masking-task by Enns, Di Lollo and Rensink (2000).** In this task subjects had to make a judgment whether or not the target circle, denoted by the four-dot cue around it, had a line drawn through the bottom of it. The combined display was presented for a brief amount of time (45 ms in this case) and was followed by the display of the trailing mask alone (masked condition), as displayed here, or by a blank screen (unmasked condition). In the masked condition, the accuracy of the subjects to correctly answer the question decreased markedly (adapted from Di Lollo et al. 2000).

The effectiveness of masking in OSM depends on a couple of variables. First, the focusing of spatial attention to the target has to be incomplete or delayed in some way for masking to occur, for example by having more than one possible target location (Enns et al. 1997; Di Lollo et al. 2000; Argyropoulos et al. 2013). Second, the masking effect is stronger with increasing set size, for example by increasing the number of distractors, or with increasing target-distractor-similarity (Di Lollo et al. 2000).

The theoretical concept behind OSM is that it is thought to occur via a mismatch of feedforward and reentrant processing. Specifically, the initial target plus mask array is processed by the visual cortex in an initial feedforward sweep of neural activity, where a first hypothesis as to the contents of the visual field is generated. To test this hypothesis, it is thought that the visual system uses a feedback loop from extrastriate to striate visual cortex to compare this hypothesis to the current percept. When now only the mask remains on display (masked condition), the visual system has two conflicting

images of the visual world. With each iteration in this loop, the target plus mask array fades in favor of the mask alone display which is constantly reinforced. Thus, only the latter is thought to eventually reach a stage where it can be consciously reported (e. g. Di Lollo et al. 2000; Boehler et al. 2008; Dux et al. 2010).

Nevertheless, it has been shown that a successfully masked target is still processed to some extent by the brain. For example, Woodman et al. did a study where they presented two potential target shapes on both sides of fixation and masked both by OSM. Before each trial sequence, one of the shapes was denoted the current target. Although subjects could not correctly state whether the target had been presented on the left or right side of fixation, they did show a shift of attention to the correct side as reflected by neurophysiological measures (Woodman et al. 2003). This implies some form of target processing, reflected in differential attentional deployment, in the absence of target awareness.

3.3 Neurophysiological index of attention

The study of cognitive functions, such as attention, can be done by visualizing them. The electroencephalography (EEG) is one way of visualizing brain functions. It was first described by Hans Berger in 1929 when he observed an electrical signal recorded by electrodes placed on the scalp of animals and humans (Berger 1929). An EEG signal is a summation of the neural activity of neurons relatively close to the scalp and is used in clinical settings to detect and categorize pathological brain activity present in some diseases, such as epilepsy. In its raw state, however, its use in the research of specific brain functions is limited. To isolate distinct components, many of which have been linked to specific brain functions, a method was developed, namely the event-related potential (ERP)-technique. For this, an experimental task is repeated multiple times, so that the component of interest is elicited many times in a row. When all these trials are superimposed on each other the random noise is cancelled out and the component of interest remains (for an excellent account of the ERP-technique see Luck 2014).

One of these components is called N2pc. It is frequently used to study attention and was first described by Luck and Hillyard in the 1990s (Heinze et al. 1990; Luck et al. 1993, 1994a,b). The N2pc is part of the N2 components of visual evoked potentials. It is a negative voltage deflection in the 200 to 300 ms latency range (e. g. Luck et al. 1993, 1994a; Hopf 2000). It occurs at posterior scalp sites contralateral to a target presented in the left or right visual hemifield and is thought to reflect the deployment of attention

to that target or the attentional selection of it (Eimer 1996; Kiss et al. 2008). More specifically, the N2pc seems to be the summation of two voltage deflections of opposite polarity, one of which enhances target processing, while the other suppresses distractor processing (Hickey et al. 2009). These components are thought to be the neurophysiological correlate of reentrant neural activity from extrastriate visual areas to hierarchically lower visual areas (Donohue et al. 2020).

The amplitude of the N2pc is said to scale at least partially with task demands (Eimer 1996; Mazza et al. 2011), with higher amplitudes for more difficult tasks, whereas low-level stimulus properties like for example stimulus intensity do not seem to affect its amplitude (Brisson et al. 2007).

In OSM, the N2pc is often used for operationalizing attentional capture in the absence of awareness (e. g. in Woodman et al. 2003; Harris et al. 2016). This form of masking does not seem to affect the physical properties of the N2pc. Specifically, it has been shown that the amplitude of the N2pc does not differ in the masked condition when compared to the unmasked condition. Moreover, the amplitude is the same for correct versus incorrect trials within the masked condition in OSM paradigms, but can be diminished by masking paradigms that interfere with feedforward sensory processing (Woodman et al. 2003). However, in a more conservative approach, a study by Harris et al. compared reported-as-seen to reported-as-missed targets (instead of just “correct” versus “incorrect”) within the masked condition of an OSM task and indeed found a smaller N2pc amplitude for missed targets (Harris et al. 2013), suggesting that there may be a smaller N2pc amplitude when a target can not be consciously reported.

3.4 The influence of reward and other motivational states on attention

Reward is known to influence behavior. When an action generates a desirable outcome, it is performed more often in situations with the same context. This principle was described by Thorndike as the “law of effect” (Thorndike 1911). But reward can also influence attention and its allocation. This can be measured behaviorally and can have a beneficial effect on the task at hand when a rewarded item is task relevant (e. g. Kiss et al. 2009) or it can worsen performance when it is not (e. g. Della Libera et al. 2006, Anderson et al. 2011). Moreover, the influence of reward can be measured neurally. Specifically, reward has been shown to influence the N2pc, a component of visual evoked potentials described above to reflect attentional selection of a lateral target. The first to show the effects of reward on the N2pc were Kiss et al., who demonstrated that pop-out

targets elicited a higher amplitude and earlier N2pc when they were of a rewarded color (Kiss et al. 2009). More recent studies have shown that even task-irrelevant non-pop-out distractors can capture attention when they contain a feature that was previously associated with a reward (Qi et al. 2013), even when the subjects are fully aware that attending to those features is disadvantageous for completion of the task at hand (Hickey et al. 2010). The effects of reward associations can not only be demonstrated for simple features like colors or certain shapes, but are also present for more complex instances, like object categories (Hickey et al. 2015; Donohue et al. 2016a).

The effect of reward associations on attention deployment has also been studied with the OSM paradigm. Specifically, a study from our group showed that a color previously associated with a reward elicited an N2pc of a higher amplitude as opposed to previously unrewarded colors (Harris et al. 2016). This amplitude enhancement was present even on trials with successful masking, meaning that even when subjects were not aware of the object with the rewarded feature, the reward association still led to an enhanced capture of attention. This speaks to an automaticity in the capture of attention by reward associations.

The influence of other motivational states on visual attention, such as addiction, is less clear. There is evidence that substance dependence may lead to attentional biases, meaning that addiction-specific stimuli capture the attention of addicted subjects more strongly than that of healthy individuals. However, as several authors have pointed out, it is sometimes difficult to interpret these results, as other plausible explanations may account for the observed attention-capturing effects (for a substantial review of the evidence for attentional bias in substance abuse and the caveats in interpreting the results see Field et al. 2008).

For example, the capture of attention by substance-related cues has been demonstrated in smokers several times (e. g. Mogg et al. 2002; Ehrman et al. 2002). In contrast to this, a study from our group found that addicted subjects may show avoidance behavior to substance-related cues under certain circumstances (Donohue et al. 2016b). The study used a visual search task, where subjects had to shift their attention to one of two colored squares, either left or right of fixation, as indicated by a predetermined target color. They had to make a judgment about missing corners of the squares. Embedded in the target and distractor square were task-irrelevant images of smoking-related objects or office supplies. The study found that when a smoking-related image was present in the target square, not only were subjects slower in reporting the missing corners, but they also displayed a weaker shift of attention towards that target, as indicated by a smaller N2pc amplitude. Likewise, when a smoking-related image was embedded in the

distractor square, subjects were faster and the N2pc towards the target was of greater amplitude. This effect was inert to whether the subjects abstained from cigarettes 3 hours prior to the measurement, or whether they were allowed to smoke directly before. Another study from our group used an OSM task to compare the N2pc to smoking-related images with that to images of office supplies (Harris et al. 2018). The images were presented parafoveally along with a number of non-object distractors and were masked by OSM. Subjects had to indicate which object category had been presented. Here, the N2pc of habitual smokers was larger for the substance-related cues and smaller for the office supplies, but only when subjects failed to see the images due to successful masking. Unlike in the study mentioned before, the images here were task-relevant, but a substance-related bias emerged only when the smoking-related images were not consciously perceived by the subjects. This indicates an automatic capture of attention of substance-related stimuli and could be the result of a failure of the aforementioned top-down avoidance mechanisms.

3.5 The role of food and how it influences attention

The above described effects on attention all hail from trained associations. The desire to eat when one is hungry, on the other hand, is a fundamental feature of human nature. Both times, the targets are motivationally highly relevant. It therefore seems likely that food cues exert influence on the allocation of attention in a similar fashion. To distinguish these concepts, food can be conceived as a primary reinforcer, while stimuli that need a training phase in order to become motivationally relevant (e. g. a monetary reward) can be viewed as secondary reinforcers.

The role of primary reinforcers, especially food, on the allocation of attention has been the subject of several studies. Research by Mogg et al. in 1998 could show that subjects display an attentional bias towards pictures of food when they are hungry (Mogg et al. 1998) and the concept of an attentional bias towards food cues has been studied extensively since then (e. g. Castellanos et al. 2009; Nijs et al. 2010; Nummenmaa et al. 2011). Moreover, electrophysiological markers linked to attention are selectively enhanced by images of food when the participants are hungry as compared to when they are not (Nijs et al. 2007a; Stockburger et al. 2008, 2009; Nijs et al. 2010). Recent research has shown that food images are even able to capture the attention of hungry subjects when they are task-irrelevant (Sänger 2019).

Under certain conditions, for example obesity and eating disorders, the desire to eat

is altered in a pathological way. Especially obesity is becoming an ever greater threat to the collective health of human society. It is characterized by a mismatch between calorie intake and calorie expenditure and has been associated with an altered attention to food-related stimuli. For example, overweight subjects showed increased gaze durations in a visual probe task even when they were sated, whereas in normal-weight adults this occurred only in a state of hunger (Castellanos et al. 2009). Another study found enhanced capture of attention in obese compared to normal-weight participants in a visual probe task (Nijs et al. 2010).

3.6 The present work

The attention capturing effects of motivationally salient stimuli in general have implications from a clinical point of view. Several studies indicate that the magnitude of substance related attentional bias is correlated with prospective use of that substance and has even been linked to a higher failure rate of withdrawal attempts across different types of drugs (e. g. Sharma et al. 2001; Cox et al. 2002; Waters et al. 2003; Field 2005; for a review see Field et al. 2008). The aforementioned evidence suggests that, under certain conditions, food as a primary reinforcer seems to capture the attention in much the same way as monetary reward or as drugs in addicted subjects. However, whether this capture of attention extends to situations in which subjects are unaware of the stimulus is not known. Yet, with all the stimuli struggling and ultimately failing to be noticed by us it is important to know how they nevertheless shape our behavior, especially when they might impair the success of withdrawal or weight loss programs. Here, we used an OSM paradigm to assess whether food captures attention outside of awareness. Specifically, we let healthy, normal-weight adults complete two sessions of an OSM task. For one session, subjects were told to refrain from eating for 12 hours, while for the other session they were instructed to eat a meal to satiety between one and two hours before. The target stimuli, images of food items and images of clothing items, were presented parafoveally, so that an N2pc as an index of lateral spatial attention allocation could be extracted and probed for enhanced attentional capture.

We expected to see larger amplitudes of the N2pc component in response to food pictures in the hungry condition, either regardless of target visibility (i. e. regardless of effective masking), or an enhanced N2pc amplitude in the unseen as compared to the seen condition (i. e. successfully masked and not seen versus not successfully masked and therefore seen). The latter possibility would speak to an automatic capture of at-

tention by food-related images much like the effect smoking-related images had on the attentional deployment in smokers in the aforementioned OSM study by Harris et al. (Harris et al. 2018). In that study, whether the subjects were craving a cigarette at the time of the measurement did not influence their N2pc amplitude or their behavior in a significant way. In the present study, however, we expected the N2pc to be greater in the hungry than in the sated condition, because other research has shown little influence of food pictures on electrophysiological markers of attention under conditions of satiety in normal-weight adults (Nijs et al. 2007a; Stockburger et al. 2008, 2009; Nijs et al. 2010). Behaviorally, we did not form a specific prediction beforehand, though there were several possible outcomes. There could either be no difference in the accuracy measures between sessions and between food and clothing images, though this seemed unlikely. Previous work of our group did usually find slight but significant differences in the accuracy within the masked condition, either in favor of previously rewarded targets (Harris et al. 2016), or due to a response bias arising from the implementation of different task strategies on the part of the participant (Harris et al. 2018). As for the latter alternative, subjects could, depending on their strategy, specifically look for certain characteristics of for example food items, and when those are not encountered, they would choose to press the button for clothing items. However, in the masked condition, this strategy would lead to a reduced accuracy for food as compared to clothing items, because effective masking of food items would lead subjects to opt for clothing more often. Aside from that, we expected to see a reduced accuracy in the masked as compared to the unmasked condition, especially due to a rise in target misses, as is the usual finding in OSM studies.

4 Materials and Methods

4.1 Participants

30 participants (15 male and 15 female; all right-handed) were recruited for the study, all of which completed three measurement sessions. Two participants were ultimately excluded due to excessive artifacts in the EEG, as described in section 4.6. This left a total of 28 subjects (15 male, 13 female), ranging in age from 20 to 39 years (mean = 28, standard deviation = 5.4). The mean BMI was 22.9 kg/m² (standard deviation = 3.6), consistent with what is considered to be normal weight according to standards established by the World Health Organization (18.5 – 24.9 kg/m²; Alwan 2011, pages 22 - 23).

Subjects were recruited primarily through an online database comprising university students, research personnel and community members. Exclusion criteria were age <18 or >40 years, any history of psychiatric or neurological illnesses, habitual illicit drug use, use of prescription drugs known to significantly affect the appetite or cognitive processes and metabolic diseases for which fasting may pose a health risk (e. g. diabetes mellitus). 27 of the participants reported a university-entrance diploma (i. e. “Abitur”, 12 to 13 years of education) or higher as their highest educational degree; one subject reported a General Certificate of Secondary Education (i. e. “Realschulabschluss”, schooling for 9 to 10 years) as their highest degree.

Prior to testing, subjects were briefed on the risks and benefits of the study, excluding information to the exact nature of the research question. Written informed consent was obtained from all participants in accordance with the protocol approved by the institutional review board of the Otto-von-Guericke-University Magdeburg.

Participants were compensated for their time and performance at a rate of 8 Euro per hour and received a total of 100 Euro for successfully completing all measurement sessions.

4.2 Overall procedure

Each participant completed three sessions. The first one was a rating session, in which the stimuli for the other two sessions were determined. Then, all participants completed two EEG recording sessions - a hungry and a sated session - during which they completed an object-substitution masking task. The order of the sessions was counterbalanced across subjects. They were always scheduled between 11:30 am and 2:30 pm

and were always on a different day. For the sated session, participants were told to behave normally during the morning and to eat lunch to satiety between one and two hours before the experiment. For the hungry session, they were asked to refrain from eating, as well as from drinking any beverages with added sugar or caffeine, starting at midnight the previous night, for a minimum of 12 hours.

4.3 Questionnaires

In order to quantify the state of hunger induced by the fasting protocol, as well as to collect information about more general habits and demographics, participants completed a battery of questionnaires prior to each recording session. First, they were asked general questions about eating habits (e. g. whether they regularly eat breakfast, are vegetarian, or follow a special diet; see section 12 for example questionnaire). Next, participants completed a German version of the General State Food-Cravings Questionnaire (G-FCQ-S). This is a modification by Nijs et al. (Nijs et al. 2007b) of the original FCQ-S developed by Cepeda-Benito et al. (Cepeda-Benito et al. 2000) and translated into German by Meule et al. (Meule et al. 2012), which assesses the current subjective state of hunger experienced by a participant with a total of 15 questions. Lastly, the subjects completed a short form with three questions in a visual analogue scale-format as suggested by Blundell et al. (Blundell et al. 2010) to indicate their subjective level of hunger.

During final session debriefing, all subjects were asked to indicate their compliance with the fasting protocol. Specifically, they were assured that they would receive full compensation regardless of their answer and that a failure to fast would result in the relevant session being considered separately, although such participants would have been excluded from the final analysis.

4.4 Tasks and stimuli

4.4.1 General

The tasks were written with the Presentation software package (Neurobehavioral Systems, Albany, CA) and were completed in a dimly lit and electrically and acoustically shielded EEG measurement chamber. The stimuli were presented on a 16:10, 24-inch computer screen with a resolution of 1440 by 900 and a refresh rate of 60 Hz at one meter viewing distance.

The targets were drawn from a set of 76 images (38 food items, 38 clothing items). All images were processed so that they were gray-scale and no text was visible on the items. Non-object distractor images were drawn from a set of 40 circular cropped gray-scale images that were scrambled using the liquefaction function of Adobe Photoshop (Adobe Systems Inc., San Jose, CA; as in Harris et al. 2013).

There were four possible target locations centered 5° from fixation at one meter viewing distance and another twelve distractor locations, eight of which were centered at 8.8° from fixation and four centered 6.2° from fixation. The diameter of the distractors was 2.9 cm. The target images were scaled such that their cropped circular diameter was equal to that of the distractors.

4.4.2 Rating task

The first session was dedicated to a rating task which would determine the specific subset of target images to be used for each participant in the EEG recording sessions. First, the participants were asked to toggle through all 76 potential target images at their own pace. They were instructed to take their time and to be sure they were able to identify each image. For the rating task itself, each of the 76 pictures was then presented in random order at one of the four target locations described in section 4.4.1 for a duration of 300 ms. After each image, participants were first asked to categorize the presented object as edible or inedible, with a third response option for those images they failed to recognize (see figure 2). They were then asked to indicate the appeal of the presented image on a scale of 1 (highly unappealing) to 5 (highly appealing). After the task, in preparation for the other two sessions, the images were sorted according to the subject's appeal rating, excluding images they failed to identify correctly. Thus, the rating task yielded a set of 48 target images consisting of the 24 food and the 24 clothing images with the highest appeal rating, respectively. If subjects did not correctly identify the minimum 24 images of a category, missing images were selected from the remaining pool according to how easily they were recognized across subjects, with preference being given to those most consistently identified. This occurred for four subjects, all of which needed additional food images and one of which needed additional food and clothing images.

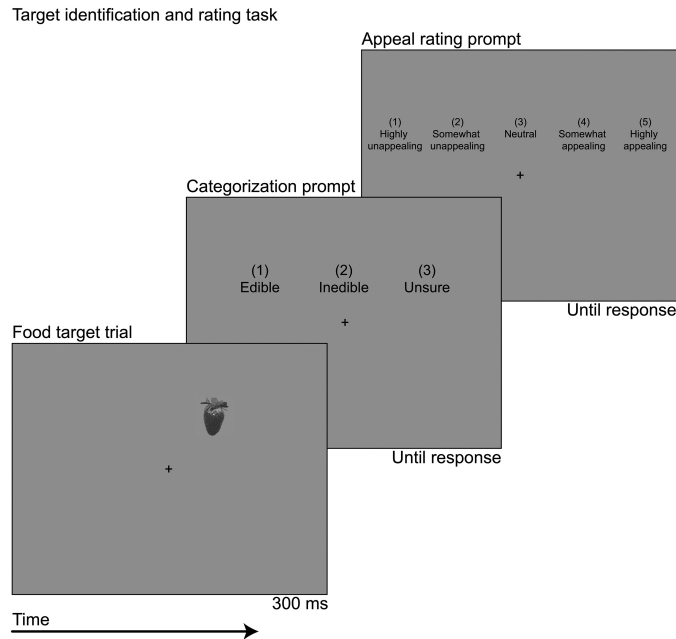


Figure 2: **Target identification and rating task.** To familiarize subjects with each stimulus and make sure they were able to identify them, all stimuli were shown to the subjects in a separate rating task. Here, the stimuli were presented at one of four different target locations at random for 300 ms. Afterwards, subjects were told to make a judgment as to the nature of the stimulus and to rate how appealing it was to them (Ilse et al. 2020).

4.4.3 Object-substitution masking task

The remaining two sessions were EEG recording sessions. In these, subjects completed twelve runs of an object-substitution masking task. Each run consisted of 144 trials (1728 total) and lasted approximately four minutes. For each trial, subjects were asked to fixate a central cross while covertly attending to a parafoveally presented target image. Targets could appear at one of four possible target locations, as described in section 4.4.1 and were denoted by a surrounding four-dot cue. The target and cue did not overlap, with the dots of the cue being 0.9 cm wide squares centered 0.5° from the target at one meter viewing distance. There were three equiprobable targets: a food item (food target), a clothing item (non-food target) or no item (i. e. “blank” trials). Along with the target and the four-dot cue, the initial array also consisted of 15 distractor images at the remaining three target locations, as well as at the twelve distractor locations. This target-plus-distractor array was presented for 17 ms and was followed by either 500 ms of fixation alone (i. e. common offset or “unmasked” trials) or 500 ms of fixation plus

the four-dot cue (i. e. delayed offset or “masked” trials). This sequence was followed by fixation alone for an inter-trial interval jittered between 700 and 1000 ms (see figure 3). The trial order was randomized such that target type, location and masking condition were unpredictable.

To indicate whether a subject had seen a food item, a clothing item or no item in between the four-dot cue, subjects were instructed to press one of three designated buttons as quickly and as accurately as possible (three-alternative forced choice task). To be counted, this button press had to occur within the post-stimulus time window of 200 to 1200 ms. The order of the buttons (food, clothing, blank) was counterbalanced across subjects.

There were three possible outcomes for non-blank trials: A correct identification was classed as “hit”; when a target was detected but misidentified as the wrong category that response was counted as “incorrect”, and when a target was falsely classed as blank this response was counted as a “miss”. For blank trials, correct responses were counted as a “hit”, while any other response was classed simply as “incorrect”. For trials in which participants did see that a target was present but were unsure of its identity, they were instructed to try and pick one of the two non-blank categories.

Each of the two EEG recording sessions lasted for a total of about 1.5 hours, including intermittent breaks to maintain participant alertness. The approximate run time for the twelve substitution masking runs was 50 to 60 minutes.

4.5 EEG Acquisition

During the hungry and the sated sessions, the participant’s continuous EEG was recorded using the BrainVision Recorder software package and a 32 channel active electrode system (actiCHamp, both from Brain Products, Gliching, Germany). The electrodes were online referenced to the right mastoid and included a right and a left horizontal eye channel placed on the outer canthi and a vertical eye channel placed below the right eye to monitor horizontal eye movements and eye blinks, respectively. A BrainAmp DC/MR plus amplifier (Brain Products, Gliching, Germany) with a sampling rate of 500 Hz was used. A conductive saline gel was introduced between subjects’ slightly abraded scalp and each electrode such that the impedance of all electrodes was maintained <5 kOhm. For the eye channels, impedances of >5 and <8 kOhm were tolerated when thorough cleaning failed to lower the impedance below 5 kOhm without risking moderate discomfort. Only once did the impedance of a scalp channel exceed 5 kOhm (Fp1 at 7

Object-substitution masking task

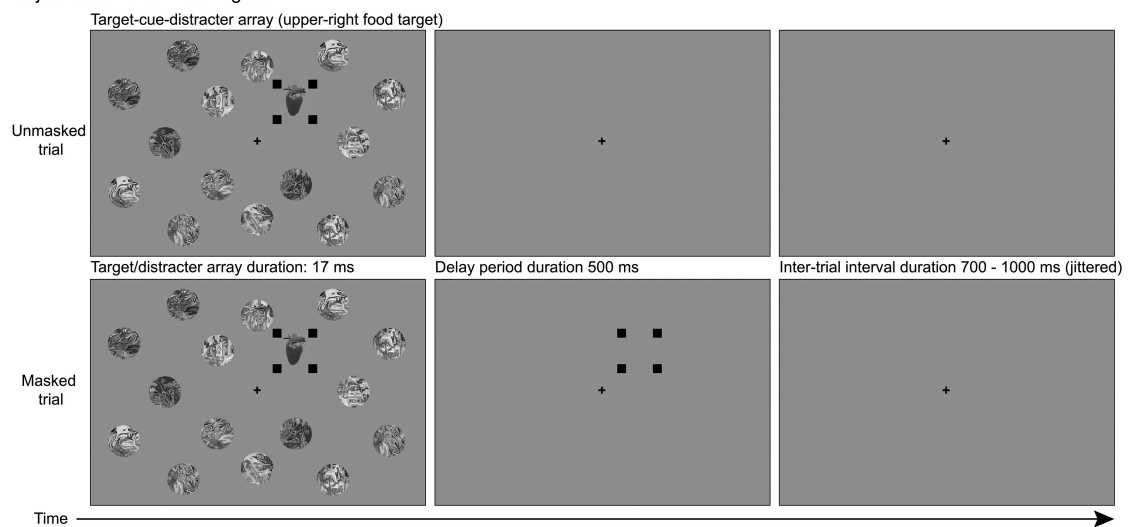


Figure 3: **Object-substitution masking task.** The object-substitution masking task consisted of two different trial types, masked and unmasked. Each trial began with a 17 ms presentation of the target, depicted in one of four possible and randomly chosen target locations and surrounded by a four-dot cue. Fifteen distractors displayed in the remaining target locations, as well as in the distractor locations, were also shown. For the unmasked trials, this display was followed by the fixation cross only, whereas for the masked trials the four-dot cue remained on display for another 500 ms. Both trials were then followed by a display of the central fixation cross for an inter-trial interval jittered between 700 and 1000 ms (Ilse et al. 2020).

kOhm for one session).

4.6 EEG offline processing

After acquisition, EEG data were preprocessed first by creating epochs during the peristimulus time window of -400 to 1600 ms. For this and the following data processing and analysis steps, the EEGLAB (Swartz Center for Computational Neuroscience, UC San Diego, CA) and ERPLAB (Lopez-Calderon et al. 2014) plugins and associated functions were used (MATLAB version R2018a, MathWorks, Inc., Natick, MA). Epoched data were then submitted to an artifact detection process. For better detection of blinks, vertical eye channel data were low-pass filtered with a high cutoff frequency of $f_c = 30$ Hz prior to artifact detection.

Artifact detection was implemented in a multi-step process, beginning with the identification and exclusion of channels chronically contaminated by noise rendering the data unusable, such as high-frequency muscle activity, external 50 Hz noise or blocking caused by offsets exceeding the amplifiers' range of sensitivity. Unusable channels were identified and excluded from further artifact detection and re-referencing. For viewing purposes, data from adjacent, uncontaminated channels were interpolated and substituted for those channels consistently contaminated by noise. Contaminated channels were not included in later statistical analyses and, in the event that a channel relevant to our attention effects of interest (i. e. P7/P8) was consistently noisy, all data associated with that particular participant would be excluded from any further analysis.

The artifact detection process employed peak-to-peak amplitude and step threshold procedures. In the peak-to-peak amplitude procedure, the highest amplitude of the data is compared to the lowest within a sliding window (e. g. 200 ms wide) inside a time span in the epoched data, here from -200 to 500 ms relative to the onset of the stimulus. If the peak-to-peak amplitude exceeds a pre-defined threshold, the entire epoch is rejected. This procedure is especially sensitive to eye blinks. The step threshold procedure is comparable. Here, the algorithm compares the mean voltage of the first half of a window (usually 400 ms wide) with the mean voltage of the second half of the same window and flags the epoch for rejection if this difference exceeds a pre-defined threshold. This function is thus sensitive to sustained changes in voltage which are characteristic of horizontal eye movement artifacts, typically lasting 200 ms and exhibiting a trapezoidal or boxcar-shaped appearance (for more information on artifact detection see Luck 2014). The thresholds for these functions were adjusted for each dataset individually and were

applied to a period of -200 to 500 ms relative to the onset of the stimulus array in each epoch. The thresholds used were in the range of 48 - 80 μV for peak-to-peak functions for the eye channels, and were set to 200 μV for all other channels, while a range of 40 - 70 μV was used for step functions. Subjects with 40 % or more rejected epochs in one or both of the two recording sessions were excluded from further analysis. This applied to two participants. The mean epoch rejection rate of all sessions was 13.65 % (SE = 1.67). The rejection rate did not differ between the hungry and sated sessions ($t(27) = .53$, $p = .60$).

Subsequently, artifact-free data were time-locked averaged to the onset of trials and sorted by trial type, and a finite impulse response low-pass gaussian filter was applied to the data from all channels with a high cutoff frequency of $f_c = 30$ Hz and order = 24 dB/octave. Data were then re-referenced to an average reference of all scalp channels, excluding those previously identified as unusable during artifact detection.

4.7 Extraction of the N2pc

As the correlate of lateralized attention deployment, the N2pc was extracted using a well-established procedure. Through the virtual flipping of electrode channel locations about the midline, visual evoked potentials of both hemispheres can be combined. Specifically, data from left scalp sites for target-right trials were combined with midline-flipped data from right scalp sites for target-left trials to create a generic “contralateral target” condition, the scalp distribution of which is symmetric about the midline. An analogous operation was performed for left scalp sites during target-left trials and right scalp sites during target-right trials, to yield a generic “ipsilateral target” condition. Finally, the ipsilateral target response was subtracted from the contralateral target response to obtain a “contralateral-minus-ipsilateral” difference wave. This difference wave contains the N2pc, in this case bilaterally and symmetrically distributed over posterior parieto-occipital scalp sites (for a detailed description of the procedure see Luck 2014). To identify the scalp sites and time window from which to extract and statistically test the mean amplitude of the N2pc across relevant conditions, we used a localizer, which compared grand-averaged data associated with contralateral target trials with that associated with ipsilateral target trials, collapsing across all other experimental factors (i. e. session, masking condition, target type; see figure 4). This yielded a maximum difference over posterior parietal scalp sites (P7/P8) during the post-stimulus time window of 225-275 ms, which is consistent with the N2pc isolated in previous work of our group

in a similar task context (Harris et al. 2018). Thus, for statistical analysis, mean amplitude values associated with contralateral-minus-ipsilateral difference waves extracted at site P7/P8 during the 225-275 ms post-stimulus time window (baseline-corrected to the 200 ms prestimulus time window) were extracted and compared in a within-subjects repeated measures analysis of variance (see section 4.8.2).

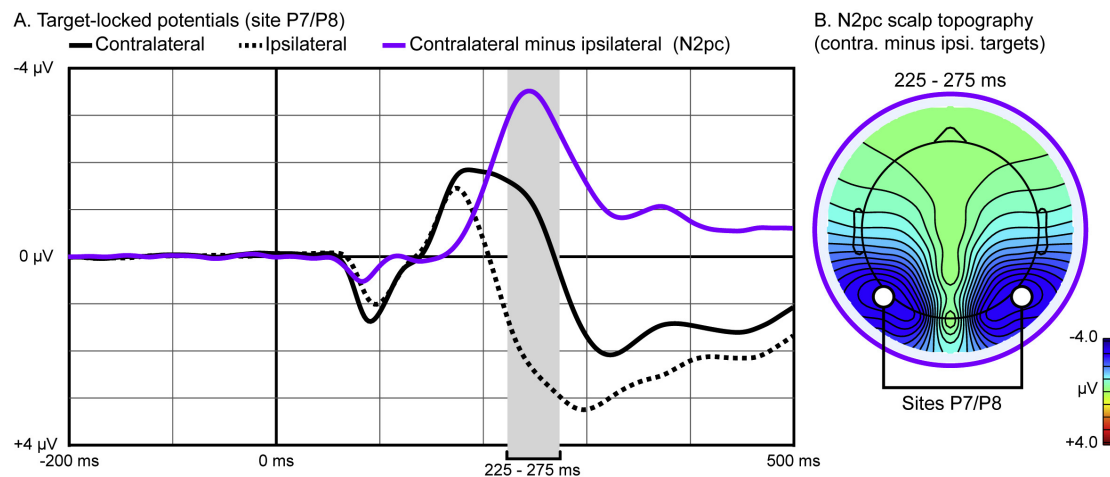


Figure 4: **N2pc localizer.** A: To identify the relevant scalp sites and time frames to extract the N2pc, a collapsed localizer was used. After subtracting the data for the target-ipsilateral trials from that for the target-contralateral trials and collapsing this across all experimental factors, we obtained a negative difference wave peaking at about 225 to 275 ms over posterior parietal scalp sites, most pronounced over P7/P8. B: This difference wave showed a scalp distribution typical for the N2pc with the most pronounced negativity over posterior scalp regions contralateral to the target (Ilse et al. 2020).

4.8 Statistical analyses and figures

4.8.1 Behavioral data

The statistical analysis was done using IBM SPSS Statistics (IBM, Armonk, NY) and Libre Office Calc (The Document Foundation). Figures were produced from .eps files exported from MATLAB and using Adobe Illustrator (Adobe Systems Inc., San Jose, CA) and the Gnu Image Manipulation Program (GIMP). The thesis was written in “ \LaTeX ” via overleaf (<https://www.overleaf.com/>).

The behavioral results were extracted from the Presentation logfiles using a MatLab script that sorted the participant’s responses as described in section 4.4.3. From the

absolute measures hits, incorrect and misses, the proportions accuracy, proportion incorrect and proportion misses, respectively, were derived. Then, the detection rate for each target type was defined as 1 - proportion misses for that target type. Lastly, the parameters d' and response bias were calculated as follows.

d' was defined as the rate of true positives minus false positives within detected trials, or

$$d' = z \left(\frac{\text{accuracy stimulus}_A}{\text{detected stimulus}_A} \right) - z \left(\frac{\text{incorrect stimulus}_B}{\text{detected stimulus}_B} \right),$$

where z is the inverse cumulative gaussian distribution. z is used to convert the true and false positive rates into standard deviation units. Conceptually, every stimulus presentation yields a probability value of how likely the stimulus falls into one of the three possible categories (food, clothing or blank). All these probability values of the three stimulus categories are part of three separate probability distributions. The distance between the means of these probability distributions represents how well a subject can differentiate between these probability distributions. The farther away, the better the subject is able to differentiate between the three categories. This distance between means is known in signal detection theory as d' (cf. Macmillan et al. 2010, pages 8 ff.). Values typically range between 0 and 4, with those approaching 0 speak to low and those close to 4 speak to high discrimination performance. For the current experiment, only the discriminability of food and clothing items was taken into account by looking only at trials where a stimulus was detected. Therefore, in the current study, d' was a measure of how well a participant was able to differentiate food from clothing stimuli.

Finally, response bias was defined as

$$c = \left[\left(\frac{\text{accuracy stimulus}_A}{\text{detected stimulus}_A} + \frac{\text{incorrect stimulus}_B}{\text{detected stimulus}_B} \right) - 1 \right] * 100.$$

Response bias can be described as an internal criterion set by each participant with which each of the aforementioned probability values is compared. If the probability value of a stimulus presentation exceeds the criterion, the subject's answer is "food", and if it does not, it is "clothing" (or vice versa). Therefore, if the criterion is shifted to the right, subjects are more likely to respond "clothing", resulting in a response bias towards this category (cf. Macmillan et al. 2010, pages 27 ff.). This shift of criterion will affect accuracy and incorrect measures, but not d' . Response bias values are centered around zero, meaning that positive values denote a response bias towards a given response option, whereas negative values denote a response bias away from that response option.

Each behavioral metric associated with non-blank trials was then submitted to a within-subjects repeated measures analysis of variance (ANOVA) with the factors session (hungry vs. sated), masking (masked vs. unmasked), target type (food vs. non-food).

Follow-up single comparisons probing significant interactions were performed using two-tailed, paired t-tests. Following this, mean accuracy and incorrect values for blank trials were submitted to a 2 by 2 repeated measures ANOVA with the factors session and masking.

4.8.2 Electrophysiology data

As for the electrophysiology data, mean amplitude N2pc measures for non-blank trials were considered separately for unmasked and masked trials. For unmasked trials (serving as a proxy for normal viewing conditions), these values were submitted to a 2 by 2 repeated measures ANOVA with the factors session and target type. For masked trials, these values were submitted to a 2 by 2 by 2 repeated measures ANOVA with the factors session, target visibility (hits versus misses), and target type. Lastly, we conducted a session by masking ANOVA for blank trials to quantify generic attentional effects unrelated to the target images. Significant main effects and interactions were probed with follow-up single comparisons using two-tailed paired t-tests. Finally, to combine behavioral and electrophysiology data, a Pearson correlation analysis between G-FCQ-S differences (hungry minus sated session) and N2pc mean amplitude of unseen targets (i. e. misses) was performed.

5 Results

5.1 Questionnaires

To test the effectiveness of the fasting period, questionnaires as described in section 4.3 were given to the participants. The G-FCQ-S part of the questionnaires yielded a point value between 15 and 75, where 15 indicated a state of subjective satiety, while a score of 75 indicated a high level of hunger (Nijs et al. 2007b).

Intraindividual paired two-tailed t-tests compared the score each participant yielded in the G-FCQ-S during the hungry session to that of the same participant's sated session. The sessions of all 28 included subjects were thus compared. The scores of all but one participant differed significantly across the two conditions ($p < 0.05$). From these, 26 subjects yielded a higher score for the hungry condition. Only one participant reached a higher score for the sated condition. A paired, two-tailed t-test comparing the score of all hungry with all sated sessions of all participants yielded a statistically significant difference ($p < 0.001$).

The other part of the questionnaires employed three questions in a visual analogue scale-format. For evaluation, the distance of the participant's mark on the line to the starting point of the line was measured. The distance measured of the second question was transformed to match the polarity of the other two questions, so that for all three questions higher distances meant a higher level of hunger.

Two of the participants could not be included in this analysis due to incomplete or missing answers. For the other participants, intraindividual paired two-tailed t-tests of the mean distance of the hungry compared to the mean distance of the sated session revealed a statistically significant difference for 21 participants ($p < 0.05$). Of these, all had a higher distance value for their hungry session (corresponding to a higher subjective feeling of hunger). The remaining five participants showed no statistically significant difference between their two sessions. A paired two-tailed t-test comparing the distance values of all hungry with all sated sessions yielded a statistically significant difference ($p < 0.001$).

The participant whose answers in the G-FCQ-S part of the questionnaires indicated a greater feeling of satiety during the hungry session showed the opposite result in the visual analogue scale-format questions. The participant whose answers in the G-FCQ-S did not differ significantly between sessions did not reach a statistically significant difference between the distance values of the visual analogue scale-format questions, though in both sections the difference was somewhat close to the confidence level of $p = 0.05$ ($p = 0.056$ and $p = 0.069$, respectively).

5.2 Behavior

The measures accuracy, proportion incorrect and proportion misses were calculated for non-blank and blank trials and for non-blank trials d' and response bias were additionally calculated as described in section 4.8.1 (see table 1 for mean values). These were submitted to repeated-measures analyses of variance, where any significant interactions were then probed using two-tailed, paired t-tests as described in section 4.8.1 (see tables 2 and 3 for non-blank trials and table 4 for blank trials for detailed results).

As for the accuracy, a main effect of masking and session by target and masking by target interactions reached statistical significance. Further t-tests confirmed a main effect of masking for both non-food ($p < 0.001$) and food ($p = 0.001$) items, due to reduced accuracy during masked trials. Specifically, an overall accuracy rate for unmasked non-blank trials of 79% dropped to 69% for masked trials. The session by target interaction was driven by a higher difference in accuracy between food and non-food items in the sated as compared to the hungry sessions ($p = 0.023$). The masking by target interaction resulted from a higher accuracy for non-food items in the unmasked condition ($p = 0.008$). Specifically, subjects correctly identified non-food items more often than food items in the unmasked condition, while no such difference was observed in the masked condition ($p = 0.461$).

Incorrect measures also showed a session by target and a masking by target interaction, but no main effect. The session by target interaction was analogous to that seen in the accuracy data, meaning that subjects miscategorized food items more often than non-food items in the sated as compared to the hungry sessions and vice versa. This was reflected in a significant difference in incorrect measures between both categories in hungry as compared to sated sessions ($p = 0.024$). Furthermore, subjects miscategorized food items more often than non-food items in the unmasked condition, resulting in a masking by target interaction ($p = 0.022$), with no such difference being observed in the masked condition ($p = 0.16$). This too was analogous to the masking by target interaction in the accuracy data.

For misses, there was a main effect of both masking ($p < 0.001$) and target type ($p = 0.024$), but no interactions. Specifically, subjects reported more often that no object was present even though there was one in the masked than in the unmasked condition. Moreover, food items were missed slightly more often than non-food items.

As for d' values, the ANOVA only showed a main effect of masking ($p < 0.001$), speaking

to a uniform reduction of discriminability of both target types in the masked compared to the unmasked condition independent of fasting condition. Though this may seem at odds with the interactions described for accuracy and incorrect measures, it is supported by the results for response bias: While there was no main effect for this measure, a session by target and a masking by target interaction similar to those found in the accuracy and incorrect data were observed. Specifically, in the sated sessions, subjects tended to pick the answer non-food more readily than the answer food ($p = 0.02$), with the reverse being true in the hungry sessions ($p = 0.02$). Moreover, subjects displayed a response bias towards non-food under conditions of full visibility (i. e. in unmasked trials; $p = 0.02$). No such preference was observed in masked trials ($p = 0.24$).

Finally, there were no statistically significant effects or interactions for blank trials, meaning that participants showed no differences in accuracy or incorrect measures between masking conditions or between hungry and sated sessions when no target image was presented.

In summary, the behavioral results showed a decrease in discriminability of target images in the masked condition that was independent of session or target type once response bias was taken into account.

5.3 Electrophysiology

The visual evoked potential component of interest in our study was the N2pc. This component was extracted as described in section 4.7. The mean amplitude values of the N2pc during the post-stimulus time window of 225 to 275 ms for masked and unmasked trials are displayed in table 5. For statistical analysis, the data were submitted to a repeated measures ANOVA and any significant interactions were then probed using two-tailed paired t-tests (see section 4.8.2). The results of the statistical analysis are displayed in table 6 for non-blank and in table 7 for blank trials, respectively.

5.3.1 Unmasked condition

In the unmasked condition, an analysis of variance revealed a main effect of target type (table 6). Specifically, the mean amplitude of the N2pc in the unmasked condition was higher for non-food targets ($p < 0.001$, see figure 5). No other main effects or significant interactions were observed, although food targets elicited a greater N2pc in the hungry as compared to the sated sessions.

Table 1: Mean values of behavioral data

Unmasked <i>Session, Target type</i>	Accuracy (SE)	% Incorrect (SE)	% Misses (SE)	d' (SE)	Response bias (SE)
Sated, Non-food	82.2 (1.7)	15.0 (1.4)	2.7 (0.6)	1.92 (.12)	+6.5 (2.2)
Sated, Food	75.2 (2.3)	21.1 (2.0)	3.7 (0.7)	1.92 (.12)	-6.6 (2.2)
Sated, Blank	83.0 (3.5)	17.0 (3.5)	n/a	n/a	n/a
Hungry, Non-food	80.4 (2.0)	16.9 (1.7)	2.8 (0.7)	1.88 (.12)	+3.2 (1.9)
Hungry, Food	76.9 (2.2)	19.8 (1.7)	3.3 (0.9)	1.87 (.12)	-3.2 (1.9)
Hungry, Blank	84.5 (2.9)	15.6 (3.0)	n/a	n/a	n/a
Masked					
<i>Session, Target type</i>					
Sated, Non-food	67.8 (3.3)	19.6 (2.0)	12.5 (2.7)	1.64 (.13)	-1.1 (2.6)
Sated, Food	68.0 (3.4)	18.2 (1.5)	13.8 (2.9)	1.64 (.13)	+1.2 (2.6)
Sated, Blank	82.0 (3.6)	18.0 (3.6)	n/a	n/a	n/a
Hungry, Non-food	67.6 (3.6)	20.4 (2.0)	12.0 (2.6)	1.69 (.13)	-5.1 (2.8)
Hungry, Food	70.7 (3.4)	15.8 (1.3)	13.5 (2.9)	1.69 (.13)	+5.0 (2.8)
Hungry, Blank	81.6 (3.2)	18.5 (3.2)	n/a	n/a	n/a

Accuracy, proportion incorrect and proportion misses were calculated for non-blank and blank trials. Additionally, d' and response bias were calculated for non-blank trials. The mean values of these measures are summarized here. SE = standard error.

Table 2: **Behavioral statistics I: Accuracy and proportion Incorrect of non-blank trials**

Accuracy rANOVA: <i>Session, Masking, Target type</i>	Statistic _{df} F _(1,27)	Significance <i>p</i>	Effect size η_p^2
Session	0.147	0.71	0.005
Masking	34.4	< 0.001	0.56
Target type	1.07	0.311	0.038
Session x Masking	0.58	0.453	0.021
Session x Target type	5.83	0.023	0.178
Masking x Target type	12.7	0.001	0.32
Session x Masking x Target type	0.279	0.601	0.01

% Incorrect rANOVA: <i>Session, Masking, Target type</i>	F _(1,27)	<i>p</i>	η_p^2
Session	0.122	0.73	0.004
Masking	0.203	0.656	0.007
Target type	0.184	0.671	0.007
Session x Masking	1.81	0.19	0.063
Session x Target type	5.74	0.024	0.175
Masking x Target type	19.29	< 0.001	0.417
Session x Masking x Target type	0.006	0.94	0

Accuracy and proportion Incorrect measures of non-blank trials were submitted to a 2 x 2 x 2 repeated measures ANOVA with the factors session (hungry vs. sated), masking (masked vs. unmasked) and target type (food vs. non-food). F statistics, significance levels and effect sizes are given and statistically significant results (i. e. $p < 0.05$) are highlighted in gray. Significant interactions were further probed using two-tailed, paired t-tests, the results of which are given in the appendix (section 12, table 8).

Table 3: **Behavioral statistics II: proportion Misses, mean d' and mean response bias of non-blank trials**

% Misses rANOVA:			
<i>Session, Masking, Target type</i>	Statistic _{df}	Significance	Effect size
	$F_{(1,27)}$	p	η_p^2
Session	0.062	0.81	0.002
Masking	20.03	< 0.001	0.426
Target type	5.69	0.024	0.174
Session x Masking	0.016	0.902	0.001
Session x Target type	0.017	0.898	0.001
Masking x Target type	1.014	0.323	0.036
Session x Masking x Target type	0.854	0.363	0.031

Mean d' rANOVA:			
<i>Session, Masking, Target type</i>	$F_{(1,27)}$	p	η_p^2
Session	0.001	0.98	0
Masking	47.4	< 0.001	0.637
Target type	0.118	0.734	0.004
Session x Masking	2.06	0.162	0.071
Session x Target type	3.28	0.081	0.108
Masking x Target type	0.220	0.642	0.008
Session x Masking x Target type	0.238	0.630	0.009

Mean response bias rANOVA:			
<i>Session, Masking, Target type</i>	$F_{(1,27)}$	p	η_p^2
Session	0.001	0.97	0
Masking	0.954	0.337	0.034
Target type	0.195	0.662	0.007
Session x Masking	1.467	0.236	0.052
Session x Target type	6.471	0.017	0.193
Masking x Target type	13.5	0.001	0.333
Session x Masking x Target type	0.165	0.688	0.006

Proportion Misses, d' and response bias measures of non-blank trials were submitted to a 2 x 2 x 2 repeated measures ANOVA with the factors session (hungry vs. sated), masking (masked vs. unmasked) and target type (food vs. non-food). F statistics, significance levels and effect sizes are given and statistically significant results (i. e. $p < 0.05$) are highlighted in gray. Significant interactions were further probed using two-tailed, paired t-tests, the results of which are given in the appendix (section 12, table 8).

Table 4: **Behavioral statistics III: Accuracy and proportion Incorrect of blank trials**

Accuracy rANOVA:	Statistic _{df}	Significance	Effect size
<i>Session, Masking</i>	F _(1,27)	<i>p</i>	η_p^2
Session	0.041	0.841	0.002
Masking	1.338	0.258	0.047
Session x Masking	1.084	0.307	0.039

% Incorrect rANOVA:	Statistic _{df}	Significance	Effect size
<i>Session, Masking</i>	F _(1,27)	<i>p</i>	η_p^2
Session	0.041	0.841	0.002
Masking	1.338	0.258	0.047
Session x Masking	1.084	0.307	0.039

Accuracy and proportion Incorrect measures of blank trials were submitted to a 2 x 2 repeated measures ANOVA with the factors session (hungry vs. sated) and masking (masked vs. unmasked). F statistics, significance levels and effect sizes are given.

5.3.2 Masked condition and further analysis

In the masked condition, a main effect of visibility, a session by target and a three-way interaction (session by visibility by target type) were observed (table 6 and figure 6). The main effect of visibility was due to a significantly smaller N2pc amplitude for missed targets (misses) versus seen targets (hits) ($p < 0.001$). The session by target type interaction was mainly driven by a higher amplitude to non-food stimuli versus food stimuli, but only in the sated sessions ($p = 0.03$), although in the hungry session, there was a tendency towards higher amplitudes to food stimuli ($p = 0.06$).

The session by visibility by target type interaction was driven by a higher N2pc amplitude to missed food versus non-food targets, but only in the hungry sessions ($p = 0.02$). In the sated sessions, there was no significant difference between the amplitudes to missed food and non-food stimuli ($p = 0.08$). The difference was, however, only present for missed targets. The mean amplitude for hits did not differ during hungry ($p = 0.25$), nor during sated sessions ($p = 0.08$).

Overall, hits elicited a greater N2pc amplitude than misses ($p < 0.001$), with the only exception being non-food items during sated sessions ($p = 0.72$).

For blank trials, there was only a main effect of masking, with a higher N2pc amplitude

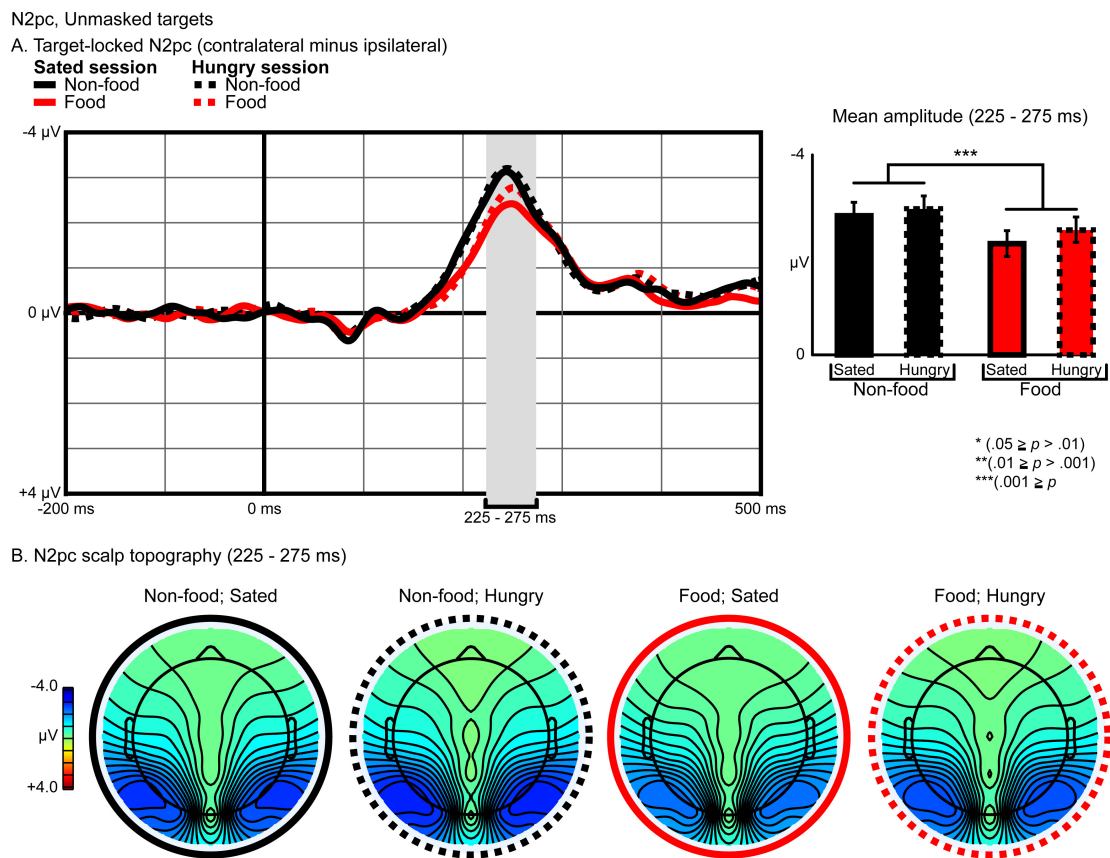


Figure 5: **N2pc mean amplitude in the unmasked condition.** A: The target-locked contralateral minus ipsilateral difference wave that contains the N2pc in the time frame of 225 to 275 ms is shown. The mean N2pc amplitude in this time frame differed significantly between target types, with an enhanced response towards non-food pictures regardless of session type (hungry or sated). Interestingly, a higher mean amplitude was also elicited by food targets in the hungry as compared to the sated sessions without any significant main effect or interactions of session type in the corresponding analysis of variance. B: The scalp topography typical for the N2pc with a negative distribution over posterior scalp regions contralateral to the target is shown for the time frame of 225 to 275 ms (Ilse et al. 2020).

in masked than in unmasked trials ($p < 0.001$, see table 7). This effect was regardless of session type.

Finally, to probe whether the difference in mean N2pc amplitude towards unseen food versus non-food targets would scale with the subjective feeling of hunger, a Pearson correlation analysis was performed. Here, a positive correlation between G-FCQ-S differences (hungry minus sated session scores) and the mean amplitude to unseen food

targets could be found, but only during the hungry sessions ($r = 0.411$; $p < 0.05$, figure 7). No correlation was present for unseen non-food targets, nor for unseen food targets during the sated sessions (all $p > 0.05$).

Table 5: **N2pc mean amplitude values**

Unmasked <i>Session, Target type</i>	N2pc mean amplitude (μV)	Standard error (SE)
Sated, Non-food	-2.78	0.27
Sated, Food	-2.22	0.26
Hungry, Non-food	-2.92	0.26
Hungry, Food	-2.50	0.25
Masked <i>Session, Visibility, Target type</i>		
Sated, Hits, Non-food	-4.10	0.30
Sated, Misses, Non-food	-3.17	0.50
Sated, Hits, Food	-3.82	0.26
Sated, Misses, Food	-2.51	0.38
Hungry, Hits, Non-food	-4.03	0.26
Hungry, Misses, Non-food	-1.83	0.41
Hungry, Hits, Food	-3.89	0.25
Hungry, Misses, Food	-2.59	0.33
Target-absent trials (blank trials) <i>Session, Masking condition</i>		
Sated, Unmasked	-2.75	0.29
Sated, Masked	-3.48	0.28
Hungry, Unmasked	-2.94	0.33
Hungry, Masked	-3.62	0.31

N2pc mean amplitude values for the post-stimulus time window of 225 to 275 ms extracted from scalp site P7/P8 are shown together with their respective standard error.

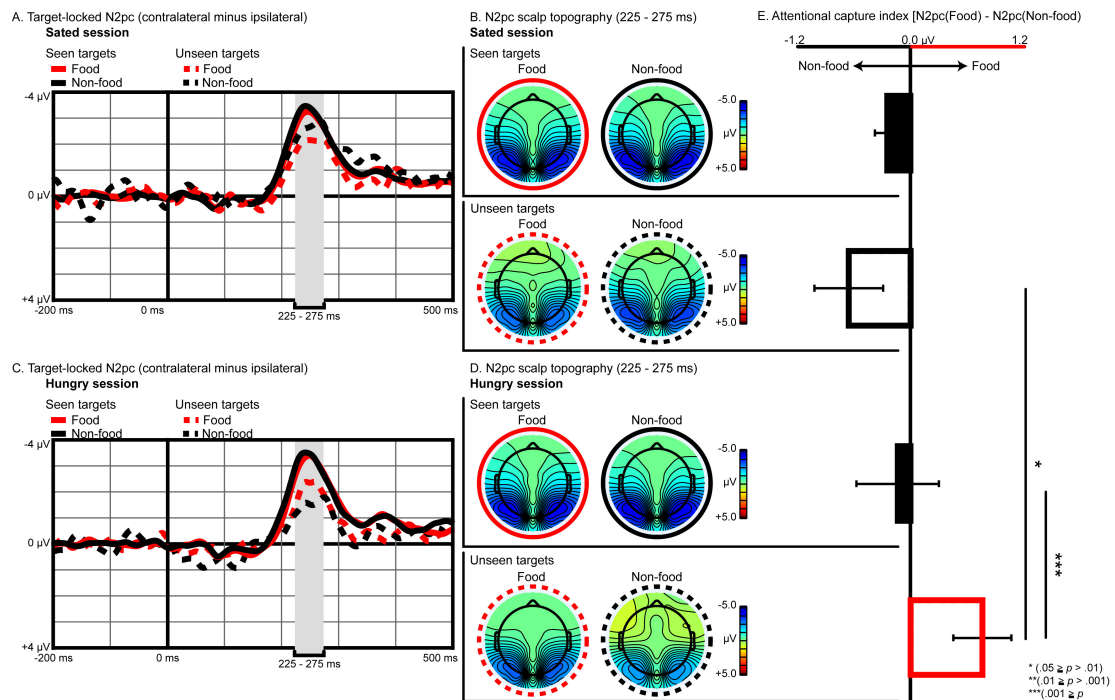


Figure 6: **N2pc mean amplitude in the masked condition.** A: The target-locked mean amplitude of the N2pc is displayed for seen and unseen food and non-food targets during the sated sessions. A smaller N2pc for unseen targets regardless of target type can be seen during the relevant time window of 225 to 275 ms. B: The corresponding scalp topography also shows the reduction in N2pc mean amplitude for reduced visibility. C: The target-locked mean amplitude of the N2pc is displayed for seen and unseen food and non-food targets during the hungry sessions. Here, a reduced mean amplitude under conditions of disrupted visibility can be seen for food and non-food targets, as was the case during the sated sessions. During the hungry sessions, however, the mean amplitude for unseen food targets was significantly greater (i. e. more negative) as compared to unseen non-food targets. D: Corresponding scalp topographies show the aforementioned differences with reduced amplitudes for unseen targets in general and a greater amplitude for unseen food versus unseen non-food targets. E: An attentional capture index obtained by subtracting the mean amplitude towards non-food from that towards food targets is shown here. This way, an attentional bias towards unseen food targets only present during hungry sessions can be seen. This relative switch in attentional status is responsible for the observed three-way session by visibility by target type interaction (Ilse et al. 2020).

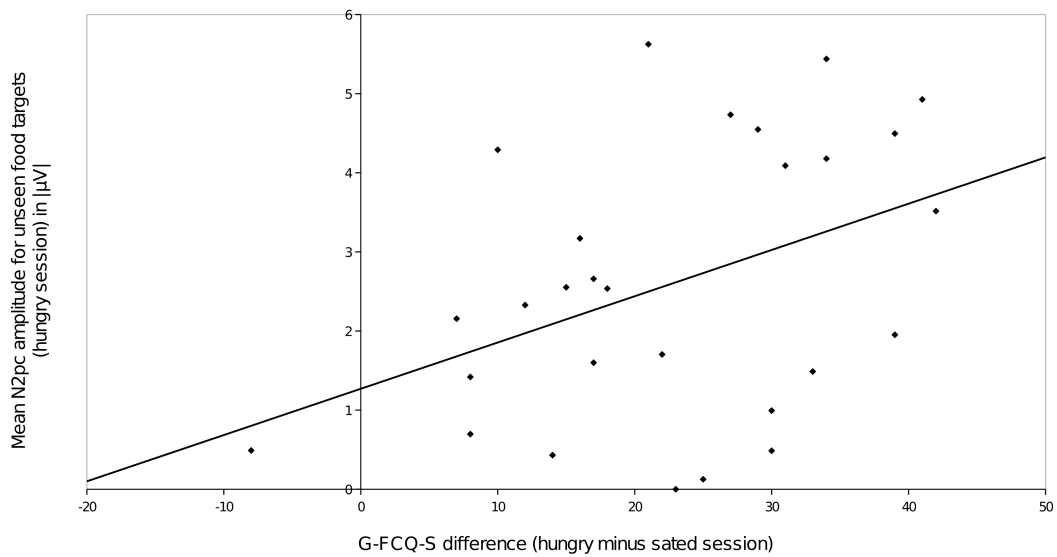


Figure 7: **Pearson correlation analysis between G-FCQ-S differences (hungry minus sated) and mean N2pc amplitude to unseen food targets.** A Pearson correlation analysis between G-FCQ-S differences (hungry minus sated session scores) and mean N2pc amplitude to unseen food targets revealed a positive correlation, but only during hungry sessions ($r = 0.411$; $p < 0.05$). Thus, the higher the subjective feeling of hunger, the higher was the mean N2pc amplitude towards unseen food targets. No such effect was detectable for unseen non-food targets, nor for unseen food targets during sated sessions.

Table 6: N2pc mean amplitude statistics of non-blank trials

N2pc mean amplitude rANOVA

Unmasked condition <i>Session x Target type</i>	Statistic _{df} F _(1,27)	Significance <i>p</i>	Effect size η_p^2
Session	2.33	0.139	0.079
Target type	34.25	< 0.001	0.559
Session x Target type	2.42	0.131	0.082

Masked condition

<i>Session x Visibility x Target type</i>	F _(1,27)	<i>p</i>	η_p^2
Session	0.951	0.338	0.034
Visibility	53.08	< 0.001	0.663
Target type	0.439	0.513	0.016
Session x Visibility	1.322	0.260	0.047
Session x Target type	6.97	0.014	0.205
Visibility x Target type	1.023	0.321	0.037
Session x Visibility x Target type	5.63	0.025	0.172

N2pc mean amplitude values were submitted to a 2 x 2 repeated measures ANOVA with the factors session (hungry vs. sated) and target type (food vs. non-food) for the unmasked condition and to a 2 x 2 x 2 repeated measures ANOVA with the factors session (hungry vs. sated), visibility (hits vs. misses) and target type (food vs. non-food) for the masked condition. F statistics, significance levels and effect sizes are given and statistically significant results (i. e. $p < 0.05$) are highlighted in gray. Significant interactions were further probed using two-tailed, paired t-tests, the results of which are given in the appendix (section 12, table 9).

Table 7: N2pc mean amplitude statistics of blank trials

N2pc mean amplitude rANOVA <i>Session x Masking</i>	Statistic _{df} F _(1,27)	Significance <i>p</i>	Effect size η_p^2
Session	1.13	0.297	0.040
Masking	18.53	< 0.001	0.407
Session x Masking	0.118	0.734	0.004

N2pc mean amplitude values were submitted to a 2 x 2 repeated measures ANOVA with the factors session (hungry vs. sated) and masking (masked vs. unmasked). F statistics, significance levels and effect sizes are given and statistically significant results (i. e. $p < 0.05$) are highlighted in gray.

6 Discussion

6.1 The automatic capture of attention by food-related stimuli

The primary assumption of this thesis that food captures the attention outside of awareness was supported by the data shown here. This capture of attention was automatic and occurred only when the participants were hungry. In other words, a higher N2pc amplitude to unseen food versus non-food stimuli was seen, but only in the hungry sessions.

The capture of attention by food-related images has been shown before, both by demonstrating a behavioral bias towards food (Mogg et al. 1998; Castellanos et al. 2009; Nijs et al. 2010; Nummenmaa et al. 2011) and by showing that electrophysiological markers of attention can be altered by food-related stimuli (Nijs et al. 2007a; Stockburger et al. 2008, 2009; Nijs et al. 2010; Sanger 2019). None of these studies, however, used the N2pc as the event-related potential (ERP) component of interest. Nevertheless, there has been some research on the influence of food images on other ERP components (for a review see Carbine et al. 2018). In one study by Stockburger et al., for example, the authors found a general increase in neuronal activity as a response to the passive viewing of food pictures. This increase was present when subjects were hungry and absent when they were sated and occurred 170 to 310 ms poststimulus over posterior scalp regions (Stockburger et al. 2008). When the same group looked at the late positive potential (LPP), a component linked to conscious allocation of attention (Cuthbert et al. 2000), they again found increased amplitudes in response to food pictures when the subjects were hungry (Stockburger et al. 2009). Likewise, the P3, another component that has been linked to the dedication of attentional resources to motivationally relevant targets (Cuthbert et al. 2000), has been shown to be influenced in the same way, for example in Nijs et al. 2007a, 2010 and Sanger 2019. Although the study from Nijs et al. from 2010 did not employ a hunger manipulation to show that the mentioned effects are restricted to a state of hunger, they did find a positive correlation between P3 amplitude and self-reported levels of hunger. In the other two studies, the attention-capturing effects of food targets were only visible in the hungry group. This pattern of results makes sense from an evolutionary point of view. Food is a fundamental resource for survival and as such motivationally highly relevant when one is hungry (Raynor et al. 2003). However, when calorie-intake has taken place, there is no immediate need for further eating and thus, its motivational value is reduced (Raynor et al. 2003).

The notion that images of food capture the attention especially in hungry viewers is further supported by the data presented here. Specifically, we observed a session by target

type interaction with a significantly higher N2pc amplitude to non-food stimuli in the sated sessions and a tendency towards higher amplitudes to food stimuli in the hungry sessions ($p = 0.03$ and 0.06 , respectively). Moreover, the Pearson correlation analysis revealed a positive correlation between the subjective level of hunger (as reflected by between-session G-FCQ-S differences) and the mean N2pc amplitude towards unseen food targets. Specifically, participants with a higher subjective feeling of hunger had higher N2pc amplitudes in response to unseen food images.

The finding that the N2pc amplitude might be mediated by situational differences such as in a craving manipulation is in contrast to a previous study of our group investigating the attentional capture by smoking-related images in smokers. By using a similar experimental setup, this study reported automatic capture of attention by smoking-related images in smokers, with higher N2pc amplitudes in masked than in unmasked trials (Harris et al. 2018). However, this difference in amplitudes was unaffected by the employed craving manipulation, as opposed to the effect the hunger manipulation had on the N2pc amplitude in the current study. This provides evidence that despite the similarities between the processing of primary reinforcers, such as food, and secondary reinforcers, such as addiction-related substances (Volkow et al. 2005), there also seem to be disparities in how they are processed by the brain.

The finding that non-food pictures elicited greater N2pc amplitudes under conditions of full visibility (unmasked condition and seen targets in masked condition), even when subjects were hungry, was unexpected. As described above, prior research has found markers of attentional selection to be generally enhanced in response to food pictures, at least when the subjects were hungry (Nijs et al. 2007a; Stockburger et al. 2008, 2009; Nijs et al. 2010; Sanger 2019). In our study, food items only elicited a higher mean N2pc amplitude under conditions of disrupted visibility. Nevertheless, as explained above, none of the aforementioned studies focused on the N2pc. It is possible that the attentional status of food items in hungry subjects is conveyed differently by different ERP components. Though studies investigating the N2pc in conjunction with food items are sparse, there is one by Kumar et al. from 2016. Here, subjects completed a cueing task with food and non-food pictures while they were sated (Kumar et al. 2016). The study is explained in section 6.2 in greater detail. Interestingly, the mean N2pc amplitude in this study was also larger for non-food than food images, at least in trials with validly cued targets (while the opposite was true for invalidly cued targets). The group did, however, use a different method to extract the N2pc and direct comparisons of mean amplitudes should thus be done with caution.

On the other hand, the reason for higher amplitudes to non-food targets under con-

ditions of full visibility could be higher task demands for this stimulus category. It is known that the N2pc scales, at least to some degree, with task demands (Eimer 1996; Mazza et al. 2011). Consistent with this are higher N2pc amplitudes for masked than for unmasked trials in the current study, because identifying masked images is generally more demanding. Studies have shown that the allocation of spatial attention and the N2pc itself can be influenced by top-down mechanisms (e. g. Wolfe et al. 1989; Yantis et al. 1990; Bacon et al. 1994; Leblanc et al. 2008; Eimer et al. 2008). It then seems likely that more processing capacity would be dedicated to identifying the stimulus category that is more demanding. Such a strategy, however, would fail in light of subconsciously perceived stimuli and could thus explain the switch in the attentional status of unseen food images in the hungry sessions, as reflected by a higher N2pc. The high motivational value of food images for a hungry viewer leads to an automatic capture of attention, because top-down control fails to prevent this capture. The behavioral data, with higher accuracy rates for non-food than food images, seems to speak against this. As I will discuss in section 6.2, however, higher accuracy rates need not necessarily be contradictory as they might simply be the result of a certain behavioral strategy.

Another, more speculative reason for such a top-down control mechanism might be that the subjects were biased by their knowledge about the task. They knew that food would be relevant to the study in some form, because they were asked to comply with a fasting protocol and they were shown food images as targets. In an effort to equate the attentional status of both stimulus categories this may have led to an overcompensation. Previous data from our group with smokers viewing smoking-related and unrelated stimuli under similar conditions support this notion (Harris et al. 2018).

Another important finding was the main effect of visibility in the masked condition with smaller N2pc amplitudes for unseen than for seen targets. Though intuitive, it might appear somewhat contradictory to the findings by Woodman et al. from 2003, where they observed no difference in N2pc amplitudes between masked and unmasked trials and between correct and incorrect responses within masked trials (Woodman et al. 2003). However, unlike Woodman et al., we introduced a third category in our paradigm (blank, i. e. no image present). With this, we could further dissociate non-correct responses into incorrect responses (miscategorization error) and misses (target image undetected). We could then compare the N2pc amplitude of unseen targets with that of seen and correctly identified targets. This more conservative approach might be responsible for the difference in amplitudes between seen and missed food targets in the current study. This approach was similar to that used in the study by Harris et al. from 2013, where they found the same pattern of results (Harris et al. 2013).

6.2 Behavioral strategies and response bias

In the behavioral data, a main effect of masking could be observed for the accuracy measure. This result is important to show that the masking manipulation works and that masked targets are less likely to be identified correctly. Interestingly, there was no main effect of masking for the incorrect measure, but a main effect of masking for the misses measure. This means that the reduced accuracy in the masked trials can not be accounted for by a rise in the number of miscategorizations, as a significant increase in incorrect responses would be expected then, but rather by a rise in target misses. This pattern of results makes sense in light of previous findings on how object substitution masking works. Specifically, in masked trials, it is thought that the first percept of the experimental setup (the target plus mask array) is processed by the visual system and via feedback loops eventually compared to the current percept (the mask alone). As this comparison leads to a conflicting result, and as the current percept is constantly reinforced while the former percept gradually fades, the target plus mask array is eventually replaced by the mask alone display (Di Lollo et al. 2000). Therefore, it seems to the subjects as though there was no target image present, and the button for “blank” is pressed.

Furthermore, an analysis of variance revealed significant session by target and masking by target interactions. These were driven by a higher accuracy for non-food items in the sated session and in the unmasked condition, respectively. In the masked condition, there was no such difference in accuracy. The same differences also emerged for the incorrect measures with an analogous (i. e. inverse) pattern. This suggests that subjects were more accurate in identifying non-food images than food images under conditions of satiety and in the context of full visibility. To interpret this result, the d' and response bias measures have to be taken into consideration. For d' , there was only a main effect of masking and no further main effects or interactions. This speaks to a uniform reduction of discriminability of both food and non-food images in the masked as compared to the unmasked condition. Moreover, it means that the reduced accuracy for food images as compared to non-food images in the sated session and in the unmasked condition can not be accounted for by differences in general target category discriminability. For response bias, there was also a session by target and a masking by target interaction. Follow-up tests showed that these interactions were driven by a tendency of the participants to choose non-food items more often than food items while they were sated and under con-

ditions of full visibility. These effects are therefore likely to be the result of a behavioral strategy in which an internal criterion (the nature of which is explained in section 4.8.1) is set in favor of non-food images, which will then be picked more readily.

The reason for a response bias towards non-food objects in the sated condition may be that when sated, food has little motivational value (Raynor et al. 2003), because there is not much need for further calorie intake. It may thus be unnecessarily distracting to shift the attention towards food items, as they are not needed at that moment. This might further explain the enhanced N2pc amplitude for non-food images in the unmasked condition observed in the current experiment. However, in the current experiment, shifting attention away from food-related images was not incentivized, as they were task-relevant here and further research should look into this question more directly. Such subconscious avoidance behavior affecting attentional deployment has been reported before. For example, in a study by Kumar et al. mentioned in section 6.1, subjects completed a cueing task while they were sated (Kumar et al. 2016). Specifically, they were presented with a food or with a non-food cue. On the subsequent display were a target and a distractor on either side of the visual hemifield. When the target was of the same category as the cue, the trial was called “valid trial” and when the distractor was of the cue category, the trial was called “invalid trial”. Subjects were told to attend to and identify the target stimulus. To assess the subjects’ shift of attention, the group used the N1pc and the N2pc, the N1pc being a marker of attentional selection occurring earlier than the N2pc (e. g. Mangun et al. 1991). When subjects were presented with a non-food cue, they shifted their attention towards the subsequently presented target when it was validly cued (target also a non-food stimulus) and towards the distractor when the cueing was invalid (target a food stimulus). When they were presented with food cues, however, the subjects’ attention was initially shifted away from the validly cued food items, as reflected in a positive N1pc, as though avoiding them. The N2pc, however, was in line again with a shift of attention towards the validly cued food item. In contrast to the current study, this avoidance behavior occurred earlier in time and was not visible any more in the N2pc time range. Furthermore, a study by Donohue et al., who used a visual search task in smokers with smoking-related images also observed avoidance behavior (Donohue et al. 2016b). Specifically, subjects had to make a judgment about missing corners of two colored squares, either left or right of fixation. Embedded in the squares were smoking-related images or images of office supplies. When the target square contained a smoking-related image, subjects were slower and displayed a weaker shift of attention towards that target. When the smoking-related image was embedded in the distractor, the opposite occurred. In contrast with the current study, however,

the smoking-related images in the study by Donohue et al. were task-irrelevant and distracting and ignoring them was thus incentivized. To summarize, these examples also show evidence of subconscious avoidance behavior, albeit differences in task design make them hard to compare directly to the current experiment. In any case, future research should look further into this phenomenon.

6.3 Limitations, clinical perspective and future prospects

A caveat of the thesis is that no adjustment for multiple testing was made. Thus, the data should be seen as descriptive and further testing will be necessary to confirm the results. However, as discussed above, the main results are in line with previous findings and in some areas (e. g. N2pc in response to food images) not much research has been done so far.

A second limitation is that the fasting manipulation relied on the honesty of the participants. However, the questionnaires indicated a feeling of satiety in almost all participants in the sated as compared to the hungry sessions. Although the answers in questionnaires can be dishonest, they are widely used tools and are generally recommended and scientifically validated for the purpose of assessing the subjective feeling of hunger and craving for food (e. g. Nijs et al. 2007b; Blundell et al. 2010). Furthermore, lying was not incentivized, as subjects were told they would still be compensated for their time and their data would still be of use for the research project.

Despite its limitations, the thesis adds to an important area of research also from a clinical perspective. Research looking into the fundamentals of decision making has implications for a wide variety of topics in medicine, for example addiction disorders or therapy adherence. The data presented here, however, is primarily useful as a basis for the study of obesity and eating disorders. Obesity in particular poses a great health risk to human society. Among the non-communicable diseases, it is one of the most important risk factors in terms of disability-adjusted life-years, especially for high- to middle-income countries (Forouzanfar et al. 2016). While the cause for obesity is likely multifactorial, research suggests that cognitive mechanisms involved in attention or reward learning might play a role (e. g. Field et al. 2016). Thus, understanding the involvement of attention in the pathogenesis of excessive weight gain might aid in developing prevention or treatment strategies.

As mentioned above, research with overweight subjects has suggested differences in attentional biases in comparison with healthy-weight subjects, including increased gaze

durations (Castellanos et al. 2009) or faster reaction times in visual probe tasks (Nijs et al. 2010) and faster times to first fixation on food-related task-irrelevant distractor images in a visual search task (Brand et al. 2020). Some studies even report an “approach-avoidance pattern”, meaning that overweight more often than healthy-weight participants direct their gaze towards food stimuli first, only to then direct attention away more quickly (Werthmann et al. 2011, see also Nijs et al. 2012). Moreover, functional magnetic resonance imaging studies comparing “Blood Oxygenation Level Dependent” effects of food versus control pictures in obese and healthy-weight individuals have found increased activation of systems implicated in networks of reward and attention (e. g. Stoeckel et al. 2008). The magnitude of this activation has even been linked to the success of dietary programs, with subjects showing greater activation in such areas being less effective at weight loss and the maintenance of lost weight (Murdaugh et al. 2012), and could even be shown to predict future weight gain (Yokum et al. 2011).

Although there are a number of studies linking body weight to an altered allocation of attention (for a review see Hendrikse et al. 2015), a recent review and meta-analysis by Hardmann et al. found no overall association between BMI and an attentional bias to food-related cues (Hardman et al. 2020). According to this group, a food-related attentional bias seems to be influenced more by state than trait variables which mediate the motivational value of food from moment to moment, specifically hunger, craving for food and food intake (Hardman et al. 2020, and see also Field et al. 2016). Whether or not there is a stronger attentional bias towards food that depends on body weight should be the subject of future research. I argue that the attentional capture in response to subliminally perceived food stimuli should be of special concern in such studies, as one reason for the above mentioned conflicting results could be cognitive strategies to suppress the attention-capturing effects of food stimuli, as suggested by our data with healthy-weight participants. This might especially be true in overweight individuals, who are likely to face motivational conflicts more often than healthy-weight individuals between the desire to eat and the intention to maintain a diet (Hardman et al. 2020). And although our understanding of the attentional processes that might contribute to excessive food intake are as yet incomplete, the data presented here can be seen as a basis on which further research can be based on.

7 Summary

The deployment of spatial attention can be modulated both bottom-up by stimulus features and top-down by intentional or unintentional mechanisms. It is not surprising that the interplay between food stimuli and a person's current state of hunger constitute such an unintentional mechanism that affects attentional deployment. However, if and how *subconsciously* perceived images of food have the same effect is not known. Here, I describe an object-substitution masking task that was completed twice by each participant ($n = 30$), once when they had abstained from eating 12 hours prior to the experiment and once when they had eaten directly before. Subjects had to make a judgment whether the presented targets were food or non-food items, or whether no target was presented. We recorded the event-related potentials throughout the experiment and focused specifically on an index of lateral spatial attention allocation, the N2pc. Behaviorally, we saw a higher accuracy for non-food targets in sated sessions and under conditions of full visibility. This could be accounted for by a strong response bias and was not mediated by differences in stimulus detectability, as represented by the d' measure. Most noteworthy, we observed a higher N2pc amplitude to unseen food versus non-food stimuli, but only when the participants were hungry. Under conditions of full visibility, non-food images elicited a higher N2pc amplitude. This speaks to an automatic capture of attention by food-related stimuli, but only when the stimuli are not consciously perceived. Overall, our data suggests some form of top-down attentional control mechanism over food-related stimuli which fails when the target is unnoticed by the observer. The data presented here contribute to the question how subconsciously perceived images of food might influence behavior and could thus contribute to research into the pathomechanisms of obesity and eating disorders.

8 References

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10 Ehrenerklärung

Ich erkläre, dass ich die der Medizinischen Fakultät der Otto-von-Guericke-Universität Magdeburg zur Promotion eingereichte Dissertation mit dem Titel

“Unseen food images capture the attention of hungry viewers: Evidence from event-related potentials”

in der Klinik für Neurologie der Medizinischen Fakultät der Otto-von-Guericke-Universität Magdeburg mit besonderer Unterstützung durch Joseph A. Harris und Hans-Jochen Heinze, sowie der unter Danksagung genannten Personen, ohne sonstige Hilfe durchgeführt und bei der Abfassung der Dissertation keine anderen als die dort aufgeführten Hilfsmittel benutzt habe.

Bei der Abfassung der Dissertation sind Rechte Dritter nicht verletzt worden.

Ich habe diese Dissertation bisher an keiner in- oder ausländischen Hochschule zur Promotion eingereicht. Ich übertrage der Medizinischen Fakultät das Recht, weitere Kopien meiner Dissertation herzustellen und zu vertreiben.

Magdeburg, den 05.08.2022

Arne Klaas

11 Darstellung des Bildungsweges

Ausbildung und Beruf

- 10/2018 - 07/2022 Weiterbildung als Assistenzarzt im Zentrum für Innere Medizin der Helios Börde klinik in Oschersleben
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Publikationen

1. A. Ilse, S. E. Donohue, M. A. Schoenfeld, J. M. Hopf, H.-J. Heinze, J. A. Harris (2020). “Unseen food images capture the attention of hungry viewers: Evidence from event-related potentials”. In *Appetite* 155 (2020) 104828.
2. A. Ilse, V. Prameswari, E. Kahl, M. Fendt (2019). “The role of trait anxiety in associative learning during and after an aversive event”. In *Learn Mem.* 2019 Jan 16;26(2):56-59.
3. J. A. Harris, S. E. Donohue, A. Ilse, M. A. Schoenfeld, H.-J. Heinze, M. G. Woldorff (2018). “EEG measures of brain activity reveal that smoking-related images capture the attention of smokers outside of awareness”. In *Neuropsychologia* 111 (2018) 324-333.
4. A. Ilse, L. Büntjen, F. C. Schmitt (2017). “Stereotaktische Laserablation für fokale Epilepsien – Eine Literaturübersicht”. In *Z Epileptol* 2/2017, Springer Medizin Verlag Berlin.

Posterpräsentationen

1. A. Ilse, M. A. Schoenfeld, S. E. Donohue, J. M. Hopf, H.-J. Heinze, J. A. Harris (2019). “Hunger potentiates the unconscious capture of attention by food-related images”. Präsentiert bei der 26. Jahrestagung der Cognitive Neuroscience Society 03/2019 in San Francisco, USA.
2. A. Ilse, F. C. Schmitt, W. Hamel, P. M. House, C. K. Moll, H. Lee, S. R. Stodieck, B. R. Voges (2016). “Tiefe-Hirn-Stimulation bei Patienten mit Temporallappenanfällen: stärkere Beeinflussung des Schlafes bei Respondern”. Präsentiert bei der 53. Jahrestagung der Deutschen Gesellschaft für Epileptologie 03/2016 in Jena, Deutschland.

12 Appendix

Overview over attachments:

1. Supplementary results tables (2 pages)
2. General information and consent form (2 pages)
3. General questionnaire (2 pages)
4. Food questionnaire (1 page)
5. G-FCQ-S (1 page)
6. Visual analogue scale questionnaire (1 page)

Table 8: Follow-up t-tests of significant interactions in the Accuracy, proportion Incorrect and response bias measures of non-blank trials

Accuracy of non-blank trials:	Statistic _{df}	Significance	Difference
Session x Target type interaction	t ₂₇	p	(A-B; %)
Food minus Non-food, Hungry vs. Sated	2.42	0.023	-3.2
Masking x Target type interaction			
Unmasked, Food vs. Non-food	2.88	0.008	5.2
Masked, Food vs. Non-food	0.75	0.461	-1.6
Non-Food, Unmasked vs. Masked	6.213	< 0.001	13.6
Food, Unmasked vs. Masked	3.84	0.001	6.7
% Incorrect of non-blank trials:			
Session x Target type interaction	t ₂₇	p	(A-B; %)
Food minus Non-food, Hungry vs. Sated	2.39	0.024	3.2
Masking x Target type interaction			
Unmasked, Food vs. Non-food	2.43	0.022	-4.5
Masked, Food vs. Non-food	1.43	0.16	3.0
Non-Food, Unmasked vs. Masked	4.18	< 0.001	-4.1
Food, Unmasked vs. Masked	2.72	0.011	3.4
Response bias of non-blank trials:			
Session x Target type interaction	t ₂₇	p	(A-B; %)
Sated, Food vs. Non-food	1.23	0.23	5.4
Hungry, Food vs. Non-food	0.45	0.65	-1.9
Non-Food, Sated vs. Hungry	2.55	0.02	3.6
Food, Sated vs. Hungry	2.54	0.02	-3.6
Masking x Target type interaction			
Unmasked, Food vs. Non-food	2.55	0.02	9.7
Masked, Food vs. Non-food	1.2	0.24	-6.2
Non-Food, Unmasked vs. Masked	3.67	0.001	8.0
Food, Unmasked vs. Masked	3.68	0.001	-8.0

Significant interactions of the Accuracy, proportion Incorrect and response bias analysis of variance for non-blank trials shown in table 2 (Accuracy and proportion Incorrect) and table 3 (response bias), respectively, were further probed using two-tailed, paired t-tests, the results of which are given here with relevant t statistics, significance levels and differences. Statistically significant results (i. e. $p < 0.05$) are highlighted in gray.

Table 9: Follow-up t-tests of significant interactions in the N2pc mean amplitude statistics for non-blank trials

Session x Target type interaction	Statistic _{df} t ₂₇	Significance p	Difference (A-B; μ V)
Hungry Food vs. Non-food	1.97	0.06	-0.32
Sated Food vs. Non-food	2.30	0.03	+0.45
Food Hungry vs. Sated	0.28	0.78	-0.08
Non-food Hungry vs. Sated	1.71	0.10	+0.69

Session x Visibility x Target interaction	t ₂₇	p	(A-B; μ V)
Hungry food hits, Hungry non-food hits	1.18	0.25	+0.14
Hungry food misses, Hungry non-food misses	2.46	0.02	-0.76
Sated food hits, Sated non-food hits	1.81	0.08	+0.09
Sated food misses, Sated non-food misses	1.80	0.08	+0.66
Hungry non-food hits, Hungry non-food misses	5.04	< 0.001	-2.20
Hungry food hits, Hungry food misses	3.78	< 0.001	-1.30
Sated non-food hits, Sated non-food misses	1.96	0.72	-0.90
Sated food hits, Sated food misses	4.84	< 0.001	-1.32
Hungry non-food hits, Sated non-food hits	0.21	0.84	+0.43
Hungry food hits, Sated food hits	0.36	0.72	-0.07
Hungry non-food misses, Sated non-food misses	1.76	0.09	+1.34
Hungry food misses, Sated food misses	0.20	0.85	-0.09

Food versus Non-food differences	t ₂₇	p	(A-B; μ V)
Food minus non-food hits Hungry vs. Sated	0.63	0.53	-0.11
Food minus non-food misses Hungry vs. Sated	2.64	0.01	-1.42
Sated food minus non-food hits vs. misses	1.06	0.30	-0.41
Hungry food minus non-food hits vs. misses	3.78	< 0.001	+0.90

Significant interactions of the N2pc mean amplitude analysis of variance for non-blank trials shown in table 6 were further probed using two-tailed, paired t-tests, the results of which are given here with relevant t statistics, significance levels and differences. Statistically significant results (i. e. $p < 0.05$) are highlighted in gray.

Informationsblatt zur EEG-Studie „AOSM“

Mit Ihrem Einverständnis wird bei Ihnen eine Untersuchung mittels Elektroenzephalographie (EEG) durchgeführt. Diese findet auf freiwilliger Basis statt. Im Folgenden erhalten Sie einige Informationen zu derartigen Messungen.

Mit Hilfe dieser Untersuchungsmethode ist es möglich, Lage und Funktion wichtiger Hirnregionen zu bestimmen. Dies geschieht durch Aufzeichnung der bioelektrischen Signale, die das Gehirn bei seiner Tätigkeit erzeugt. Die Messung erfolgt mit einer Kappe mit integrierten Elektroden, welche direkt auf Ihren Kopf gesetzt wird.

Dabei werden keinerlei Strahlung oder Felder erzeugt, sondern lediglich die vom Körper ausgehenden elektromagnetischen Felder gemessen. Ein gesundheitliches Risiko der Untersuchung ist nicht bekannt.

In der Studie messen wir Ihre kognitive Aufmerksamkeit indem Sie auf optische Reize reagieren. Die Aufgaben und der Versuchsaufbau werden Ihnen vor dem Experiment gezeigt und ausführlich erläutert. Dabei haben Sie die Möglichkeit mit dem Experimentator zu sprechen und Fragen zu stellen.

Die Studie umfasst insgesamt drei Termine. Für einen dieser drei Termine ist es wichtig, dass Sie zur Messung hungrig erscheinen, indem Sie seit Mitternacht (also ca. 12 Stunden lang) nichts gegessen und keine zuckerhaltigen Getränke zu sich genommen haben. Damit dieses 12-stündige Fasten kein gesundheitliches Risiko für Sie darstellt, ist es wichtig, dass Sie nicht an Stoffwechselerkrankungen, wie zum Beispiel Diabetes mellitus („Zuckerkrankheit“) leiden. Wenn Sie sich unsicher sind, oder wenn eine solche Krankheit bei Ihnen bekannt ist, sprechen Sie bitte unbedingt vorher mit Ihrem betreuenden Arzt.

DURCHFÜHRUNG DER MESSUNG

Die in einer Haube befestigten EEG-Elektroden werden mit einem leitfähigen Gel direkt an der Kopfoberfläche angebracht. Die Messung besteht aus mehreren Durchläufen, in denen die jeweiligen Bewegungsanleitungen präsentiert werden.

Zur Vermeidung ungenauer Ergebnisse werden Sie gebeten, sich während der Aufzeichnung nicht zu bewegen, außer den Handgelenksbewegungen nach Anleitung. Die gesamte Untersuchungszeit einschließlich Vorbereitung liegt zwischen 1,5 - 2 Stunden.

Zum Zweck der Auswertung und Dokumentation werden die erfassten Daten in rechnerzugreifbarer Form archiviert. Die Vorschriften des Datenschutzes werden dabei beachtet.

EINWILLIGUNGSERKLÄRUNG DES PROBANDEN

Über Art und Durchführung des Experimentes bin ich eingehend unterrichtet worden, dazu lag mir ein entsprechendes Informationsblatt vor. Den Inhalt dieser Informationsschrift habe ich verstanden. Des Weiteren konnte ich Fragen zu dem Experiment stellen und wurde über die Details vom Versuchsleiter informiert.

Ich willige hiermit in die Teilnahme an der Studie ein. Mir ist bekannt, dass ich meine Einwilligung jederzeit ohne Angabe von Gründen widerrufen kann.

Ich weiß, dass die bei den Untersuchungen mit mir gewonnenen Daten mit Computern weiterverarbeitet und eventuell für wissenschaftliche Veröffentlichungen verwendet werden sollen. Hiermit bin ich einverstanden, wenn die Verarbeitung und Veröffentlichung in einer Form erfolgt, die eine Zuordnung zu meiner Person ausschließt. Auch diese Einwilligung kann ich jederzeit ohne Angabe von Gründen widerrufen.

Name: _____ Vorname: _____

Geburtsdatum: _____

Magdeburg,

Datum

Unterschrift ProbandIn

Magdeburg,

Datum

Unterschrift VersuchsleiterIn

Datum:

Subj.-Nr.:

Trial Type: Hungry/Sated/Rating

Der folgende Fragebogen umfasst persönliche Fragen, die für diese Studie von Bedeutung sind. Wir möchten dich bitten alle Fragen sorgfältig zu beantworten. Selbstverständlich werden alle erhobenen Daten vertraulich behandelt. Eine personenbezogene Auswertung erfolgt nicht. Vielen Dank für deine Teilnahme.

1.) Wann hast du das letzte Mal Kaffee oder ein anderes koffeinhaltiges Getränk (z.B. Cola, schwarzer Tee, Energy-Drink) getrunken? _____

2.) Wann hast du das letzte Mal Alkohol getrunken und wie viel? _____

3.) Wie viele alkoholische Getränke trinkst du durchschnittlich pro Woche? _____

4.) Hast du innerhalb der letzten 24 Stunden andere Drogen genommen? _____

5.) Hast du innerhalb der letzten 24 Stunden Medikamente eingenommen? (z.B. Schmerzmittel, Beruhigungsmittel) _____

6.) Nimmst du regelmäßig Medikamente ein? (z.B. Blutdruckmittel, Antidepressiva) _____

7.) Hast du jemals regelmäßig illegale Drogen konsumiert? _____

Falls ja, welche? _____

Falls ja, wie lange ist das her? _____

8.) Hast du jemals eine Hirnverletzung (z.B. Gehirnerschütterung, Hirnblutung, Aneurysma) erlitten? _____

Falls ja, welche Folgen hatte diese Verletzung? _____

9.) Wurde jemals eine Operation am Kopf durchgeführt? _____

Falls ja, beschreibe dies bitte etwas näher: _____

Datum:

Subj.-Nr.:

Trial Type: Hungry/Sated/Rating

10.) Wurde bei dir jemals eine Hirnerkrankung diagnostiziert? _____

11.) Ist bei dir jemals ein Anfallsleiden (Epilepsie) aufgetreten? _____

Falls ja, wann? _____

12.) Bist du an Diabetes erkrankt? _____

13.) Leidest du an einer Essstörung? _____

14.) Wurde eine der folgenden Diagnosen jemals gestellt: Depression, Bipolare Störung,
Schizophrenie, Borderline-Persönlichkeitsstörung, Burnout-Syndrom, PTBS, Zwangsstörung,
ADHS, Asperger-Syndrom, Autismus oder eine andere hier nicht aufgelistete Erkrankung?

15.) Welcher ist dein höchster Bildungsabschluss? _____

Datum:

Subj.-Nr.:

Trial Type: Hungry/Sated/Rating

Fragebogen zu Essensgewohnheiten und zum Hungergefühl

Im Folgenden findest du ein paar Fragen zu deinem aktuellen Hungergefühl, sowie zu Dingen, die mit Essen zu tun haben. Bitte beantworte alle Fragen ehrlich und spontan, das ist für die Studie von größter Wichtigkeit. Solltest du gestern nach 24 Uhr, in der Nacht oder direkt vor dem Experiment gegessen haben, so gib dies bitte in jedem Fall an, auch wenn du eigentlich hättest fasten sollen. Wir müssen das wissen, damit wir die Ergebnisse der Studie richtig einordnen können. Vielen Dank für deine Hilfe!

Zuerst ein paar allgemeine Fragen:

1. Hast du gestern nach 24 Uhr, in der Nacht, am Morgen oder direkt vor dem Experiment etwas gegessen oder zuckerhaltige Getränke getrunken? Ja Nein

2. Wie lange ist es ungefähr her, dass du etwas gegessen oder zuckerhaltige Getränke getrunken hast? _____

3. Isst du normalerweise Frühstück? (fast) immer oft selten (fast) nie

4. Hältst du aktuell eine Diät ein? Ja Nein

5. Falls ja, kannst du diese kurz beschreiben? _____

6. Ernährst du dich vegetarisch oder vegan? _____

7. Wie groß bist du? _____

8. Wie viel wiegst du? _____

Datum:

Subj.-Nr.:

Trial Type: Hungry/Sated/Rating

		Stimme überhaupt nicht zu	Stimme nicht zu	neutral	Stimme zu	Stimme sehr stark zu
1.	Ich verspüre den intensiven Wunsch etwas leckeres zu essen.	1	2	3	4	5
2.	Ich verspüre ein starkes Verlangen nach leckerem Essen.	1	2	3	4	5
3.	Ich verspüre den Drang, leckeres Essen zu essen.	1	2	3	4	5
4.	Etwas leckeres zu essen, würde mir alles einfach perfekt erscheinen lassen.	1	2	3	4	5
5.	Wenn ich das essen würde, wonach ich mich gerade sehne, würde sich sicher meine Stimmung verbessern.	1	2	3	4	5
6.	Etwas leckeres zu essen würde sich großartig anfühlen.	1	2	3	4	5
7.	Wenn ich etwas essen würde, würde ich mich nicht so träge und antriebslos fühlen.	1	2	3	4	5
8.	Wenn ich mein Verlangen stillen könnte, würde ich mich weniger schlecht gelaunt und gereizt fühlen.	1	2	3	4	5
9.	Wenn ich mein Verlangen stillen könnte, würde ich michmunterer fühlen.	1	2	3	4	5
10.	Wenn ich etwas leckeres zu essen hätte, könnte ich nicht aufhören, davon zu essen.	1	2	3	4	5
11.	Mein Verlangen, etwas leckeres zu essen, scheint überwältigend zu sein.	1	2	3	4	5
12.	Ich weiß, dass ich solange an leckeres Essen denken werde, bis ich es tatsächlich habe.	1	2	3	4	5
13.	Ich habe Hunger.	1	2	3	4	5
14.	Wenn ich jetzt etwas essen würde, würde sich mein Magen nicht mehr so leer anfühlen.	1	2	3	4	5
15.	Ich fühle mich schwach, weil ich nichts gegessen habe.	1	2	3	4	5

Datum:

Subj.-Nr.:

Trial Type: Hungry/Sated/Rating

Wie hungrig bist du? Mache ein Kreuz an dem Punkt auf der Linie, der deinem Hunger am ehesten entspricht.

Ich bin überhaupt nicht hungrig.



Ich bin so hungrig wie noch nie.

Wie satt bist du? Mache ein Kreuz an dem Punkt auf der Linie, der deinem Sättigungsgefühl am ehesten entspricht.

Ich bin überhaupt nicht satt.



Ich bin sehr satt.

Wie viel könntest du gerade essen? Mache ein Kreuz an dem Punkt auf der Linie, der der Menge an Essen, die du im Moment gerne essen würdest, am ehesten entspricht.

Überhaupt nichts.



Eine sehr große Menge.