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# Sporadic fasting reduces attentional control without altering overall executive function in a binary classification task

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ABSTRACT

Diets with intermittent fasting are an efficient method for producing clinically significant weight loss and preventing the development of obesity. However, individuals following intermittent fasting must face the difficulty of avoiding eating when experiencing the feeling of hunger. In this study, we investigated which aspects of executive function were affected following a prolonged period of food deprivation in participants that have never previously undergone intermittent fasting. Twenty-six participants with normal weight performed two binary classification tasks (Stop Signal (SST) and Go/NoGo) after either a 12 h fasting or a nonfasting period in separate sessions. We measured their performance in several underlying decision-making processes, such as response inhibition and attentional control. In line with previous studies, our results revealed that decision-making processes to resolve the classification task were unaffected by fasting. Response inhibition, as indexed by the stop signal reaction time in the SST, remained as well unaltered after food deprivation. Rather, we observed a higher error rate in NoGo trials following a fasting period, which was associated with disrupted attentional control. Overall, these results indicate that when a hunger feeling reaches consciousness, it induces deficits over certain aspects of attentional control. Our findings hint at the importance of structured behavioral change strategies to cope with fasting-induced difficulties in attentional control, to help achieve weight management goals through successful self-monitoring of food intake.

## 1. Introduction

Cognition and metabolism interact to create the motivational drive that leads to consummatory eating behaviors [1]. This drive is heightened under food deprivation leading to craving for food consumption, sometimes resulting in compulsive eating behaviors frequently observed in obesity and binge eating disorders. On the one hand, there is extensive evidence both in mice and humans supporting the benefits of food deprivation and caloric restriction in increasing life span [2,3], decrease aging-related learning and memory impairments [4], easing type 2 diabetes symptoms [5] and reducing the risk of cardiovascular disease [6]. Both fasting and calorie restriction have as well widely demonstrated significant weight loss in overweight and obese adults [7]. On the other hand, several studies show that long-term food restriction, depending on the type of intermittent fasting, can negatively impact cognitive function and physical performance [8–10]. Attention is reduced under conditions of thirst [11,12], and intermittent fasting during Ramadan yielded heterogeneous effects on cognitive function in Muslim athletes [13,14]. Other studies found that executive function is impaired following breakfast omission at rest, but improved when practicing physical exercises [15]. Accordingly, impulsivity has been associated with insufficient inhibitory control, and thus with greater difficulties in overruling automatic behaviors evoked by food stimuli, which can turn into an inability to control food intake [16,17]. Converging evidence thus suggests that dysfunctional inhibitory control might be at the root of overeating [18–20].

The role of the inhibitory function in response selection is at the core of formal decision-making models that aim to describe how we decide and select appropriate actions [21]. Diets that incorporate caloric restriction are inherently associated with the appearance of subjective hunger feelings in their practitioners, which may influence on eating behaviors thus making it difficult to overrule inappropriate food

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selection. Some studies addressed the question of how hunger –as a self-reported measurement– affects inhibitory function and found that subjective hunger affected not only inhibitory function related to food consumption but also attentional control [22], especially in obese individuals in which hunger was systematically manipulated [23]. Hunger was associated in one study with higher error rates in a response suppression task, specifically when food-associated stimuli served as distractors. Interestingly, in the same study blood glucose levels were associated with an attentional bias towards food-related cues but not with an impairment in response inhibition [22]. In this vein, there is limited evidence on the effects of blood glucose levels on cognitive performance [24], with only some scarce results suggesting that glucose consumption has a momentary beneficial effect on attentional processes in older adults after a fasting period of 12 h [25].

Overall, accumulating evidence supports a causal role of executive function (e.g., attentional control) in modulating craving for food consumption [26]. As well, there is solid evidence suggesting that humans have a heightened craving for calorie-dense foods, with high doses of fat and sugar [27,28]. It is then reasonable to think that humans may have developed a reliable preference for high-energetic foods, as such preference would be adaptive from an evolutionary perspective [29]. However, preference for high-calorie foods could also turn into craving when the subjective feeling of hunger reaches consciousness. In this regard, several studies have shown the existence of an attentional bias for high-calorie foods prompted under conditions of food deprivation [30–32]. Furthermore, deficits in the inhibitory function were found in obese individuals towards high-calorie food items [33] (but see [34]).

Based on all these premises, we tested in this study whether two executive functions –response inhibition and attentional control– could be altered after following an unusual fasting period. For this purpose, we designed an experiment in which participants performed two executive function tasks in two separate sessions: one following their normal eating habits and another after a fasting period of approximately 12 h. We used two well established paradigms to investigate executive function and response inhibition: the Go/NoGo (GNG) task and the Stop Signal Task (SST) [35]. Poor performance in these two tasks has been already associated with weight gain and obesity prevalence [36,37]. While the inhibitory process engaged in the GNG task is driven by consistent stimulus-response mapping, (i.e., images must be classified as belonging or not to the food category in order to implement the correct response), successful response inhibition in the SST relied on a reactive response suppression process independent of the categorical classification [35]. Therefore, NoGo trials in the GNG task require the constant monitoring of task demands, namely the stimulus-response mapping and maintaining goal-relevant representations, which are more consistent with supervisory attentional processes than with inhibitory function per se.

We hypothesized that fasting would affect inhibitory functions, but not performance in decision-making processes. If we observe a fasting-related alteration of the inhibitory function, we should find larger stop signal reaction time (SSRT) in the SST following a fasting period, especially for high-caloric food images. Alternatively, a higher error rate in NoGo trials of the GNG task following fasting would be indicative of affecting attentional control processes engaged in facilitating food obtention.

## 2. Method

### 2.1. Participants

Thirty-three healthy volunteers participated in the experiment, none of them with a history of neurological deficits or eating disorders, as reported by them and as further stated by the scores obtained with the EDI-2 questionnaire [38]. All participants were students from the Faculty of Psychology of the University of Barcelona and were recruited through advertisement in an institutional website specific for research related purposes. All of them were compensated with a small snack (juice/coffee + preselected sandwich) after finishing the fasting session and were paid 30€ after completing the whole experiment.

A power analysis using G*Power [39] indicated that a sample of 23 participants was sufficient to assess the effect of three within-subjects variables (with a power = 95% and an a-priori alpha set at $p = 0.05$), for a moderate effect size estimate ($\eta_p^2 = 0.06$). Data from 7 participants were discarded because the probability of responding correctly in a stop trial was lower than 0.25 or higher than 0.75 for one or more conditions in the SST [40]. Three participants declared to be on a non-caloric restriction diet supervised by a nutritionist and were considered valid for the purpose of the experiment. All participants in the study provided informed consent as approved by the local ethics committee prior to their participation in each experimental session. Thus, the final sample was composed of 26 participants (24 females; *M* age = 20.8 years; S.D. = 2.3; range: 18–26] with normal body mass index (mean BMI = 22.6; S.D. = 3.1). All of them were paid after completing the experiment.

### 2.2. Stimuli

Three sets of 20 images were selected for the study from the foodcast research image database (FRIDa) [41]. Image sets consisted of familiar pictures of high-calorie food (320.1 kcal (S.D. = 124.3)/100 g), low-calorie food [88.1 Kcal (S.D. = 96.9)/100 g], and office supplies. Both sets of food images contained natural and prepared food. All three sets of images were comparable in terms of size, spatial frequency, brightness, familiarity, typicality, and ambiguity. However, compared with the office supply images, the food images yielded significantly higher values for valence [food = 68.15; office supply = 61.91; $t(19) = 1.985$; $p = 0.054$] and arousal [food = 46.99; office supply = 28.31; $t(19) = 4.48$; $p < 0.001$]. A sound (22050 Hz, 200 msec, 5 msec ramp on and off) was used as a stop signal. Another two sets of 20 images, food, and kitchen supplies were selected following the same procedure, to be used in the practice blocks.

### 2.3. Experimental task

We implemented two commonly used tasks to evaluate executive function and response inhibition: the GNG task and the SST. In both tasks, participants were asked in each trial to classify images as food or nonfood as rapidly and as accurately as possible. In the GNG task, participants were required to proactively refrain from responding only to each target category in separate blocks; whereas in the SST, participants were required to suppress an already initiated response when a stop signal was presented. Furthermore, we manipulated the caloric content of food images in separate blocks to investigate whether a possible altered performance due to fasting was associated with the saliency of the food items, by comparing participants' performance when images corresponded to high- and low-calorie foods.

To control for possible confounders, the same stimuli, number of trials, duration of stimulus presentation, and response pattern were used in both tasks. The images of food and office supplies served as stimuli in both tasks and were presented on a screen (white background), subtending 8.9° of the visual angle. Participants sat in front of a table positioned 45–50 cm below their eyes. Stimuli were presented using Presentation® software (v.0.52, Neurobehavioral Systems, Inc., Berkeley, CA, https://www.neurobs.com), running on Windows XP-32SP3 in an Intel Core-i3 computer, and displayed on a 21" Philips Brilliance 202P4 CRT monitor with a refresh rate of 144 Hz and a resolution of 1024 × 768 pixels. Participants were required in both tasks to respond using left- and right-hand responses with the corresponding index finger, and the response hands were equally frequent and pseudorandomly distributed within each block.

#### 2.3.1. Stop-signal task

In the SST, stimuli were presented one at a time at the center of the

screen, replacing a central fixation cross. In each trial, the stimulus was presented for 500 msec, and the stimulus onset asynchrony (SOA, range: 1100–1500 msec; mean = 1315 msec; S.D. = 118) was fixed across trials and randomized between participants and sessions separately for the Go and Go + Stop trials. The task consisted of 4 blocks of 200 trials, in which 75% of the trials corresponded to Go responses and the other 2 % corresponded to Go + Stop responses. The stop signal was presented following a variable delay after stimulus onset. The stop-signal delay (SSD) was initially set to 250 msec at the beginning of each set of 2 consecutive blocks with different category-response assignments and was adjusted separately for food and nonfood conditions. The SSD was adapted to each participant's behavior by means of a staircase-tracking algorithm [42]. Thus, the SSD was increased or decreased by 25 msec after successful or unsuccessful response inhibition, respectively. Dynamic tracking procedure ensured an overall ratio of p(response|stop-signal) of 0.5 in each participant, regardless of their baseline performance and task instructions.

High-calorie and low-calorie food images were presented in different blocks, and block order and category-response assignment were counterbalanced across participants and sessions. Furthermore, the stimuli presentation was constrained as follows: i) the same image category was not presented in more than three consecutive trials, ii) two consecutive Go + Stop trials never occurred, and iii) the same stimulus was never immediately repeated.

The image category was assigned to right/left responses, and participants were required to classify images accordingly, but to withdraw a response whenever they heard the stop-signal sound, presented through headphones. The category-response pattern was reversed after completing half of the task and notifying participants. To allow participants to rest, short breaks of 15 sec were also included in the task every hundred trials. A practice block of 40 trials was presented prior to the task, with 50% of the trials corresponding Go + Stop trials to guarantee a full proof and a complete understanding of the task at hand. Furthermore, in practice trials only two equally distributed SSD values, 100 and 500 msec, were implemented. The practice block was repeated whenever the percentage of inhibitory errors was larger than 50%, the error in the Go trials was larger than 20%, or the average RT was slower than 700 msec.

#### 2.3.2. Go/NoGo task

In the GNG task one stimulus at a time was presented 2.4 cm on the left or right side of a permanent central fixation cross. In each trial, the stimulus was presented for 500 msec, and the stimulus onset asynchrony (SOA) was fixed across trials (range: 1100–1500 msec; mean = 1315 msec; S.D. = 118) and randomized between participants and sessions separately for the Go and NoGo trials. The task consisted of 8 blocks of 100 trials, in which 75% of the trials corresponded to Go responses and the other 25% corresponded to NoGo responses. In 4 consecutive blocks, food images were assigned as Go and office supplies images as NoGo, and vice versa for the other 4 blocks. Images corresponding to high- and low-calorie foods were presented in different blocks. Category-response assignment and block order were counterbalanced across participants and sessions. Participants responded to the side where images in the category assigned as Go appeared, and were asked to withhold responding to the other category (NoGo condition). The following constraints were introduced in the task: i) no more than three consecutive stimuli appeared on the same side, ii) two consecutive NoGo trials never occurred, and iii) the same stimulus was never immediately repeated.

The category-response assignment was reversed after completing half of the experiment; participants were informed at the time. Short breaks of 15 sec were included in the task every hundred trials to allow participants to rest. Like in the SST, the task always began with the practice block that consisted in 40 trials, with 50% of them corresponding to NoGo to guarantee a full proof and a complete understanding of the task. Finally, the practice block was repeated when the error rate was larger than 30%, or the average reaction time (RT) was longer than 700 msec.

### 2.4. Experimental procedure

Each subject participated in three sessions. In the first session, participants were evaluated for any psychological or eating disorder that could hinder a ~12 h fasting period. Weight and height data were collected from all participants.

Participants then completed 2 experimental sessions that lasted for ~55 min and took place in the morning (~10.30 a.m.). The order of the experimental sessions was counterbalanced across participants, and the intersession intervals were at least one week-long. In the fasting session, participants were asked to refrain from consuming any solid or liquid food other than water after 10.30 p.m. of the previous day; while in the nonfasting session, participants were asked to follow their usual eating habits before participating in the experiment. For each participant, the blood glucose concentration was measured twice, before and after completing the experiment in both experimental sessions using a glucometer (SD Biosensor Inc.), and following a standardized safety protocol [43,44]. Furthermore, the subjective hunger feeling was measured at the beginning of the experimental session using a visual analog rating scale corresponding to a 10 cm line drawn on a sheet of paper with marked intervals from 0 to 10 points, where 0 meant *not hungry at all* and 10 corresponded to *starving*.

### 2.5. Statistical analyses

First, the blood glucose levels and hunger feeling of each participant were subjected to analysis of variance and *t*-tests, respectively, to validate the efficiency of the chosen fasting period. We evaluated participants' executive performance in both tasks by analyzing the measurements of accuracy and reaction times (RT) on correct Go trials. We evaluated these parameters in the SST and the GNG task in separate 2 × 2 × 2 repeated measure analysis of variance (RMANOVA), with within-subject factors *fasting* (fasting vs. nonfasting), *image category* (food vs. nonfood), and *caloric content* (high-calorie vs. low-calorie). An additional analysis comparing RTs on Go trials and unsuccessful stop trials in the SST was conducted to validate the computations of the so-called Stop-Signal RT (SSRT) [40]. SSRT was estimated by means of the integration method [35,45] to measure the effective response inhibition process required for the stop process to occur. We computed SSRT by subtracting the averaged SSD from the $n^{th}$ RT separately for food and nonfood conditions, as well as for high- and low-calorie conditions, where $n$ is equal to the number of RTs in the RT distribution multiplied by the overall p(respond|stop-signal) [46,47]. Importantly, the independent horse-race model predicts that p(respond|stop-signal) will be the same for different conditions even though SSD, go RT distribution and the SSRT may be different, as the p(respond|stop-signal) depends on the relative finishing time of the go and stop processes, rather than their relative starting time [45]. In the context of the independent horse-race model [40], the stop and go processes have to be unrelated to use go RT on no-stop-signal as an estimate of go RTs on stop-signal trials to predict the signal-respond RTs and then, to calculate the SSRT [48].

The effect of fasting on attentional control was evaluated by measuring the percentage of commission errors on NoGo trials in the GNG task. The same 2 × 2 × 2 RMANOVA, with fasting, image category, and caloric content as the variables to study were calculated in line with all previous analysis. All data were log-transformed prior statistical analysis to normalize their distribution [49]. The effect sizes were reported as Cohen's d for *t*-tests and as partial eta-squared values for RMANOVAs.

The modulation of attentional control was further analyzed by fitting the binary data (correct-error) from NoGo trials into a logistic regression model using the lme4 R-package [50]. The factors fasting, image category and caloric content were entered in the model as fixed effects, while

the intercepts for subjects, items, and SOA were entered as random effects. This model was used to evaluate the RMANOVA results with respect to inter-individual and inter-trail random variability. Therefore, this type of analysis has the advantage of incorporating random effects by subjects and items in the same model [51], and in this way all responses (i.e., number of subjects x number of items) are taken into account independently for modeling the data, instead of having different types of averaged scores [52]. The overall fit of each effect was assessed using *p*-values obtained by the likelihood ratio test, comparing the model with the effect against the same model without the effect. The simplest model included image category as a fixed factor and by-items and by-SOAs as random intercepts. The random by-subjects intercept was incorporated into the model when *fasting* was added to the model. The main rationale for choosing hierarchical regression was to evaluate if the fasting factor predicted a better performance on attentional control above and beyond the effect of the rest of the factors in the model. This approach would then let us determine the predictive power that fasting adds to the model.

## 3. Results

### 3.1. Fasting effect on hunger and blood glucose levels

The fasting period implemented in the experiment was effective in modulating both hunger feeling [fasting: M = 7.3; SD = 2.2; nonfasting: M = 3.7; SD = 2.4; $t(25) = 6.3$; $p < 0.001$; $d = 1.56$] and blood glucose levels [fasting: $F(1,25) = 15.2$; $p < 0.001$; $\eta_p^2 = 0.38$; pre-post: $F(1,25) = 8.8$; $p = 0.007$; $\eta_p^2 = 0.26$; fasting x pre-post-experiment *p*-value = 0.8].

### 3.2. SST results

#### 3.2.1. SST RTs results

No difference in RTs were observed for *fasting* [$F(1,25) = 0.138$; $p > 0.7$; $\eta_p^2 = 0.005$], *image category* [$F(1,25) = 0.742$; $p > 0.3$; $\eta_p^2 = 0.029$], or *caloric content* [$F(1,25) = 0.008$; $p > 0.9$; $\eta_p^2 < 0.001$; see Fig. 1 and Table 1].

#### 3.2.2. SST accuracy results

On average and across conditions, accuracy on Go trials reached 87.4% (SD = 9.0). Participants' performance on Go trials was comparable between fasting and nonfasting sessions [$F(1,25) = 3.0$; $p = 0.095$; $\eta_p^2 = 0.101$]. Similarly, no differences were observed as a function of *caloric content* [$F(1,25) = 0.093$; $p > 0.7$; $\eta_p^2 = 0.004$], whereas we found a trend for higher accuracy responding to food images [$F(1,25) = 3.77$; $p = 0.064$; $\eta_p^2 = 0.131$].

#### 3.2.3. SSRT

We began examining different parameters of the SST to validate the correct implementation of the SST task and guarantee that the SSRT could be correctly estimated using the integration method. Thus, as expected based on the tenets of the independent horse-race model, the RTs in erroneous stop trials were faster than in correct Go trials [462 msec (SD = 121) vs. 505 msec (SD = 121); $t(25) = 8.26$; $p < 0.001$; $d = 0.41$]. Likewise, we observed that stopping accuracy was close to 50% (M = 51.6%; SD = 6.7), and that no difference in inhibitory performance was found across conditions.

The analysis of the SSRT revealed that fasting did not modulate participants' inhibitory performance [$F(1,25) = 1.072$; $p > 0.3$; $\eta_p^2 = 0.043$; see Fig. 1]. No effects of image category, caloric content or significant interactions were found (all *p*-values > 0.2).

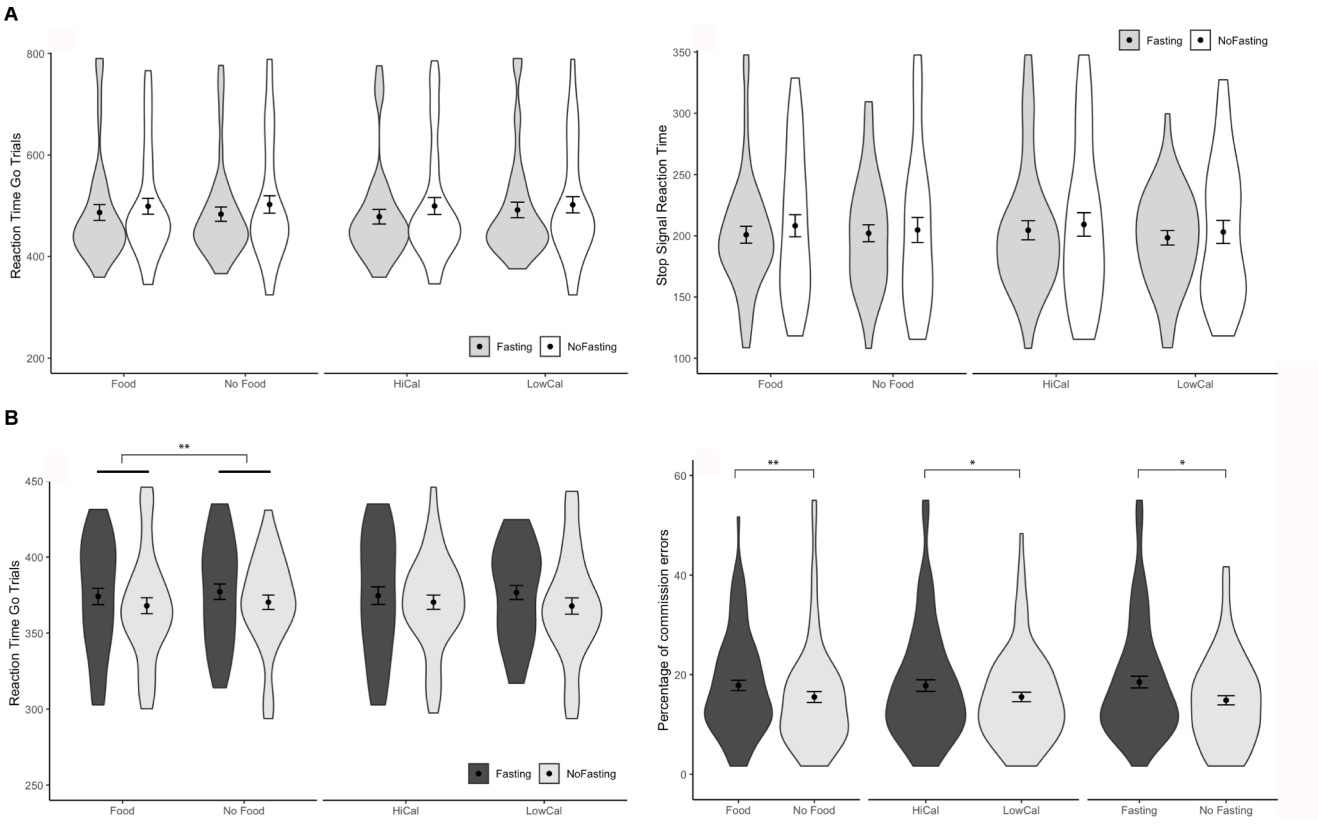


**Fig. 1.** A) Results of the stop signal task (SST) in Go trials for all conditions; reaction times (RTs) are plotted on the upper-left side of the figure, and the stop signal reaction times (SSRTs) is plotted on the upper-right side. B) Results for RTs in the Go/NoGo task (GNG) on Go trials (bottom-left), and for commission errors on NoGo trials (bottom-right). Note that commission errors results are presented separately for the 3 factors, depicting the statistically significant main effect found for *fasting, image category*, and *caloric content*. Asterisk in the figure indicates statistically significant differences (* = *p*-value < 0.05; ** = *p*-value < 0.01).

**Table 1**
Mean values and standard deviations for the *fasting* and *image category* conditions with *low- high-caloric* food in the in the stop signal task (SST). The presented results correspond to the mean accuracy and reaction time (RT) in go trials. The stop signal reaction time (SSRT) was calculated following the integration method.

| | | ***Fasting*** | | | | ***Nonfasting*** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ***Food*** | | ***Nonfood*** | | ***Food*** | | ***Nonfood*** | |
| | | M | S.D. | M | S.D. | M | S.D. | M | S.D. |
| **Accuracy (%) Go trials** | *High-calorie* | 89.5 | 6.8 | 87.9 | 14.3 | 86.3 | 8.1 | 85.8 | 9.2 |
| | *Low-calorie* | 90.8 | 5.1 | 87.3 | 8.4 | 86.9 | 7.6 | 84.4 | 9.5 |
| **RT (msec) Go trials** | *High-calorie* | 499 | 131.4 | 501 | 128.9 | 508 | 124.8 | 512 | 134.4 |
| | *Low-calorie* | 504 | 132.7 | 510 | 134.1 | 501 | 105.0 | 502 | 114.3 |
| **SSRT (msec)** | *High-calorie* | 202 | 47.0 | 209 | 50.7 | 210 | 71.6 | 211 | 70.0 |
| | *Low-calorie* | 191 | 83.3 | 207 | 48.2 | 214 | 76.3 | 216 | 84.4 |

### 3.3. GNG task results

#### 3.3.1. GNG RTs results

RTs were similar in the fasting and nonfasting sessions [$F(1,25) = 0.519$; $p > 0.4$; $\eta_p{}^2 = 0.020$] and for the high- and low-calorie conditions [$F(1,25) = 0.008$; $p > 0.9$; $\eta_p^2 < 0.001$]. However, RTs were faster for the food than for the nonfood condition [373 vs. 381 ms; $F(1,25) = 14.467$; $p = 0.001$; $\eta_p{}^2 = 0.367$]. Again, none of the interactions reached statistical significance (all $p$-values $> 0.1$).

#### 3.3.2. GNG accuracy results

The results of the GNG task are summarized in Fig. 1 and Table 2. Participants' accuracies on Go trials, averaged across conditions, was 99% (SD = 1.3). Accuracy in Go trials was comparable in all conditions [*fasting:* $F(1,25) = 0.473$; $p > 0.4$; $\eta_p{}^2 = 0.019$; *image category:* $F(1,25) = 0.197$; $p = 0.661$; $\eta_p^2 = 0.008$; *caloric content:* $F(1,25) = 1.564$; $p > 0.2$; $\eta_p{}^2 = 0.059$]. None of the interactions reached statistical significance (all $p$-values $> 0.4$).

When considering the error rate in NoGo trials for the analysis, data from two participants was discarded because log-transformed values were not possible to compute as the percentage of commission errors was 0 in some conditions. The obtained results revealed a higher error rate in NoGo trials during the fasting session [fasting: M = 18.4%; SD = 13.4; nonfasting: M = 14.3%; SD = 9.0; $F(1,23) = 8.004$; $p = 0.010$; $\eta_p{}^2 = 0.258$], as well as a main effect of *image category* [$F(1,23) = 8.251$; $p = 0.009$; $\eta_p{}^2 = 0.264$] and *caloric content* [$F(1,25) = 5.293$; $p = 0.031$; $\eta_p{}^2 = 0.187$] (see Fig. 1). None of the interactions reached statistical significance (all $p$-values $> 0.2$).

#### 3.3.3. Logistic regression modeling of NoGo performance

We also tested whether the inter-trial and inter-individual variability influenced the above-mentioned fasting effect on the NoGo condition. For such a purpose, we entered commission errors on NoGo trials into a logistic linear regression model. First, the results indicated that convergence was reached in all models constructed. The estimates of the full model are reported in Table 3. Crucially, the model in which image category and caloric content were assigned as fixed factors was compared with another model in which fasting was added as a fixed factor (see Fig. 2). This comparison revealed an improvement in the model fit [$\chi^2(2) = 91.79$; $p < 0.001$], indicating a clear influence of fasting on attentional control. Specifically, the presence of sporadic fasting reduced the predicted probability for an accurate response inhibition to food items with both high and low caloric content (Fig. 2B).

## 4. Discussion

In the present study we evaluated the influence of fasting on executive function, and more specifically, on response inhibition and attentional control. To that end, we first measured RTs in Go trials of the SST and GNG task to evaluate performance on decision-making processes. Our results revealed that cognitive processes related to decision-making in a binary classification task were not affected by fasting, as pointed out by the absence of a fasting effect on Go trials in both tasks. Secondly, we investigated whether fasting modulated response inhibition and executive attentional control on the SST and GNG tasks. Contrary to our predictions, a 12 h period of food deprivation did not disrupt response inhibition. Instead, fasting reduced participants' attentional control, as indicated by the significant increase in commission errors in NoGo trials in the fasting session. This effect was further validated with a logistic regression model which demonstrated a significant improvement of the fit when fasting was included in the model. Furthermore, the rate of commission errors was larger for food than for nonfood images, as well as for high- compared to low-calorie food images. Taken together, our findings suggest that neither decision-making processes nor response inhibition were altered by fasting. However, it seems that fasting causes a general disturbance of executive attentional control which enhances the underlying attentional bias toward food cues that has been usually observed in other studies [53–56], possibly related to difficulties in disengaging sustained attention from the predominant stimulus-response mapping.

The effects of intermittent fasting on executive function have been scarcely explored, but several studies have associated the hunger feeling

**Table 2**
Mean values and standard deviations for the fasting and image category conditions with low- high-caloric food in the Go-Nogo (GNG) task. The presented results correspond to the mean accuracy and reaction time (RT) in Go trials. Mean percentage of commission errors for Nogo trials is also presented and correspond to the measurement of attentional-control in this task.

| | | ***Fasting*** | | | | ***Nonfasting*** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ***Food*** | | ***Nonfood*** | | ***Food*** | | ***Nonfood*** | |
| | | M | S.D. | M | S.D. | M | S.D. | M | S.D. |
| **Accuracy (%) Go trials** | *High-calorie* | 98.4 | 3.9 | 98.9 | 1.2 | 99.0 | 3.2 | 99.0 | 3.2 |
| | *Low-calorie* | 99.2 | 1.3 | 99.2 | 1.3 | 99.5 | 0.6 | 99.4 | 1.2 |
| **RT (msec) Go trials** | *High-calorie* | 374 | 44.0 | 382 | 43.5 | 369 | 30.5 | 381 | 43.6 |
| | *Low-calorie* | 380 | 36.8 | 380 | 36.8 | 367 | 39.4 | 381 | 41.0 |
| **Commission errors (%) NoGo trials** | *High-calorie* | 23.7 | 15.3 | 17.6 | 13.5 | 17.8 | 10.4 | 14.3 | 8.6 |
| | *Low-calorie* | 20.1 | 12.8 | 16.8 | 11.2 | 13.9 | 7.5 | 13.4 | 8.9 |

**Table 3**
Comparison of mixed logistic regression models.

| | **Model 1** *image category* | | | | **Model 2** *Image cat. + caloric-content* | | | | **Model 3** *Image cat + caloric-cont. + Fasting* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random effects | *Variance* | | *SD* | | *Variance* | | *SD* | | *Variance* | | *SD* | |
| **Item** | 0.184 | | 0.43 | | 0.178 | | 0.42 | | 0.183 | | 0.43 | |
| **ITI** | 0.5 | | 0.7 | | 0.5 | | 0.7 | | 0.191 | | 0.44 | |
| **Participant** | - | | - | | - | | - | | 0.306 | | 0.55 | |
| Fixed effects | *Estimate* | *SE* | *z-value* | *p-value* | *Estimate* | *SE* | *z-value* | *p-value* | *Estimate* | *SE* | *t- value* | *p-value* |
| **(Intercept)** | 1.67 | 0.15 | 10.86 | <2e-16 | 1.67 | 0.15 | 10.89 | <2e-16 | 1.75 | 0.16 | 11.04 | < 2e-16 |
| **Food/Nonfood** | 0.14 | 0.06 | 2.18 | **0.029** | 0.14 | 0.06 | 2.21 | **0.027** | 0.14 | 0.06 | 2.14 | **0.027** |
| **Caloric content** | - | - | - | - | 0.05 | 0.03 | 1.48 | 0.14 | 0.05 | 0.03 | 1.48 | 0.14 |
| **Fasting** | - | - | - | - | - | - | - | - | 0.11 | 0.05 | 2.08 | **0.038** |

| | **Model fit criteria** | | **LRT** | |
|---|---|---|---|---|
| MODEL | *AIC* | *BIC* | *Chi-sq* | *df* | *p-val* |
| **Model 1 vs Model 2** | 9944.7 vs 9944.5 | 9974.1 vs 9981.3 | 2.16 | 1 | 0.14 |
| **Model 1 vs Model 3** | 9944.7 vs **9856.7** | 9974.1 vs **9908.2** | 93.95 | 3 | **3.1e-20** |
| **Model 2 vs Model 3** | 9944.5 vs **9856.7** | 9981.3 vs **9908.2** | 91.79 | 2 | **1.17e-20** |

caused by food deprivation with self-control disruption of the inhibitory function [22,23,57,58]. Similarly, a poorer inhibitory control has been associated with high-sensitivity for food cues [59,60]. Nevertheless, studies that have investigated the role of response inhibition training on food consummatory behaviors have implicated attentional control rather than response inhibition as a key cognitive process in regulating food intake. Two recent meta-analyses reported relevant effects of inhibitory training on food consumption, larger for the GNG task than for the SST [61,62], suggesting a distinctive cognitive process underlying these two tasks and indicating that training may promote an improvement in adjusting stimulus-response mapping rather than overriding responses. Numerous studies support the notion that GNG task is tightly associated to sustained attention-to-response, since GNG requires action restraint rather than action cancellation [63–66]. Therefore, our findings suggest that optimizing attentional control instead of response inhibition might be a pivotal strategy to cope with the adverse effects derived from diets that involve food deprivation. Similarly, the results we obtained here support the hypothesis that hunger affects self-control, but not response inhibition per se.

Executive attentional control regarding food-related cues might be a cognitive component intrinsically related to the motivational drive to eat, initiated as a metabolic reaction to an energy deficit when food deprivation persists over time. It has been proposed that food deprivation enhances later processing stages related to stimulus recognition and focused attention of food stimuli [67,68]. In a similar vein, it has been postulated that attention is primarily driven by motivation in natural environments [69]. Thus, one could argue that food-related stimuli must become the focus of attention to implement the behaviors required for restoring energy balance. This view has been supported by electrophysiological evidence such that modulations in early and later time processing windows specific for food pictures under fasting conditions [67]. From this perspective, it could be stated that food deprivation may facilitate bottom-up attentional processes toward food cues, as evidenced by the attentional bias typically observed for food-related cues, as well as an enhanced sustained attentional for food items, which might explain the difficulties for disengaging attention from food stimuli.

It has been hypothesized that a motivational drive is manifested as an increased hedonic value and an incentive salience [70] for primary and conditioned food cues [71]. Under this framework, it could be argued that the inhibitory function is an unnecessary executive function for controlling energy balance [72] and that optimizing attentional monitoring and detection would be sufficient for reaching adequate proactive control of food intake [73–75]. This hypothesis is consistent with our findings of a disruption in attentional control for withholding inappropriate task responses, which we observed in addition to an enhanced attentional bias toward food and high-caloric items [30,76,77]. Thus, food representations are thought to trigger a motivational drive to eat –accompanied by a subjective feeling of hunger– instigated by fasting. However, it has been observed that the hunger feeling can drastically be reduced or even abolished over time in individuals undergoing diets that incorporate intermittent fasting [78,79]. Similarly, a clear distinction between hunger and motivation to eat has been shown in individuals with obesity exhibiting a behavioral food cue reactivity in the absence of hunger [80].

A promising dietary strategy to prevent the development of obesity as well as to aid losing weight has been shown in the form of intermittent fasting [81–83] and caloric restriction [84,85]. However, individuals following such a diet might face the difficulty to avoid or regulate food intake when the feeling of hunger turns into craving, and consequently, self-control becomes difficult to achieve [58,86]. The interest in diets that implement some type of caloric restriction or intermittent fasting has arisen in recent years, with numerous studies highlighting their beneficial effects in health and quality of life [6]. However, the risk that those diets could drive to maladaptive eating behaviors emphasizes the need to consider the prevention of compulsive consummatory or binge eating behaviors [87]. Diets including food restriction should consider implementing strategies to deal with possible failures of self-control and attentional processes that contribute to food craving and ultimately, lead to compulsive consummatory behaviors. In fact, several studies have pointed out the psychological impact of dieting, then advising for an individualized and careful balance of the risks and benefits [88,89]. Therefore, understanding the behavioral patterns that derive from a metabolic deficit is crucial to develop effective dietary plans to control and restrict food consumption.

This study presents some limitations that deserve further discussion. Although we have provided supporting evidence of the impact of sporadic fasting in attentional control, our study lacks a properly balanced gender ratio. Our sample was composed of healthy normal-weight individuals, but males were underrepresented. Tentatively, the inclusion of a well-powered and gender-balanced sample in future studies would be needed to unveil potential gender-specific effects of fasting on executive function. Moreover, another limitation is that our study exclusively evaluates the impact of a certain, sporadic type of fasting. Future research is warranted to assess fasting effects with populations for whom food deprivation represents by no means an exceptional phenomenon, but rather a frequent one. This is deeply rooted in training effects previously observed on attention [90].

## 5. Conclusions

We employed two extensively used paradigms in executive function to evaluate the effect of sporadic fasting on decision-making related

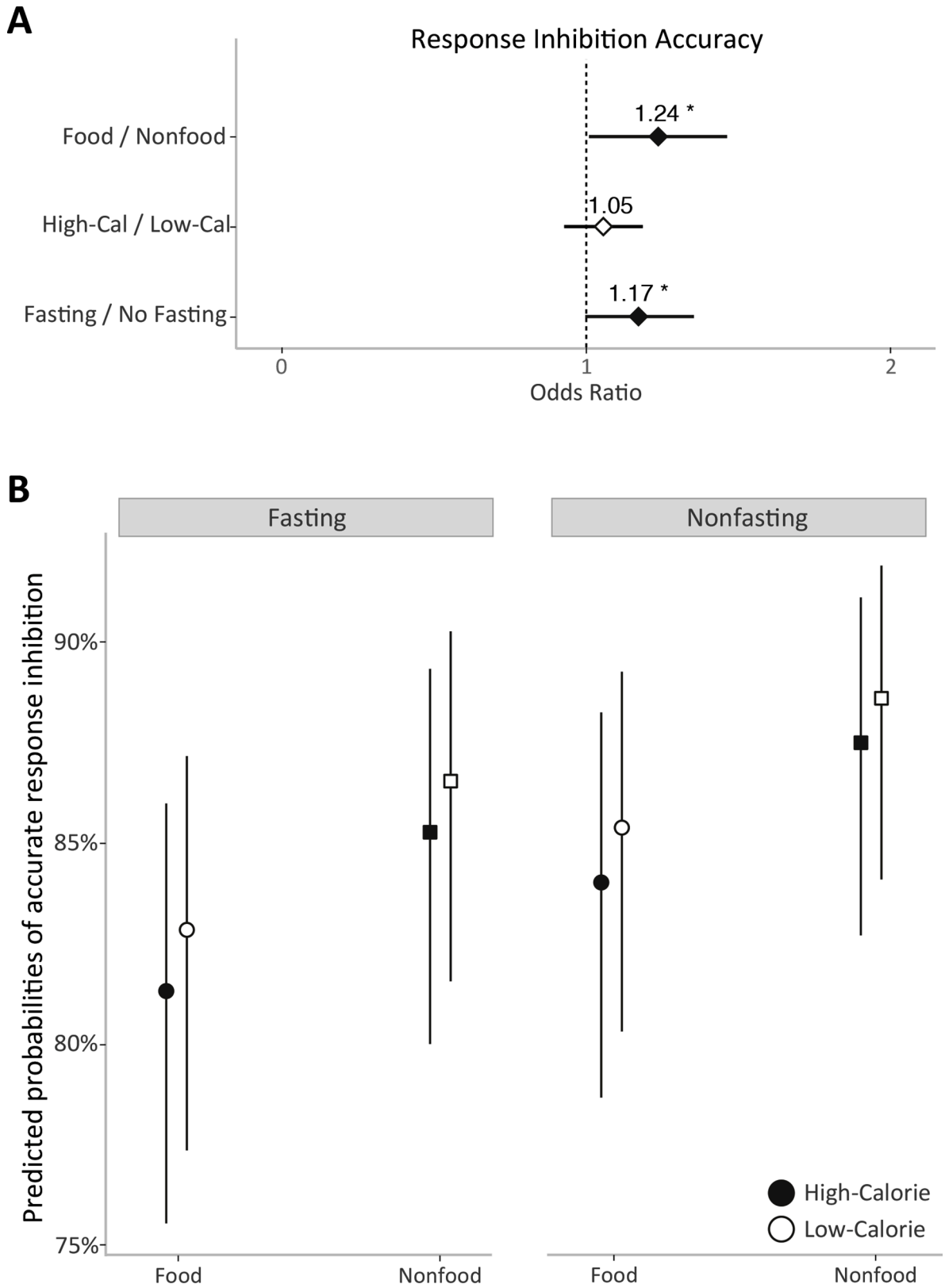


**Fig. 2.** A) Forest plot of the odds ratios for all fixed factors (*image category*, *caloric content* and *fasting*) of the mixed effects logistic regression that fits the accuracy of NoGo trials in the GNG task. Error bars represent 95% confidence intervals. B) Percentages of accuracy in NoGo trials predicted by the mixed effects logistic regression for each image category (food in circles, nonfood in squares) and caloric content (high-calorie in black, low-calorie in white) under *fasting* and *nonfasting* conditions. Error bars represent 95% confidence intervals.

processes, response inhibition, and attentional control. In line with previous studies, our results showed that fasting did not affect either participant's performance in the binary classification task or their inhibitory function as measured in a response inhibition task. However, we did observe that fasting disrupted attentional control processes implicated in alternating stimulus-response mapping, monitoring task demands and maintaining goal-relevant representations. While diets that incorporate intermittent fasting seem to effectively improve several relevant markers of metabolic health, it is noteworthy that dieters will inevitably face self-control difficulties when confronting the hunger feeling caused by food deprivation, putting them at risk to develop compulsive eating behaviors.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on request.

## Data availability

Data will be made available on request.

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## References

[1] H. Zheng, H.-R.R. Berthoud, Neural systems controlling the drive to eat: mind versus metabolism, Physiology 23 (2008) 75–83, https://doi.org/10.1152/physiol.00047.2007.
[2] E.J. Masoro, B.P. Yu, H.A. Bertrand, Action of food restriction in delaying the aging process, Proc. Natl. Acad. Sci. U. S. A. 79 (1982) 4239–4241, https://doi.org/10.1073/pnas.79.13.4239.
[3] R.J. Colman, R.M. Anderson, S.C. Johnson, E.K. Kastman, K.J. Kosmatka, T. M. Beasley, D.B. Allison, C. Cruzen, H.A. Simmons, J.W. Kemnitz, R. Weindruch, Caloric restriction delays disease onset and mortality in rhesus monkeys, Science (80-.) 325 (2009) 201–204, https://doi.org/10.1126/science.1173635.
[4] D.K. Ingram, R. Weindruch, E.L. Spangler, J.R. Freeman, R.L. Walford, Dietary restriction benefits learning and motor performance of aged mice, J. Gerontol 42 (1987) 78–81, https://doi.org/10.1093/geronj/42.1.78.
[5] Z. Liu, X. Dai, H. Zhang, R. Shi, Y. Hui, X. Jin, W. Zhang, L. Wang, Q. Wang, D. Wang, J. Wang, X. Tan, B. Ren, X. Liu, T. Zhao, J. Wang, J. Pan, T. Yuan, C. Chu, L. Lan, F. Yin, E. Cadenas, L. Shi, S. Zhao, X. Liu, Gut microbiota mediates intermittent-fasting alleviation of diabetes-induced cognitive impairment, Nat. Commun. 11 (2020), https://doi.org/10.1038/s41467-020-14676-4.
[6] R. de Cabo, M.P. Mattson, Effects of intermittent fasting on health, aging, and disease, N. Engl. J. Med. 381 (2019) 2541–2551, https://doi.org/10.1056/nejmra1905136.
[7] M. Harvie, A. Howell, Potential benefits and harms of intermittent energy restriction and intermittent fasting amongst obese, overweight and normal weight subjects-a narrative review of human and animal evidence, Behav. Sci. (Basel). 7 (2017), https://doi.org/10.3390/bs7010004.
[8] P.J. Rogers, M.W. Green, Dieting, dietary restraint and cognitive performance, Br. J. Clin. Psychol. 32 (1993) 113–116, https://doi.org/10.1111/j.2044-8260.1993.tb01034.x.
[9] E.M. Benau, N.C. Orloff, E.A. Janke, L. Serpell, C.A. Timko, A systematic review of the effects of experimental fasting on cognition, Appetite 77 (2014) 52–61, https://doi.org/10.1016/j.appet.2014.02.014.
[10] E.M. Benau, A. Makara, N.C. Orloff, E. Benner, L. Serpell, C.A. Timko, How does fasting affect cognition? An updated systematic review (2013–2020), Curr. Nutr. Rep. 10 (2021) 376–390, https://doi.org/10.1007/s13668-021-00370-4.
[11] C.J. Edmonds, R. Crombie, M.R. Gardner, Subjective thirst moderates changes in speed of responding associated with water consumption, Front. Hum. Neurosci. 7 (2013) 1–8, https://doi.org/10.3389/fnhum.2013.00363.
[12] S.K. Riebl, B.M. Davy, The hydration equation: update on water balance and cognitive performance, ACSMs. Health Fit. J. 17 (2013) 21–28, https://doi.org/10.1249/FIT.0b013e3182a9570f.
[13] H.H. Tian, A.R. Aziz, W. Png, M.F. Wahid, D. Yeo, A.L.C. Png, Effects of fasting during Ramadan month on cognitive function in Muslim athletes, Asian J. Sports Med. 2 (2011) 145–153, https://doi.org/10.5812/asjsm.34753.
[14] A. Cherif, B. Roelands, R. Meeusen, K. Chamari, Effects of intermittent fasting, caloric restriction, and Ramadan intermittent fasting on cognitive performance at rest and during exercise in adults, Sport. Med. 46 (2016) 35–47, https://doi.org/10.1007/s40279-015-0408-6.
[15] T. Komiyama, M. Sudo, N. Okuda, T. Yasuno, A. Kiyonaga, H. Tanaka, Y. Higaki, S. Ando, Cognitive function at rest and during exercise following breakfast omission, Physiol. Behav. 157 (2016) 178–184, https://doi.org/10.1016/j.physbeh.2016.02.013.
[16] M.R. Lowe, Self-regulation of energy intake in the prevention and treatment of obesity: is it feasible? Obes. Res. 11 (2003) https://doi.org/10.1038/oby.2003.223.
[17] C. Nederkoorn, K. Houben, W. Hofmann, A. Roefs, A. Jansen, Control yourself or just eat what you like? Weight gain over a year is predicted by an interactive effect of response inhibition and implicit preference for snack foods, Heal. Psychol. 29 (2010) 389–393, https://doi.org/10.1037/a0019921.
[18] L. Claes, C. Nederkoorn, W. Vandereycken, R. Guerrieri, H. Vertommen, Impulsiveness and lack of inhibitory control in eating disorders, Eat. Behav. 7 (2006) 196–203, https://doi.org/10.1016/j.eatbeh.2006.05.001.
[19] R. Guerrieri, C. Nederkoorn, K. Stankiewicz, H. Alberts, N. Geschwind, C. Martijn, A. Jansen, The influence of trait and induced state impulsivity on food intake in normal-weight healthy women, Appetite 49 (2007) 66–73, https://doi.org/10.1016/j.appet.2006.11.008.
[20] C. Nederkoorn, F.T.Y. Smulders, R.C. Havermans, A. Roefs, A. Jansen, Impulsivity in obese women, Appetite 47 (2006) 253–256, https://doi.org/10.1016/j.appet.2006.05.008.
[21] R. Bogacz, E. Brown, J. Moehlis, P. Holmes, J.D. Cohen, The physics of optimal decision making: a formal analysis of models of performance in two-alternative forced-choice tasks, Psychol. Rev. 113 (2006) 700–765, https://doi.org/10.1037/0033-295X.113.4.700.
[22] S. Loeber, M. Grosshans, S. Herpertz, F. Kiefer, S.C. Herpertz, Hunger modulates behavioral disinhibition and attention allocation to food-associated cues in normal-weight controls, Appetite 71 (2013) 32–39, https://doi.org/10.1016/j.appet.2013.07.008.
[23] I. Kollei, M. Rustemeier, S. Schroeder, S. Jongen, S. Herpertz, S. Loeber, Cognitive control functions in individuals with obesity with and without binge-eating disorder, Int. J. Eat. Disord. 51 (2018) 233–240, https://doi.org/10.1002/eat.22824.
[24] C.R. García, C. Piernas, A. Martínez-Rodríguez, J.J. Hernández-Morante, Effect of glucose and sucrose on cognition in healthy humans: a systematic review and meta-analysis of interventional studies, Nutr. Rev. 79 (2021) 171–187, https://doi.org/10.1093/nutrit/nuaa036.
[25] C. Gagnon, C.E. Greenwood, L. Bherer, The acute effects of glucose ingestion on attentional control in fasting healthy older adults, Psychopharmacology (Berl) 211 (2010) 337–346, https://doi.org/10.1007/s00213-010-1905-9.
[26] P.A. Hall, Executive-control processes in high-calorie food consumption, Curr. Dir. Psychol. Sci. 25 (2016) 91–98, https://doi.org/10.1177/0963721415625049.
[27] P. Hall, B. Tran, C. Lowe, C. Vincent, M. Mourtzakis, T. Liu-Ambrose, H. Prapavessis, Y. Gidron, Expression of executive control in situational context: effects of facilitating versus restraining cues on snack food consumption, Heal. Psychol. 34 (2015) 539–546, https://doi.org/10.1037/hea0000134.
[28] C.J. Lowe, P.A. Hall, W.R. Staines, The effects of continuous theta burst stimulation to the left dorsolateral prefrontal cortex on executive function, food cravings, and snack food consumption, Psychosom. Med. 76 (2014) 503–511, https://doi.org/10.1097/PSY.0000000000000090.
[29] P.A.S. Breslin, An evolutionary perspective on food and human taste, Curr. Biol. 23 (2013) R409–R418, https://doi.org/10.1016/j.cub.2013.04.010.
[30] C.A. Cunningham, H.E. Egeth, The capture of attention by entirely irrelevant pictures of calorie-dense foods, Psychon. Bull. Rev. 25 (2018) 586–595, https://doi.org/10.3758/s13423-017-1375-8.
[31] M. Lee, J.H. Lee, Automatic attentional bias toward high-calorie food cues and body shape concerns in individuals with a high level of weight suppression: preliminary findings, Eat. Behav. 40 (2021), 101471, https://doi.org/10.1016/j.eatbeh.2020.101471.
[32] L.F. Van Dillen, E.K. Papies, W. Hofmann, Turning a blind eye to temptation: how cognitive load can facilitate self-regulation, J. Pers. Soc. Psychol. 104 (2013) 427–443, https://doi.org/10.1037/a0031262.
[33] G. Gerdan, M. Kurt, Response inhibition according to the stimulus and food type in exogenous obesity, Appetite 150 (2020), 104651, https://doi.org/10.1016/j.appet.2020.104651.
[34] Z. Lyu, P. Zheng, H. Chen, T. Jackson, Approach and inhibition responses to external food cues among average-weight women who binge eat and weight-matched controls, Appetite 108 (2017) 367–374, https://doi.org/10.1016/j.appet.2016.10.025.
[35] F. Verbruggen, G.D. Logan, Models of response inhibition in the stop-signal and stop-change paradigms, Neurosci. Biobehav. Rev. 33 (2009) 647–661, https://doi.org/10.1016/j.neubiorev.2008.08.014.
[36] L. Lavagnino, D. Arnone, B. Cao, J.C. Soares, S. Selvaraj, Inhibitory control in obesity and binge eating disorder: a systematic review and meta-analysis of neurocognitive and neuroimaging studies, Neurosci. Biobehav. Rev. 68 (2016) 714–726, https://doi.org/10.1016/j.neubiorev.2016.06.041.
[37] Y. Yang, G.S. Shields, C. Guo, Y. Liu, Executive function performance in obesity and overweight individuals: a meta-analysis and review, Neurosci. Biobehav. Rev. 84 (2018) 225–244, https://doi.org/10.1016/j.neubiorev.2017.11.020.
[38] B. Seibt, M. Häfner, R. Deutsch, Prepared to eat: How immediate affective and motivational responses to food cues are influenced by food deprivation, Eur. J. Soc. Psychol. 37 (2007) 359–379, https://doi.org/10.1002/ejsp.365.

[39] E. Erdfelder, F. Faul, A. Buchner, A.G. Lang, Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses, Behav. Res. Methods. 41 (2009) 1149–1160, https://doi.org/10.3758/BRM.41.4.1149.
[40] F. Verbruggen, A.R. Aron, G.P.H. Band, C. Beste, P.G. Bissett, A.T. Brockett, J. W. Brown, S.R. Chamberlain, C.D. Chambers, H. Colonius, L.S. Colzato, B. D. Corneil, J.P. Coxon, A. Dupuis, D.M. Eagle, H. Garavan, I. Greenhouse, A. Heathcote, R.J. Huster, S. Jahfari, J.L. Kenemans, I. Leunissen, C.S.R. Li, G. D. Logan, D. Matzke, S. Morein-Zamir, A. Murthy, M. Paré, R.A. Poldrack, K. R. Ridderinkhof, T.W. Robbins, M. Roesch, K. Rubia, R.J. Schachar, J.D. Schall, A. K. Stock, N.C. Swann, K.N. Thakkar, M.W. Van Der Molen, L. Vermeylen, M. Vink, J.R. Wessel, R. Whelan, B.B. Zandbelt, C.N. Boehler, A consensus guide to capturing the ability to inhibit actions and impulsive behaviors in the stop-signal task, Elife 8 (2019) 1–26, https://doi.org/10.7554/eLife.46323.
[41] F. Foroni, G. Pergola, G. Argiris, R.I. Rumiati, The FoodCast research image database (FRIDa), Front. Hum. Neurosci. 7 (2013) 1–19, https://doi.org/10.3389/fnhum.2013.00051.
[42] G.D. Logan, R.J. Schachar, R. Tannock, Impulsivity and inhibitory control, Psychol. Sci. 8 (1997) 60–64, https://doi.org/10.1111/j.1467-9280.1997.tb00545.x.
[43] D.C. Klonoff, Improving the safety of blood glucose monitoring, J. Diabetes Sci. Technol. 5 (2011) 1307–1311, https://doi.org/10.1177/193229681100500601.
[44] Infection prevention during blood glucose monitoring and insulin administration, Centers Dis. Control Prev. (n.d.). https://www.cdc.gov/injectionsafety/blood-glucose-monitoring.html (accessed June 27, 2019).
[45] G.D. Logan, W.B. Cowan, On the ability to inhibit thought and action: a theory of an act of control, Psychol. Rev. 91 (1984) 295–327, https://doi.org/10.1037/a0035230.
[46] G.D. Logan, Attention, automaticity, and the ability to stop a speeded choice response, L.J. & B.A. D., in: Atten. Perform. IX, Hillsdale, NJ, 1981, pp. 205–222.
[47] T. Cunillera, L. Fuentemilla, D. Brignani, D. Cucurell, C. Miniussi, A simultaneous modulation of reactive and proactive inhibition processes by anodal tDCS on the right inferior frontal cortex, PLoS One 9 (2014), https://doi.org/10.1371/journal.pone.0113537.
[48] F. Verbruggen, G.D. Logan, Control in response inhibition, in: Wiley Handb. Cogn. Control, 2017: pp. 97–110. https://doi.org/https://doi.org/10.1002/9781118920497.ch6.
[49] R. Ratcliff, Methods for dealing with response time outliers, Psychol. Bull. 114 (1993) 510–532.
[50] D. Bates, M. Mächler, B.M. Bolker, S.C. Walker, Fitting linear mixed-effects models using lme4, J. Stat. Softw. 67 (2015), https://doi.org/10.18637/jss.v067.i01.
[51] K.I. Forster, R.G. Dickinson, More on the language-as-fixed-effect fallacy: Monte Carlo estimates of error rates for F1,F2,F′, and min F′, J. Verbal Learn. Verbal Behav. 15 (1976) 135–142, https://doi.org/10.1016/0022-5371(76)90014-1.
[52] R. Kliegl, P. Wei, M. Dambacher, M. Yan, X. Zhou, Experimental effects and individual differences in linear mixed models: estimating the relationship between spatial, object, and attraction effects in visual attention, Front. Psychol. 1 (2011) 1–12, https://doi.org/10.3389/fpsyg.2010.00238.
[53] E.H. Castellanos, E. Charboneau, M.S. Dietrich, S. Park, B.P. Bradley, K. Mogg, R. L. Cowan, Obese adults have visual attention bias for food cue images: evidence for altered reward system function, Int. J. Obes. 33 (2009) 1063–1073, https://doi.org/10.1038/ijo.2009.138.
[54] I.M.T. Nijs, I.H.A. Franken, P. Muris, Enhanced processing of food-related pictures in female external eaters, Appetite 53 (2009) 376–383, https://doi.org/10.1016/j.appet.2009.07.022.
[55] C.A. Forestell, P. Lau, I.I. Gyurovski, C.L. Dickter, S.S. Haque, Attentional biases to foods: the effects of caloric content and cognitive restraint, Appetite 59 (2012) 748–754, https://doi.org/10.1016/j.appet.2012.07.006.
[56] K. Mogg, B.P. Bradley, H. Hyare, S. Lee, Selective attention to food-related stimuli in hunger: are attentional biases specific to emotional and psychopathological states, or are they also found in normal drive states? Behav. Res. Ther. 36 (1998) 227–237, https://doi.org/10.1016/S0005-7967(97)00062-4.
[57] C. Nederkoorn, F.C.M. Dassen, L. Franken, C. Resch, K. Houben, Impulsivity and overeating in children in the absence and presence of hunger, Appetite 93 (2015) 57–61, https://doi.org/10.1016/j.appet.2015.03.032.
[58] E.C. Standen, T. Mann, Calorie deprivation impairs the self-control of eating, but not of other behaviors, Psychol. Heal. 0 (2021) 1–15, https://doi.org/10.1080/08870446.2021.1934469.
[59] R. Guerrieri, C. Nederkoorn, A. Jansen, How impulsiveness and variety influence food intake in a sample of healthy women, Appetite 48 (2007) 119–122, https://doi.org/10.1016/j.appet.2006.06.004.
[60] C. Nederkoorn, Effects of sales promotions, weight status, and impulsivity on purchases in a supermarket, Obesity 22 (2014) E2–E5, https://doi.org/10.1002/oby.20621.
[61] V. Allom, B. Mullan, M. Hagger, Does inhibitory control training improve health behaviour? A meta-analysis, Health Psychol. Rev. 10 (2016) 168–186, https://doi.org/10.1080/17437199.2015.1051078.
[62] A. Jones, L.C.G. Di Lemma, E. Robinson, P. Christiansen, S. Nolan, C. Tudur-Smith, M. Field, Inhibitory control training for appetitive behaviour change: a meta-analytic investigation of mechanisms of action and moderators of effectiveness, Appetite 97 (2016) 16–28, https://doi.org/10.1016/j.appet.2015.11.013.
[63] A. Bari, T.W. Robbins, Inhibition and impulsivity: behavioral and neural basis of response control, Prog. Neurobiol. 108 (2013) 44–79, https://doi.org/10.1016/j.pneurobio.2013.06.005.
[64] D.M. Eagle, A. Bari, T.W. Robbins, The neuropsychopharmacology of action inhibition: cross-species translation of the stop-signal and go/no-go tasks, Psychopharmacology (Berl) 199 (2008) 439–456, https://doi.org/10.1007/s00213-008-1127-6.
[65] R. Littman, Á. Takács, Do all inhibitions act alike? A study of go/no-go and stop-signal paradigms, PLoS ONE 12 (2017) 1–20, https://doi.org/10.1371/journal.pone.0186774.
[66] L. Raud, R. Westerhausen, N. Dooley, R.J. Huster, Differences in unity: the go/no-go and stop signal tasks rely on different mechanisms, Neuroimage 210 (2020), https://doi.org/10.1016/j.neuroimage.2020.116582.
[67] J. Stockburger, R. Schmälzle, T. Flaisch, F. Bublatzky, H.T. Schupp, The impact of hunger on food cue processing: an event-related brain potential study, Neuroimage 47 (2009) 1819–1829, https://doi.org/10.1016/j.neuroimage.2009.04.071.
[68] R.M. Piech, M.T. Pastorino, D.H. Zald, All I saw was the cake. Hunger effects on attentional capture by visual food cues, Appetite 54 (2010) 579–582, https://doi.org/10.1016/j.appet.2009.11.003.
[69] P. Lang, M. Bradley, B. Cuthbert, Motivated attention: affect, activation, and action, in: R.F. Simons, P.J. Lang, M. Balaban (Eds.), Atten. Orienting Sens. Motiv. Process., Lawrence Erlbaum Associates, Inc., New York, 1997, pp. 97–136.
[70] K.C. Berridge, Liking" and "wanting" food rewards: Brain substrates and roles in eating disorders, Physiol. Behav. 97 (2009) 537–550, https://doi.org/10.1016/j.physbeh.2009.02.044.
[71] H.R. Berthoud, Interactions between the "cognitive" and "metabolic" brain in the control of food intake, Physiol. Behav. 91 (2007) 486–498, https://doi.org/10.1016/j.physbeh.2006.12.016.
[72] A. Hampshire, S.R. Chamberlain, M.M. Monti, J. Duncan, A.M. Owen, The role of the right inferior frontal gyrus: inhibition and attentional control, Neuroimage 50 (2010) 1313–1319, https://doi.org/10.1016/j.neuroimage.2009.12.109.
[73] S. Dehaene, M. Kerszberg, J.P. Changeux, A neuronal model of a global workspace in effortful cognitive tasks, Proc. Natl. Acad. Sci. U. S. A. 95 (1998) 14529–14534, https://doi.org/10.1073/pnas.95.24.14529.
[74] P.A. Hall, Executive control resources and frequency of fatty food consumption: findings from an age-stratified community sample, Heal. Psychol. 31 (2012) 235–241, https://doi.org/10.1037/a0025407.
[75] D.T. Stuss, M.P. Alexander, Is there a dysexecutive syndrome? Philos. Trans. R. Soc. B Biol. Sci. 362 (2007) 901–915, https://doi.org/10.1098/rstb.2007.2096.
[76] M. Ballestero-Arnau, M. Moreno-Sánchez, T. Cunillera, Food is special by itself: neither valence, arousal, food appeal, nor caloric content modulate the attentional bias induced by food images, Appetite 156 (2021), https://doi.org/10.1016/j.appet.2020.104984.
[77] L. Pimpini, S. Kochs, W. van Zoest, A. Jansen, A. Roefs, Food captures attention, but not the eyes: an eye-tracking study on mindset and BMI's impact on attentional capture by high-caloric visual food stimuli, J. Cogn. 5 (2022) 1–21, https://doi.org/10.5334/joc.210.
[78] R. Lappalainen, P.O. Sjödén, T. Hursti, V. Vesa, Hunger/craving responses and reactivity to food stimuli during fasting and dieting, Int. J. Obes. 14 (1990) 679–688. http://europepmc.org/abstract/MED/2228402.
[79] F. Wilhelmi de Toledo, F. Grundler, A. Bergouignan, S. Drinda, A. Michalsen, Safety, health improvement and well-being during a 4 to 21-day fasting period in an observational study including 1422 subjects, PLoS One 14 (2019), e0209353, https://doi.org/10.1371/journal.pone.0209353.
[80] I.E. de Araujo, M. Schatzker, D.M. Small, Rethinking food reward, Annu. Rev. Psychol. 71 (2020) 139–164, https://doi.org/10.1146/annurev-psych-122216-011643.
[81] A. Johnstone, Fasting for weight loss: an effective strategy or latest dieting trend? Int. J. Obes. 39 (2015) 727–733, https://doi.org/10.1038/ijo.2014.214.
[82] A. Di Francesco, C. Di Germanio, M. Bernier, R. De Cabo, A time to fast, Science (80-.) 362 (2018) 770–775, https://doi.org/10.1126/science.aau2095.
[83] K.A. Varady, S. Cienfuegos, M. Ezpeleta, K. Gabel, Clinical application of intermittent fasting for weight loss: progress and future directions, Nat. Rev. Endocrinol. (2022), https://doi.org/10.1038/s41574-022-00638-x, 0123456789.
[84] T.A. Wadden, Treatment of obesity by moderate and severe caloric restriction: results of clinical research trials, Ann. Intern. Med. 119 (1993) 688–693, https://doi.org/10.7326/0003-4819-119-7_Part_2-199310011-00012.
[85] J.D. Cameron, G.S. Goldfield, M.J. Cyr, É. Doucet, The effects of prolonged caloric restriction leading to weight-loss on food hedonics and reinforcement, Physiol. Behav. 94 (2008) 474–480, https://doi.org/10.1016/j.physbeh.2008.02.014.
[86] L.F. Nordgren, E.Y. Chou, The push and pull of temptation: the bidirectional influence of temptation on self-control, Psychol. Sci. 22 (2011) 1386–1390, https://doi.org/10.1177/0956797611418349.
[87] K. Schaumberg, D.A. Anderson, E.E. Reilly, L.M. Anderson, Does short-term fasting promote pathological eating patterns? Eat. Behav. 19 (2015) 168–172, https://doi.org/10.1016/j.eatbeh.2015.09.005.
[88] M.R. Lowe, C.A. Timko, Dieting: really harmful, merely ineffective or actually helpful? Br. J. Nutr. 92 (2004) S19–S22, https://doi.org/10.1079/bjn20041136.
[89] A.N. Memon, A.S. Gowda, B. Rallabhandi, E. Bidika, H. Fayyaz, M. Salib, I. Cancarevic, Have our attempts to curb obesity done more harm than good? Cureus 12 (2020) https://doi.org/10.7759/cureus.10275.
[90] T.F. Münte, E. Altenmüller, L. Jäncke, The musician's brain as a model of neuroplasticity, Nat. Rev. Neurosci. 3 (2002) 473–478, https://doi.org/10.1038/nrn843, papers2://publication/doi/.