No evidence of calorie-related modulation of N2 in food-related Go/No-Go training: a
pre-registered ERP study

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Abstract

Go/No-Go tasks, which require participants to inhibit automatic responses to images of palatable foods, have shown diagnostic value in quantifying food-related impulses. Moreover, they have shown potential for training to control impulsive eating. To test a suggested hypothesis that training modulates early neural markers of response inhibition, the current study investigated how N2 event-related brain potential to high and low-calorie food images changes along the Go-/No-Go training and how the N2 is related to later eating behavior. Participants first completed a food Go/No-Go task in which high and low calorie food images were accompanied by Go- and No-Go-cues with equal frequency. Participants then completed a training block in which high-calorie foods were predominantly paired with a No-Go cue and the low-calorie foods with a Go cue, followed by a block with reversed coupling (order of the training blocks counterbalanced between participants). After each training, there was a snacking opportunity during which calorie intake was measured. Against our pre-registered hypotheses, the N2 amplitudes were not affected by calorie-content and there was no training-related modulation in the N2. Additionally, food intake did not differ between the preceding training blocks and the N2 amplitude did not predict food intake. Our study suggests that the link between N2 obtained in a food-related Go/No-Go task and impulse control is not clear-cut and may be limited to specific task characteristics. The results are of high importance as they question previously assumed mechanism of Go/No-Go training in food-related inhibitory control.

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1 Introduction

Approximately 40 percent of adults worldwide are overweight World Health Organization (2018). This is, according to the WHO a major health issue, as it is a risk factor for many avoidable diseases, such as cardiovascular diseases, diabetes, and cancers. Becoming overweight is mainly caused by the precarious balance of energy intake and expenditure being shaken due to the pleasure of consuming tasty foods (World Health Organization, 2015). This balance is further threatened by the ubiquitous presence of unhealthy food.

Therefore, the encounter of tasty, yet unhealthy food cues, for example during grocery shopping, prompts a goal conflict for individuals who wish to maintain a healthy diet. While the mere presence of high calorie food activates a tendency to respond by approaching and consuming the food (P. Watson, Wiers, Hommel, & de Wit, 2014), other external and internal cues (e.g. a goal to lose weight) may trigger a tendency to avoid the food. This type of situation has been distilled into the Go/No-Go task, in which people are asked to respond to a certain visual cue (i.e., a circle shown on computer display) by pressing a button as fast as possible, but withhold responses when seeing a slightly different cue (i.e., a dotted circle) (Donders, 1969). Studies using the Go/No-Go task have shown that withholding of responses when encountering desirable stimuli is harder than when encountering less desirable ones. In a food context, this means that withholding responses towards food items is more difficult than withholding responses towards neutral objects (Price, Lee, & Higgs, 2015; T. D. Watson & Garvey, 2013) and appetizing foods are harder than less appetizing ones (Appelhans et al., 2011; Carbine et al., 2017).

Independently of foods and other emotionally salient stimuli, the goal conflict evoked by a standard Go/No-Go task can be observed on a neural level. For instance, utilizing electroencephalography (EEG), researchers have shown that a negative-going deflection peaking at 200-350 ms post stimulus, also known as the N2 event-related

potential (ERP), is enhanced when withholding a dominant response (such as pressing a button in a Go/No-Go task) (Folstein & Van Petten, 2008). Two competing theories have been proposed for the N2 effect: one states that the Go/No-Go task activates two actions simultaneously, triggering a conflict monitoring response expressed as the N2 (Donkers & Van Boxtel, 2004). The other assumes that the Go/No-Go task induces a dominant response style (tendency to press a button) which then needs to be inhibited and the N2 is indicative of this response inhibition process (Folstein & Van Petten, 2008; Gajewski & Falkenstein, 2013). However, both theories propose that the N2 is more pronounced when participants need to react in a way that is contrary to what would be the automatically activated reaction tendency. Therefore, if assuming that high vs. low calorie foods are associated with stronger reaction tendencies, withholding a response to high calorie foods should result in larger N2 amplitude than withholding a response to low calorie foods (Carbine et al., 2017). While some support has been found for this assumption, the evidence is still scarce (for a review see Carbine, Duraccio, et al. (2018)).

Testing the real-world relevance of the food-related N2 effect in Go/No-Go task, Carbine et al. (2017) investigated whether inhibition-evoked N2 positively correlated with people's food intake outside the laboratory. In their study, participants completed two versions of a Go/No-Go Task. In the low-calorie-go condition, pictures of high-caloric food functioned as a No-Go cue, requiring participants to withhold their response when seeing a picture of high calorie food and press a button in response to pictures of low-caloric food. In the high-calorie-go version, the pairing between Go/No-Go and low/high-calorie was reversed. As expected, they found that the N2 was stronger in trials in which participants inhibited their responses to high-calorie, appetizing food than when inhibiting responses to low-calorie, less appetizing food. Moreover, a stronger N2-response was related to lower caloric intake days after the Go/No-Go task as reported in food diary entries (Carbine et al., 2017). The obtained finding, which was recently replicated in an fMRI study by Carbine, Duraccio, et al. (2018), gives support to the idea of the N2 being indicative of response inhibition: the

stronger participants' N2 when stopping to high calorie food, the lower their intake was in the food diary.

In recent years, the Go/No-Go task has also been used as an intervention tool in which people are asked to withhold their response in reaction to high-calorie foods in order to reduce the approach tendency to unhealthy food stimuli. This type of inhibition training has been shown to reduce subsequent food intake in a laboratory setting and has therefore been proposed as an efficient intervention method to improve dietary behavior (Allom, Mullan, & Hagger, 2016; Aulbach, Knittle, & Haukkala, 2019; Jones et al., 2016). While the Go/No-Go based training may be useful in reducing consumption of unhealthy foods, at least in the short run, the psychological mechanisms through which the behavioral change takes place remains unclear. Some authors have argued that the training strengthens stimulus-specific top-down inhibitory control (Allom et al., 2016). Others have hypothesized and demonstrated that instead (or additionally), repeatedly inhibiting responses to highly evaluated stimuli leads to devaluation of those stimuli, thereby making it easier to control eating behavior even outside the laboratory (Jones et al., 2016; Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017). However, only few studies have investigated changes in implicit attitudes towards trained food items as a mechanism of Go/No-Go training Aulbach et al. (2019); Houben and Jansen (2015); Kakoschke, Kemps, and Tiggemann (2017); Verbeken, Braet, Naets, Houben, and Boendermaker (2018).

Carbine and colleagues' findings are valuable as they demonstrate a correlation between the N2 amplitude and everyday calorie intake. However, they do not give insights into the neural changes throughout the course of a Go/No-Go intervention. Fortunately, in another recent study by van de Vijver, van Schie, Veling, van Dooren, and Holland (2018), the neural effects of Go/No-Go training on response inhibition (i.e., food consumption) were measured more directly. In their study, participants were asked to passively view pictures of food and non-food items followed by a food-related Go/No-Go training, where the food/non-food items were consistently paired with Go/No-Go response. When viewing the food pictures again, the food items that were

previously associated with response omission resulted in stronger theta oscillations at frontal midline electrodes. Given that frontal midline theta power is typically associated with response control and conflict detection (Brier et al., 2010; Cavanagh & Frank, 2014), the obtained theta rhythm is likely to reflect the same online regulation process of anterior cingulate cortex (ACC) as the earlier found N2 ERP component (Cavanagh & Frank, 2014). This indicates that food Go/No-Go training leads to more efficient activation of response inhibition (van de Vijver et al., 2018). However, theta oscillations in this study were recorded during passive viewing of the food images and not during the completion of the Go/No-Go task, thus not giving conclusive evidence of the processes happening during the training itself.

Therefore, we conducted the present pre-registered study (find the pre-registration here: <https://osf.io/2j8vt/>) to examine changes in the N2 amplitude over the course of food-related Go/No-Go inhibition training to better understand through which mechanisms the training influences eating behavior. Investigating the change in N2 amplitude over the course of the training revealed whether the N2 response enhanced as a result of the training, as indirectly suggested by the recent oscillation findings van de Vijver et al. (2018). Moreover, we examined the influence of Go/No-Go training on immediate calorie intake by using a lab-based measure of calorie intake in addition to a food diary. To this end, participants completed three versions of a food-related Go/No-Go task: in the baseline block, high- and low-calorie pictures were evenly paired with Go- and No-Go-cues. This was followed by two training blocks in counterbalanced order in which one type of food was predominantly paired with Go-cues and the other with No-Go-cues. After each training block, participants had the opportunity to eat candy ad libitum.

Derived from the above considerations, we tested the following hypotheses. Firstly, we predicted an interaction between the Go/No-Go cue and food type with high-calorie No-Go-trials evoking the most negative amplitudes in the N2 range (H1). Secondly, we expected participants to eat less candy after the No-Go training block which paired high calorie foods with No-Go cues compared to when the pairing was the other way

around (H2). Thirdly, we assume (H3) that participants who exhibit a stronger N2-bias towards high-calorie food (i.e. larger difference in N2-responses between high-calorie no-go trials and low-calorie no-go trials) in the baseline block, will consume fewer calories both in and outside the laboratory. Lastly, we expected the N2 amplitudes to No-Go trials to become more negative over the course of the training blocks, the change being more pronounced in the high-calorie No-Go block (H4). We examine this hypothesis by comparing the No-Go vs Go difference values of the N2 components in high and low-calorie No-Go training in the first and second half of the training blocks. *Figure 1* shows a schematic illustration of the assumed two-way interaction between No-Go training (high vs. low calorie) and time (first and second half of the training) ¹.

2 Methods

2.1 Participants and sample size estimation

Participants were recruited through the student organization e-mailing lists within the University of Helsinki and Aalto University as well as through social media. They were screened for exclusion criteria before participation and were not included in the study if reporting any psychiatric or neurological disease, use of recreational drugs, being pregnant or lactating, or having any food allergies, metabolic diseases, or other special diets that limit their dietary choices. The experiment was conducted following the guidelines of the National Advisory Board on Research Ethics in Finland and approved by the Research Ethics Committee of University of Helsinki. Participants were always briefed of the experimental procedure, its purpose and of their rights to withdraw from the experiment at any time without offering any explanation. Before leaving the lab, participants were thanked and compensated by two movie tickets.

Due to time and resource constraints, data from N=50 participants were collected. Power analysis was conducted with G*Power software to see whether the targeted sample size was sufficiently powered to detect a two-way interaction between two

¹ Note that there was an additional hypothesis regarding reaction times in the pre-registration. We removed it to streamline the current manuscript but report the analyses in the supplemental materials

repeated measures factors: calorie (high vs low caloric) and task (go vs no-go), while using a two-way repeated measures analysis of variance (ANOVA) for significance testing. The power analysis revealed that when a large effect of $\eta_p^2 = 0.26$ (based on Carbine et al., 2017) was assumed for the interaction between calorie (high vs low caloric) and task (go vs no-go), and a 5 % level of significance and α/β - ratio = 1 were used, the sample size of 50 participants resulted in .97 power to detect the interaction effect.

The average age of the 50 recruited participants (26 female, one "Other/Don't want to disclose") was 28 years (range 18-46) and BMI ranged from 18.5 to 30.5 ($m = 23.0$). The data from one female participant could not be used due to technical failure with the EEG measurement and four additional participants did not return a food diary. Another participant reported unrealistically high food intake and was treated like having a missing value. We report all analyses including those four participants but excluded them from the analyses related to diary food intake.

2.2 Procedure

The whole procedure can be seen in *Figure 2*. Participants were asked not to eat or drink anything but water two hours prior to participation in order to attain a certain hunger level and to exclude the possibility of being fully sated during the experiment. Upon arrival at the laboratory, participants were told about the experiment and asked to sign an informed consent form. After this, the EEG electrodes were applied after which participants entered information about themselves (age, gender, handedness, height, weight, and how long ago they last ate), answered 6 questions related to satiety and indicated how much they liked a set of food items. Descriptive statistics are displayed in *Table 1*.

They then started the Go/No-Go task in which participants had to react as fast as possible in trials that contained a visual go cue and to withhold their response in trials with a visual no-go cue (the course of two trials can be seen in *Figure 3*. The food images were shown with a parallel onset and offset with the Go/No-Go cue for 1000 ms

or until the participant responded. Upon response, the food image and Go/No-Go cue were replaced by the fixation cross shown for 1000 ms after which the next trial started. Trials in which participants committed an error, a frowning smiley was shown alongside the message "Please don't respond" (for commission errors) or "Faster" (for omission errors).

Following 15 practice trials, participants started the baseline block which contained 84 trials for each of the four condition cells (i.e., high calorie Go, high calorie No-Go, low calorie Go, and low calorie No-Go). In addition, there were 28 Go and No-Go trials presented alongside a food-unrelated distractor stimulus. In the high calorie No-Go training block, there were 140 trials in which the high calorie food image was accompanied by No-Go cue and 28 trials in which the high calorie food was accompanied by Go cue. In addition, there were 140 low calorie Go trials and 28 low calorie No-Go trials. Moreover, 28 Go and No-Go trials were presented alongside distractor objects. In the low calorie No-Go training block, this pairing was reversed so that high calorie food images were more often paired with Go cue whereas low calorie food images were more likely to be presented alongside a No-Go cue. The order of these high and low calorie No-Go training blocks was counterbalanced between participants. Each block contained 4 sub-blocks, so that participants were able to take short self-timed breaks. Before each sub-block, participants were asked to use either their right or left hand to respond (50% of blocks with each hand, order counterbalanced between participants).

After each training block, the experimenter entered the lab room with a cup of water and a bowl filled with 133g of M&M candies. Participants were told to help themselves with the water and candy and to answer a questionnaire (not related to the purpose of the study) and that the experimenter would be back in a few minutes. After five minutes, the experimenter returned to pick up the candy bowl and water cup and started the next block or, in case of the second snacking opportunity, ended the session. For the second snacking opportunity, the bowl was filled with the same amount of candies as for the first one, i.e. 133g.

Within one week after the laboratory session, participants received an e-mail with a link to an online food diary which they were asked to fill out for a 24-hour period retrospectively (National Institute for Health and Welfare, 2017).

2.3 Stimuli and Apparatus

Stimulus presentation. All the stimuli and questionnaires were presented at a distance of ca. 60 cm on a LCD with 1024 x 768 pixel resolution and 60 Hz refresh rate. E-prime 3.0.3.60 (Psychology Software Tools Inc, Sharpsburg, PA) software running on Windows 10 Pro were used for stimulus presentation, recording of responses, and sending triggers to the EEG amplifier.

Go/No-Go cues and Food images. Food images were presented on a white background with a resolution of 640x480 pixels inside full or interrupted circles (17 cm diameter) serving as Go/No-Go cues (cue meaning counterbalanced between participants). The food images were selected from the food-pics database (Blechert, Meule, Busch, & Ohla, 2014) depicting the highest and lowest-caloric food items in the database which were highly recognizable, excluding exceptionally dark and bright images and those high-calorie pictures that depicted also healthy foods such as nuts (Selected picture numbers are: 7, 9, 15, 27, 84, 101, 112, 151, 155, 161, 164, 168, 177, 286, 287, 293, 296, 298, 351, 510 for high calorie foods; 197, 198, 199, 242, 243, 245, 249, 250, 253, 256, 260, 263, 267, 275, 285, 334, 364, 367, 389, 429 for low calorie foods). In addition, we added a sample of distractor pictures that showed stationary items such as flowers or pieces of furniture. Before beginning the Go/No-Go task, participants reported their liking of all 40 food items (20 high- and 20 low-calorie food pictures) and a random selection of seven from each category were used in the Go/No-Go tasks.

2.3 Food intake

In the laboratory. The amount of calories consumed in the lab was measured by scaling the candy bowl with a digital kitchen scale (Idéale+, Tokmanni Oy) after each inhibition training block. Two similar pre-scaled and filled plastic bowls were used to avoid measurement error.

Food Diary. Within a week of the laboratory session, participants received a link to an online food diary (National Institute for Health and Welfare, 2017) which they were asked to fill out in hindsight for a 24 hour period and to send the corresponding file back. Participants who did not send a file back were contacted again to keep drop-out low.

2.4 EEG Recording and Pre-Processing

The EEG signals were obtained at 2000 Hz sample rate using 32 Ag/AgCl electrodes attached to a QuickAmp (BrainProducts GmbH, Gilching, Germany) amplifier. An elastic EEG cap (EasyCap, GmbH, Herrsching, Germany) was used to position the electrodes on equidistant electrode sites over FP1, FP2, F7, F3, Fz, F4, F8, FT9, FC5, FC1, FC2, FC6, FT10, T7, C4, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, O1, Oz, O2 and AFz (worked as the ground). The electrode impedance was maintained below 5 kilo ohms. The EEG recordings were accompanied by horizontal and vertical electro-oculographic (EOG) recordings that were obtained using bipolar electrodes placed 1 cm lateral to the outer canthi of left and right eye and 1 cm above and below the left eye. The EEG and EOG signals were then down-sampled to 500 after which a high-pass filter at 0.2 Hz and low-pass filter at 80 Hz were applied. This off-line pre-processing was done using the EEGLAB software (Delorme & Makeig, 2004).

Artifact correction was carried out using independent component analysis (ICA) as implemented in the EEGLAB. To ensure optimal ICA decomposition, the data was filtered with 1 Hz high-pass and 50 Hz notch filters and segmented to wide (-500 +1200 ms) trial-based epochs. Epochs with extreme amplitudes (>500 μV) were also removed before decomposition to reduce occurrence of components accounting only for rare artifactual events. The resulting components were manually screened and classified to artifactual (such as muscle contractions, eye-movements and line noise) and clean components (with a neural source). The EEG was reconstructed applying the obtained ICA weights on unfiltered continuous data while projecting only the artifact free

components on the electrode level.

The reconstructed and cleaned continuous data was then re-referenced to average mastoid activity, low-pass filtered at 40 Hz and segmented to 1000 ms epochs time-locking the epoch to Go/No-Go cue so that there were 200 ms baseline activity used for baseline correction. Stricter artifact-rejection criteria was applied to the epoched and baseline corrected data to remove approximately 10 % of the epochs with greater than 35-75 μ V absolute amplitude and > 55 -60 μ V difference between the maximum and minimum amplitude. Finally, we plotted the average ERP waveforms of the Go/No-Go conditions for each participant at the fronto-central electrodes (i.e., Cz, FC1, FC2, Fz) to visually inspect the local minimum voltages between 200 and 350 ms in both conditions. The N2s were found to have a sharp form with clear peaks with substantial variation between participants in the peak latency (the minimum latency = 210 and the maximum 290 ms). Therefore, we decided to define the latency windows individually for each participant based on the local minimum voltage between 200 and 290 ms from their averaged ERP waveform of the No-Go trials.

Finally, average amplitudes for each trial were calculated separately for four fronto-central electrodes (Cz, FC1, FC2, Fz) using 40 ms time window surrounding the peak latency of each participant's average N2 response. After this, the data was aggregated to condition level in order to get one cell for each condition and for each participant (e.g., high calorie No-Go, high calorie Go, low calorie No-Go, low calorie Go).

Other Data

In the beginning of the laboratory session, the participants rated all food items on a 7-point Likert scale ("How much do you like this item?"). In addition, information of participants' age, gender, height, and weight were obtained at this point. Additional six items on 7-point Likert scales adapted from Carbine et al. (2017) were used to assess participants' hunger, fullness, desire to eat, the extend of how much one could eat, the urge one has to eat, and preoccupation with food which were combined to form a single

hunger variable. Furthermore, participants indicated how many hours ago they last ate something (*Table 1*).

3 Results

Participants performed the different versions of the Go/No-Go task with very high accuracy (error rates under 1% in each block for both errors of commission and omission). Reaction times in the baseline block were $m = 357\text{ms}$ ($sd = 31.7$) for high-calorie and 359ms (32.3) for low-calorie food pictures. In the training blocks, the respective mean reaction times for the dominant trials were 343ms (32.3) for high-calorie and 344ms (29.6) for low-calorie food pictures.

3.1 Hypothesis 1: baseline bias in N2

To test the first hypothesis (H1) that high-calorie food pictures lead to stronger N2-amplitudes than low-calorie food pictures in No-Go trials, we conducted a full-factorial two-way repeated measures analysis of variance (rmANOVA) with stimulus type (high calorie vs. low-calorie) and trial type (Go vs. No-Go) set as repeated measures factors and average N2 amplitude set as dependent variable. The ERP waveforms for high-and low-calorie Go- and No-Go-trials are shown in *Figure 4* and scalp distributions in *Figure 5*. The waveforms show a clear and distinct N2 in all blocks and for Go- and No-Go-trials for both high- and low-calorie foods. We can also see clearly that No-Go-trials elicit stronger N2-amplitudes than Go-trials, regardless of the stimulus type. The repeated measures ANOVA delivered a significant main effect of trial type (i.e. Go vs No-Go trials) with No-Go-trials leading to a mean N2-amplitude of $m = -5.44$ ($sd = 4.91$) and Go trials $m = -3.66$ ($sd = 5.11$), $F(1, 48) = 79.74$, $p < .0001$, $\eta_p^2 = 0.29$). However, against the H1, there was no effect of calorie content of the food item ($m(\text{high-calorie food}) = -4.40$, $sd = 5.16$; $m(\text{low-calorie food}) = -4.64$, $sd = 5.03$), $p = .32$, $\eta_p^2 = 0.02$) and no significant interaction effect between the calorie content and trial type ($p = .17$, $\eta_p^2 = 0.04$).

3.2 Hypothesis 2: Food intake in the laboratory

We compared calorie intake (i.e., amount of consumed M&M's) between the two inhibition training blocks in the laboratory by conducting a one-sided dependent samples t-test. Against our hypothesis, the one-sided paired samples t-test was not significant ($t(48) = -1.51, p = .93$). Descriptively, food intake in the laboratory was higher after the *High-Calorie No-Go* condition ($m = 13.33, sd = 12.57$) than after the *Low-Calorie No-Go* condition ($m = 11.80, sd = 11.57$). To explore whether the training had an effect on intake at the first snacking opportunity, we tested differences between blocks at T1 only. The participants who first did the High-Calorie No-Go task first ate on average $m = 13.75$ ($sd = 14.37$) grams of candy whereas the other group ate $m = 11.36$ ($sd = 9.57$). This difference was not significant ($t(47) = 0.69, p = .50$).

3.3 Hypothesis 3: predicting food intake with N2 difference scores

To test hypothesis 3, we created a difference score of high-calorie N2 difference (No-Go minus Go) minus low-calorie N2 difference and used it as a predictor in a stepwise regression model, using BMI, age, gender, and the hunger variable in a first step and adding the N2-bias variable in a second step to predict total calorie intake in the lab as measured with the consumption of M&M's and outside the laboratory as measured with the food diary. The analysis revealed that the baseline N2 difference score (i.e. (High-Calorie No-Go - High-Calorie Go) - (Low-Calorie No-Go - Low-Calorie Go)) averaged across the four scalp sites of interest was not predictive of food intake as measured with the food diary ($B = -88.52, t(39) = -0.21, p = .83$) or inside the laboratory ($B = -3.49, t(43) = -1.86, p = .07$) after controlling for age, gender, BMI, and reported hunger.

3.4 Hypothesis 4: Training effects on N2

In our fourth hypothesis, we assumed a change in the No-Go N2 for the food category that was repeatedly paired with a No-Go cue in the inhibition training task and that this temporal change should be more pronounced in the context of high calorie

foods (H4). For the test of H4, we created N2 amplitude difference scores as high-calorie No-Go minus low-calorie Go for the high-calorie No-Go block and vice versa for the low-calorie No-Go block. Difference scores were computed for both halves of each training block. A 2 (training block: High-No-Go vs. Low-No-Go) $\times$ 2 (first half vs. second half of the block) full-factorial repeated measures ANOVA was then conducted to test for the main effects of block and time and interaction effect between the two indicating different effects of training for the two kinds of stimuli (high vs low calorie foods). The repeated measures ANOVA indicated no significant main effects of part of the training block (first vs second half, $F(1, 48) = 6.20$, $p = .02$, $\eta_p^2 = 0.02$) or training block (i.e. High-Calorie-No-Go vs Low-Calorie-No-Go blocks, $F(1, 48) = 1.01$, $p = .32$, $\eta_p^2 = 0.02$) and no interaction effect between the two, $F(1, 48) = 0.33$, $p = .57$, $\eta_p^2 = 0.57$. Following up on these analyses, we conducted an exploratory repeated measures 2x2x2-ANOVA using the respective Go- and No-Go-N2 instead of the difference scores. We again found a main effect of Go- vs No-Go trials ($F(1, 48) = 17.73$, $p < .0001$, $\eta_p^2 = 0.03$) but none of the other possible effects were significant (all $ps > .14$, all $\eta_p^2 < 0.0005$). Dividing the training blocks into four instead of two parts did not change results, indicating stable N2-amplitudes over the course of training.²

4 Discussion

In this study, participants completed three versions of a Go/No-Go task with food stimuli: first, a baseline task in which high and low caloric foods were paired with Go- and No-Go cues equally often, followed by two versions in which one food category was predominantly paired with Go- and No-Go cues respectively. While we demonstrated the fundamental difference in N2 amplitudes between Go- and No-Go trials, we found neither significant differences between the food categories nor changes in N2-amplitudes over the course of the training. In addition, N2-amplitudes were not related to food intake in the laboratory or as measured with a food diary and no direct effect of the

² We conducted a series of additional exploratory analyses which are reported in the supplemental materials.

Go/No-Go training on immediate candy consumption.

Our results indicate that inhibiting responses to pictures of unhealthy foods does not reduce immediate calorie intake. This is contrast with a growing literature which has found these interventions to be effective (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016). The current experiment differs from such intervention studies in that calorie intake was measured at two successive snacking opportunities. The within-subject design might have made the measurement less sensitive to the manipulation effect by satiating participants already at the first time point. Future research using within-subject designs to test behavioral effects of Go/No-Go training should use a longer delay between measurement time points to avoid this problem.

Regarding the neural responses, calorie content of food images in the Go/No-Go task did not influence N2-amplitudes, indicating that inhibiting responses to high-calorie foods activated inhibitory resources (or evoking goal conflict) to the same extent as inhibiting reactions to low-calorie foods. This was true both in the baseline block where Go/No-Go-trials were equally distributed across high- and low-calorie foods and in the training blocks where either combination was dominant. Calorie content of the food might therefore be processed only at later stages which are not captured by the N2. Future research should therefore consider later event-related potentials reflecting higher-order processes such as the P3, late positive potential (LPP, (Feig et al., 2017)), or early posterior negativity (EPN, (Marmolejo-Ramos et al., 2015)). For a review of this literature, see (Carbine, Rodeback, et al., 2018).

Alternatively, it is possible that effects of calorie content are sensitive to specific task features. Interventions using food Go/No-Go training typically present food pictures together with a reaction cue, i.e. the content of the picture is irrelevant to the task Lawrence, Verbruggen, Morrison, Adams, and Chambers (2015). Since our aim was to examine neural processes of such interventions, we adopted the same setup with Go/No-Go-cues being separate from food items. Since calorie density was not relevant for reaction and is a relatively abstract construct, participants might have ignored the food items and might not have categorized the foods at all, consciously or

unconsciously. In fact, a recent study demonstrated that participants often misjudge food items' calorie content Horne, Palermo, Neumann, Housley, and Bell (2019). This raises the question to what extent people encode calorie content in typical food Go/No-Go interventions and indicates that interventions using Go/No-Go training with separate response cues do not actually target early processes of response inhibition and conflict monitoring of the anterior cingulate cortex (Cavanagh & Frank, 2014).

Perhaps most surprisingly, we found no significant effect of training on N2 differences between Go- and No-Go-trials for either food category. Thus, it seems that performing a Go/No-Go task for a significant amount of time does not alter the N2 response to Go or No-Go trials. In light of findings that performing food Go/No-Go training can decrease food intake (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016), it leaves the question of psychological and neural mechanisms of this kind of intervention unanswered but adds to evidence indicating that activation of inhibitory control does not increase through training Stice, Yokum, Veling, Kemps, and Lawrence (2017). It is important to point out that the N2 should have changed over training irrespective of the task-irrelevant food images if we assume that it is sensitive to training. Since the N2 response did not change over time, we conclude that it is not a good index of behavioral training effects in the Go/No-Go paradigm.

Against our Hypothesis 3, we did not find N2 bias to be predictive of dietary intake, in- or outside the laboratory, challenging the relevance of N2 for real-world eating behavior. However, the N2 was not sensitive to calorie content of the foods which indicates that participants might not have created meaningful food categories (high- vs low-caloric foods), a pre-requisite for persistent effects of training on stimulus evaluation Serfas, Florack, Büttner, and Voegeding (2017).

4.1 Strengths and Limitations

This study has several strengths and limitations. While we did control for picture brightness, we did not control for color composition of the food stimuli which might have influenced attention allocation. Unfortunately, participants indicated their food

liking only before the Go/No-Go tasks, not allowing us to investigate whether No-Go foods were devalued due to training (Veling, Holland, & van Knippenberg, 2008). Another limitation of the study lies in the assessment of food intake. While our study did measure food intake in- and outside the laboratory, both measures have their problems. The two measurement time points in the laboratory were only some minutes apart, so participants might have been satiated after the first snacking opportunity, obscuring any training effects. The food diary only spanned a 24 hour period, giving us only a very rough measurement of participants' eating behavior.

Recently, concerns have been raised about the ability of response inhibition tasks to reveal individual differences (Rouder, Kumar, & Haaf, 2019) with the main reason being the large amount of noise relative to signal in those tasks. It might well be that the current study suffers from the same problem: while variation across trials in the N2 is large, variation across participants is comparably small. When using participant-level means scores as is common practice, covariation of the N2 with other variables such as consumption behavior is necessarily small.

As a the strength of this study, we closely re-created commonly used Go/No-Go intervention tasks (Lawrence et al., 2015) to be able to investigate the processes happening in these very tasks. Second, and related to the first, we contrasted different kinds of foods (as opposed to neutral stimuli Kong, Zhang, and Chen (2015); T. D. Watson and Garvey (2013)), something that has rarely been done in the literature on food-related ERP research (Carbine, Duraccio, et al., 2018). Third, to our knowledge, this study is the first to investigate changes in ERPs over the course of Go/No-Go training (Carbine, Duraccio, et al., 2018). Fourth, this study was pre-registered before completion of data collection and before data analysis.

4.2 Conclusion

In this well-powered study, the N2 event-related potential did not differentiate between high- and low-calorie food items in a food-specific Go/No-Go task that closely resembled typical food-Go/No-Go interventions. In addition, there were no apparent

effects of training on the N2-amplitude. This implies that the N2 is generally not sensitive to training and is therefore a poor indicator to study neural mechanisms of behavioral training effects. Furthermore, it questions the assumption that Go/No-Go training strengthens inhibitory control or helps to decrease the intensity of goal conflict. Studying later event-related potentials such as the P3, late positive potential or early posterior negativity might therefore seem more promising to understand how food-Go/No-Go training attains its effect on consumption behavior.

References

Allom, V., Mullan, B., & Hagger, M. S. (2016, apr). Does inhibitory control training improve health behaviour? A meta-analysis. *Health Psychology Review*, 10(2), 168–186. Retrieved from
<http://www.tandfonline.com/doi/full/10.1080/17437199.2015.1051078>
 doi: 10.1080/17437199.2015.1051078

Appelhans, B. M., Woolf, K., Pagoto, S. L., Schneider, K. L., Whited, M. C., & Liebman, R. (2011). *Inhibiting food reward: Delay discounting, food reward sensitivity, and palatable food intake in overweight and obese women*. (Vol. 19) (No. 11). Appelhans, Bradley M., brad_appelhans@rush.edu: Nature Publishing Group. Retrieved from
<http://ovidsp.ovid.com/ovidweb.cgi?T=JSPAGE=referenceD=psyc8NEWS=NAN=2011-25354-0>

Aulbach, M. B., Knittle, K., & Haukkala, A. (2019). Implicit process interventions in eating behaviour: a meta-analysis examining mediators and moderators. *Health Psychology Review*, 13(2), 179–208. doi: 10.1080/17437199.2019.1571933

Blechert, J., Meule, A., Busch, N. A., & Ohla, K. (2014, jun). Food-pics: an image database for experimental research on eating and appetite. *FRONTIERS IN PSYCHOLOGY*, 5, 1–10. Retrieved from
<http://www.ncbi.nlm.nih.gov/pubmed/25009514> doi:
 10.3389/fpsyg.2014.00617

Brier, M. R., Ferree, T. C., Maguire, M. J., Moore, P., Spence, J., Tillman, G. D., ... Kraut, M. A. (2010, dec). Frontal theta and alpha power and coherence changes are modulated by semantic complexity in Go/NoGo tasks. *International Journal of Psychophysiology*, 78(3), 215–224. Retrieved from

Carbine, K. A., Christensen, E., LeCheminant, J. D., Bailey, B. W., Tucker, L. A., & Larson, M. J. (2017, jul). Testing food-related inhibitory control to high- and low-calorie food stimuli: Electrophysiological responses to high-calorie food stimuli predict calorie and carbohydrate intake. *Psychophysiology*, 54(7), 982–997.

- Retrieved from <http://doi.wiley.com/10.1111/psyp.12860> doi:
10.1111/psyp.12860
- Carbine, K. A., Duraccio, K. M., Kirwan, C. B., Muncy, N. M., LeCheminant, J. D., & Larson, M. J. (2018). A direct comparison between ERP and fMRI measurements of food-related inhibitory control: Implications for BMI status and dietary intake. *NeuroImage*, 166(November 2017), 335–348. Retrieved from
<https://doi.org/10.1016/j.neuroimage.2017.11.008> doi:
10.1016/j.neuroimage.2017.11.008
- Carbine, K. A., Rodeback, R., Modersitzki, E., Miner, M., LeCheminant, J. D., & Larson, M. J. (2018). *The utility of event-related potentials (ERPs) in understanding food-related cognition: A systematic review and recommendations* (Vol. 128). Retrieved from
https://ac.els-cdn.com/S0195666318300746/1-s2.0-S0195666318300746-main.pdf?_tid=4
doi: 10.1016/j.appet.2018.05.135
- Cavanagh, J. F., & Frank, M. J. (2014, aug). Frontal theta as a mechanism for cognitive control. *Trends in Cognitive Sciences*, 18(8), 414–421. Retrieved from
<https://www.sciencedirect.com/science/article/pii/S1364661314001077>
doi: 10.1016/J.TICS.2014.04.012
- Delorme, A., & Makeig, S. (2004, mar). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9–21. Retrieved from
<https://www.sciencedirect.com/science/article/pii/S0165027003003479>
doi: 10.1016/J.JNEUMETH.2003.10.009
- Donders, F. (1969). On the speed of mental processes. In W. G. Koster (Ed.), *Attention and performance ii* (pp. 412–431). Amsterdam: North-Holland Publishing Company. doi: 10.1016/0001-6918(69)90065-1
- Donkers, F. C., & Van Boxtel, G. J. (2004). The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. *Brain and Cognition*, 56(2 SPEC. ISS.), 165–176. Retrieved from www.elsevier.com/locate/bc doi:

10.1016/j.bandc.2004.04.005

Feig, E. H., Winter, S. R., Kounios, J., Erickson, B., Berkowitz, S. A., & Lowe, M. R. (2017, oct). The role of hunger state and dieting history in neural response to food cues: An event-related potential study. *Physiology Behavior*, 179, 126–134. Retrieved from <https://linkinghub.elsevier.com/retrieve/pii/S0031938417301695> doi: 10.1016/j.physbeh.2017.05.031

Folstein, J. R., & Van Petten, C. (2008, jan). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, 45(1), 152–170. Retrieved from <http://doi.wiley.com/10.1111/j.1469-8986.2007.00602.x> doi: 10.1111/j.1469-8986.2007.00602.x

Gajewski, P. D., & Falkenstein, M. (2013). Effects of task complexity on ERP components in Go/Nogo tasks. *International Journal of Psychophysiology*, 87(3), 273–278. Retrieved from <http://dx.doi.org/10.1016/j.ijpsycho.2012.08.007> doi: 10.1016/j.ijpsycho.2012.08.007

Horne, D., Palermo, R., Neumann, M., Housley, R., & Bell, J. (2019, apr). Can People Accurately Estimate the Calories in Food Images? An Optimised Set of Low- and High- Calorie Images from the food-pics database. *Appetite*. Retrieved from <https://linkinghub.elsevier.com/retrieve/pii/S0195666319300200> doi: 10.1016/j.appet.2019.04.017

Houben, K., & Jansen, A. (2015). Chocolate equals stop: Chocolate-specific inhibition training reduces chocolate intake and go associations with chocolate. *Appetite*, 87, 318–323. Retrieved from <http://dx.doi.org/10.1016/j.appet.2015.01.005> doi: 10.1016/j.appet.2015.01.005

Jones, A., Di Lemma, L. C. G., Robinson, E., Christiansen, P., Nolan, S., Tudur-Smith, C., & Field, M. (2016). Inhibitory control training for appetitive behaviour change: A meta-analytic investigation of mechanisms of action and moderators of

- effectiveness. *Appetite*, 97, 16–28. Retrieved from <http://dx.doi.org/10.1016/j.appet.2015.11.013> doi: 10.1016/j.appet.2015.11.013
- Kakoschke, N., Kemps, E., & Tiggemann, M. (2017). The effect of combined avoidance and control training on implicit food evaluation and choice. *Journal of Behavior Therapy and Experimental Psychiatry*, 55, 99–105. Retrieved from <http://dx.doi.org/10.1016/j.jbtep.2017.01.002> <http://ovidsp.ovid.com/ovidweb.cgi?T=JSPAGE=referenceD=psyc13NEWS=NAN=2017-07247> doi: 10.1016/j.jbtep.2017.01.002
- Kong, F., Zhang, Y., & Chen, H. (2015). Inhibition ability of food cues between successful and unsuccessful restrained eaters: A two-choice oddball task. *PLoS ONE*, 10(4). doi: 10.1371/journal.pone.0120522
- Lawrence, N. S., Verbruggen, F., Morrison, S., Adams, R. C., & Chambers, C. D. (2015). Stopping to food can reduce intake. Effects of stimulus-specificity and individual differences in dietary restraint. *Appetite*, 85, 91–103. Retrieved from <http://dx.doi.org/10.1016/j.appet.2014.11.006> doi: 10.1016/j.appet.2014.11.006
- Marmolejo-Ramos, F., Hellemans, K., Comeau, A., Heenan, A., Faulkner, A., Abizaid, A., & D'Angiulli, A. (2015). Event-related potential signatures of perceived and imagined emotional and food real-life photos. *Neuroscience Bulletin*, 31(3), 317–330. Retrieved from <http://www.neurosci.cn> doi: 10.1007/s12264-014-1520-6
- National Institute for Health and Welfare, N. U. (2017). *No Title*. Retrieved from www.fineli.fi
- Price, M., Lee, M., & Higgs, S. (2015, may). Food-specific response inhibition, dietary restraint and snack intake in lean and overweight/obese adults: a moderated-mediation model. *International Journal of Obesity*, 40(5), 877–882. Retrieved from <http://www.nature.com/doifinder/10.1038/ijo.2015.235> doi: 10.1038/ijo.2015.235

Rouder, J. N., Kumar, A., & Haaf, J. M. (2019). Why most studies of individual differences with inhibition tasks are bound to fail. , 1–37. Retrieved from psyarxiv.com/3cjr5

Serfas, B. G., Florack, A., Büttner, O. B., & Voegeding, T. (2017). What does it take for sour grapes to remain sour? Persistent effects of behavioral inhibition in go/no-go tasks on the evaluation of appetitive stimuli. *Motivation Science*, 3(1), 1–18. doi: 10.1037/mot0000051

Stice, E., Yokum, S., Veling, H., Kemps, E., & Lawrence, N. S. (2017). Pilot test of a novel food response and attention training treatment for obesity: Brain imaging data suggest actions shape valuation. *Behaviour Research and Therapy*, 94, 60–70. Retrieved from http://ac.els-cdn.com/S0005796717300852/1-s2.0-S0005796717300852-main.pdf?_tid=ea doi: 10.1016/j.brat.2017.04.007

van de Vijver, I., van Schie, H. T., Veling, H., van Dooren, R., & Holland, R. W. (2018). Go/no-go training affects frontal midline theta and mu oscillations to passively observed food stimuli. *Neuropsychologia*, 119(August), 280–291. Retrieved from <https://doi.org/10.1016/j.neuropsychologia.2018.08.023> doi: 10.1016/j.neuropsychologia.2018.08.023

Veling, H., Holland, R. W., & van Knippenberg, A. (2008). When approach motivation and behavioral inhibition collide: Behavior regulation through stimulus devaluation. *Journal of Experimental Social Psychology*, 44(4), 1013–1019. Retrieved from http://ac.els-cdn.com/S0022103108000371/1-s2.0-S0022103108000371-main.pdf?_tid=60 <http://dx.doi.org/10.1016/> doi: 10.1016/j.jesp.2008.03.004

Veling, H., Lawrence, N. S., Chen, Z., van Koningsbruggen, G. M., & Holland, R. W. (2017, mar). What Is Trained During Food Go/No-Go Training? A Review Focusing on Mechanisms and a Research Agenda. *Current Addiction Reports*, 4(1), 35–41. Retrieved from <http://link.springer.com/10.1007/s40429-017-0131-5> doi: 10.1007/s40429-017-0131-5

Verbeken, S., Braet, C., Naets, T., Houben, K., & Boendermaker, W. (2018, apr).

Computer training of attention and inhibition for youngsters with obesity: A pilot study. *Appetite*, 123, 439–447. Retrieved from

Watson, P., Wiers, R., Hommel, B., & de Wit, S. (2014, aug). Working for food you don't desire. Cues interfere with goal-directed food-seeking. *Appetite*, 79, 139–148. Retrieved from

Watson, T. D., & Garvey, K. T. (2013, dec). Neurocognitive correlates of processing food-related stimuli in a Go/No-go paradigm. *Appetite*, 71, 40–47. Retrieved from <https://www.sciencedirect.com/science/article/pii/S019566631300336X> doi: 10.1016/j.appet.2013.07.007

World Health Organization. (2015). World Health Statistics. *World Health Organisation: Cardiovascular Disease Factsheet*, 112. Retrieved from <http://www.who.int/mediacentre/factsheets/fs317/en/> doi: 10.2307/3348165

World Health Organization. (2018). *Obesity and Overweight*. Retrieved 2019-05-06, from <https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight> doi: 10.1007/978-3-319-33228-4_47

Author notes

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Supplementary materials

Supplementary materials, including the analysis file in R, can be found under the following link: <https://osf.io/agrhe/>

Statistic	Mean	St. Dev.	Min	Max
Age	27.92	6.48	18	46
BMI	23.01	2.60	18.51	30.45
Hours since last food intake	4.31	3.01	1	10
Hungry	3.18	1.45	1	6
Full (reverse coded)	3.39	1.63	1	6
Desire to eat	3.22	1.33	1	6
How much could eat	3.86	1.21	1	7
Urge to eat	2.96	1.32	1	7
Preoccupation with food	3.49	1.47	1	7
Average of six items	3.49	1.12	1.20	6.60

Table 1

Descriptive statistics for the sample of $n = 49$.

effect.png

Figure 1. Predicted training effect.

Figure 2. Overview of the experimental procedure.

Figure 3. The course of two trials (first a low-calorie No-Go trial, second a high-calorie Go-trial). The use of full vs interrupted circles as Go- vs No-Go cues was counterbalanced between participants.

Figure 4. Grand average ERPs over Fz (top) and Cz (bottom) sites, time-locked to the onset of go/no-go cues for the baseline (left) and training (right) blocks.

Figure 5. Scalp distributions for all kinds of trials in the baseline (left) and training (right) blocks 224-277 ms post stimulus.