Obesity: can environmental food odours make you lose control?
Investigation of implicit priming effects on reactivity and inhibitory control towards foods

Marine Mas\(^{*}\), Marie-Claude Brindisi\(^{1,2}\), Claire Chabanet\(^{1}\), Stéphanie Chambaron\(^{1}\)

\(^{1}\)Centre des Sciences du Goût et de l’Alimentation, AgroSup Dijon, CNRS, INRAE, Université Bourgogne Franche-Comté, Dijon, France

\(^{2}\)Department of Diabetes and Clinical Nutrition, Centre Hospitalier Universitaire de Dijon, Dijon, France

* Corresponding author

E-mail: marine.mas@inrae.fr (MM)
Abstract (150 mots max)

The food environment can interact with cognitive processing and influence eating behaviour. Our objective was to characterize the impact of implicit olfactory priming on inhibitory control towards food, in groups with different weight status. Ninety-two adults completed the Food Inhibition Task: they had to detect target stimuli and ignore distractor stimuli while primed with non-attentively perceived odours. We measured reactivity and inhibitory control towards food pictures. In all participants, food pictures were detected more quickly and induced more disinhibition than neutral pictures. Only individuals with obesity were slower to detect foods when primed with a high energy-dense food odour than in control conditions. Common mechanisms were observed for the top-down processing of foods, regardless of weight status, but we observed specific priming effects related to weight status on bottom-up processes. Our results contribute to current knowledge regarding the relationship between cognitive load and food reactivity in an obesogenic environment.

INTRODUCTION

Studies have shown that individuals with obesity tend to have poorer inhibition capacities when it comes to food (1,2). In our food-abundant environment, this tendency inevitably leads to overeating, i.e. eating more than one’s physiological needs. This type of impaired inhibition can naturally lead to weight gain and even to obesity.

Environmental factors and bottom-up cognitive processing of foods.

The combination of excess calorie intake and a lack of caloric expenditure results in weight excess, overweight, and often obesity. This phenomenon is related to our environment: for most people in modern day society, food is abundant and easily accessible. Moreover, daily exercise is now a choice rather than an obligation. Scientists have therefore introduced the idea of the “obesogenic” environment, inferring that the influence of the environment is a key feature of the current obesity epidemic. According to Swinburn et al., “the physiology of energy balance is proximally determined by behaviours and distally by environments” (3). However, it is still difficult to explain how, why, and under which conditions the obesogenic environment can influence food choices on an information-processing level. Indeed, obesity has a multifactorial aetiology, and researchers have highlighted genetic, metabolic, social, psychological, cognitive, and environmental factors that contribute to the maintenance and development of obesity (3–6).

People are, by nature, attracted to food (7). Food stimuli seem to be more salient and to bias individuals’ attention in an exogenous manner (8). Such processes are referred to as “bottom-up” or stimulus-driven
processes, meaning that data from the environment drive our perception of stimuli. In a previous study, we highlighted the differing influence of insidious environmental olfactory food cues on the stimulus-driven cognitive processing of food pictures in individuals with different weight statuses (9). Indeed, when primed with non-attentively perceived odours signalling high energy-dense (HED) foods, participants with obesity tended to show greater orienting attentional biases \(i.e.\) the individual tendency to automatically orient one’s attention toward specific stimuli\) toward food pictures than when primed with non-attentively perceived odours signalling low energy-dense (LED) foods. This tendency was reversed for individuals with normal weight status, and different from the pattern of attentional orienting toward foods in individuals with overweight. In sum, implicit olfactory priming with food odours can either increase or decrease the perceptual salience of foods in different ways according to weight status by influencing the cognitive processing of such stimuli, and, hypothetically, further food choices.

These results highlight that, even if the exogenous attentional processing of foods seems to be similar all along the weight status continuum (9,10), there might be some cognitive vulnerability to HED food cues among individuals with higher weight statuses. Food cues may thus create a context that facilitates consumption of HED foods, and, within this context, those with a higher weight status could be influenced on a cognitive level. In our obesogenic environment, this vulnerability might contribute to the maintenance of weight excess by influencing food choices in individuals with obesity. Since our previous study focused exclusively on bottom-up processing, we consequently wondered whether olfactory priming with food cues could also have differentiated effects on goal-directed or “top-down” processes such as inhibitory control. This contribution would help us to clarify the links between the processing of food cues and food-related decision-making.

**Inhibitory control and its implications in the decisional process**

Inhibitory control is part of the executive functions, which are cognitive functions responsible for transmission between endogenous (mood, thoughts, sensations) and exogenous (environmental) events. Executive functions are involved in problem-solving and decision-making, which are necessary for the execution of goal-directed actions (11–13). Inhibitory control is a remarkable executive function that makes it possible for us to stay consistent with our behavioural intentions on attentional, cognitive and behavioural levels. There are three defined components of inhibitory control: (a) attentional control, allowing us to focus our attention on stimuli of interest and to avoid wasting mental resources on non-pertinent stimuli, (b) cognitive inhibition, namely the ability to resist proactive interference from prepotent stimuli in information processing, and (c) self-control, the ability to control one’s behaviour instead of acting impulsively (14). Each of these three components is involved
in a specific type of stimulus processing, which helps individuals to adapt to changing situations by enabling voluntary behaviours and inhibiting possible perturbations.

The hypothesis of a deficit in inhibitory control among individuals with obesity has been widely explored by researchers in an effort to explain why weight loss remains difficult, and to find innovative opportunities to reduce obesity (15). Such a deficit could lead to a decrease in the ability to pursue goal-directed behaviour, such as maintaining a healthy lifestyle. In this line of study, some authors showed that individuals with obesity have lower inhibitory control, (2,12,16,17) while other studies found no differences related to weight status (18,19).

No consensus has been found so far, potentially due to the diversity of methodologies (20). Additionally, other variables (such as frequent comorbidities in obesity, or specific eating styles) are susceptible to modulate inhibitory control capacities beyond weight status (19,21–23). Applied to food-choice behaviour, low inhibitory control is related to excessive consumption of HED foods, especially in contexts of consumption facilitation (24,25). Moreover, in an obesogenic context where there is an overload of information, few cognitive resources remain available to inhibit one’s attention, thoughts and behaviours. This may guide individuals toward default choices, namely palatable but unhealthy foods (7).

Some sensory cues create a context of facilitation by guiding the individual toward consumption (26) while offering opportunities to succumb to the temptation of palatable foods. Among these cues, food odours have a strong influence; they signal the availability of foods without necessarily raising awareness (27,28). Indeed, we found that non-attentively-primed olfactory HED food cues led individuals with obesity to direct their attention more toward foods (9). These observations led us to question whether olfactory priming could facilitate a deficit of inhibitory control toward foods. Previously, we demonstrated the differentiated effects of non-attentively perceived food cues on attentional biases (implicit measure of a bottom-up process) depending on weight status; here we aimed to measure the same effects on inhibitory control toward foods. To our knowledge, our study is the first to explore the relationship between a context of facilitation and inhibitory control toward foods (high and low energy-dense foods vs. neutral non-food stimuli) in male and female adults of various weight statuses (normal-weight, overweight, obese) and with no eating disorder.

The first aim of this study was to characterize inhibitory control toward food pictures in individuals with normal-weight, overweight and obesity. Our second aim was to study how olfactory priming affected top-down processes in individuals with various weight statuses, by measuring their inhibitory control capacities when non-attentively exposed to olfactory food cues compared to non-exposed. Our main hypothesis was that, compared
with neutral stimuli (objects), individuals facing food stimuli would have decreased inhibitory control, especially
when the food stimuli were HED. We expected that this deficit would be increased in individuals with higher
weight status, especially when non-attentively primed with olfactory food cues.

MATERIAL & METHODS

Participants.

124 adults aged from 20 to 60 years old were recruited and grouped according to their body mass index (BMI, kg/m², (29,30); 38 individuals with obesity (OB), 45 individuals with overweight (OW), and 41 individuals with normal weight (NW). The study was conducted in accordance with the Declaration of Helsinki and was approved by the Comité d’Evaluation Ethique de l’Inserm (CEEI, File number IRB 0000388817-417–Project number X 467). This research study adhered to all applicable institutional and governmental regulations concerning the ethical use of human volunteers.

Exclusion criteria were: age under 18 or over 60 years old, diagnosis of a chronic disease (such as type II diabetes, cardiovascular disease, or hypertension), regular medical treatment causing cognitive impairment (antipsychotic, anxiolytic, or antidepressant), olfactory impairment (anosmia, hyposmia, chronic sinusitis) and a history of bariatric surgery. Additionally, participants who were sick (cold or flu symptoms) at the time of the experiment were asked to postpone their appointment with the laboratory in order to ensure that they did not have an impaired sense of smell during the session.

Written informed consent was obtained from participants before their participation, though they came to the session under a false pretense (i.e., to participate to a computerized experiment on picture categorization). At the end of the experiment, participants were entirely debriefed and told the real purpose of the study. In return for their participation, the participants received a €10 voucher at the end of the session.

Measurements

An adaptation of the Affective Shifting Task: The Food Inhibition Task (F.I.T)

In order to measure inhibition toward foods, we adapted the affective shifting task (31,32) modified by Mobbs, Iglesias, Golay, & Van der Linden, 2011. This task is based on the Go/No-go paradigm (for a review, see Gomez, Ratcliff, & Perea, 2007). In this task, participants must both (a) detect target stimuli (go trials) by pressing the spacebar on a computer keyboard and (b) withhold their response to distracter stimuli (no-go trials). Participants were instructed to respond as fast and as accurately as they could. During the task, two instruction
types alternated: target stimuli were either food stimuli (“food set”, HED or LED food pictures) or objects
(“object set”, tools or household objects). Stimuli were selected from FoodPics (35) and rigorously paired in
terms of perceptual and consumer properties according to the procedure used in (9).

The task comprised 3 blocks of 112 trials each. Each block comprised 4 sets (order: food-object-food-object) of
28 trials each (28% HED trials, 28% LED trials and 44% objects trial, in a pseudo-random order without three
pictures of the same type appearing consecutively). See fig 1. for details. Each set began with oral instructions
about the target stimuli (food or object) given through a headset, then a fixation cross appeared for 500ms at the
centre of a black screen. Subsequently, pictures appeared one by one for 500ms, with an inter-stimuli-interval of
900ms consisting of a white fixation cross on a black screen that participants were instructed to fixate.

Commission and omission errors were signalled to the participant by a short sound conveyed by the headset.
Blocks were separated by 1-minute pauses during which experimenters took the headsets off participants and
invited them to relax. Prior to measurements, participants completed a brief training session comprising 4 sets of
10 trials in order to familiarize them with the task. They were asked to rate their hunger level on a 10-point
Likert scale before and after the Food Inhibition Task.

For each subject and for each experimental trial, we collected the reaction times (RT), the presence of a
commission error (detecting a distractor stimulus) and the presence of an omission error (not detecting a target
stimulus). Reaction times corresponded to the time between the appearance of the stimulus on screen and the
moment the participant pressed the space bar to detect it (0 to 500ms). Commission errors corresponded to
situations in the no-go trials in which the participant pressed the space bar, indicating a lack of response
inhibition to distractor stimuli. Omission errors corresponded to go-trials for which the participant did not press
the space bar to detect the target stimulus, indicating a lack of attention to the given stimulus (32,36).

**Priming.**

In order to non-attentively expose participants to olfactory food cues, we used the olfactory priming paradigm
developed by Marty & al. in 2017 (9,37). In this paradigm, participants perform three identical blocks of a
computerized task (here, the Food Inhibition Task) while wearing a headset with a microphone. The headsets are
used to provide instructions to participants, and, unbeknownst to participants, the microphones are used as
brackets for odorized microphone foams. Task blocks are separated by short pauses during which experimenters
discreetly switch the headsets in order to non-attentively expose participants to different olfactory food cues
through the odorized foams of the headset’s microphone. Our study had three different olfactory priming
conditions: odour signalling HED foods (fatty sweet pound cake odour), odour signalling LED foods (fruity pear odour) and control condition in which the foam was not odorized.

**Fig. 1.** Composition of blocks, sets and trials of the Food Inhibition Task (FIT). F = food, O = object.

Participants come to the laboratory under a false pretence (here, taking part in a study on picture categorization) so they do not guess the presence of olfactory cues during the session. At the end of the three blocks of the task, participants complete an investigation questionnaire in which they have to guess the aim of the experiment and indicate whether they noticed anything particular during the task that could have influenced their performance. Participants mentioning odours or headsets in this questionnaire are excluded from the study. This step ensures that no odour or headset change was perceived, which allows the implicit quality of the priming (9).

**Global Cognitive Capacities**

In order to measure the global inhibition performance in our sample, participants performed standardized tests, namely the Go/No-go and flexibility subtests of the computerized Test of Attentional Performance (TAP) neuropsychological test battery (38).

The Go/no-Go subtest explores response inhibition through a simple task in which the participant must detect target stimuli “X” and withhold a response when presented with distractor stimuli “+”. The flexibility subtest assesses shifting abilities in mental flexibility. In this subtest, two stimuli appear, one on the left and one on the right side of the screen. One of the stimuli is round while the other is an angular shape. The participant must detect whether the round shape is on the left or on the right side of the screen by pressing the corresponding key with the dominant hand through several trials. Participants were given a brief training before each subtest. The assessment began systematically with the Go/No-go subtest.

**Session**

Participants came to the laboratory at 12 p.m. They were instructed to refrain from eating, drinking anything except water, wearing scented cosmetics, smoking or chewing gum for 3 hours prior to the session. They began the session with the three blocks of the Food Inhibition Task (FIT), followed by the investigation questionnaire and a hunger rating on a 10-point Likert scale. Then, they were administered the two subtests of the TAP (38), namely Go/No-go and Flexibility, in order to check their global cognitive performance. Afterwards, participants filled a computerized version of the Questionnaire for Eating Disorder Diagnosis – Q-EDD (39,40) in order to
identify and exclude participants with potential eating disorders. Finally, participants passed the European Test for Olfactory Capacities – ETOC (41) in order to ensure that they could correctly detect and identify odours. At the end of the session, the weight and height of each participant were measured, individually, in a separate room by the experimenter.

**RESULTS**

*Sample characteristics*

At the end of the tests, 32 participants were excluded from the sample (see details in Fig. 2). Indeed, 25 declared that they had smelled an odour during the session, meaning that the priming was not implicit for those participants. Five participants were screened as disordered eaters according to the Q-EDD, and two more participants were excluded because their answers to the ETOC indicated that they had low olfactory capacities (hyposmia or anosmia).

Finally, 92 participants remained eligible for analysis: 31 participants with normal weight, 33 participants with overweight and 28 participants with obesity (according to their BMI measurements).

When comparing the sociodemographic data of the 3 BMI groups, ANOVA test were used for quantitative variables and Chi2 tests were used for categorical variables (sex ratio, educational level). No significant differences were observed in age, sex ratio, educational level, hunger level before the session or variations in hunger during the session. To measure the change in hunger, the hunger level before the session was subtracted from hunger level after session (both had been rated on a 10-point Likert scale before and after the FIT).

For the scores on the TAP sub-tests, performances are indicated in T-scores for the number of errors (reflective of inhibitory control capacities) in the Go/No-go subtest. For the flexibility subtest, a global performance index (GPI, (38)) was calculated for each participant, based on the T-scores for reaction times and the T-scores concerning the number of errors for each participant (0.707 * (T_{Median RT} + T_{Number of errors} – 100). If the GPI is positive (>0), individual performance is interpreted as being above the mean performance of the reference sample (normative data), while if it is negative (< 0), it is interpreted as being lower than the average performance of the reference sample (normative data). T-scores are normalized scores based on the percentile of...
scores in a reference population (mean=50, SD=10, (38). Average performance is comprised between 43 and 57 (corresponding to the 25 and 75 percentile, respectively) and T-scores are adjusted on sex, gender and educational level. No significant difference in global inhibition (Go/No-go) and flexibility were found between weight status groups. Details of sociodemographic characteristics are displayed in Tab 1.

| Weight status | Normal-weight (NW) | Overweight (OW) | Obesity (O) |
|---------------|--------------------|----------------|-------------|
| n             | 31 (34%)           | 33 (36%)       | 28 (30%)    |
| Age (y): p=0.73 | 43.41 (11.07)     | 43.96 (8.69)   | 41.89 (11.30) |
| BMI (kg/m²): p<0.001 | 21.95a (1.77)     | 27.35b (1.40)  | 36.43c (5.75)  |
| Hunger level before session (1-10): p=0.18 | 6.33 (2.14)       | 5.45 (2.86)    | 5.07 (2.97)    |
| Variation in hunger: p=0.65 | 0.45 (0.75)       | 0.73 (1.40)    | 0.43 (1.82)    |
| TAP Go/No-go subtest – (T-score): p=0.18 | 48.30 (6.72)      | 45.90 (7.66)   | 44.40 (9.28)   |
| TAP Flexibility subtest – (GPI): p=0.92 | 1.32 (6.17)       | 1.98 (8.74)    | 1.27 (7.6)     |

| Sex: p=0.67 | n | % | n | % | n | % |
|-------------|---|---|---|---|---|---|
| Women       | 19 (61%) | 17 (52%) | 17 (61%) |
| Men         | 12 (39%) | 16 (48%) | 11 (39%) |

| Level of education: p=0.89 | n | % | n | % | n | % |
|---------------------------|---|---|---|---|---|---|
| < 14 years                | 16 (52%) | 17 (52%) | 16 (57%) |
| > 14 years                | 15 (48%) | 16 (48%) | 12 (43%) |

Tab. 1: Participant characteristics. Quantitative variables expressed as mean (SD)

a, b, c Superscript letters are associated with values (means or numbers), same letters indicating that the difference between values is not significant. P values indicate the significance of the weight status effect. GPI = Global Performance Index.
Data preparation

Instruction shifts modulate task difficulty (42), so we created a two-level covariate to account for the cognitive load generated by the change of instructions between tasks (food-object-food-object). The two levels were “CL+” for the first 14 trials of each set and “CL−” for the second 14 trials of each set (total of 28 trials). The CL+ condition refers to a situation in which the individual becomes familiar with new instructions (detecting foods in food sets and detecting objects in object sets) and the implementation of the instructions is automatized during the set. In the CL− condition, the individual is already familiar with the instructions, implicating a lower cognitive load. This two-level covariate was integrated in further linear mixed models that are described below.

During data preparation, reaction times (RTs) inferior to 150ms were excluded from analysis because they reflect stimulus anticipation (33). In order to analyse global reaction speed, we summarized, for each participant, RTs for which the spacebar was pressed (go trials without omissions and no-go trials with errors) by using the median per condition (olfactory prime type x stimulus type x cognitive load). For errors, we calculated the proportion of errors on no-go trials for each participant in each condition (olfactory prime type x stimulus type x cognitive load). For omission errors, the proportion of omissions among the go trials per condition was calculated for each participant.

For each dependent variable (RTs, proportion of commission errors, proportion of omission errors), we estimated a linear mixed model. The model initially involved four fixed factors (weight status group x stimulus type x olfactory prime type x cognitive load), all interactions, and the individual as a random factor. We then simplified the model by removing non-significant terms except if they were involved in a significant higher-order term.

Contrasts were used to interpret significant main effects and interactions.

Statistical analysis was performed with R.3.4.3 software (43) using linear mixed models (nlme package v. 3.1-131,(44) to explain reactivity to stimuli expressed in median RTs, inhibitory control deficit expressed in proportion of errors, and inattention expressed in proportion of omissions. Specific contrasts were subsequently tested using the contrast package (45,46). The significance threshold was set at 0.05.

Reaction times (global detection speed)

The main effect of the type of stimulus [F(2, 1553)=46.57, p<.0001], the interaction between weight status and olfactory prime type [F(4, 1553)= 3.13, p=0.014] and the interaction between weight status and cognitive load [F(2,1553)]=5.29, p=0.005] reached significance in the RT linear mixed model. Results are shown in Fig 3.
Regarding the main effect of stimulus type, individuals detected food pictures faster than object pictures [HED vs objects = -6.20ms (p<0.001), LED vs objects = -11.39ms (p<0.001)], and responded quicker to LED food pictures than HED food pictures [LED vs HED = -5.18ms, (p<0.001)].

Regarding the interaction between weight status and olfactory prime type, participants with obesity were slower to detect stimuli of all types when primed with a pound cake odour [OB, pound cake odour vs none=+5.30ms, (p=0.01) and, non-significantly, when primed with a pear odour [OB, pear vs. none=+3.54ms, (p=0.09)]. Participants with overweight were slower to detect stimuli when primed with a pound cake odour [OW, pear vs pound cake=+5.10ms (p=0.01) and non-significantly, when they were primed with a pear odour vs. no odour [OW, pear vs none=+3.6ms, (p=0.07)]. On the contrary, participants with normal weight showed no significant difference between RT when primed with a pound cake odour (p=0.58) or with a pear odour (p=0.30). Without priming, individuals with normal-weight were slower than individuals with obesity to detect stimuli (no odour, NW vs OB=+12.41ms, (p=0.03)).

When we looked at the interaction between weight status and cognitive load, only normal-weight individuals had different reaction times depending on cognitive load conditions. More specifically, they were slower when the cognitive load was higher [NW, CL+ vs CL-=+5.22ms, (p=0.002)]. In addition, in the higher cognitive load conditions, normal-weight participants tended to be slower than participants with overweight [CL+, NW vs. OW=+9.96ms, (p=0.06)] and obesity [CL+, NW vs. OB=+10.58ms, (p=0.06)]. However, these results only approached significance.

**Fig 3.** (left) RT by stimulus type, CTL=objects (control) pictures, HED=high energy-dense foods pictures, LED=low energy-dense foods pictures, averaged on olfactory prime type, cognitive load condition and weight status. Each bar is significantly different from the 2 others (p<.001). (right) RT by olfactory prime type and weight status (NW=Normal-weight, OW=overweight, OB=obesity), averaged on stimulus type and cognitive load condition. Predicted values and 95% confidence intervals.

**Proportion of commission errors**

Three terms of the commission errors linear mixed model reached significance: the main effect of stimulus type [F(2, 1559)=51.37, p<0.0001], the main effect of cognitive load condition [F(1,1559)=26.43, p<0.001] and the interaction between cognitive load and stimulus type [F(2, 1559)= 5.32, p=0.005]. Results are shown in Fig 4.
Concerning the effect of cognitive load, participants made 32.4% more commission errors in the CL+ condition than in the CL- condition. \([\text{CL+ vs. CL- } = +2.14 \text{ errors, p}<0.001]\).

Stimulus type effect was dependent on cognitive load condition. In both the high and low cognitive conditions, participants made on average 87.5% more commission errors when facing HED food stimuli than when facing objects \([\text{HED vs objects} = +3.92 \text{ errors, p}<0.0001]\). Participants also made 140.5% more commission errors when facing HED food stimuli than when facing LED food stimuli \([\text{HED vs. LED} = +4.89 \text{ errors, p}<0.0001]\). A slight difference in the amount of commission errors made was observed between LED food stimuli and objects, but it did not reach significance in the CL+ condition \([\text{CL+, LED vs. objects} = -0.9 \text{ errors, (NS, p}=0.058)\] ). Nevertheless, in the CL- condition, participants made 94.1% more commission errors for objects than for LED food stimuli \([\text{CL-, objects vs LED} = +2.08 \text{ errors, (p}=0.004)\] ).

Participants made more commission errors in CL+ conditions than in CL- conditions for food stimuli: 52.7% and 113% more commission errors were made in the CL+ condition for HED and LED food stimuli, respectively \([\text{HED, CL+ vs. CL- } = +3.58 \text{ errors, p}<0.001 ; \text{LED, CL+ vs. CL- } = +2.54 \text{ errors, p}<0.001]\). Participants did not make a significantly different proportion of commission errors between high and low cognitive load conditions when facing object stimuli \([\text{objects, CL+ vs. CL- } = +0.32 \text{ errors, p}=0.66]\).

In sum, HED food pictures induced more disinhibition than LED food and object pictures. The cognitive load modulated this disinhibition for food stimuli but not for neutral stimuli.

**Fig 4.** Proportion of commission errors by stimulus type and cognitive load condition averaged on olfactory prime type and weight status. CL+=high cognitive load condition, CL-=low cognitive load condition, CTL=objects (control) pictures, HED=high energy-dense food pictures, LED=low energy-dense food pictures. Predicted values and 95% confidence intervals.

**Proportion of omission errors**

Only two terms of the linear mixed model reached significance for the proportion of omission errors: main effect of type of stimulus \([F(2,1558)=91.18, p<0.0001]\) and interaction of weight status group x type of stimulus \([F(4,1558)=2.61, p=0.03]\).

Concerning the main effects of stimulus type, participants made 89.5% more omission errors when facing HED food stimuli than facing LED food stimuli \([\text{HED vs. LED} = +6.40 \text{ omissions errors, p}<0.0001]\). They also made
significantly fewer omission errors for food stimuli than for objects: 20.1% and 57.9% less errors were made for HED and LED food stimuli, respectively, in comparison with object stimuli [HED vs. objects= -3.43% omission errors, p<0.0001, LED vs. objects= -9.83%, p<0.0001].

When we focused on the interaction between weight status group and stimulus type, we found that NW participants made more omissions than OW participants when facing HED food stimuli, but this effect did not reach significance [HED, NW vs. OW= +4.62 omission errors, (p=0.05)]. No other effects approached significance. In sum, food pictures, especially HED foods, elicited more omission errors than neutral pictures in all participants.

**DISCUSSION**

Our objective was to characterize deficits in inhibitory control toward foods in different weight status groups (NW, OW, OB), and to assess the impact of implicit olfactory priming (pound cake, pear, control) on such processes.

**Global performance**

Global performance for inhibitory control was similar for all groups in our sample, as measured by the Go/no-Go subtest from the TAP, and in flexibility as measured with the flexibility subtest from the same battery. Contrary to previous findings (16,17,47–49), inhibitory control and mental flexibility capacities were similar regardless of weight status. In addition, the number of commission errors, omission errors and reaction times in the Food Inhibition Task revealed no significant differences according to weight status when participants were not primed with a non-attentively perceived food cue. This suggests that common processes in the detection of stimuli and inhibition capacities are not dependent on weight status.

In our experiment, all participants reacted more quickly to food pictures than to neutral pictures. This highlights that food stimuli undergoes faster processing, which is in line with previous literature (9,50–54). Indeed, food is essential for survival (i.e. a primary motivated goal of the individual) and has a rewarding quality, which are characteristics of a salient stimulus (55). So food stimuli appear to be processed more quickly, which explains the increased reactivity to foods in all individuals. In the literature focusing on the Go/no-Go paradigm, it has been suggested that short reaction times indicate an approach tendency (20,42). This supports the hypothesis that a person needs more cognitive resources to inhibit stimulus-driven approach tendencies as compared to more neutral stimuli (15,25,56). We can therefore state that this approach bias for foods of all kinds is a prepotent response in individuals, regardless of the type of food stimuli (HED or LED) or the perceiver’s weight status.
Moreover, the present study separated the approach bias for low energy-dense (LED) foods and for high energy-dense (HED) foods. Comparing RTs for high-calorie and low-calorie foods, suggested that longer RTs for HED foods indicated increased attention toward them. This relates to the fact that HED foods capture attention more forcefully than LED foods in the early stages of cognitive processing, which is consistent with our previous work on orienting attentional biases. Moreover, it seems that HED food stimuli tend to capture attentional focus for longer periods of time than LED food stimuli. This might be behaviourally reflected in reaction times, as highlighted by neuroimaging studies showing discriminative patterns of activity in the brain for high and low calorie food stimuli. In our experiment, individuals were faster to detect LED food stimuli than HED food stimuli. This finding may relate to the attentional dimension of inhibitory control, which could be impaired by the perception of HED food pictures.

HED food stimuli processing might initially be facilitated by the high perceptual saliency of high calorie foods. We suggest that over time, the detection of HED food stimuli is impaired by their capacity to attract the focus of attention (slowed disengagement), which slows behavioural responses. On the contrary, LED food stimuli processing might be facilitated by the earlier identification of fruit stimuli in our experiment. As food stimuli, LED stimuli are also salient. However, their processing is not impaired by the attentional approach bias elicited by the higher appetitive quality of HED food stimuli. This effect results in a decrease in reaction times for LED foods compared with HED foods, partly explaining why participants had shorter RT and fewer omission errors for LED food stimuli than for HED food stimuli in our experiment.

**Modulation of inhibitory control capacities toward food by cognitive load**

The high cognitive load condition induced slower reaction times and more commission errors for all participants facing all types of stimuli in each olfactory condition. This reflects the worse performance and higher mental effort required to complete the task and confirms that the first half of each set was more difficult, validating the cognitive load effect when the instructions are changed between two sets.

Participants made more commission errors in high cognitive load situations when faced with food stimuli. This was not the case for neutral stimuli, seeing as the proportion of errors for object pictures did not differ between the high cognitive load and the low cognitive load condition. This led us to conclude that cognitive load modulates inhibitory control, but only toward foods. The increase in mental effort that was required to process the instructions led participants to make significantly more impulsive detections, resulting in more commission errors. We can deduce that significant cognitive resources were needed for the integration and automatization of
the new instructions. In the meantime, the amount of cognitive resources needed to inhibit the approach tendency elicited by HED foods was increased by the higher cognitive load. There were thus not enough resources allocated to inhibit interferences from prepotent responses, triggering commission errors. Indeed, the cognitive load effect indicates that there is a cognitive deficit in inhibitory control prior to behavioural disinhibition, as indicated by commission errors. This result correlates with previous research investigating the role of cognitive load in inhibitory control (61) and showing that working memory load (resulting here from the new set of instructions) interacts heavily with inhibitory control (62).

Inhibitory control toward foods

Though we hypothesized that individuals with higher weight status would show less inhibitory control toward foods than lean individuals, it was not the case in our experiment. In fact, we found common patterns of inhibitory control toward food stimuli in individuals across the weight status spectrum.

In our experiment, participants made more commission errors when they were facing HED food stimuli. No difference was found in regard to weight status, which is congruent with part of the literature (63,64). This observation strongly suggests that the lack of inhibition toward foods is a common process for all individuals and it is also consistent with the idea that the rewarding quality of HED foods makes them more appealing (65–67), leading to an increased approach bias. The saliency of HED foods combined with the associated approach bias makes the detection of HED food stimuli a prepotent response for the individual. A prepotent response is cognitively more difficult to inhibit than other response options, which need to be inhibited in order to exhibit goal-congruent behaviour. This effect appears to be even stronger when cognitive load is high because individuals make significantly more commission errors toward HED food stimuli in this condition.

We found different patterns of inhibitory control toward HED and LED foods, indicating that the top-down processing of those stimuli is differentiated. In lower cognitive load conditions, individuals made fewer commission errors when facing LED food stimuli than when facing HED food or object stimuli. We can thus presume that fruits (LED foods) are processed faster than other stimuli. This assumption is supported by the work of Leleu et al., 2016 (68), who showed that fruit pictures elicited earlier event-related responses in the brain than other food types (vegetables, HED foods) during a food discrimination task.

Food stimuli are salient, which induces an approach bias that interferes with the initiation of goal-directed behaviour on a cognitive level, leading to cognitive and behavioural deficits in inhibitory control. This process occurs in individuals regardless of weight status, and its intensity seems to vary in function of food
characteristics (i.e. category and/or energy density). Moreover, the deficit in inhibitory control induced by food
stimuli is modulated by the cognitive load in working memory, which means that the more mental effort the
individual has to make while performing a task, the fewer resources are available to inhibit prepotent responses.
This phenomenon leads to more disinhibition, meaning that individuals may be more likely to eat more HED
foods when their cognitive load is heavier.

**Priming effects: why does implicit priming only impact bottom-up processes?**

In our study, we tested whether implicit priming with olfactory food cues would impact inhibitory control, a
decision-driven, or “top-down” process measured by the proportion of commission errors made by participants
in each olfactory condition. Unexpectedly, no priming effect was observed for commission errors, contrary to the
effects observed with the exact same olfactory priming paradigm used in a Visual Probe Task to measure
orienting attentional biases (a stimulus-driven, bottom-up process) (9). Because orienting attentional biases are
data-driven processes, sensory inputs are important determiners of behavioural response in such tasks (69).
Moreover, the Visual Probe Task needed less top-down cognitive effort than the Food Inhibition Task. Hoffman-
Hensel & al, 2017, who observed that cognitive effort altered the neural processing of food odours, found that
involvement in multiple tasks decreased participants’ perception of odour intensity (70). Moreover, olfaction has
been characterized as an implicit sense, which means that olfactory cues, even when non-attentively perceived,
may not be strong enough to be taken into account for top-down cognitive processes (27,28).

We focused on inhibitory control dictated by the changing instructions: attentional resources were thus
theoretically allocated to the pictorial stimuli which left 500ms to participants for: (a) identification of the
stimulus (b) decision-making about whether detecting it or not in line with the instructions of the current set (c)
behavioural response (inhibition or spacebar-pressing). Such processing implies more cognitive involvement in
the task than simply detecting a target on the right or left side of the screen (as in the Visual Probe Task).
Therefore, the Food Inhibition Task does not seem to leave enough resources for the participant to implicitly
integrate the perception of the odorants on the microphone foams within top-down cognitive processing of
information. Another type of less subtle but still implicitly perceived cues should be tested in order to observe
the effects we were expecting in this study.

**Differences in vulnerability to food cues in individuals with higher weight status**

Concerning global reaction times, we found some priming effects for individuals with overweight and obesity.
More specifically, individuals with obesity and with overweight were slower to detect all kinds of stimuli when
primed with a pound cake odour and a pear odour, respectively, regardless of the go/no-go instructions. In our study, the odour signalling HED or LED foods could have slowed the bottom-up processing of foods by adding another element to take into account in the detection of stimuli. This indicates that olfactory food cues were implicated in the detection process by slowing RT in individuals of higher weight status. We consequently hypothesize that priming effects only influence the bottom-up processing of food cues.

The result of the priming effect seen here is congruent with the results of our previous study on attentional biases. In this earlier study we found that implicit priming of olfactory food cues had differentiated effects: individuals with obesity were more vulnerable to a non-attentively perceived pound cake odour (9). For individuals with overweight in the present study, the effect of the pear odour is consistent with a study by Marty & al (37) in which olfactory pear and pound cake primes had differentiated effects when they were non-attentively perceived by children with overweight. Indeed, these children were more prone to choose fruit in a forced-choice task when they were non-attentively primed with a pear odour. The authors explained this result by hypothesizing that individuals with overweight might be more confronted to the idea of “dieting” in their daily lives, and so this concept might be more easily activated by a non-attentively perceived odour signalling a LED food. Future research could focus on understanding why odours signalling LED foods seem to affect individuals with overweight while odours signalling HED foods affect individuals with obesity. These food types may differentially activate certain concepts and mental representations in individuals according to weight status. Future contributions to the cognitive and psychological characterization of different subtypes of overweight and obesity could lead to a better understanding of environmental effects on food choices in obesity.

LIMITATIONS

As discussed above, our study presents some limitations. First, we question the use of fruit stimuli as LED food stimuli. Indeed, fruits are frequently consumed in non-processed and raw forms, making it easier to distinguish them from objects than HED foods in the earliest stages of feature perception. Some empirical data from electroencephalography demonstrated that fruits do indeed undergo earlier processing. The pattern of evoked potentials (EPs) for the fruity quality of food stimuli seems distinct from the patterns of EPs observed for sweetness/saltiness and low/high energetic value (68). Moreover, there is less diversity in the presentation of fruit in everyday life when compared with sweet HED foods (chocolate bars, cakes and pastries), which come in a variety of forms. In terms of perception, the distinction between raw and transformed food goes beyond the calorie content (71). We hypothesize that identifying pictures of fruit over a short time during a single
presentation might thus be facilitated because fruits are well-known and belong to a universal category (72).

There are limited options in the pairing of fruits to comparable HED foods because it is difficult to find sweet calorie-dense foods that are not processed and that belong to a universal category. In our study, we only used sweet stimuli for odour-congruency and literature fidelity reasons, but this remark may or may not refer to vegetables, which are also consumed raw and non-processed, but do not benefit from early perception facilitation (68). There is a need to find pictorial LED stimuli that fit HED stimuli in visual and hedonic properties, but also in their intrinsic features such as degree of processing and distance from categorical prototype.

Several studies have observed interesting priming effects with the pear and pound cake odour, which are odorant mixtures (9,37,73). These effects were observed in relation to weight status, which indicates the need to identify olfactory components that tap into specific (and unknown to date) mental representations contributing to weight-status specific responses. Concerning the implicit priming, we suggest that a context of more incentive facilitation (involving a less implicit sensory modality than olfaction, or in multi-modal priming) might have a stronger influence on top-down processing. However, we insist on using implicit priming to experimentally manipulate the effects of insidious cues from the environment in laboratory experiments seeing as non-attentively perceived cues appear to have a stronger effect on cognitive processing (9) and behaviour (26) than explicitly primed cues. In addition, they are more reflective of the influences of environmental cues which often occur out of the individual’s attentional focus (7).

Moreover, we suppose that the different stimuli types elicited different attentional control patterns, with HED food stimuli more likely to attract attention, thus impairing attentional control. Unfortunately, our experiment was not designed to identify the phenomenon of attentional control toward foods, and reaction times do not represent a pure measure of distinct attentional mechanisms (20). Such measures should be included in further experiments in order to refine our understanding of the role of the attentional functions in food stimuli processing, for instance by adding eye-tracking measurements into the experimental design, similar to the method tested by Doolan et al (74).

**PERSPECTIVES**

*Cognitive load in obesity*

In the Ironic Process Theory (75), the daily life stressors increase cognitive load, which modulates inhibitory control. These synergic effects tend to produce behaviours opposite to what was primarily intended by the individual. Considerable research has shown that individuals with obesity and overweight are more at risk of
exposure to daily life stressors: low income (76), anxiety (77), psychological health impairments (78), physical comorbidities (79), and discrimination and stigmatization in relation to body weight (80,81). Considering all these aspects leads us to suppose that individuals with obesity might be subject to higher cognitive loads during daily decision-making, which could alter their inhibitory control and consequently, produce goal-unrelated behaviours. In our study, individuals were experimentally confronted to the same amount of cognitive load, which did make it impossible to discriminate individual levels of inhibitory control toward foods according to weight status. We now suggest that variations in everyday cognitive load might explain some of the relationships between behaviourally reflected lack of inhibitory control facing foods and weight status that was identified in other studies. In future research, these relationships should be characterized in order to better understand overweight and obesity.

Implicit priming as a context of facilitation

Several studies focusing on inhibitory control manipulated the cognitive processing of food stimuli by creating a context of facilitation with priming (priming concepts of impulsivity (24) and unrestrained food consumption (25), which led to interesting results. Nevertheless, such priming was explicit and is therefore not reflective of incidental food cues from the environment, which was part of the objective of our study. Different forms of implicit priming could be used in future research in order to assess the effects of implicit food cues on inhibitory control or other top-down processes toward foods in a unimodal or multimodal manner. For instance, the combination of auditory and olfactory priming has already been suggested as a means to influence individual food choices (82). In future research, this type of multimodal priming could be used as an experimental context of facilitation in order to elicit a lack of inhibitory control for food intake.

CONCLUSION

Our study highlights common mechanisms relative to the top-down processing of foods, regardless of individual weight status. We demonstrated that an increase in cognitive load leads to more disinhibition. This research helps to clarify the relationship between cognitive load and reactivity to food. Future research should focus on weight status in relation to cognitive load in order to improve our understanding of unhealthy food choices in obesity. The specific priming effects of food cues by weight status were characterized in bottom-up processing, which opens a new path for research on mental representations activated by food cues among the weight status continuum. Moreover, because goal-directed cognitive processing relies on controlled treatment of information,
characterizing weight-status specific psychological and behavioural features might help us to recognize the link between priming, cognitive processing of food information, context, and weight status.

Acknowledgments

We would like to thank the society Psytest, for lending us the five TAP versions, and especially Mr Benjamin Steves for his informative help about the material. We also would like to thank Jacques Maratray for developing the Food Inhibition Task and Suzanne Rankin for English proofreading. We also thank the Chemosens platform for their help with participants’ recruitment, as well as Maya Filhon for her technical help during experimental sessions.
REFERENCES

1. Batterink L, Yokum S, Stice E. Body mass correlates inversely with inhibitory control in response to food among adolescent girls: an fMRI study. NeuroImage. 1 oct 2010;52(4):1696-703.

2. Houben K, Nederkoorn C, Jansen A. Eating on impulse: The relation between overweight and food-specific inhibitory control. Obesity. 2014;22(5):E6-8.

3. Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, et al. The global obesity pandemic: shaped by global drivers and local environments. The Lancet. 27 août 2011;378(9793):804-14.

4. Glanz K, Sallis JF, Saelens BE, Frank LD. Healthy Nutrition Environments: Concepts and Measures. Am J Health Promot. 1 mai 2005;19(5):330-3.

5. Paquet C, de Montigny L, Labban A, Buckeridge D, Ma Y, Arora N, et al. The moderating role of food cue sensitivity in the behavioral response of children to their neighborhood food environment: a cross-sectional study. Int J Behav Nutr Phys Act. 5 juill 2017;14(1):86.

6. Townshend T, Lake A. Obesogenic environments: current evidence of the built and food environments. Perspect Public Health. janv 2017;137(1):38-44.

7. Cohen DA. Neurophysiological pathways to obesity: below awareness and beyond individual control. Diabetes. juill 2008;57(7):1768-73.

8. Manohar SG, Husain M. Attention as foraging for information and value. Front Hum Neurosci. 2013;7:711.

9. Mas M, Brindisi M-C, Chabanet C, Nicklaus S, Chambaron S. Weight Status and Attentional Biases Toward Foods: Impact of Implicit Olfactory Priming. Front Psychol [Internet]. 2019 [cité 9 août 2019];10. Disponible sur: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01789/full

10. Ahern AL, Field M, Yokum S, Bohon C, Stice E. Relation of dietary restraint scores to cognitive biases and reward sensitivity. Appetite. 1 août 2010;55(1):61-8.

11. Barkley RA. Executive Functions: What They Are, How They Work, and Why They Evolved. Guilford Press; 2012. 258 p.

12. Cserjési R, Luminet O, Poncelet A-S, Lénárd L. Altered executive function in obesity. Exploration of the role of affective states on cognitive abilities. Appetite. avr 2009;52(2):535-9.

13. Friedman NP, Miyake A. The relations among inhibition and interference control functions: a latent-variable analysis. J Exp Psychol Gen. mars 2004;133(1):101-35.

14. Diamond A. Executive Functions. Annu Rev Psychol. 2013;64(1):135-68.

15. Appelhans BM. Neurobehavioral Inhibition of Reward-driven Feeding: Implications for Dieting and Obesity. Obesity. 2009;17(4):640-7.

16. Boeka AG, Lokken KL. Neuropsychological performance of a clinical sample of extremely obese individuals. Arch Clin Neuropsychol. 1 juill 2008;23(4):467-74.

17. Fagundo AB, de la Torre R, Jiménez-Murcia S, Agüera Z, Granero R, Tárrega S, et al. Executive functions profile in extreme eating/weight conditions: From anorexia nervosa to obesity. PLoS ONE. 2012;7(8).

18. Nederkoorn C, Smulders FTY, Havermans RC, Roefs A, Jansen A. Impulsivity in obese women. Appetite. 1 sept 2006;47(2):253-6.
19. Prickett C, Brennan L, Stolwyk R. Examining the relationship between obesity and cognitive function: A systematic literature review. Obes Res Clin Pract. 1 mars 2015;9(2):93-113.

20. Meule A, Lutz APC, Krawietz V, Stützer J, Vögele C, Kübler A. Food-cue affected motor response inhibition and self-reported dieting success: a pictorial affective shifting task. Front Psychol [Internet]. 13 mars 2014 [cité 24 oct 2019];5. Disponible sur: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3952046/

21. Kulendran M, Vlaev I, Sugden C, King D, Ashrafian H, Gately P, et al. Neuropsychological assessment as a predictor of weight loss in obese adolescents. Int J Obes. avr 2014;38(4):507-12.

22. Meule A, Kübler A. Double trouble. Trait food craving and impulsivity interactively predict food-cue affected behavioral inhibition. Appetite. 1 août 2014;79:174-82.

23. Price M, Lee M, Higgs S. Food-specific response inhibition, dietary restraint and snack intake in lean and overweight/obese adults: a moderated-mediation model. Int J Obes 2005. mai 2016;40(5):877-82.

24. Guerrieri R, Nederkoorn C, Jansen A. Disinhibition is easier learned than inhibition. The effects of (dis)inhibition training on food intake. Appetite. août 2012;59(1):96-9.

25. Hall PA. Executive control resources and frequency of fatty food consumption: Findings from an age-stratified community sample. Health Psychol. 2012;31(2):235-41.

26. Marteau TM, Hollands GJ, Fletcher PC. Changing human behavior to prevent disease: the importance of targeting automatic processes. Science. 21 sept 2012;337(6101):1492-5.

27. Köster EP. The Specific Characteristics of the Sense of Smell. In: Rouby C, Schaal B, Dubois D, Gervais R, Holley A, éditeurs. Olfaction, Taste, and Cognition. 1 edition. New York: Cambridge University Press; 2002.

28. Smeets MAM, Dijksterhuis GB. Smelly primes – when olfactory primes do or do not work. Front Psychol [Internet]. 12 févr 2014 [cité 6 déc 2019];5. Disponible sur: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3921890/

29. Komaroff M. For Researchers on Obesity: Historical Review of Extra Body Weight Definitions [Internet]. Journal of Obesity. 2016 [cité 13 sept 2018]. Disponible sur: https://www.hindawi.com/journals/jobe/2016/2460285/

30. Nuttall FQ. Body Mass Index. Nutr Today. mai 2015;50(3):117-28.

31. Dias R, Robbins TW, Roberts AC. Dissociation in prefrontal cortex of affective and attentional shifts. Nature. mars 1996;380(6569):69-72.

32. Murphy FC, Sahakian BJ, Rubinsztein JS, Michael A, Rogers RD, Robbins TW, et al. Emotional bias and inhibitory control processes in mania and depression. Psychol Med. nov 1999;29(6):1307-21.

33. Mobbs O, Iglesias K, Golay A, Van der Linden M. Cognitive deficits in obese persons with and without binge eating disorder. Investigation using a mental flexibility task. Appetite. août 2011;57(1):263-71.

34. Gomez P, Ratcliff R, Perea M. A Model of the Go/No-Go Task. J Exp Psychol Gen. août 2007;136(3):389-413.

35. Blechert J, Lender A, Polk S, Busch NA, Ohla K. Food-Pics_Extended—An Image Database for Experimental Research on Eating and Appetite: Additional Images, Normative Ratings and an Updated Review. Front Psychol [Internet]. 2019 [cité 14 nov 2019];10. Disponible sur: https://www froniersin.org/articles/10.3389/fpsyg.2019.00307/full

36. Bezdjian S, Baker LA, Lozano DI, Raine A. Assessing inattention and impulsivity in children during the Go/NoGo task. Br J Dev Psychol. 1 juin 2009;27(2):365-83.
37. Marty L, Bentivegna H, Nicklaus S, Monnery-Patris S, Chambaron S. Non-Conscious Effect of Food Odors on Children’s Food Choices Varies by Weight Status. Front Nutr. 2017;4:16.

38. Zimmermann P, Fimm B. Tests d’Évaluation de l’Attention (TAP) - Version 2.3.1. Herzogenrath: Psytest.; 2010.

39. Callahan S, Rousseau A, Knotter A, Bru V, Danel M, Cueto C, et al. [Diagnosing eating disorders: presentation of a new diagnostic test and an initial epidemiological study of eating disorders in adolescents]. L’Encephale. 2003;29(3 Pt 1):239-47.

40. Mintz LB, O’Halloran MS, Mulholland AM, Schneider PA. Questionnaire for Eating Disorder Diagnoses: Reliability and validity of operationalizing DSM—IV criteria into a self-report format. J Couns Psychol. 1997;44(1):63-79.

41. Thomas-Danguin T, Roubey C, Sicard G, Vigouroux M, Farget V, Johanson A, et al. [Diagnosing eating disorders: presentation of a new diagnostic test and an initial epidemiological study of eating disorders in adolescents]. L’Encephale. 2003;29(3 Pt 1):239-47.

42. Meule A. Reporting and Interpreting Task Performance in Go/No-Go Affective Shifting Tasks. Front Psychol [Internet]. 9 mai 2017 [cité 24 oct 2019];8. Disponible sur: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5422529/

43. R Development Core Team. R: A Language and Environment for Statistical Computing [Internet]. Vienna, Austria: R Foundation for Statistical Computing; 2008. Disponible sur: http://www.r-project.org%

44. Pinheiro J, Bates D. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-137 [Internet]. R core team; 2018 [cité 21 août 2018]. Disponible sur: https://CRAN.R-project.org/package=nlme

45. Chambers JM, Hastie T. Statistical Models in S. Wadsworth & Brooks/Cole Advanced Books & Software; 1992. 630 p.

46. Kuhn M. contrast: A Collection of Contrast Methods [Internet]. 2016. Disponible sur: https://CRAN.R-project.org/package=contrast

47. Fergenbaum JH, Bruce S, Lou W, Hanley AJG, Greenwood C, Young TK. Obesity and Lowered Cognitive Performance in a Canadian First Nations Population. Obesity. 2009;17(10):1957-63.

48. Meo SA, Altuwaym AA, Alfalilj RM, Alduraibi KA, Alhamoudi AM, Alghamdi SM, et al. Effect of Obesity on Cognitive Function among School Adolescents: A Cross-Sectional Study. Obes Facts. 2019;12(2):150-6.

49. Prickett C, Stolwyk R, O’Brien P, Brennan L. Neuropsychological Functioning in Mid-life Treatment-Seeking Adults with Obesity: a Cross-sectional Study. Obes Surg. 1 févr 2018;28(2):532-40.

50. de Oca BM, Black AA. Bullets versus burgers: is it threat or relevance that captures attention? Am J Psycho. 2013;126(3):287-300.

51. Junghans AF, Evers C, Ridder DTDD. Eat Me If You Can: Cognitive Mechanisms Underlying the Distance Effect. PLOS ONE. 18 déc 2013;8(12):e84643.

52. Nummenmaa L, Hietanen JK, Calvo MG, Hyönnä J. Food Catches the Eye but Not for Everyone: A BMI-Contingent Attentional Bias in Rapid Detection of Nutriments. PLOS ONE. 16 mai 2011;6(5):e19215.

53. Sawada R, Sato W, Toichi M, Fushiki T. Fat Content Modulates Rapid Detection of Food: A Visual Search Study Using Fast Food and Japanese Diet. Front Psychol [Internet]. 22 juin 2017 [cité 1 oct 2019];8. Disponible sur: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5479904/

54. Teslovich T, Freidl EK, Kostro K, Weigel J, Davidow JY, Riddle MC, et al. Probing behavioral responses to food: development of a food-specific go/no-go task. Psychiatry Res. 30 sept 2014;219(1):166-70.
55. Munneke J, Belopolsky AV, Theeuwes J. Distractors associated with reward break through the focus of attention. Atten Percept Psychophys. 2016;78(7):2213-25.

56. Carbine KA, Christensen E, LeCheminant JD, Bailey BW, Tucker LA, Larson MJ. Testing food-related inhibitory control to high- and low-calorie food stimuli: Electrophysiological responses to high-calorie food stimuli predict calorie and carbohydrate intake. Psychophysiology. 1 juill 2017;54(7):982-97.

57. Frank S, Laharnar N, Kullmann S, Veit R, Canova C, Hegner YL, et al. Processing of food pictures: Influence of hunger, gender and calorie content. Brain Res. 2 sept 2010;1350:159-66.

58. Smeets E, Roefs A, van Furth E, Jansen A. Attentional bias for body and food in eating disorders: Increased distraction, speeded detection, or both? Behav Res Ther. 1 févr 2008;46(2):229-38.

59. Wilson C, Wallis DJ. Attentional Bias and Slowed Disengagement from Food and Threat Stimuli in Restrained Eaters Using a Modified Stroop Task. Cogn Ther Res. 1 févr 2013;37(1):127-38.

60. Paas F, Renkl A, Sweller J. Cognitive Load Theory and Instructional Design: Recent Developments. Educ Psychol. 1 mars 2003;38(1):1-4.

61. Kohane IS, Franks PW, Szilagyi PG. Information technology, computing, and health care. Arch Intern Med. 1 févr 2003;163(3):277-82.

62. Tiego J, Testa R, Bellgrove MA, Pantelis C, Whittle S. A Hierarchical Model of Inhibitory Control. Front Psychol [Internet]. 2 août 2018 [cité 14 nov 2019];9. Disponible sur: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6085548/

63. Deux N, Schlarb AA, Martin F, Holtmann M, Hebebrand J, Legenbauer T. Overweight in adolescent, psychiatric inpatients: A problem of general or food-specific impulsivity? Appetite. 01 2017;112:157-66.

64. Loebel S, Grosshans M, Korucuoglu O, Vollmert C, Vollstädt-Klein S, Schneider S, et al. Impairment of inhibitory control in response to food-associated cues and attentional bias of obese participants and normal-weight controls. Int J Obes. oct 2012;36(10):1334-9.

65. Alonso-Alonso M, Woods SC, Pelchat M, Grigson PS, Stice E, Faroqui S, et al. Food reward system: current perspectives and future research needs. Nutr Rev. mai 2015;73(5):296-307.

66. Berridge KC, Kringelbach ML. Pleasure systems in the brain. Neuron. 6 mai 2015;86(3):646-64.

67. Joyner MA, Kim S, Gearhardt AN. Investigating an Incentive-Sensitization Model of Eating Behavior: Impact of a Simulated Fast-Food Laboratory. Clin Psychol Sci. 1 nov 2017;5(6):1014-26.

68. Leleu A. Temporal dynamics of odor integration in the visual categorization of food. 7th European Conférence on Sensory and Consumer Research (EuroSense); 2016 sept 11; Dijon (France).

69. Posner MI. Orienting of attention. Q J Exp Psychol. 1 févr 1980;32(1):3-25.

70. Hoffmann-Hensel SM, Sijben R, Rodriguez-Raecke R, Freiherr J. Cognitive Load Alters Neuronal Processing of Food Odors. Chem Senses. 31 oct 2017;42(9):723-36.

71. Rumiati RI, Foroni F. We are what we eat: How food is represented in our mind/brain. Psychon Bull Rev. 1 aout 2016;23(4):1043-54.

72. Toet A, Kaneko D, de Kruijf I, Ushiaima S, van Schaik MG, Brouwer A-M, et al. CROCUFID: A Cross-Cultural Food Image Database for Research on Food Elicited Affective Responses. Front Psychol [Internet]. 2019 [cité 6 déc 2019];10. Disponible sur: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00058/full

73. Gaillet M, Sulmont-Rossé C, Issanchou S, Chabanet C, Chambaron S. Priming effects of an olfactory food cue on subsequent food-related behaviour. Food Qual Prefer. 1 déc 2013;30(2):274-81.
74. Doolan KJ, Breslin G, Hanna D, Murphy K, Gallagher AM. Visual attention to food cues in obesity: An eye-tracking study. Obesity. 2014;22(12):2501-7.

75. Wegner DM. Ironic processes of mental control. Psychol Rev. 1994;101(1):34-52.

76. Kim TJ, Knesebeck O von dem. Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis. BMJ Open [Internet]. 1 janv 2018 [cité 6 déc 2019];8(1). Disponible sur: https://bmjopen.bmj.com/content/8/1/e019862

77. Amiri S, Behnezhad S. Obesity and anxiety symptoms: a systematic review and meta-analysis. neuropsychiatrie. 1 juin 2019;33(2):72-89.

78. Sarwer DB, Polonsky HM. The Psychosocial Burden of Obesity. Endocrinol Metab Clin North Am. 1 sept 2016;45(3):677-88.

79. Djalalinia S, Qorbani M, Peykari N, Kelishadi R. Health impacts of Obesity. Pak J Med Sci. 2015;31(1):239-42.

80. Major B, Hunger JM, Bunyan DP, Miller CT. The ironic effects of weight stigma. J Exp Soc Psychol. 1 mars 2014;51:74-80.

81. Puhl R, Brownell KD. Bias, Discrimination, and Obesity. Obes Res. 2001;9(12):788-805.

82. Chambaron S, Chisin Q, Chabanet C, Issanchou S, Brand G. Impact of olfactory and auditory priming on the attraction to foods with high energy density. Appetite. 1 déc 2015;95:74-80.
336 trials per participant

Training: 4 sets of 10 trials each

Block 1: 112 trials

Block 2: 112 trials

Block 3: 112 trials

112 trials per block

Block composition

Food pictures (50% HDE, 50% LDE)

- **50%**
  - **GO**
    - Participant has to press space bar in order to detect target stimulus
  - **NO GO**
    - Participant must withhold his/her response to ignore distractor stimulus

- **56%**
  - **Food pictures**

Object pictures

- **44%**
  - **NO GO**
    - Participant must withhold his/her response to ignore distractor stimulus
  - **GO**
    - Participant has to press space bar in order to detect target stimulus

Stimuli examples:
- Food: apples, waffles
- Object: broom, brush

Figure 1
Inclusion n=124
NW=41, OW=45, OB=38

Excluded for detection of the odour during session (n=25)
NW=9, OW=8, OB=8

Excluded for presence of eating disorder screened with Q-EDD (n=5)
NW=1, OW=3, OB=1

Excluded for impaired olfactory capacities according to ETOC (n=2)
OW=1, OB=1

Included for analysis n=92
NW=31, OW=33, OB=28

Figure 2
Proportion of commission errors by stimulus type and cognitive load condition

Figure 4