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5 Implicit food odour priming effects on reactivity and inhibitory control towards
6 foods

7 Marine Mas^{1*}, Marie-Claude Brindisi^{1,2}, Claire Chabanet¹, Stéphanie Chambaron¹

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9 ¹Centre des Sciences du Goût et de l'Alimentation, AgroSup Dijon, CNRS, INRAE,

10 Université Bourgogne Franche-Comté, Dijon, France

11• ²Department of Diabetes and Clinical Nutrition, Centre Hospitalier Universitaire de Dijon,

12 Dijon, France

13

14 * Corresponding author

15 E-mail: marine.mas@inrae.fr (MM)

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20 **Abstract (150 mots max)**

21 The food environment can interact with cognitive processing and influence eating behaviour. Our objective was
22 to characterize the impact of implicit olfactory priming on inhibitory control towards food, in groups with
23 different weight status. Ninety-two adults completed a modified Affective Shifting Task: they had to detect
24 target stimuli and ignore distractor stimuli while being primed with non-attentively perceived odours. We
25 measured reactivity and inhibitory control towards food pictures. Priming effects were observed on reactivity:
26 participants with overweight and obesity were slower when primed with pear and pound cake odour respectively.
27 Common inhibitory control patterns toward foods were observed between groups. We suggest that non-
28 attentively perceived food cues influence bottom-up processing by activating distinguished mental
29 representations according to weight status. Also, our data show that cognitive load influences inhibitory control
30 toward foods. Those results contribute to understanding how the environment can influence eating behaviour in
31 individuals with obesity.

32

33 **Introduction**

34 Studies have shown that individuals with obesity tend to have poorer inhibition capacities when it comes to food
35 [1,2]. In our food-abundant environment, this tendency inevitably leads to overeating, i.e. eating more than one's
36 physiological needs. This type of impaired inhibition can naturally lead to weight gain and even to obesity.

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

47 Independently of their surroundings, people are, by nature, attracted to food [7]. Indeed, foraging for nutritious
48 food is one of the key roles of the brain functions as food is essential for survival [8]. The brain preferentially

49 directs its limited resources toward energy-dense food stimuli [8,9]. Food also induces reward in the form of
50 pleasure in the dopaminergic pathways of the brain, which is similar to the cognitive processing of addictive
51 substance cues [10,11]. Those two aspects provide a solid base to establish that food stimuli are salient in the
52 environment [12]: they are more prone to visually attract attention, and consequently, undergo quickly cognitive
53 processing, which affects decision-making. [13]. In an obesogenic environment, biased decision-making in
54 favour of high energy-dense food choices inevitably leads to weight gain.

55 To study the modulation of behaviour by food cues, several studies focused on using priming [14,15]. Priming is
56 how incidental stimuli (stimuli that are perceived without the individual's awareness or appreciation of their
57 influence) are shown to influence higher-order cognitive and behavioural outcomes [16]. Incidental stimuli that
58 alter human food behaviour can be visual (advertisements, [15]), auditive [17], but also olfactive. Indeed,
59 olfaction is strongly tied to food intake as food odours generally signal food availability [18]. Several studies
60 have shown that food odour priming might modify several aspects of eating behaviour, such as attitudes to foods
61 [19], food choices [20], food intake [21,22], and bottom-up cognitive processing of food stimuli [23].

62 In a previous study, we highlighted the differing influence of incidental olfactory food cues on the stimulus-
63 driven¹ cognitive processing of food pictures in individuals with different weight statuses [23]. Indeed, when
64 primed with non-attentively perceived odours signalling high energy-dense (HED) foods, participants with
65 obesity tended to show greater orienting attentional biases (*i.e. the individual tendency to automatically orient*
66 *one's attention toward specific stimuli*) toward food pictures than when primed with non-attentively perceived
67 odours signalling low energy-dense (LED) foods. This tendency was reversed for individuals with normal weight
68 status, and different from the pattern of attentional orienting toward foods in individuals with overweight. In
69 sum, implicit olfactory priming with food odours can either increase or decrease the perceptual salience² of foods
70 in different ways according to weight status by influencing the bottom-up processing of such stimuli. We
71 consequently wondered whether olfactory priming with food cues could also have differentiated effects on goal-
72 directed or "top-down" processes such as inhibitory control. This contribution would help us to clarify the links
73 between the processing of food cues and food-related decision-making.

74

75 Inhibitory control is part of the executive functions, which are cognitive functions responsible for transmission
76 between endogenous (mood, thoughts, sensations) and exogenous (environmental) events. Executive functions

¹ Such processes are referred to as "bottom-up" or stimulus-driven processes, meaning that data from the environment drive our perception of stimuli

² The extent of which a stimulus is salient

77 are involved in problem-solving and decision-making, which are necessary for the execution of goal-directed
78 actions [24–26]. Inhibitory control is a remarkable executive function that makes it possible for us to stay
79 consistent with our behavioural intentions on attentional, cognitive and behavioural levels. Many researchers
80 have conceptualized several theoretical models of its structure [27,28]. According to Friedman and Miyake
81 (2004), there are three defined components of inhibitory control: (a) attentional control, allowing us to focus our
82 attention on stimuli of interest and to avoid wasting mental resources on non-pertinent stimuli, (b) cognitive
83 inhibition, namely the ability to resist proactive interference from prepotent stimuli in information processing,
84 and (c) self-control, the ability to control one’s behaviour instead of acting impulsively [27]. Each of these three
85 components is involved in a specific type of stimulus processing, which helps individuals to adapt to changing
86 situations by enabling voluntary behaviours and inhibiting possible perturbations.

87 The hypothesis of a deficit in inhibitory control among individuals with obesity has been widely explored by
88 researchers in an effort to explain why weight loss remains difficult, and to find innovative opportunities to
89 reduce obesity [10]. Such a deficit could lead to a decrease in the ability to pursue goal-directed behaviour, such
90 as maintaining a healthy lifestyle. In this line of study, some authors showed that individuals with obesity have
91 lower inhibitory control, [2,25,29,30] while other studies found no differences related to weight status [31,32].
92 No consensus has been found so far, potentially due to the diversity of methodologies [33]. Additionally, other
93 variables (such as frequent comorbidities in obesity, or specific eating styles) are susceptible to modulate
94 inhibitory control capacities beyond weight status [32,34–36]. Applied to food-choice behaviour, low inhibitory
95 control is related to excessive consumption of HED foods, especially in contexts of consumption facilitation
96 [37,38]. Moreover, in an obesogenic context where there is an overload of information, few cognitive resources
97 remain available to inhibit one’s attention, thoughts and behaviours. This may guide individuals toward default
98 choices, namely palatable but unhealthy foods [7].

99 Some sensory cues create a context of facilitation by guiding the individual toward consumption [39] while
100 offering opportunities to succumb to the temptation of palatable foods. Among these cues, food odours have a
101 strong influence; they signal the availability of foods without necessarily raising awareness [40,41]. To our
102 knowledge, our study is the first to explore the relationship between a context of facilitation and inhibitory
103 control toward foods (high and low energy-dense foods vs. neutral non-food stimuli) in male and female adults
104 of various weight statuses (normal-weight, overweight, obese) and with no eating disorder. New data on how
105 food stimuli modulate cognitive processing might help to understand how individuals are influenced by our

106 obesogenic environment. Moreover, the lack of inhibitory control toward foods is one problematic aspect of
107 eating behaviour. Disentangling its mechanisms could explain some health-deleterious food choices in obesity.

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

115 **Material and methods**

116 **Participants.**

117 One hundred and twenty-four adults aged from 20 to 60 years old were recruited and grouped according to their
118 body mass index (BMI, kg/m², [42,43]; 38 individuals with obesity (OB), 45 individuals with overweight (OW),
119 and 41 individuals with normal weight (NW). Participants were recruited from the population registered in the
120 Chemosens Platform's PanelSens database. This database complies with national data protection rules and has
121 been vetted by the appropriate authorities (Commission Nationale Informatique et Libertés – CNIL). Participants
122 were contacted by an e-mail from the platform which invited them to respond to a questionnaire investigating
123 inclusion and exclusion criteria mentioned below. The study was conducted in accordance with the Declaration
124 of Helsinki and was approved by the Comité d'Evaluation Ethique de l'Inserm (CEEI, File number IRB
125 0000388817-417). This research study adhered to all applicable institutional and governmental regulations
126 concerning the ethical use of human volunteers.

127 Exclusion criteria were: age under 18 or over 60 years old, diagnosis of a chronic disease (such as type 2
128 diabetes, cardiovascular disease, or hypertension), regular medical treatment causing cognitive impairment
129 (antipsychotic, anxiolytic, or antidepressant), olfactory impairment (anosmia, hyposmia, chronic sinusitis) and a
130 history of bariatric surgery. Additionally, participants who were sick (cold or flu symptoms) at the time of the
131 experiment were asked to postpone their appointment with the laboratory in order to ensure that they did not
132 have an impaired sense of smell during the session.

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

137 **Measurements**

138 **An adaptation of the Affective Shifting Task:**

139 In order to measure inhibition toward foods, we adapted the affective shifting task [44,45] modified by Mobbs,
140 Iglesias, Golay, & Van der Linden, 2011. This task is based on the Go/No-go paradigm (for a review, see
141 Gomez, Ratcliff, & Perea, 2007). In this task, participants must both (a) detect target stimuli (go trials) by
142 pressing the spacebar on a computer keyboard and (b) withhold their response to distracter stimuli (no-go trials).
143 Participants were instructed to respond as fast and as accurately as they could. During the task, two instruction
144 types alternated: target stimuli were either food stimuli (“food set”, HED or LED food pictures) or objects
145 (“object set”, tools or household objects). Stimuli were selected from FoodPics [48] and rigorously paired in
146 terms of perceptual and consumer properties according to the procedure used in [23].

147 The task comprised 3 blocks of 112 trials each. Each block comprised 4 sets (order: food-object-food-object) of
148 28 trials each (28% HED trials, 28% LED trials and 44% objects trials, in a pseudo-random order without three
149 pictures of the same type appearing consecutively). See fig 1. for details. Each set began with oral instructions
150 about the target stimuli (food or object) given through a headset, then a fixation cross appeared for 500ms at the
151 centre of a black screen. Subsequently, pictures appeared one by one for 500ms, with an inter-stimuli-interval of
152 900ms consisting of a white fixation cross on a black screen that participants were instructed to fixate.
153 Commission and omission errors were signalled to the participant by a short sound conveyed by the headset.
154 Blocks were separated by 1-minute pauses during which experimenters took the headsets off participants and
155 invited them to relax. Prior to measurements, participants completed a brief training session comprising 4 sets of
156 10 trials in order to familiarize them with the task. They were asked to rate their hunger level on a 10-point
157 Likert scale before and after the modified Affective Shifting Task.

158 **Fig 1. Composition of blocks, sets and trials of the modified Affective Shifting Task.** F = food, O = object.

159 For each subject and for each experimental trial, we collected the reaction times (RT), the presence of a
160 commission error (detecting a distractor stimulus) and the presence of an omission error (not detecting a target

161 stimulus). Reaction times corresponded to the time between the appearance of the stimulus on screen and the
162 moment the participant pressed the space bar to detect it (0 to 500ms). Commission errors corresponded to
163 situations in the no-go trials in which the participant pressed the space bar, indicating a lack of response
164 inhibition to distractor stimuli. Omission errors corresponded to go-trials for which the participant did not press
165 the space bar to detect the target stimulus, indicating a lack of attention to the given stimulus [45,49].

166 **Priming.**

167 In order to non-attentively expose participants to olfactory food cues, we used the olfactory priming paradigm
168 developed by Marty & al. in 2017 [19,23]. In this paradigm, participants perform three identical blocks of a
169 computerized task (here, the modified Affective Shifting Task) while wearing a headset with a microphone. The
170 headsets are used to provide instructions to participants, and, unbeknownst to participants, the microphones are
171 used as brackets for odorized microphone foams. Task blocks are separated by short pauses during which
172 experimenters discreetly switch the headsets in order to non-attentively expose participants to different olfactory
173 food cues through the odorized foams of the headset's microphone. Our study had three different olfactory
174 priming conditions: odour signalling HED foods (fatty sweet pound cake odour), odour signalling LED foods
175 (fruity pear odour) and control condition in which the foam was not odorized.

176 Participants come to the laboratory under a false pretence (here, taking part in a study on picture categorization)
177 so they do not guess the presence of olfactory cues during the session. At the end of the three blocks of the task,
178 participants complete an investigation questionnaire in which they have to guess the aim of the experiment and
179 indicate whether they noticed anything particular during the task that could have influenced their performance.
180 Participants mentioning odours or headsets in this questionnaire are excluded from the study. This step ensures
181 that no odour or headset change was perceived, which allows the implicit quality of the priming [23].

182 **Global Cognitive Capacities**

183 To ensure that differences in cognitive performance during the modified Affective Shifting Task were not due to
184 general cognitive deficits, participants performed standardized tests, namely the Go/No-go and flexibility
185 subtests of the computerized Test of Attentional Performance (TAP) neuropsychological test battery [50].

186 The Go/no-Go subtest explores response inhibition through a simple task in which the participant must detect
187 target stimuli "X" and withhold a response when presented with distractor stimuli "+". The flexibility subtest
188 assesses shifting abilities in mental flexibility. In this subtest, two stimuli appear, one on the left and one on the

189 right side of the screen. One of the stimuli is round while the other is an angular shape. The participant must
190 detect whether the round shape is on the left or on the right side of the screen by pressing the corresponding key
191 with the dominant hand through several trials. Participants were given a brief training before each subtest. The
192 assessment began systematically with the Go/No-go subtest.

193 **Session**

194 Participants came to the laboratory at 12 p.m. They were instructed to refrain from eating, drinking anything
195 except water, wearing scented cosmetics, smoking or chewing gum for 3 hours prior to the session. They began
196 the session with the three blocks of modified Affective Shifting Task, followed by the investigation
197 questionnaire and a hunger rating on a 10-point Likert scale. Then, they were administered the two subtests of
198 the TAP [50], namely Go/No-go and Flexibility, in order to check their global cognitive performance.
199 Afterwards, participants filled a computerized version of the Questionnaire for Eating Disorder Diagnosis – Q-
200 EDD [51,52] in order to identify and exclude participants with potential eating disorders. Finally, participants
201 passed the European Test for Olfactory Capacities – ETOC [53] in order to ensure that they could correctly
202 detect and identify odours. At the end of the session, the weight and height of each participant were measured,
203 individually, in a separate room by the experimenter.

204 **Data preparation**

205 Since instruction shifts modulate task difficulty [54], so we created a two-level covariate to account for the
206 cognitive load generated by the change of instructions between tasks (food-object-food-object). The two levels
207 were “CL+” for the first 14 trials of each set and “CL-” for the second 14 trials of each set (total of 28 trials).
208 The CL+ condition refers to a situation in which the individual becomes familiar with new instructions
209 (detecting foods in food sets and detecting objects in object sets) and the implementation of the instructions is
210 automatized during the set. In the CL- condition, the individual is already familiar with the instructions,
211 implicating a lower cognitive load. This two-level covariate was integrated in further linear mixed models that
212 are described below.

213 During data preparation, reaction times (RTs) inferior to 150ms were excluded from analysis because they
214 reflect stimulus anticipation [46]. In order to analyse global reaction speed, we summarized, for each participant,
215 RTs for which the spacebar was pressed (go trials without omissions and no-go trials with errors) by using the
216 median per condition (olfactory prime type x stimulus type x cognitive load). For errors, we calculated the

217 proportion of errors on no-go trials for each participant in each condition (olfactory prime type x stimulus type x
218 cognitive load). For omission errors, the proportion of omissions among the go trials per condition was
219 calculated for each participant.

220 For each dependent variable (RTs, proportion of commission errors, proportion of omission errors), we estimated
221 a linear mixed model. The model initially involved four fixed factors (weight status group x stimulus type x
222 olfactory prime type x cognitive load), all interactions, and the individual as a random factor. We also added
223 covariates such as age, global cognitive performance (flexibility and Go/no-Go) and sex. We then simplified the
224 model by removing non-significant terms except if they were involved in a significant higher-order term.
225 Contrasts were used to interpret significant main effects and interactions.

226 Statistical analysis was performed with R.3.4.3 software [55] using linear mixed models (nlme package v. 3.1-
227 131 [56]) to explain reactivity to stimuli expressed in median RTs, inhibitory control deficit expressed in
228 proportion of errors, and inattention expressed in proportion of omissions. Specific contrasts were subsequently
229 tested using the contrast package [57,58]. The significance threshold was set at 0.05. Full data are available in
230 the Supporting Information Files, see S1 Dataset.

231

232 **Results**

233 **Sample characteristics**

234 At the end of the tests, 33 participants were excluded from the sample (see details in Fig 2). Indeed, 25 declared
235 that they had smelled an odour during the session, meaning that the priming was not implicit for those
236 participants. Five participants were screened as disordered eaters according to the Q-EDD, and two more
237 participants were excluded because their answers to the ETOC indicated that they had low olfactory capacities
238 (hyposmia or anosmia). One participant was excluded from analysis because data from the flexibility subtest
239 were missing.

240

241 **Fig 2. Flowchart of exclusions.** NW = participants with normal weight, OW = participants with overweight, OB
242 = participants with obesity.

243 Finally, 91 participants remained eligible for analysis: 31 participants with normal-weight, 32 participants with
244 overweight and 28 participants with obesity (according to their BMI measurements).

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

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

262 **Table 1: Participants characteristics.**

	Weight status					
	Normal-weight (NW)		Overweight		Obesity	
	n=31 (34%)		n=32 (35%)		n=28 (31%)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age (y): p=0.70	43.41	(11.07)	44.15	(8.76)	41.89	(11.30)
BMI (kg/m²): p<0.001	21.95 ^a	(1.77)	27.28 ^b	(1.37)	36.43 ^c	(5.75)
Hunger level before session (1-10): p=0.19	6.33	(2.14)	5.62	(2.75)	5.07	(2.97)
Variation in hunger: p=0.60	0.45	(0.75)	0.75	(1.42)	0.44	(1.82)
TAP Go/No-go subtest – (T-score): p=0.15	48.45	(6.65)	46.71	(6.03)	44.67	(9.22)
TAP Flexibility subtest – (GPI): p=0.92	1.41	(6.09)	1.96	(8.60)	1.26	(7.45)
	n	%	n	%	n	%
Sex: p=0.69						
Women	19	(61%)	16	(50%)	17	(61%)
Men	12	(39%)	16	(40%)	11	(39%)
Level of education: p=0.85						
< 14 years	16	(52%)	16	(50%)	16	(57%)
> 14 years	15	(48%)	16	(50%)	12	(43%)

263

264 Quantitative variables expressed as mean (SD)

265 ^{a, b, c} Superscript letters are associated with values (means or numbers), same letters indicating that the difference

266 between values is not significant. P values indicate the significance of the weight status effect. GPI = Global

267 Performance Index.

268 **Reaction times**

269 The main effect of the type of stimulus [$F_{(2, 1536)}=46.94, p<0.001$], the interaction between weight status and

270 olfactory prime type [$F_{(4, 1536)}= 3.21, p=0.012$] and the interaction between weight status and cognitive load

271 [$F_{(2,1536)}=5.47, p=0.004$] reached significance in the RT linear mixed model. Age and global cognitive

272 performance (Flexibility and Go/no-Go performances) were also kept in the model as they were significant as
273 covariates. Main results are shown in Fig 3.

274 **Fig 3. (left) RT by stimulus type, CTL=objects (control) pictures, HED=high energy-dense foods pictures,**
275 **LED=low energy-dense foods pictures, averaged on olfactory prime type, cognitive load condition and**
276 **weight status. (right) RT by olfactory prime type and weight status (NW=normal-weight,**
277 **OW=overweight, OB=obesity), averaged on stimulus type and cognitive load condition.** Predicted values
278 and 95% confidence intervals. * $p < 0.05$.

279 Regarding the main effect of stimulus type, individuals detected food pictures faster than object pictures [HED
280 vs objects = -6.20ms ($p < 0.001$), LED vs objects = -11.53ms ($p < 0.001$)], and responded quicker to LED food
281 pictures than HED food pictures [LED vs HED = -5.33ms, ($p < 0.001$)].

282 Regarding the interaction between weight status and olfactory prime type, participants with obesity were slower
283 to detect stimuli of all types when primed with a pound cake odour [OB, pound cake odour vs none=+5.30ms,
284 ($p = 0.01$) and, non-significantly, when primed with a pear odour [OB, pear vs. none=+3.54ms, ($p = 0.09$)].
285 Participants with overweight were slower to detect stimuli when primed with a pear odour [OW, pear vs pound
286 cake=+5.33ms ($p = 0.01$)] and ~~non-significantly~~, when they were primed with a pear odour vs. no odour [OW,
287 pear vs none=+3.95ms, ($p = 0.049$)]. On the contrary, participants with normal weight showed no significant
288 difference between RT when primed with a pound cake odour ($p = 0.58$) or with a pear odour ($p = 0.30$).

289 When we looked at the interaction between weight status and cognitive load, only normal-weight individuals had
290 different reaction times depending on cognitive load conditions. More specifically, they were slower when the
291 cognitive load was higher [NW, CL+ vs CL-=+5.22ms, ($p = 0.002$)]. In addition, in the higher cognitive load
292 conditions, normal-weight participants tended to be slower than participants with overweight [CL+, NW vs.
293 OW=+8.34ms, ($p = 0.07$)]. However, these results only approached significance.

294 **Proportion of commission errors**

295 Three terms of the commission errors linear mixed model reached significance: the main effect of stimulus type
296 [$F_{(2, 1542)} = 51.36$, $p < 0.001$], the main effect of cognitive load condition [$F_{(1, 1542)} = 24.29$, $p < 0.001$] and the
297 interaction between cognitive load and stimulus type [$F_{(2, 1542)} = 5.29$, $p = 0.005$]. Sex and global cognitive
298 performance on the Go/no-Go subtest were also kept in the model as they were significant as covariates. Results
299 are shown in Fig 4.

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

304

305 Concerning the effect of cognitive load, participants made 43% more commission errors in the CL+ condition
306 than in the CL- condition. [CL+ vs. CL- = +2.07 errors, $p < 0.001$].

307 Stimulus type effect was dependent on cognitive load condition. In both the high and low cognitive conditions,
308 participants made on average 84% more commission errors when facing HED food stimuli than when facing
309 objects [HED vs objects=+3.95 errors, $p < 0.001$]. Participants also made 142% more commission errors when
310 facing HED food stimuli than when facing LED food stimuli [HED vs. LED=+4.92 errors, $p < 0.0001$]. A slight
311 difference in the amount of commission errors made was observed between LED food stimuli and objects, but it
312 did not reach significance in the CL+ condition [CL+, LED vs. objects= -1 error, (NS, $p = 0.059$)]. Nevertheless,
313 in the CL- condition, participants made 90% more commission errors for objects than for LED food stimuli [CL-
314 , objects vs LED=+2.09 errors, ($p = 0.004$)].

315 Participants made more commission errors in CL+ conditions than in CL- conditions for food stimuli: 48% and
316 96% more commission errors were made in the CL+ condition for HED and LED food stimuli, respectively
317 [HED, CL+ vs. CL-= +3.50 errors, $p < 0.001$; LED, CL+ vs. CL-= +2.48 errors, $p < 0.001$]. Participants did not
318 make a significantly different proportion of commission errors between high and low cognitive load conditions
319 when facing object stimuli [objects, CL+ vs. CL-=+0.22 errors, $p = 0.75$].

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

322

323 **Proportion of omission errors**

324 Only two terms of the linear mixed model reached significance for the proportion of omission errors: main effect
325 of type of stimulus [$F_{(2,1541)} = 90.45$, $p < 0.001$] and interaction of weight status group and type of stimulus

326 [F_(4,1541)=2.67, p=0.03]. Age and global cognitive performance on the Go/no-Go subtest were also kept in the
327 model as they were significant as covariates.

328 Concerning the main effects of stimulus type, participants made 117.2% more omission errors when facing HED
329 food stimuli than facing LED food stimuli [HED vs. LED=+6.35 omissions errors, p<0.001]. They also made
330 significantly fewer omission errors for food stimuli than for objects: 15.6% and 61.2% less omission errors were
331 made for HED and LED food stimuli, respectively, in comparison with object stimuli [HED vs. objects=-3.49
332 omission errors, p<0.0001, LED vs. objects=-9.85 omission errors, p<0.001].

333 When we focused on the interaction between weight status group and stimulus type, we found that NW
334 participants made more omissions than OW participants when facing HED food stimuli [HED, NW vs.
335 OW=+4.32 omission errors, (p=0.044)]. No other effects approached significance. In sum, food pictures,
336 especially HED foods, elicited more omission errors than neutral pictures in all participants.

337

338 **Discussion**

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

342 **Global performance**

343 Global performance for inhibitory control was similar for all groups in our sample, as measured by the Go/no-Go
344 subtest from the TAP, and for flexibility as measured with the flexibility subtest from the same battery. Contrary
345 to previous findings [29,30,59–61], inhibitory control and mental flexibility capacities were similar regardless of
346 weight status. In addition, the number of commission errors, omission errors and reaction times in the modified
347 Affective Shifting Task revealed no significant differences according to weight status when participants were not
348 primed with a non-attentively perceived food cue. This suggests that common processes in the detection of
349 stimuli and inhibition capacities are not dependent on weight status.

350 **Reactivity to foods**

351 In our experiment, all participants reacted more quickly to food pictures than to neutral pictures. This highlights
352 that food stimuli undergo faster processing, which is in line with previous literature [23,62–66]. Indeed, food is
353 essential for survival (i.e. a primary motivated goal of the individual) and has a rewarding quality, which are
354 characteristics of a salient stimulus [12]. ~~So food stimuli appear to be processed more quickly, which explains~~
355 ~~the increased reactivity to foods in all individuals.~~

356

357 The present study distinguished the approach bias for low energy-dense (LED) foods and for high energy-dense
358 (HED) foods. While comparing RTs for high-calorie and low-calorie foods, Meule et al. suggested that longer
359 RTs for HED foods indicated increased attention toward them. This relates to the fact that HED foods capture
360 attention more forcefully than LED foods in the early stages of cognitive processing, which is consistent with
361 our previous work on orienting attentional biases [23]. Moreover, it seems that HED food stimuli tend to capture
362 attentional focus for longer periods of time than LED food stimuli. This might be behaviourally reflected in
363 reaction times, as highlighted by neuroimaging studies showing discriminative patterns of activity in the brain
364 for high and low-calorie food stimuli [67,68]. In our experiment, individuals were faster to detect LED food
365 stimuli than HED food stimuli. This finding may relate to the attentional dimension of inhibitory control [27],
366 which could be impaired by the perception of HED food pictures.

367 HED food stimuli processing might initially be facilitated by the high perceptual salience of high-calorie foods.
368 We suggest that over time, the detection of HED food stimuli is impaired by their capacity to attract the focus of
369 attention (slowed disengagement, [69,70]), which slows behavioural responses. On the contrary, LED food
370 stimuli processing might be facilitated by the earlier identification of fruit stimuli in our experiment. As food
371 stimuli, LED stimuli are also salient. However, their processing is not impaired by the attentional approach bias
372 elicited by the higher appetitive quality of HED food stimuli. This effect results in a decrease in reaction times
373 for LED foods compared with HED foods, partly explaining why participants had shorter RT and fewer omission
374 errors for LED food stimuli than for HED food stimuli in our experiment.

375 **Differences in vulnerability to food cues in individuals with higher** 376 **weight status**

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

384 The result of the priming effect seen here is congruent with the results of previous studies [19,23]. In an earlier
385 study, we found that implicit priming of olfactory food cues had differentiated effects: individuals with obesity
386 were more vulnerable to a non-attentively perceived pound cake odour in their bottom-up processing of food
387 cues [23]. For individuals with overweight in the present study, the effect of the pear odour is consistent with a
388 study by Marty & al [19] in which olfactory pear and pound cake primes had differentiated effects when they
389 were non-attentively perceived by children with overweight. Indeed, these children were more prone to choose
390 fruit in a forced-choice task when they were non-attentively primed with a pear odour. The authors explained
391 this result by hypothesizing that individuals with overweight might be more confronted to the idea of “dieting” in
392 their daily lives, and so this concept might be more easily activated by a non-attentively perceived odour
393 signalling a LED food. Future research could focus on understanding why odours signalling LED foods seem to
394 affect individuals with overweight while odours signalling HED foods affect individuals with obesity. These
395 food types may differentially activate certain concepts and mental representations in individuals according to
396 weight status.

397 **Inhibitory control toward foods**

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

401 In our experiment, participants made more commission errors when they were facing HED food stimuli. No
402 difference was found in regard to weight status, which is congruent with part of the literature [71,72]. This

403 observation strongly suggests that the lack of inhibition toward foods is a common process for all individuals and
404 it is also consistent with the idea that the rewarding quality of HED foods makes them more appealing [73–75],
405 leading to an increased approach bias. The salience of HED foods combined with the associated approach bias
406 makes the detection of HED food stimuli a prepotent response for the individual. A prepotent response is
407 cognitively more difficult to inhibit than other response options, which need to be inhibited in order to exhibit
408 goal-congruent behaviour. This effect appears to be even stronger when cognitive load is high because
409 individuals make significantly more commission errors toward HED food stimuli in this condition.

410 We found different patterns of inhibitory control toward HED and LED foods, indicating that the top-down
411 processing of those stimuli is differentiated. In lower cognitive load conditions, individuals made fewer
412 commission errors when facing LED food stimuli than when facing HED food or object stimuli. We can thus
413 presume that fruits (LED foods) are processed faster than other stimuli. This assumption is supported by the
414 work of Leleu et al., 2016 [76], who showed that fruit pictures elicited earlier event-related responses in the brain
415 than other food types (vegetables, HED foods) during a food discrimination task.

416 **Priming effects: why does implicit priming only impact bottom-up** 417 **processes?**

418 In our study, we tested whether implicit priming with olfactory food cues would impact inhibitory control, a
419 decision-driven, or “top-down” process measured by the proportion of commission errors made by participants
420 in each olfactory condition. Unexpectedly, no priming effect was observed for commission errors, contrary to the
421 effects observed with the exact same olfactory priming paradigm used in a Visual Probe Task to measure
422 orienting attentional biases (a stimulus-driven, bottom-up process) [23]. Because orienting attentional biases are
423 data-driven processes, sensory inputs are important determiners of behavioural response in such tasks [77].
424 Moreover, the Visual Probe Task needed less top-down cognitive effort than the modified Affective Shifting
425 Task. Hoffman-Hensel & al, 2017, who observed that cognitive effort altered the neural processing of food
426 odours, found that involvement in multiple tasks decreased participants’ perception of odour intensity [78]. We
427 can suppose that implicit olfactory cues effects may not have been strong enough to act as a facilitation context
428 impairing the inhibitory control.

429 According to the I-RISA model of addictive behaviour, rewarding cues have an increased salience for
430 individuals, which is related to lower inhibitory control in cognitive tasks and associated with specific

431 activations in the brain [11,79,80]. In our study, participants showed similar patterns of inhibitory control toward
432 foods, but the implicit priming of olfactory food cues (supposed to act as a facilitation context and increase the
433 salience of visual food stimuli) did not seem to modulate inhibitory control performance. Some works from the
434 field of addictions and neuroscience suggest that implicit cues (such as masked cues or subliminal pictures)
435 might activate different areas of the brain (limbic system) than explicit rewarding cues (prefrontal cortex) in
436 addicted individuals [79,81,82]. This assumption supports the fact that implicit and explicit priming might
437 differentially modulate bottom-up and top-down processing of stimuli. An alternative explanation for the
438 absence of priming effect on inhibitory control in our study might be that implicit olfactory stimuli might only
439 target the bottom-up processing of food pictures.

440

441 **Modulation of inhibitory control capacities toward food by** 442 **cognitive load**

443 Finally, the high cognitive load condition induced slower reaction times and more commission errors for all
444 participants facing all types of stimuli in each olfactory condition. This reflects the worse performance and
445 higher mental effort required to complete the task [83] and confirms that the first half of each set was more
446 difficult, validating the cognitive load effect when the instructions are changed between two sets.

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

458 load in inhibitory control [84] and showing that working memory load (resulting here from the new set of
459 instructions) interacts heavily with inhibitory control [28].

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

468

469 **Limitations**

470 As discussed above, our study presents some limitations. First, we question the use of fruit stimuli as LED food
471 stimuli. Indeed, fruits are frequently consumed in non-processed and raw forms, making it easier to distinguish
472 them from objects than HED foods in the earliest stages of feature perception. Some empirical data from
473 electroencephalography demonstrated that fruits do indeed undergo earlier processing. The pattern of evoked
474 potentials (EPs) for the fruity quality of food stimuli seems distinct from the patterns of EPs observed for
475 sweetness/saltiness and low/high energetic value [76]. Moreover, there is less diversity in the presentation of
476 fruit in everyday life when compared with sweet HED foods (chocolate bars, cakes and pastries), which come in
477 a variety of forms. In terms of perception, the distinction between raw and transformed food goes beyond the
478 calorie content [85]. We hypothesize that identifying pictures of fruit over a short time during a single
479 presentation might thus be facilitated because fruits are well-known and belong to a universal category [86].
480 There are limited options in the pairing of fruits to comparable HED foods because it is difficult to find sweet
481 calorie-dense foods that are not processed and that belong to a universal category. In our study, we only used
482 sweet stimuli for odour-congruency and literature fidelity reasons, but this remark may or may not refer to
483 vegetables, which are also consumed raw and non-processed, but do not benefit from early perception facilitation
484 [76]. There is a need to find pictorial LED stimuli that fit HED stimuli in visual and hedonic properties, but also
485 in their intrinsic features such as degree of processing and distance from categorical prototype.

486 Several studies have observed interesting priming effects with the pear and pound cake odour, which are odorant
487 mixtures [19,20,23]. These effects were observed in relation to weight status, which indicates the need to
488 identify olfactory components that tap into specific (and unknown to date) mental representations contributing to
489 weight-status specific responses. Concerning the implicit priming, we suggest that a context of more incentive
490 facilitation (involving a less implicit sensory modality than olfaction, or in multi-modal priming) might have a
491 stronger influence on top-down processing. However, we insist on using implicit priming to experimentally
492 manipulate the effects of incidental cues from the environment in laboratory experiments seeing as non-
493 attentively perceived cues appear to have a stronger effect on cognitive processing [23] and behaviour [39] than
494 explicitly primed cues. Also, they are more reflective of the influences of environmental cues which often occur
495 out of the individual's attentional focus [7].

496 Moreover, we suppose that the different stimuli types elicited different attentional control patterns, with HED
497 food stimuli more likely to attract attention, thus impairing attentional control. Unfortunately, our experiment
498 was not designed to identify the phenomenon of attentional control toward foods, and reaction times do not
499 represent a pure measure of distinct attentional mechanisms [33]. Such measures should be included in further
500 experiments in order to refine our understanding of the role of the attentional functions in food stimuli
501 processing, for instance by adding eye-tracking measurements into the experimental design, similar to the
502 method tested by Doolan et al [87].

503 **Perspectives**

504 **Cognitive load in obesity**

505 In the Ironic Process Theory [88], the daily life stressors increase cognitive load, which modulates inhibitory
506 control. These synergic effects tend to produce behaviours opposite to what was primarily intended by the
507 individual. Considerable research has shown that individuals with obesity and overweight are more at risk of
508 exposure to daily life stressors: low income [89], anxiety [90], psychological health impairments [91], physical
509 comorbidities [92], and discrimination and stigmatization in relation to body weight [93,94]. Considering all
510 these aspects leads us to suppose that individuals with obesity might be subject to higher cognitive loads during
511 daily decision-making, which could alter their inhibitory control and consequently, produce goal-unrelated
512 behaviours. In our study, individuals were experimentally confronted to the same amount of cognitive load,
513 which made it impossible to discriminate individual levels of inhibitory control toward foods according to

514 weight status. We now suggest that variations in everyday cognitive load might explain some of the relationships
515 between behaviourally reflected lack of inhibitory control facing foods and weight status that was identified in
516 other studies. In future research, these relationships should be characterized in order to better understand
517 overweight and obesity.

518 **Implicit priming as a context of facilitation**

519 Several studies focusing on inhibitory control manipulated the cognitive processing of food stimuli by creating a
520 context of facilitation with priming (priming concepts of impulsivity [37] and unrestrained food consumption
521 [38]), which led to interesting results. Nevertheless, such priming was explicit and is therefore not reflective of
522 incidental food cues from the environment, which was part of the objective of our study. Different forms of
523 implicit priming could be used in future research in order to assess the effects of implicit food cues on inhibitory
524 control or other top-down processes toward foods in a unimodal or multimodal manner. For instance, the
525 combination of auditory and olfactory priming has already been suggested as a means to influence individual
526 food choices [17]. In future research, this type of multimodal priming could be used as an experimental context
527 of facilitation in order to elicit a lack of inhibitory control for food intake.

528

529 **Conclusion**

530 Our study highlights common mechanisms relative to the top-down processing of foods, regardless of individual
531 weight status. Food stimuli are salient, which induces an approach bias that interferes with the initiation of goal-
532 directed behaviour on a cognitive level, leading to cognitive and behavioural deficits in inhibitory control. This
533 process occurs in individuals regardless of weight status, and its intensity seems to vary in function of food
534 characteristics (i.e. category and/or energy density). This deficit in inhibitory control induced by food stimuli is
535 modulated by the cognitive load in working memory, which means that the more mental effort the individual has
536 to make while performing a task, the fewer resources are available to inhibit prepotent responses. Future research
537 should focus on weight status in relation to cognitive load in order to improve our understanding of unhealthy
538 food choices in obesity. Our data support that implicit priming selectively modulates bottom-up processing.
539 Specific priming effects of food cues by weight status were also characterized in bottom-up processing, which
540 opens a new path for research on mental representations activated by food cues among the weight status
541 continuum.

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543

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549 S1 Dataset. Full data available.

References

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- 552 1. Batterink L, Yokum S, Stice E. Body mass correlates inversely with inhibitory control in response to food
553 among adolescent girls: an fMRI study. *NeuroImage*. 2010 Oct 1;52(4):1696–703.
- 554 2. Houben K, Nederkoorn C, Jansen A. Eating on impulse: The relation between overweight and food-
555 specific inhibitory control. *Obesity*. 2014;22(5):E6–8.
- 556 3. Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, et al. The global obesity
557 pandemic: shaped by global drivers and local environments. *The Lancet*. 2011 Aug 27;378(9793):804–14.
- 558 4. Glanz K, Sallis JF, Saelens BE, Frank LD. Healthy Nutrition Environments: Concepts and Measures. *Am*
559 *J Health Promot*. 2005 May 1;19(5):330–3.
- 560 5. Paquet C, de Montigny L, Labban A, Buckeridge D, Ma Y, Arora N, et al. The moderating role of food
561 cue sensitivity in the behavioral response of children to their neighborhood food environment: a cross-
562 sectional study. *Int J Behav Nutr Phys Act*. 2017 Jul 5;14(1):86.
- 563 6. Townshend T, Lake A. Obesogenic environments: current evidence of the built and food environments.
564 *Perspect Public Health*. 2017 Jan;137(1):38–44.
- 565 7. Cohen DA. Neurophysiological pathways to obesity: below awareness and beyond individual control.
566 *Diabetes*. 2008 Jul;57(7):1768–73.
- 567 8. Spence C, Okajima K, Cheok AD, Petit O, Michel C. Eating with our eyes: From visual hunger to digital
568 satiation. *Brain Cogn*. 2016;110:53–63.
- 569 9. Bailey RL. Modern foraging: Presence of food and energy density influence motivational processing of
570 food advertisements. *Appetite*. 2016 Dec 1;107:568–74.
- 571 10. Appelhans BM. Neurobehavioral Inhibition of Reward-driven Feeding: Implications for Dieting and
572 Obesity. *Obesity*. 2009;17(4):640–7.
- 573 11. Volkow ND, Wang G-J, Telang F, Fowler JS, Goldstein RZ, Alia Klein N, et al. Inverse Association
574 Between BMI and Prefrontal Metabolic Activity in Healthy Adults. *Obesity*. 2009;17(1):60–5.
- 575 12. Munneke J, Belopolsky AV, Theeuwes J. Distractors associated with reward break through the focus of
576 attention. *Atten Percept Psychophys*. 2016;78(7):2213–25.
- 577 13. Dai J, Cone J, Moher J. Perceptual salience influences food choices independently of health and taste
578 preferences. *Cogn Res Princ Implic [Internet]*. 2020 Jan 3 [cited 2020 Apr 7];5. Available from:
579 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6942074/>
- 580 14. Buckland NJ, Er V, Redpath I, Beaulieu K. Priming food intake with weight control cues: systematic
581 review with a meta-analysis. *Int J Behav Nutr Phys Act*. 2018 Jul 9;15(1):66.
- 582 15. Forwood SE, Ahern AL, Hollands GJ, Ng Y-L, Marteau TM. Priming healthy eating. You can't prime all
583 the people all of the time. *Appetite*. 2015 Jun 1;89:93–102.
- 584 16. Bargh JA, Williams LE, Huang JY, Song H, Ackerman JM. From the physical to the psychological:
585 Mundane experiences influence social judgment and interpersonal behavior. *Behav Brain Sci*. 2010
586 Aug;33(4):267–8.
- 587 17. Chambaron S, Chisin Q, Chabanet C, Issanchou S, Brand G. Impact of olfactory and auditory priming on
588 the attraction to foods with high energy density. *Appetite*. 2015 Dec 1;95:74–80.
- 589 18. Stevenson RJ. An Initial Evaluation of the Functions of Human Olfaction. *Chem Senses*. 2010 Jan
590 1;35(1):3–20.

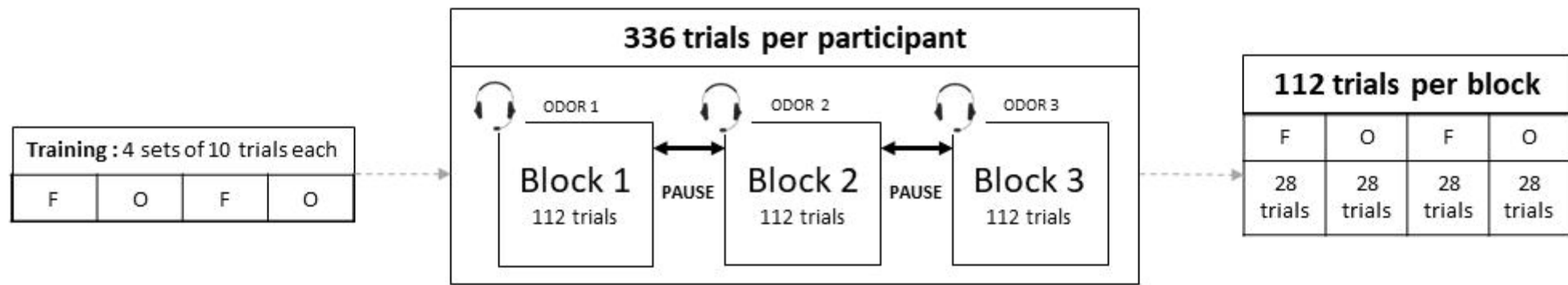
- 591 19. Marty L, Bentivegna H, Nicklaus S, Monnery-Patris S, Chamberon S. Non-Conscious Effect of Food
592 Odors on Children's Food Choices Varies by Weight Status. *Front Nutr.* 2017;4:16.
- 593 20. Gaillet M, Sulmont-Rossé C, Issanchou S, Chabanet C, Chamberon S. Priming effects of an olfactory food
594 cue on subsequent food-related behaviour. *Food Qual Prefer.* 2013 Dec 1;30(2):274–81.
- 595 21. Coelho JS, Polivy J, Peter Herman C, Pliner P. Wake up and smell the cookies. Effects of olfactory food-
596 cue exposure in restrained and unrestrained eaters. *Appetite.* 2009 Apr 1;52(2):517–20.
- 597 22. Proserpio C, Invitti C, Boesveldt S, Pasqualinotto L, Laureati M, Cattaneo C, et al. Ambient Odor
598 Exposure Affects Food Intake and Sensory Specific Appetite in Obese Women. *Front Psychol [Internet].*
599 2019 Jan 15 [cited 2020 Apr 7];10. Available from:
600 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6340985/>
- 601 23. Mas M, Brindisi M-C, Chabanet C, Nicklaus S, Chamberon S. Weight Status and Attentional Biases
602 Toward Foods: Impact of Implicit Olfactory Priming. *Front Psychol [Internet].* 2019 [cited 2019 Aug
603 9];10. Available from: <https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01789/full>
- 604 24. Barkley RA. *Executive Functions: What They Are, How They Work, and Why They Evolved.* Guilford
605 Press; 2012. 258 p.
- 606 25. Cserjési R, Luminet O, Poncelet A-S, Lénárd L. Altered executive function in obesity. Exploration of the
607 role of affective states on cognitive abilities. *Appetite.* 2009 Apr;52(2):535–9.
- 608 26. Friedman NP, Miyake A. The relations among inhibition and interference control functions: a latent-
609 variable analysis. *J Exp Psychol Gen.* 2004 Mar;133(1):101–35.
- 610 27. Diamond A. Executive Functions. *Annu Rev Psychol.* 2013;64(1):135–68.
- 611 28. Tiego J, Testa R, Bellgrove MA, Pantelis C, Whittle S. A Hierarchical Model of Inhibitory Control. *Front*
612 *Psychol [Internet].* 2018 Aug 2 [cited 2019 Nov 14];9. Available from:
613 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6085548/>
- 614 29. Boeka AG, Lokken KL. Neuropsychological performance of a clinical sample of extremely obese
615 individuals. *Arch Clin Neuropsychol.* 2008 Jul 1;23(4):467–74.
- 616 30. Fagundo AB, de la Torre R, Jiménez-Murcia S, Agüera Z, Granero R, Tárrega S, et al. Executive functions
617 profile in extreme eating/weight conditions: From anorexia nervosa to obesity. *PLoS ONE.* 2012;7(8).
- 618 31. Nederkoorn C, Smulders FTY, Havermans RC, Roefs A, Jansen A. Impulsivity in obese women. *Appetite.*
619 2006 Sep 1;47(2):253–6.
- 620 32. Prickett C, Brennan L, Stolwyk R. Examining the relationship between obesity and cognitive function: A
621 systematic literature review. *Obes Res Clin Pract.* 2015 Mar 1;9(2):93–113.
- 622 33. Meule A, Lutz APC, Krawietz V, Stützer J, Vögele C, Kübler A. Food-cue affected motor response
623 inhibition and self-reported dieting success: a pictorial affective shifting task. *Front Psychol [Internet].*
624 2014 Mar 13 [cited 2019 Oct 24];5. Available from:
625 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3952046/>
- 626 34. Kulendran M, Vlaev I, Sugden C, King D, Ashrafian H, Gately P, et al. Neuropsychological assessment as
627 a predictor of weight loss in obese adolescents. *Int J Obes.* 2014 Apr;38(4):507–12.
- 628 35. Meule A, Kübler A. Double trouble. Trait food craving and impulsivity interactively predict food-cue
629 affected behavioral inhibition. *Appetite.* 2014 Aug 1;79:174–82.
- 630 36. Price M, Lee M, Higgs S. Food-specific response inhibition, dietary restraint and snack intake in lean and
631 overweight/obese adults: a moderated-mediation model. *Int J Obes.* 2016 May;40(5):877–82.

- 632 37. Guerrieri R, Nederkoom C, Jansen A. Disinhibition is easier learned than inhibition. The effects of
633 (dis)inhibition training on food intake. *Appetite*. 2012 Aug;59(1):96–9.
- 634 38. Hall PA. Executive control resources and frequency of fatty food consumption: Findings from an age-
635 stratified community sample. *Health Psychol*. 2012;31(2):235–41.
- 636 39. Marteau TM, Hollands GJ, Fletcher PC. Changing human behavior to prevent disease: the importance of
637 targeting automatic processes. *Science*. 2012 Sep 21;337(6101):1492–5.
- 638 40. Köster EP. The Specific Characteristics of the Sense of Smell. In: Rouby C, Schaal B, Dubois D, Gervais
639 R, Holley A, editors. *Olfaction, Taste, and Cognition*. 1 edition. New York: Cambridge University Press;
640 2002.
- 641 41. Smeets MAM, Dijksterhuis GB. Smelly primes – when olfactory primes do or do not work. *Front Psychol*
642 [Internet]. 2014 Feb 12 [cited 2019 Dec 6];5. Available from:
643 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3921890/>
- 644 42. Komaroff M. For Researchers on Obesity: Historical Review of Extra Body Weight Definitions [Internet].
645 *Journal of Obesity*. 2016 [cited 2018 Sep 13]. Available from:
646 <https://www.hindawi.com/journals/job/2016/2460285/>
- 647 43. Nuttall FQ. Body Mass Index. *Nutr Today*. 2015 May;50(3):117–28.
- 648 44. Dias R, Robbins TW, Roberts AC. Dissociation in prefrontal cortex of affective and attentional shifts.
649 *Nature*. 1996 Mar;380(6569):69–72.
- 650 45. Murphy FC, Sahakian BJ, Rubinsztein JS, Michael A, Rogers RD, Robbins TW, et al. Emotional bias and
651 inhibitory control processes in mania and depression. *Psychol Med*. 1999 Nov;29(6):1307–21.
- 652 46. Mobbs O, Iglesias K, Golay A, Van der Linden M. Cognitive deficits in obese persons with and without
653 binge eating disorder. Investigation using a mental flexibility task. *Appetite*. 2011 Aug;57(1):263–71.
- 654 47. Gomez P, Ratcliff R, Perea M. A Model of the Go/No-Go Task. *J Exp Psychol Gen*. 2007
655 Aug;136(3):389–413.
- 656 48. Blechert J, Lender A, Polk S, Busch NA, Ohla K. Food-Pics_Extended—An Image Database for
657 Experimental Research on Eating and Appetite: Additional Images, Normative Ratings and an Updated
658 Review. *Front Psychol* [Internet]. 2019 [cited 2019 Nov 14];10. Available from:
659 <https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00307/full>
- 660 49. Bezdjian S, Baker LA, Lozano DI, Raine A. Assessing inattention and impulsivity in children during the
661 Go/NoGo task. *Br J Dev Psychol*. 2009 Jun 1;27(2):365–83.
- 662 50. Zimmermann P, Fimm B. Tests d'Évaluation de l'Attention (TAP) - Version 2.3.1. Herzogenrath: Psytest.;
663 2010.
- 664 51. Callahan S, Rousseau A, Knotter A, Bru V, Danel M, Cueto C, et al. [Diagnosing eating disorders:
665 presentation of a new diagnostic test and an initial epidemiological study of eating disorders in
666 adolescents]. *L'Encephale*. 2003;29(3 Pt 1):239–47.
- 667 52. Mintz LB, O'Halloran MS, Mulholland AM, Schneider PA. Questionnaire for Eating Disorder Diagnoses:
668 Reliability and validity of operationalizing DSM—IV criteria into a self-report format. *J Couns Psychol*.
669 1997;44(1):63–79.
- 670 53. Thomas-Danguin T, Rouby C, Sicard G, Vigouroux M, Farget V, Johanson A, et al. Development of the
671 ETOC: a European test of olfactory capabilities. *Rhinology*. 2003 Sep;41(3):142–51.
- 672 54. Meule A. Reporting and Interpreting Task Performance in Go/No-Go Affective Shifting Tasks. *Front*
673 *Psychol* [Internet]. 2017 May 9 [cited 2019 Oct 24];8. Available from:
674 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5422529/>





- 675 55. R Development Core Team. R: A Language and Environment for Statistical Computing [Internet]. Vienna,
676 Austria: R Foundation for Statistical Computing; 2008. Available from: [http://www.r-](http://www.r-project.org%7D%2C/)
677 [project.org%7D%2C/](http://www.r-project.org%7D%2C/)
- 678 56. Pinheiro J, Bates D. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-137
679 [Internet]. R core team; 2018 [cited 2018 Aug 21]. Available from: [https://CRAN.R-](https://CRAN.R-project.org/package=nlme)
680 [project.org/package=nlme](https://CRAN.R-project.org/package=nlme)
- 681 57. Chambers JM, Hastie T. Statistical Models in S. Wadsworth & Brooks/Cole Advanced Books & Software;
682 1992. 630 p.
- 683 58. Kuhn M. contrast: A Collection of Contrast Methods [Internet]. 2016. Available from: [https://CRAN.R-](https://CRAN.R-project.org/package=contrast)
684 [project.org/package=contrast](https://CRAN.R-project.org/package=contrast)
- 685 59. Fergenbaum JH, Bruce S, Lou W, Hanley AJG, Greenwood C, Young TK. Obesity and Lowered
686 Cognitive Performance in a Canadian First Nations Population. *Obesity*. 2009;17(10):1957–63.
- 687 60. Meo SA, Altuwaym AA, Alfallaj RM, Alduraibi KA, Alhamoudi AM, Alghamdi SM, et al. Effect of
688 Obesity on Cognitive Function among School Adolescents: A Cross-Sectional Study. *Obes Facts*.
689 2019;12(2):150–6.
- 690 61. Prickett C, Stolwyk R, O'Brien P, Brennan L. Neuropsychological Functioning in Mid-life Treatment-
691 Seeking Adults with Obesity: a Cross-sectional Study. *Obes Surg*. 2018 Feb 1;28(2):532–40.
- 692 62. de Oca BM, Black AA. Bullets versus burgers: is it threat or relevance that captures attention? *Am J*
693 *Psychol*. 2013;126(3):287–300.
- 694 63. Junghans AF, Evers C, Ridder DTDD. Eat Me If You Can: Cognitive Mechanisms Underlying the
695 Distance Effect. *PLOS ONE*. 2013 déc;8(12):e84643.
- 696 64. Nummenmaa L, Hietanen JK, Calvo MG, Hyönä J. Food Catches the Eye but Not for Everyone: A BMI-
697 Contingent Attentional Bias in Rapid Detection of Nutriment. *PLOS ONE*. 2011 mai;6(5):e19215.
- 698 65. Sawada R, Sato W, Toichi M, Fushiki T. Fat Content Modulates Rapid Detection of Food: A Visual
699 Search Study Using Fast Food and Japanese Diet. *Front Psychol* [Internet]. 2017 Jun 22 [cited 2019 Oct
700 1];8. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5479904/>
- 701 66. Teslovich T, Freidl EK, Kostro K, Weigel J, Davidow JY, Riddle MC, et al. Probing behavioral responses
702 to food: development of a food-specific go/no-go task. *Psychiatry Res*. 2014 Sep 30;219(1):166–70.
- 703 67. Carbine KA, Christensen E, LeCheminant JD, Bailey BW, Tucker LA, Larson MJ. Testing food-related
704 inhibitory control to high and low calorie food stimuli: Electrophysiological responses to high calorie
705 food stimuli predict calorie and carbohydrate intake. *Psychophysiology*. 2017 Jul 1;54(7):982–97.
- 706 68. Frank S, Laharnar N, Kullmann S, Veit R, Canova C, Hegner YL, et al. Processing of food pictures:
707 Influence of hunger, gender and calorie content. *Brain Res*. 2010 Sep 2;1350:159–66.
- 708 69. Smeets E, Roefs A, van Furth E, Jansen A. Attentional bias for body and food in eating disorders:
709 Increased distraction, speeded detection, or both? *Behav Res Ther*. 2008 Feb 1;46(2):229–38.
- 710 70. Wilson C, Wallis DJ. Attentional Bias and Slowed Disengagement from Food and Threat Stimuli in
711 Restrained Eaters Using a Modified Stroop Task. *Cogn Ther Res*. 2013 Feb 1;37(1):127–38.
- 712 71. Deux N, Schlarb AA, Martin F, Holtmann M, Hebebrand J, Legenbauer T. Overweight in adolescent,
713 psychiatric inpatients: A problem of general or food-specific impulsivity? *Appetite*. 2017 01;112:157–66.
- 714 72. Loeber S, Grosshans M, Korucuoglu O, Vollmert C, Vollstädt-Klein S, Schneider S, et al. Impairment of
715 inhibitory control in response to food-associated cues and attentional bias of obese participants and
716 normal-weight controls. *Int J Obes*. 2012 Oct;36(10):1334–9.

- 717 73. Alonso-Alonso M, Woods SC, Pelchat M, Grigson PS, Stice E, Farooqi S, et al. Food reward system:
718 current perspectives and future research needs. *Nutr Rev*. 2015 May;73(5):296–307.
- 719 74. Berridge KC, Kringelbach ML. Pleasure systems in the brain. *Neuron*. 2015 May 6;86(3):646–64.
- 720 75. Joyner MA, Kim S, Gearhardt AN. Investigating an Incentive-Sensitization Model of Eating Behavior:
721 Impact of a Simulated Fast-Food Laboratory. *Clin Psychol Sci*. 2017 Nov 1;5(6):1014–26.
- 722 76. Leleu A. Temporal dynamics of odor integration in the visual categorization of food. 7th European
723 Conference on Sensory and Consumer Research (EuroSense); 2016 Sep 11; Dijon (France).
- 724 77. Posner MI. Orienting of attention. *Q J Exp Psychol*. 1980 Feb 1;32(1):3–25.
- 725 78. Hoffmann-Hensel SM, Sijben R, Rodriguez-Raecke R, Freiherr J. Cognitive Load Alters Neuronal
726 Processing of Food Odors. *Chem Senses*. 2017 Oct 31;42(9):723–36.
- 727 79. Goldstein RZ, Volkow ND. Dysfunction of the prefrontal cortex in addiction: neuroimaging findings and
728 clinical implications. *Nat Rev Neurosci*. 2011 Oct 20;12(11):652–69.
- 729 80. Goldstein RZ, Volkow ND. Drug Addiction and Its Underlying Neurobiological Basis: Neuroimaging
730 Evidence for the Involvement of the Frontal Cortex. *Am J Psychiatry*. 2002 Oct;159(10):1642–52.
- 731 81. Childress AR, Ehrman RN, Wang Z, Li Y, Sciortino N, Hakun J, et al. Prelude to Passion: Limbic
732 Activation by “Unseen” Drug and Sexual Cues. *PLOS ONE*. 2008 Jan 30;3(1):e1506.
- 733 82. Zhang X, Chen X, Yu Y, Sun D, Ma N, He S, et al. Masked smoking-related images modulate brain
734 activity in smokers. *Hum Brain Mapp*. 2009;30(3):896–907.
- 735 83. Paas F, Renkl A, Sweller J. Cognitive Load Theory and Instructional Design: Recent Developments. *Educ*
736 *Psychol*. 2003 Mar 1;38(1):1–4.
- 737 84. Dohle S, Diel K, Hofmann W. Executive functions and the self-regulation of eating behavior: A review.
738 *Appetite*. 2018 01;124:4–9.
- 739 85. Rumiaty RI, Foroni F. We are what we eat: How food is represented in our mind/brain. *Psychon Bull Rev*.
740 2016 Aug 1;23(4):1043–54.
- 741 86. Toet A, Kaneko D, de Kruijff I, Ushiyama S, van Schaik MG, Brouwer A-M, et al. CROCUFID: A Cross-
742 Cultural Food Image Database for Research on Food Elicited Affective Responses. *Front Psychol*
743 [Internet]. 2019 [cited 2019 Dec 6];10. Available from:
744 <https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00058/full>
- 745 87. Doolan KJ, Breslin G, Hanna D, Murphy K, Gallagher AM. Visual attention to food cues in obesity: An
746 eye-tracking study. *Obesity*. 2014;22(12):2501–7.
- 747 88. Wegner DM. Ironic processes of mental control. *Psychol Rev*. 1994;101(1):34–52.
- 748 89. Kim TJ, Knesebeck O von dem. Income and obesity: what is the direction of the relationship? A
749 systematic review and meta-analysis. *BMJ Open* [Internet]. 2018 Jan 1 [cited 2019 Dec 6];8(1). Available
750 from: <https://bmjopen.bmj.com/content/8/1/e019862>
- 751 90. Amiri S, Behnezhad S. Obesity and anxiety symptoms: a systematic review and meta-analysis.
752 *neuropsychiatrie*. 2019 Jun 1;33(2):72–89.
- 753 91. Sarwer DB, Polonsky HM. The Psychosocial Burden of Obesity. *Endocrinol Metab Clin North Am*. 2016
754 Sep 1;45(3):677–88.
- 755 92. Djalalinia S, Qorbani M, Peykari N, Kelishadi R. Health impacts of Obesity. *Pak J Med Sci*.
756 2015;31(1):239–42.

- 757 93. Major B, Hunger JM, Bunyan DP, Miller CT. The ironic effects of weight stigma. *J Exp Soc Psychol.*
758 2014 Mar 1;51:74–80.
- 759 94. Puhl R, Brownell KD. Bias, Discrimination, and Obesity. *Obes Res.* 2001;9(12):788–805.
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Block composition

		50%	50%	Stimuli examples
		FOOD set (F)	OBJECT set (O)	
56%	Food pictures (50% HDE, 50% LDE)	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	 
	Object pictures	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	 
44%				

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

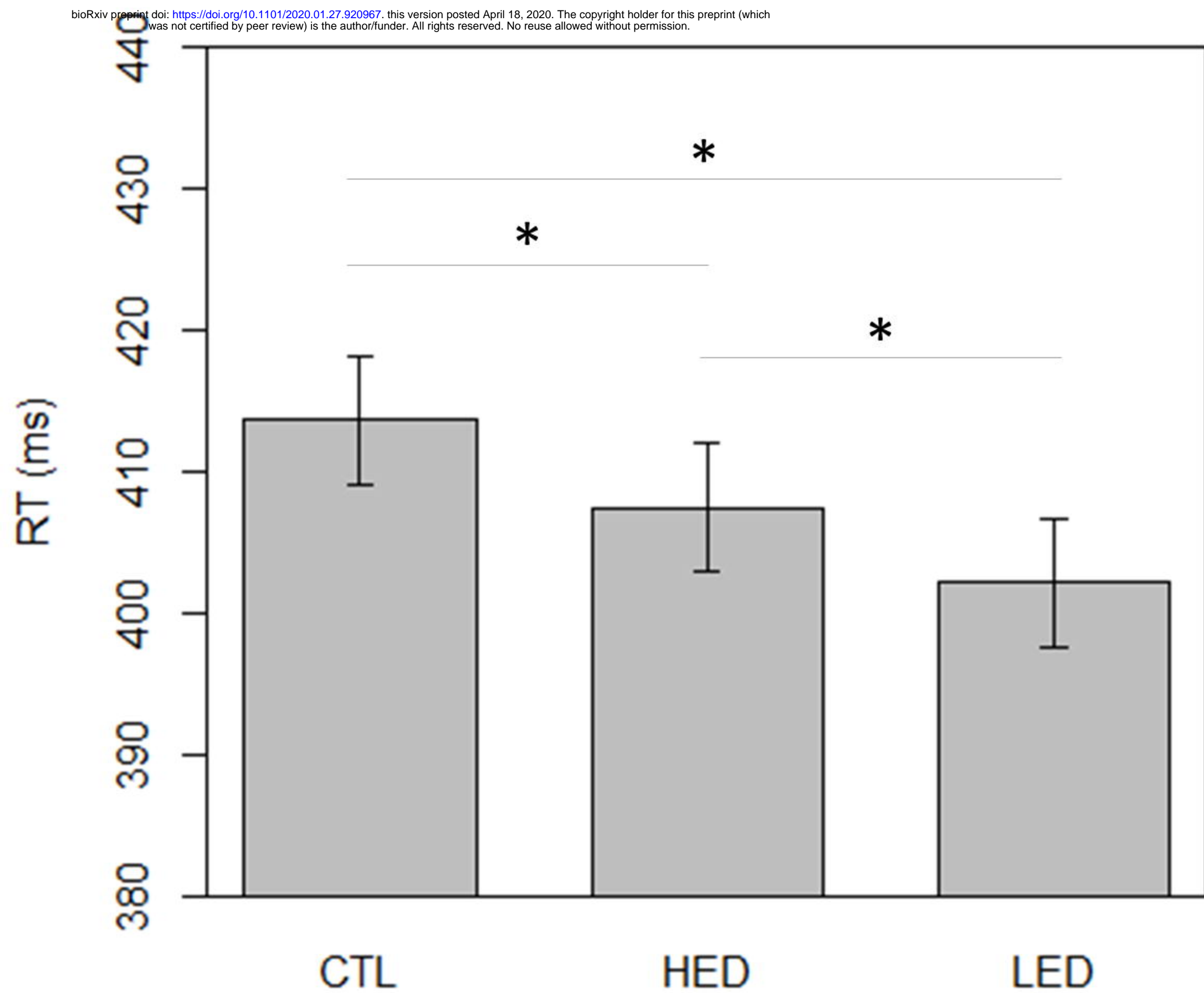
Excluded for presence of eating disorder screened with Q-EDD (n=5)
NW=1, OW=3, OB=1

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

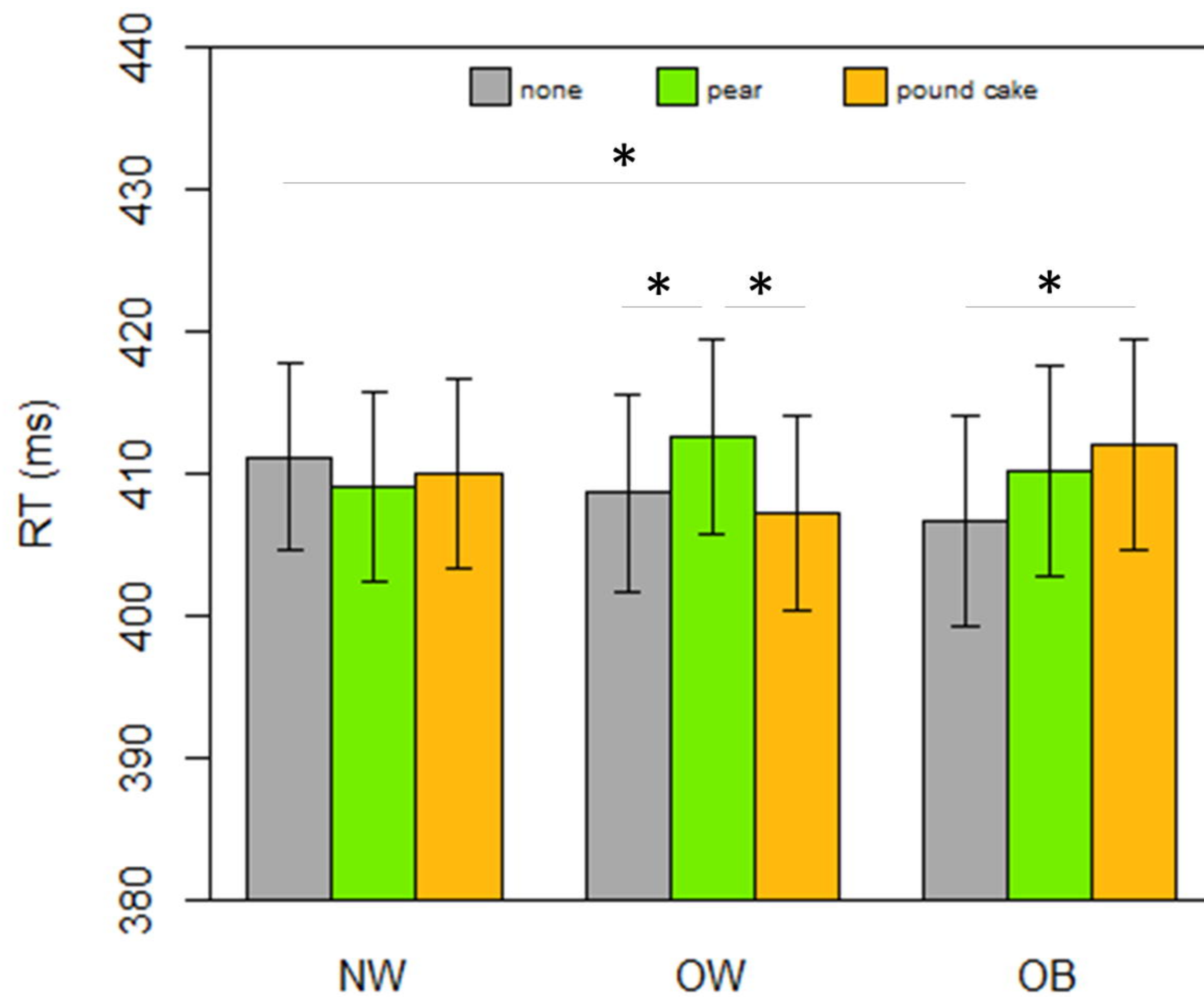
Excluded for missing data in the flexibility subtest (n=1)
OW=1

Included for analysis n=91
NW=31, OW=32, OB=28

RT by stimulus type



RT by olfactory prime type and weight status



**Proportion of commission errors
by stimulus type and cognitive load condition**

