Food-related inhibitory control training reduces food liking but not snacking frequency or weight in a large healthy adult sample

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Abstract

Inhibitory control training has recently been used as an intervention to aid healthy eating and encourage weight loss. The aim of this pre-registered study was to explore the effects of training on food liking, food consumption and weight loss in a large (n=366), predominantly healthy-weight sample. Participants received four training sessions within a week, in which they had to inhibit their responses to either energy-dense foods (active group) or non-food images (control group). Subjective food ratings, food consumption frequency and weight were measured pre- and post-training. At two-weeks post-training, the active group reported a greater reduction in liking for energy-dense foods, compared to the control group. Active participants also reported a significantly greater increase in healthy food liking, immediately post-training, relative to the control group. There was no statistically significant difference between groups for the change in consumption of trained foods or for weight loss. These findings are partially consistent with previous research conducted in smaller, more overweight samples. Exploratory analyses suggest that some effects of training may be driven by awareness effects. Methodological differences across findings and avenues for future investigation are discussed.

Keywords: Response inhibition; Cognitive training; Disinhibition; Food liking; Food consumption; Weight loss;

Introduction

Overweight and obesity remains a global epidemic with substantial personal and economic implications (Bray, Nielsen, & Popkin, 2004; Fry & Finley, 2007; Mokdad et al., 2003; Ng et al., 2014; WHO, 2018). The abundance and variety of palatable, energy-dense foods is often cited as a leading cause of overeating (Cummins & Macintyre, 2006; Jeffery & Utter, 2003). Despite living in such an 'obesogenic environment' there is considerable variation in weight status across individuals. While some can easily resist temptation and maintain a healthy weight, others face a constant battle to control their food intake.

Dual process models argue that such variation in individual susceptibility can be explained by the interaction of two cognitive systems that we all possess (Strack & Deutsch, 2004). One 'reflective' system is driven by conscious thought and deliberation, resulting in reasoned action that is consistent with one's long term goals. The other 'impulsive' system, however, is driven by our hedonic needs and desires and can result in impulsive action with little-to-no thought of the consequences. For overeating, it is thought that behaviour is determined by a weak reflective system and/or a strong impulsive system (e.g. Houben, Nederkoorn, & Jansen, 2012; Lawrence, Hinton, Parkinson, & Lawrence, 2012; for a review see Stice, Lawrence, Kemps, & Veling, 2016). Individuals who are overweight or obese have been shown to demonstrate poor self-control and increased impulsivity across a range of questionnaires and behavioural measures, and in particular, they have been shown to demonstrate these characteristics in relation to food (Batterink, Yokum, & Stice, 2010; Chalmers, Bowyer, & Olenick, 1990; Davis et al., 2008; Davis, Patte, Curtis, & Reid, 2010; Houben, Nederkoorn, & Jansen, 2014; Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016; Nederkoorn, Coelho, Guerrieri, Houben, & Jansen, 2012; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006;). Houben et al. (2014) demonstrated such a deficit in food-related self-control when they found that increased body mass index (BMI) was associated with poor inhibitory control in response to images of energy-dense foods but not to general stimuli.

Such findings have sparked interest in developing new behavioural interventions to aid reduced energy intake and weight loss by targeting these two cognitive systems (Jones, Hardman, Lawrence, & Field, 2018; Turton, Bruidegom, Cardi, Hirsch, & Treasure, 2016). One intervention that has been used with some degree of success is food-related inhibitory control training, with recent meta-analyses citing small-to-medium effect sizes when compared to control training (Allom, Mullan, & Hagger, 2016; Jones et al., 2016). In a typical inhibitory control training paradigm, participants are presented with relevant stimuli, such as images of unhealthy foods, and are instructed to make a speeded response to each stimulus, but to withhold that response when a signal occurs. In order to bias behaviour towards healthy eating, for example, healthy foods are associated with a response (go foods) and unhealthy foods are paired with a stop or no-go signal (no-go foods). Repeatedly pairing a stimulus with the inhibition of a response has been demonstrated to improve the ability to stop to that stimulus on future trials (Verbruggen & Logan, 2008). In the case of food-related inhibition training, repeatedly stopping to unhealthy foods has also been shown to influence eating behaviour. Studies have shown effects of training on reduced calorie consumption (Adams, Lawrence, Verbruggen, & Chambers, 2017; Houben, 2011; Houben & Jansen, 2011, 2015; Lawrence, Verbruggen, Morrison, Adams, & Chambers, 2015a; Oomen, Grol, Spronk, Booth, & Fox, 2018; Veling, Aarts, & Papies, 2011), decreased unhealthy food choices (van Koningsbruggen, Veling, Stroebe, & Aarts, 2013; Veling, Aarts, & Stroebe, 2013a, 2013b) and even weight loss (Lawrence et al., 2015b; Veling, van Koningsbruggen, Aarts, & Stroebe, 2014).

Several mechanisms have been proposed to explain the effects of inhibitory control training on behaviour with the most evidence to date supporting stimulus devaluation (Driscoll, de Launay, & Fenske, 2018; Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017a, but see Jones et al., 2016), which is the primary focus of this study. It has been shown that repeatedly pairing a stimulus with the inhibition of a response can lead to a reduction in rated valence for that stimulus; an effect that has been demonstrated across a range of stimuli including faces, arbitrary shapes, sexual images, alcohol and food (Doallo et al., 2012; Driscoll et al., 2018; Houben, Havermans, Nederkoorn, & Jansen, 2012; Lawrence et al., 2015b; Veling et al., 2013a; Wessel, O'Doherty, Berkebile, Linderman, & Aron, 2014). A number of explanations for this devaluation effect have been proposed (Veling et al., 2017a), including the "Behaviour Stimulus Interaction" theory whereby devaluation occurs in order to reconcile the conflict between the automatic approach response elicited by rewarding stimuli and the need to inhibit that response. Another suggestion is that during training, associations are created between the food stimuli and inherent appetitive/aversive 'centres' (McLaren & Verbruggen, 2016; Verbruggen, Best, Bowditch, Stevens, & McLaren, 2014). Associative learning theories have argued that hard-wired associations exist between actions and appetite/aversion, whereby stopping and avoidance are linked to an aversive system and responding and approach are linked to an appetitive system (Chen & Bargh, 1999; Dickinson & Balleine, 2002; Dickinson & Dearing, 1979; Guitart-Masip et al., 2012; Konorski, 1967). It is plausible therefore that associations between going and stopping and the respective appetitive/aversive 'centres' can spillover to food stimuli presented during inhibition training. This would suggest that the associative link between foods, action tendencies and the appetitive/aversive centres may be strengthened throughout training such that no-go foods become increasingly disliked and go foods increasingly liked (see Jones et al., 2016).

In a study investigating the effect of inhibition training and appetite on food choice, Veling et al. (2013b) paired palatable, energy-dense, foods with either a go cue or a no-go cue in a within-subjects design. Participants then rated the foods according to attractiveness and tastiness before selecting three of the foods for consumption. Their results demonstrated that participants with a high appetite rated the no-go foods less favourably (a combined measure of attractiveness and tastiness) and were less likely to select those foods, compared to the go foods. Furthermore, the effect of appetite on food choice was mediated by the devaluation of no-go foods, although, there was no evidence of mediation for the evaluation of go foods. In a similar study, with a community sample who were predominately overweight or obese, Lawrence et al. (2015b) also demonstrated the devaluation of energy-dense foods following inhibition training in a between-groups design. For this study, participants completed four sessions of go/no-go training over a one-week period. The active task involved responding to images of healthy foods (go foods) and withholding responses to images of energy-dense snack foods (no-go foods). The control task, conversely, consisted solely of non-food images; participants were trained to respond to some household items and to stop to others. Measures of weight loss, snacking frequency and energy intake were recorded along with ratings for the liking and attractiveness of the trained foods. Lawrence et al. found that participants in the active group lost a significant amount of weight and reduced their daily energy intake, relative to the control group. They also showed a significant reduction in liking for energy-dense snack foods from pre- to two weeks post-training; this is compared to the control group who showed a slight increase in liking over the same time period. Although the active group were also trained to repeatedly respond to healthy foods, there were no group differences in either liking or attractiveness ratings for these foods. This finding is in contrast to recent results showing that similar training methods can also bias behaviour towards healthy eating.

Training participants to respond to certain foods using a go-cue (cued-approach training) has been shown to result in increased choice behaviour and valuation of those foods (Chen, Holland, Quandt, Dijksterhuis, & Veling, 2019; Chen, Veling, Dijksterhuis, & Holland, 2016, 2018a; Schonberg et al., 2014; Veling et al., 2017b; Zoltak, Veling, Chen, & Holland, 2018). In a series of experiments, Chen et al. (2016) investigated the effect of inhibition training on stimulus devaluation by pairing foods (both healthy and unhealthy) with a go cue, a no-go cue or no cue. Participants rated each of the foods according to how attractive they were, at that moment in time, pre- and post- training. These ratings were then compared across conditions and also to stimuli that were not presented during training (untrained foods). In addition to the expected effects on devaluation for no-go foods, Chen et al. also found evidence for increased ratings of go foods, relative to untrained foods. To see whether such effects would translate to behaviour, Veling et al. (2017b) used a food choice task, comparing equally valued foods that had been associated with either a cued response (cued go foods) or no response (non-cued no-go food). Their results showed that participants were more likely to choose go foods, compared to no-go foods. Moreover, these effects were demonstrated when comparing both energy-dense snacks and fruits and vegetables. These findings were later replicated in a series of seven pre-registered studies (Chen et al., 2019). Furthermore, it was shown that training could be used to promote healthy foods over unhealthy foods (when a choice between healthy cued-go and unhealthy cued-no-go foods was compared to a choice between healthy and unhealthy untrained foods). Together these results suggest that go/no-go training can also be used to increase food preferences and choice behaviour, even for healthy foods.

The current study followed the methods used by Lawrence et al. (2015b), but in a much larger, less selective sample that was predominantly of healthy weight. Our primary aim was to replicate previous results showing effects of go/no-go training on reduced liking for energy-dense no-go foods (Lawrence et al., 2015b; Veling et al., 2013a). We focused on food devaluation because it seems to be a robust outcome, even in healthy-weight samples such as ours, and we had planned to examine the influence of individual differences (see below). Participants were randomly assigned to receive either active training, in which energy-dense foods were paired with inhibition (100% cued no-go) and healthy foods were paired with responding (100% go), or control training, which included only non-food stimuli (where half the images were 100% go and half were 100% no-go). The training schedule involved four ten-minute sessions over a one-week period. Our primary outcome measure was a subjective liking rating for each food at two weeks post-training (as measured in Lawrence et al., 2015b), but we also measured changes immediately after the first training session (i.e. similar to single-session studies such as Chen et al., 2016). Participants were therefore asked to rate trained and untrained foods at pre-training, immediately after a single training session, and at two weeks post-training. Effects on healthy food liking were also measured along with food consumption frequency and weight loss. Participants were able to complete the study either entirely online or with two lab sessions at the beginning and end of the study. It was hypothesised that active training would reduce self-reported liking of energy-dense foods from pre- to two weeks post-training, relative to control training (primary outcome). In addition, we predicted increased liking of healthy (go) foods, reduced consumption frequency for trained (no-go) snack foods and increased weight loss in the active group, compared to the control group, as measured at two weeks post-training. We also expected similar changes in food liking immediately after the first training session. All hypotheses, methods and statistical analyses were pre-registered for transparency and are available online[1]. The current study was part of the GW4 Undergraduate Psychology Consortium which aims to promote collaborative and reproducible science for undergraduate students (Button, Chambers, Lawrence, & Munafò, 2020). Several measures of individual differences (e.g. self-esteem, self-efficacy, emotional regulation) were included for pedagogical reason as part of the student project to test moderation effects of training. These moderation analyses are not presented in the current paper (see Deviations from Pre-registered Protocol).

Method

Participants

A total of 431 participants took part in the study (337 female; age: M=24.51, SD =11.38; see Figure 1). For laboratory-based sessions participants were recruited from three University campuses (Cardiff University, University of Bath and University of Exeter) using research participation schemes and word of mouth. For the online arm of the study participants were recruited using social media (e.g. Facebook, Twitter). The study was presented as testing "a new simple computer-based technique that may help people reduce their intake of snack foods. We will compare the snacking behaviour of two groups of participants; one given an 'active' and one given a 'control' computer-based 'training' task." Based on our pre-registered criteria, 30 participants were excluded from the analysis due to ineligibility according to age (1 participant aged below 18 years) or body mass index (BMI; 29

[1] https://osf.io/wxyra/

participants with a BMI <18.5). Due to the potential influence of training on weight loss we excluded participants with a BMI in the underweight range (<18.5; Lawrence et al., 2015b). A further 35 participants were excluded for not having any training data or for having duplicate identification numbers (n=4). The final sample size was 366; data for 308 participants was included in the two weeks post-training analysis (data was missing for 58 participants due to attrition) and data for 312 participants was analysed for the immediate post-training outcomes (there was no session 1 post-training data for 54 participants due to attrition or technical issues). Ethical approval for the trial was granted by the Psychology Department Board of Ethics at the University of Exeter (initially, and all participating institutions thereafter).

Sample Size and Statistical Power

Sample size was determined using *a priori* power calculations based on Lawrence et al.'s (2015b) finding for the effect of training on changes in energy-dense food liking (*d*=.55). With 80% power and a two-tailed alpha of .05, a sample size of 106 was required to detect an effect size of *d*=.55 (53 per group; calculated using G*Power; Faul, Erdfelder, Lang, & Buchner, 2007). This sample size was exceeded in an attempt to power for additional moderators that were included as part of the student consortia project (see Deviations from Pre-registered Protocol). The final sample was 366 before missing data considerations. Sensitivity analyses for the main comparisons revealed that we had 80% power to detect an effect size of *d*=.32 at both time points (for two weeks post-training, timepoints 1-3; N=308; 167 active, 141 control; immediately post-training, timepoints 1-2; N=312; 166 active, 146 control).

Deviations from Pre-registered Protocol

Additional moderators (binge eating behaviour, self esteem, self efficacy, restrained eating, disinhibited eating, emotional regulation) were added by the students so that each could demonstrate individual input into the design, and answer a unique question for their empirical project (BPS, 2019; Button et al., 2020). We also pre-registered our plan to explore the moderating role of baseline BMI and food consumption frequency. The calculated sample size was multiplied fourfold in the pre-registered analysis to account for these analyses (424; Leon & Heo, 2009). However, with time and resource limits this target sample size was not reached, post exclusions. Due to insufficient statistical power these moderators are not included in the analyses but all data are available online[1].

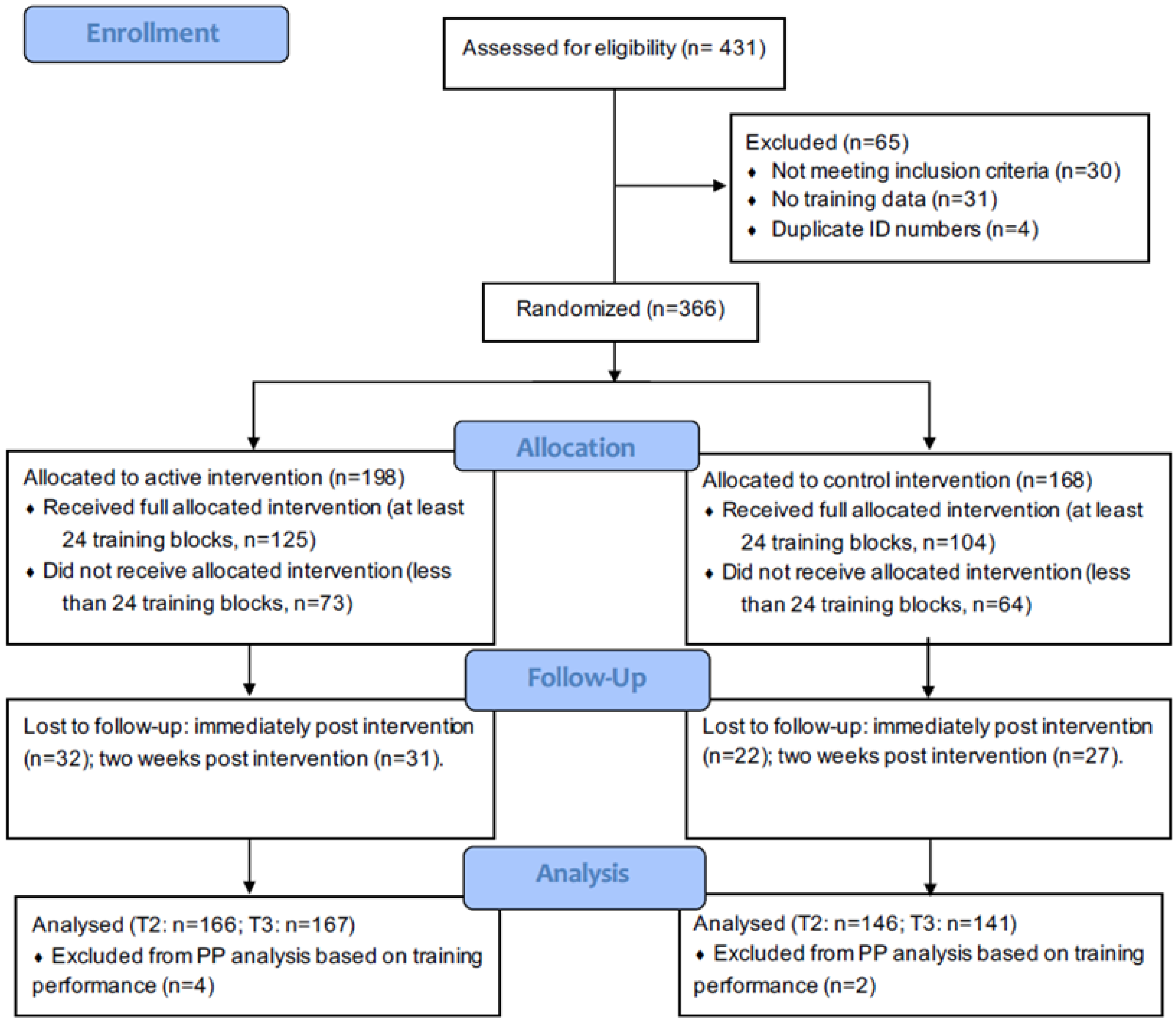

Figure 1. Recruitment flow diagram showing numbers of participants included in each intervention group at each stage of the study (see Supplementary Information for details of each sample).

Note. T2 = timepoint 2 (immediately post-training); T3 = timepoint 3 (two weeks post-training); PP = per protocol

Procedure

An overview of the study procedure is provided in Figure 2 and details of all measures and materials are provided below. In the first session, participants provided consent and demographic information. They then completed measures of food liking and food consumption frequency before answering questions on their height and weight. Participants were then presented with a series of individual differences questionnaires as part of the student consortia element of the study. Following these questionnaires, participants were directed to the training task in a separate browser window. At this point they were randomly allocated to the active or control training by the computer program. To complete the first session, participants answered post-training measures of food liking (immediately post-training; timepoint 2) and if participants were attending a laboratory session their height and weight was measured by a researcher. Participants were then asked to complete the training task at home over the next three consecutive days. Two weeks after the first session participants were asked to complete self-reported weight, food liking and food consumption frequency (two weeks post-training; timepoint 3). They then answered a series of debrief questions and were provided with a full debrief of the study's aims. If participants were in the lab they were weighed by one of the researchers.

Session 1				**2 weeks**		**Session 2**
Timepoint 1		**Timepoint 2**				**Timepoint 3**
Consent/ screening Food liking Food frequency SR height/weight Individual difference measures	Training	Food liking Height/weight (lab only)	…	Training (3+ sessions)	…	SR weight Food liking Food frequency Debrief Weight (lab only)
15-20 mins	10 mins	10 mins				15-20 mins

Figure 2. Schematic diagram of the study procedure. In session 1 participants completed baseline outcome measures, including food liking, food consumption frequency and self-reported (SR) weight. As part of the student consortia project, they also completed measures of individual differences. They were then randomly assigned to active or control training before completing the immediate post-training outcome measures (timepoint 2). Participants were asked to complete three training sessions at home over the following week before the second session, two weeks later. In session 2 they completed post-training outcome measures and were debriefed.

Materials/Measures

Training

The training task was a modified version of the go/no-go task and is identical to that used by Lawrence et al. (2015b). The task lasted approximately 10 minutes and consisted of six blocks of 36 trials. Each block randomly presented one each of 36 food and non-food images. The active task included 9 energy-dense food images (biscuits, chocolate, crisps, cake; >4kcal/g), 9 healthy food images (fruit, vegetables, rice cakes) and 18 non-food filler images (clothes; jeans, shirts, jumpers, socks, skirts and ties). The control version used the same filler images in addition to 18 images of household objects (furniture, stationery, gardening tools).

Food and non-food images were presented against a white background and were matched as closely as possible for size, colour and visual complexity. All images and experimental materials are available from the authors on request.

Each trial began with a central black rectangle presented against a white screen (1250 ms; Figure 3). Images were then presented, within the rectangle, to either the left or right hand side (1250 ms). Participants were instructed to press the ‘C’ and ‘M’ keys, respectively, as quickly and as accurately as possible (using a standard keyboard; go trial). On half of the trials, the rectangle was bold indicating that the participant should withhold their response (no-go trial). In the active task, 100% of energy-dense foods were no-go trials and 100% of healthy foods were go trials (i.e. food images were consistently associated with no-go and go responses, respectively). The filler images were 50% no-go trials and 50% go trials (i.e. inconsistently associated with no-go and go responses). In the control task, certain household objects (DIY tools, gardening tools and stationery) were 100% no-go trials and certain objects were 100% go trials (electrical items, furniture and buckets; i.e. consistent mapping). The filler images were 50% no-go and 50% go (i.e. inconsistent mapping). Breaks were provided between blocks and feedback was presented to increase motivation (accuracy and mean go RT).

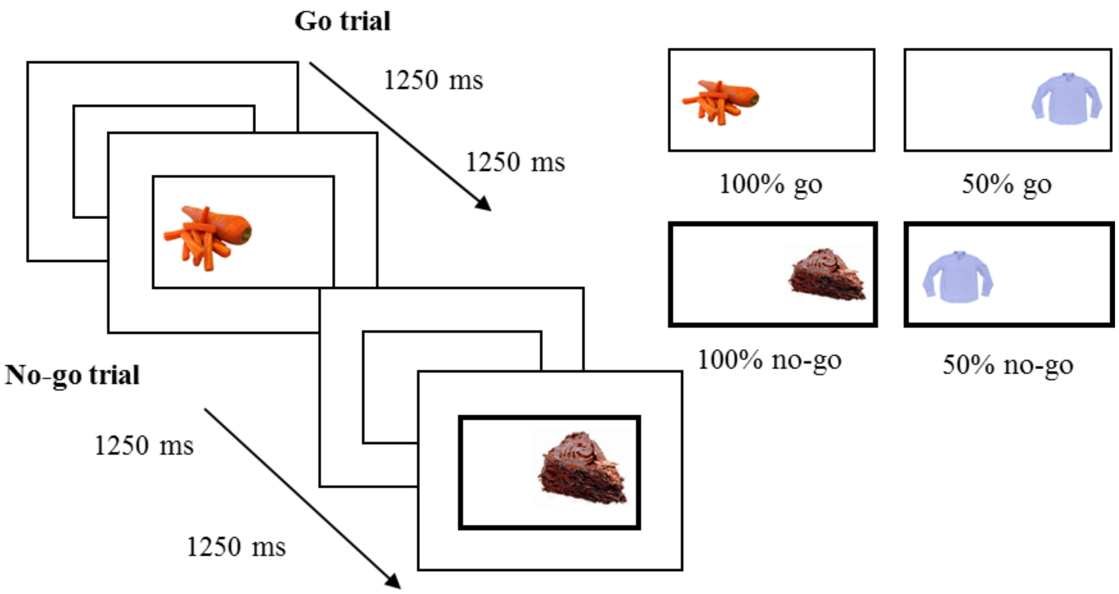

Figure 3. A) Display sequence for the training task. For go trials a fixation rectangle was presented, followed by a stimulus on the left or right hand side. Participants were instructed to respond to the stimulus location using the ‘C’ and ‘M’ keys, respectively. For no-go trials, the rectangle was bold, indicating that the participant should withhold their response. **B)** Mapping for the stimuli to go and no-go trials in the active task; energy-dense foods: 100% no-go; healthy foods: 100% go; filler images: 50% no-go, 50% go.

Food Liking

Subjective food liking ratings were measured using 100-point visual analogue scales (VAS; presented in Qualtrics, Provo, UT). Each food from the training task was included plus an additional 9 untrained foods (dried fruit, a sandwich, soup, pizza, jacket potato with butter, mushrooms, quiche, pancakes, and vegetarian cannelloni; food images were identical to those in Lawrence et al., 2015b). Each trial presented a single food image above a slider. Participants were instructed to imagine that some of the food was in their mouth and to rate the image according to how much they liked the taste. The slider used the anchors 'not at all' and 'very much'; the slider was initially positioned at 50 for each food. Trials were self-timed and the order of images was randomised.

Food Consumption Frequency

Participants were asked to indicate how often they consumed each of the foods presented during training plus four additional categories for ice-cream, chips, sweets, and pastries / sweet pies (untrained foods). Ratings were made on a 9-point scale (scoring from 8 down to 0) according to how often they had been consumed within the last month (4 or more times a day, 2 or 3 times a day, Once a day, 5 or 6 times a week, 2 to 4 times a week, Once a week, 1 to 3 times a month, Less often or never, I am allergic to this food so I avoid it; Churchill & Jessop, 2011). All foods were presented simultaneously in fixed order (Qualtrics, Provo, UT).

Weight and BMI

As part of the online survey, participants were asked to self-report their height and weight. In the laboratory sessions, participants were also asked whether the researcher could record their height and weight using a tape measure and set of bathroom scales. All weights were converted to kg and BMI was calculated (weight [kg]/ height^2 [m]).

Debrief Questions

At the end of the study participants were asked a) whether they thought the training helped to reduce their food intake, and b) would they recommend the training to a friend who was trying to reduce their food intake. Both questions allowed participants to respond 'yes', 'no' or 'not sure'. They were also asked to guess whether they thought they were in the active or the control condition (dichotomous choice) and whether they had any additional comments for how the training affected them or how it could be improved (all comments are available online[1]).

Individual Difference Measures

Several questionnaires were included in the study as part of the student consortia project. These questionnaires were included to see whether certain personality traits moderated the effect of training on outcomes. Due to insufficient statistical power these measures were not included in the analyses and will therefore only be described briefly (see Deviations from Pre-registered Protocol). Data from these questionnaires is provided online[1]. The following questionnaires were presented in a randomised order: the Binge Eating Scale (Gormally, Black, Daston, & Rardin, 1982); the Three-Factor Eating Questionnaire (Disinhibition subscale only; Stunkard & Messick, 1985); Rosenberg's Self-Esteem Scale (Rosenberg, 1965); the

General Self-Efficacy Scale (Schwarzer & Jerusalem, 1995); the Dutch Eating Behavior Questionnaire (Van Strien et al., 1986); the Emotional Regulation Questionnaire (Gross & John, 2003). The Binge Eating Scale, the Three-Factor Eating Questionnaire – Disinhibition subscale and the Dutch Eating Behavior Questionnaire – restraint subscale were analysed to ensure that there were no differences between our training groups on these measures of eating behaviour.

Statistical Analysis

As outlined in our pre-registered protocol, all participants who met eligibility criteria, and for whom change scores could be calculated, were included in the analysis in the groups to which they were randomised irrespective of how much training they had completed. In accordance with our previous research (Adams et al., 2017; Lawrence et al., 2015b) we also excluded six participants who did not perform as expected during training in a per-protocol analysis (based on proportion of errors for go and no-go trials and mean reaction time for go trials). This analysis did not change the pattern of results and the full details can be found in the Supplementary Information.

Following our pre-registered protocol[1], our primary analysis was for change in energy-dense liking ratings from pre- to post-training. To replicate Lawrence et al. (2015b), this is based on change scores from baseline to two weeks post-training (timepoints 1-3). We have also analysed immediate post-training changes to consider single-session training effects consistent with other lab-based studies (timepoints 1-2). Secondary outcomes include changes in healthy food liking, food consumption frequency and weight. Mean scores were calculated by averaging across each food type for liking scores and across the four no-go foods (biscuits, chocolate, crisps, cake) for food consumption frequency. For weight measures we had two variables: self-reported weight and experimenter-recorded weight for lab participants only. The correlation between these two weights in lab participants was very high (at baseline r (214) = .97, $p < .001$; at post-training r (169) = .92, $p < .001$), suggesting self-reported weights were valid. To calculate weight change we used experimenter-recorded values where both pre- and post-training values were available (150/289; 51.9%), otherwise, self-reported values were used (139/289; 48.1%). Some participants were excluded from this analysis based on extreme change scores (values > ±7kg, n=19). For all change scores, pre-training values were subtracted from post-training values such that negative scores reflect reductions in these outcome measures.

All outcomes were analysed using pre-registered simple linear regressions. The number of completed training blocks (range: 6-54; M=21.76; SD=6.82) was also added to these models to investigate whether there was a ‘dose-response’ relationship between training and each outcome measure. We also pre-registered a 2 x 3 mixed ANOVA (between subjects factor: *condition* [active, control]; within subjects factor: *food type* [energy-dense, healthy, untrained]) to further investigate changes in food liking according to food type and training condition. This complements our more focused linear regressions conducted separately for unhealthy and healthy foods. Details of exploratory analyses are provided in the results section below, and further analyses comparing lab-based and online training can be found in the Supplementary Information. All analyses were carried out using SPSS 25 (IBM Corp, 2017) and all study data is provided online[1].

Results

Group Differences

There were no significant differences between the two groups for sex ($\chi^2(1)=.48$, $p=.49$), age, baseline BMI, baseline consumption of trained energy-dense foods, BES, TFEQD or DEBQRE (all *t*s <1.4, all *p*s >.16, all *d*s <.15; see Table 1).

Table 1. Group characteristics and training data with between-group significance tests (SD within parentheses).

	Active (n=198)	Control (n=168)	*t*	*p*
Sex (% female)	76.8	79.8		
Age	23.69 (10.18)	24 (10.88)	.28	.78
Baseline BMI	23.57 (3.84)	23.78 (4.78)	.46	.65
FCF-energy-dense	2.96 (0.9)	2.83 (0.84)	1.4	.16
BES	15.21 (5.95)	14.81 (6.4)	.62	.53
TFEQD	7.33 (3.96)	6.95 (3.47)	1	.32
DEBQRE	2.72 (0.88)	2.73 (0.86)	.13	.89
# training blocks	20.75 (7.93)	20.53 (7.35)	.27	.79
Proportion no-go errors	.06 (.1)	.06 (.11)	.17	.86
Proportion go errors	.03 (.06)	.02 (.05)	.62	.54
GoRT	527.18 (90.05)	513.7 (76.12)	1.53	.13

Note. BMI = body mass index; FCF = Food consumption frequency; BES = Binge Eating Scale; TFEQD = Three Factor Eating Questionnaire – Disinhibition scale; DEBQRE = Dutch Eating Behavior Questionnaire – Restrained Eating scale; GoRT = go reaction time

Training Performance

On average, participants completed 20 out of the requested 24 blocks of training (*M*=20.65, *SD*=7.66, range: 6–54) and 62.6% completed the four training sessions. Importantly, there was no statistically significant difference between groups for the number of completed training blocks ($t(364) = .27$, $p=.79$, $d=.03$; see Table 1). Participants also showed good performance on the training tasks; the proportion of errors was low (no-go: *M*=.06, *SD*=.1; go: *M*=.02, *SD*=.05), indicating that participants engaged well with the training.

As in our previous studies, we examined the training data to check for evidence of learning stimulus-response associations. Such learning would be demonstrated with reduced errors and/or reaction times for the consistently associated stimuli compared to the inconsistently associated stimuli (e.g. comparing the 100% no-go energy-dense items with the 50% no-go filler items, and the 100% go healthy items with the 50% go filler items in the active group). Due to the large variation in the number of completed training blocks we analysed the first session only (6 blocks) and overall performance. Evidence of learning stimulus-response associations was found for both analyses in the no-go errors and go reaction times. The results showed that the mean proportion of no-go errors was significantly lower for the stimuli consistently paired with stopping compared to the inconsistent (filler) stimuli (both Fs>40.94, both *p*s <.001, both η_p^2s >.1) This was not dependent on training group (both Fs<.44, both *ps* >.51, both η_p^2s <.001). Go reaction times were also significantly faster for stimuli that were consistently paired with a go response compared to those that were inconsistently paired with going (both Fs>291.59, both *p*s <.001, both η_p^2s >.45). There was a statistical trend for an interaction between stimulus type and training group for session one ($p=.09$, $\eta_p^2 =.008$), and this interaction was significant for overall performance ($p=.04$, $\eta_p^2 =.01$). The interactions showed a greater difference between stimulus types for the active group, compared to the control group, suggesting that learning effects may have been greater in the active condition. However, pairwise comparisons showed that the difference between stimuli was statistically significant for both groups (all *p*s<.001). There was no evidence of learning in the go error rates, which may have been due to floor effects (see Supplementary Information for the full analyses of training data).

Pre-registered Analyses

Tables 2 and 3 show all outcome means and change scores by training condition for timepoints 1 and 3 (pre-training to two weeks post-training; our primary focus) and timepoints 1 and 2 (pre-training to immediately post-training), respectively.

Table 2. Descriptive statistics for means and change scores (Δ) across timepoints 1–3 (n=308; SD within parentheses).

	Time 1		Time 3		Δ Time 1–3	
	Active	Control	Active	Control	Active	Control
Liking-Energy-dense	68.84 (16.18)	66.11 (16)	63.61 (17.07)	63.56 (16.93)	-5.22 (10.47)	-2.55 (9.42)
Liking-Healthy	58.85 (12.89)	59.7 (13.08)	60.33 (12.81)	59.37 (12.49)	1.48 (8.91)	-0.33 (7.94)
Liking-Untrained	62.86 (12.34)	65.16 (12.03)	62.14 (12.67)	63.7 (11.91)	-0.72 (7.5)	-1.46 (7.57)
FCF-Energy-dense	3 (0.9)	2.9 (0.84)	2.82 (0.87)	2.83 (0.86)	-0.18 (0.65)	-0.07 (0.62)
FCF-Healthy	4.87 (1.07)	4.74 (1.06)	4.83 (1.14)	4.76 (1.13)	.004 (0.83)	0.02 (0.58)
FCF-Untrained	2.16 (0.67)	2.23 (0.71)	2.23 (0.87)	2.27 (0.8)	0.07 (0.75)	0.04 (0.75)
Weight (kg)	67.23 (13.56)	67.99 (14.39)	66.75 (13.39)	67.73 (14.3)	-0.47 (2.03)	-0.26 (1.95)

Note. FCF = Food consumption frequency

Table 3. Descriptive statistics for means and change scores (Δ) across timepoints 1–2 (n=312; SD within parentheses).

	Time 1		Time 2		Δ Time 1–2	
	Active	Control	Active	Control	Active	Control
Liking-Energy-dense	67.97 (17.17)	65.73 (15.22)	65.95 (17.63)	64.19 (15.8)	-2.02 (7.46)	-1.55 (6.09)
Liking-Healthy	58.18 (12.53)	59.89 (13.08)	59.68 (13.16)	60.18 (13.43)	1.5 (6.12)	0.29 (3.96)
Liking-Untrained	62.16 (12.53)	65.18 (12.14)	62.1 (13.35)	65.6 (12.44)	-0.06 (4.29)	0.43 (4.74)

Changes in Food Liking

Both training groups showed a reduction in liking for energy-dense foods at two weeks post-training and this devaluation effect was significantly greater for the active compared to the control group (r^2 =.02, F(1, 307) = 5.46, p=.02; B = 2.67, 95% CI [.42, 4.92]; Table 2, Figure 4). Adding the number of completed training blocks to the regression model revealed that there was no statistically significant ‘dose-response’ relationship between training and devaluation (r^2 =.03, F(3, 307) = 2.81, *p*=.04; training blocks: B = -.34, 95% CI [-.84, .16], *p*=.18; interaction: B = .28, 95% CI [-.06, .61], *p*=.11). A reduction in energy-dense food liking was also demonstrated for both groups immediately post-training (Table 3), and although the difference between groups was in the expected direction, this was not statistically significant (r^2=.001, F(1, 311) = .37, *p*=.54; B = .47, 95% CI [-1.06, 2]).

For healthy food liking at two weeks post-training, there was an increase in ratings for the active group and a decrease in ratings for the control group (Table 2, Figure 4). This difference in evaluative ratings was partially confirmed with a statistical trend (r^2 =.01, F(1, 307) = 3.45, *p*=.06; B = -1.8, 95% CI [-3.7, .11]). We found no evidence for a 'dose-response' relationship when adding the number of completed training blocks (r^2 =.02, F(3, 307) = 1.51, *p*=.21; training blocks: B = .22, 95% CI [-.2, .65], *p*=.3; interaction: B = -.14, 95% CI [-.43, .15], *p*=.34). Immediately post-training, both groups showed an increase in liking for healthy foods (Table 3); this increase was significantly greater in the active group compared to the control group (r^2 =.01, F(1, 311) = 4.16, *p*=.04; B = -1.21, 95% CI [-2.38, -.04]).

To further investigate changes in energy-dense and healthy food liking, relative to untrained foods, we used a (pre-registered) 2 x 3 mixed ANOVA (between-subjects factor: *condition* [active or control]; within-subjects factor: *food type* [energy-dense, healthy, untrained]). There was no statistically significant effect of condition (F(1, 306) =.003, *p*=.96, $\eta_p^2 < .001$); however, there was a significant effect of food type (F(1.83, 558.57) =32.08, *p*<.001, $\eta_p^2 = .1$, with Huynh-Feldt correction), and importantly, there was a significant interaction between the two (F(1.83, 558.57) =8.64, *p*<.001, $\eta_p^2 = .03$, with Huynh-Feldt correction). Pairwise comparisons showed a significantly greater reduction in energy-dense food liking for the active group, compared to the control group (*p*=.02). There was also a statistical trend for a greater increase in healthy food liking in the active group, compared to the control group (*p*=.06). There was no statistically significant difference between training groups for the untrained foods (*p*=.39).

The above results were partially replicated with immediate post-training ratings. We found no significant effect of condition (F(1, 310) =.04, *p*=.85, $\eta_p^2 < .001$), a significant effect of food type (F(1.75, 542.6) =23.57, *p*<.001, $\eta_p^2 = .07$, with Huynh-Feldt correction) and a statistical trend for the interaction (F(1.75, 542.6) =2.92, *p*=.06, $\eta_p^2 = .01$, with Huynh-Feldt correction). Pairwise comparisons showed a significant difference between training groups for the healthy foods only (*p*=.04); there was no statistically significant difference for energy-dense foods (*p*=.54) or untrained foods (*p*=.34).

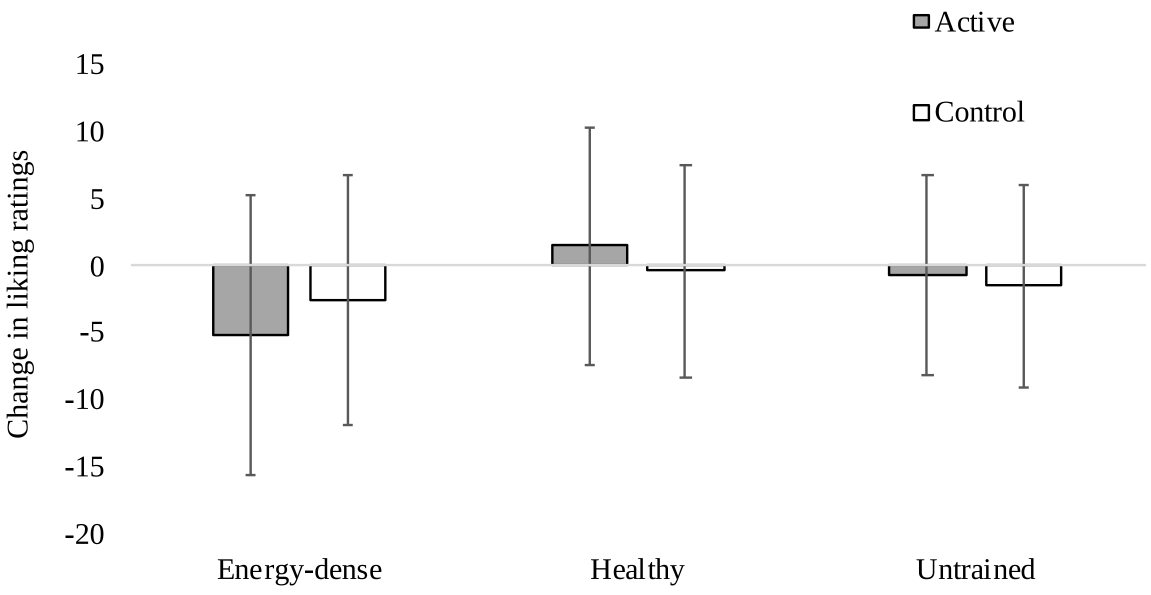

Figure 4. Changes in food liking ratings from pre- to two weeks post-training (timepoints 1-3) as a function of food type and training condition. A negative value indicates a reduction in food liking scores. Error bars: ±1SD

Changes in Food Consumption Frequency – Energy-Dense Foods

Self-reported consumption frequency for the trained energy-dense foods decreased for both groups across the two-week period (Table 2). Although, the results were in the expected direction, with the active group reporting a greater decrease than the control group, this difference was not statistically significant (r^2 =.01, F(1, 307) = 2.47, p=.12; B = .11, 95% CI [-.03, .26]). There was also no significant effect of the number of completed training blocks (r^2 =.01, F(3, 307) = .87, p=.46; training blocks: B = -.003, 95% CI [-.04, .03], p=.85; interaction: B =.003, 95% CI [-.02, .03], p=.76).

Changes in Weight

Weight was recorded at baseline and at two weeks post-training (timepoint 3). Both groups showed a reduction in weight during this time, with a mean loss of .37kg (*SD* = 1.99; Table 2). The active group lost more weight than the control group, however, the difference between groups was not statistically significant (r^2 =.003, F(1, 288) = .82, p=.37; B = .21, 95% CI [-.25, .68]; see Table 2). Further, there was no significant effect of the number of training blocks completed on weight change (r^2 =.003, F(3, 288) = .33, p=.81; training blocks: B = -.02, 95% CI [-.12, .08], p=.69; interaction: B = .01, 95% CI [-.06, .08], p=.74).

Exploratory analyses

Changes in Food Liking

Additional analyses were conducted to examine whether the reduction in liking for energy-dense foods in the active vs. control group varied over time, and to compare changes to trained and untrained foods within the same category (healthy or energy-dense).

To examine the devaluation of energy-dense foods over time we conducted a 2 x 2 mixed ANOVA on change scores (between subjects factor: *condition* [active or control], within subjects factor: *time* [immediately after training vs. two weeks post-training]). There was a main effect of time (F(1, 265) = 6.25, p = .013, η_p^2 =.023) with greater devaluation at two weeks (M = -3.29, SD = 9.67) than immediately post-training (M = -1.83, SD = 6.91). The effect of group approached significance (F(1, 265) = 3.53, p = .061, η_p^2 =.013), with greater devaluation in active (M = -3.35, SD = 6.91) than control participants (M = -1.76, SD = 6.96). The group x time interaction was not significant (F(1, 265) = 2.82, p = .095, η_p^2 =.011), although pairwise contrasts indicated that the difference between time-points was driven by the active (M = -2.44, SD = 9.54, p = .003) rather than the control group (M = -0.48, SD = 9.53, p = 0.57).

The pre-registered 2 x 3 ANOVA on changes in food liking found greater devaluation of energy-dense foods relative to healthy and untrained foods in the active vs. control group. However, this comparison was partly confounded by food category because go-trained foods were always healthy and no-go trained foods were always energy-dense. We therefore split untrained foods into healthy and more energy-dense categories to compare trained and untrained foods of similar types (see supplementary materials for full descriptive and inferential statistics). Separate exploratory 2 x 2 ANOVAs examined change scores for healthy and energy-dense foods (between subjects factor: *condition* [active or control], within subjects factor: *food type* [trained vs. untrained]). Results were consistent with our main analyses, suggesting significantly greater devaluation of trained vs. untrained energy-dense foods in the active vs. control group at two weeks post-training (group x food type interaction, F(1,306) = 6.92, p = .009, η_p^2 = .022; significant difference between food types in the active group M = -3.32, SD = 10.05, p < .001, but not in the control group M = -0.29, SD = 10.06, p = .73). For healthy foods, there was greater increased valuation of trained vs. untrained foods in the active vs. control group immediately post-training (group x food type interaction, F(1,310) = 4.69, p = .031, η_p^2 = .015; significant difference between food types in the active group M = 1.35, SD = 6.42, p = .007, but not in the control group M = -0.23, SD = 6.42, p = 0.66). There were no significant group x food type interactions for healthy foods at two weeks post-training or for energy-dense foods immediately post-training.

Food Consumption Frequency

A 2 x 3 mixed ANOVA (between subjects factor: *condition* [active or control], within subjects factor: *food type* [energy-dense, healthy, untrained] was conducted to see whether changes in food consumption frequency were dependent on food type. Results revealed a significant main effect of food type (F(1.92, 588.86) =5.93, p=.003, η_p^2 =.02, with Huynh-

Feldt correction). There was a significant difference between energy-dense foods, which reduced in consumption frequency (*M* = -.13, *SD* =.63) and healthy foods which slightly increased in consumption frequency (*M*=.01, *SD* =.72; *p*=.02). There was also a significant difference between energy-dense foods and untrained foods, which also increased in frequency (*M*=.06, *SD*=.75; *p*<.001), but there was no statistically significant difference between healthy and untrained foods (*p*=.42). There was no main effect of training condition (F(1, 306) =.44, *p*=.51, η_p^2 =.001), and importantly, no interaction between condition and food type (F(1.92, 588.86) =.89, *p*=.41, η_p^2 =.003, with Huynh-Feldt correction).

Task Feedback and Awareness

At the end of the study we gathered feedback and assessed awareness of training condition (see Supplementary Information for full analyses). Only a minority of participants reported that the training (active or control) helped to reduce food intake (7.2%) - most were either 'not sure' (33.9%) or negative (59%). A larger proportion reported that they would recommend it to a friend (20.2%), with 30.9% 'not sure' and 48.9% negative. Ratings were more positive in the active vs. control group but there were no significant differences between training groups (both χ^2s<3.42, both *p*s>.18). Importantly, we did find that participants in the control group were significantly better at correctly guessing their training condition (86.5%) than those in the active group, who were at chance (49%; χ^2(1)=48.04, *p*<.001). We conducted exploratory analyses to investigate whether such awareness of training condition had any influence on outcomes (for timepoints 1-3 in the active condition only, see Supplementary Information for full details). We found evidence to suggest that changes in healthy food liking (*p*=.09), frequency of consumption for energy-dense foods (*p*=.04) and weight change (*p*=.04) were moderated by awareness. However, training effects on our primary outcome of devaluation of energy-dense foods were independent of awareness of condition (*p*=.27).

Discussion

The current study aimed to investigate the effects of go/no-go training on food liking, food consumption frequency and weight loss in a large, predominantly healthy-weight sample. Our methods largely replicated those used by Lawrence et al. (2015b) who studied a smaller, more selective (overweight, disinhibited eating) sample. Participants were randomly assigned to one of two training conditions: active training involved inhibiting responses to energy-dense foods and responding to healthy foods, while control training included non-food stimuli only (50% go, 50% no-go). Relative to the control group, participants in the active group showed evidence for decreased liking of energy-dense foods and increased liking of healthy foods. However, there was no evidence for reliable training effects on changes in food consumption frequency or weight loss. Analyses also suggest that awareness of training condition in active participants may have been associated with greater increases in healthy food liking, and greater decreases in consumption frequency of energy-dense foods and weight. Our results are partially consistent with previous studies examining effects of inhibition training on eating behaviour; the differences, potential explanations and directions for future investigation are discussed.

The primary outcome in the current study was change in self-reported liking for trained, energy-dense foods at two weeks post-training. Our results revealed that both training groups showed a decrease in liking, both immediately post-training and two weeks later. This devaluation was significantly greater in the active compared to the control group at two weeks post-training, but not following a single training session where devaluation effects were generally smaller (by about 1.5 points on the VAS, ~half the size). Effects of inhibition training on stimulus devaluation have previously been demonstrated for a range of stimuli, including foods (Doallo et al., 2012; Driscoll et al., 2018; Houben, Havermans, et al., 2012; Wessel et al., 2014). Using a very similar methodology to the current study, Lawrence et al. (2015b) found that four sessions of active training resulted in a significant reduction in liking of trained, energy-dense foods, when compared to control training, with very similar effects in the active group to those shown here (a mean reduction of 4.6 [SD=11.35; d_z=.41] vs. 5.22 [SD=10.47; d_z=.5] here). Devaluation following a single training session has also been reported (Veling et al., 2013a; Chen et al., 2016, 2018a). It is possible that we did not find significant single-session effects here due to methodological differences resulting in reduced sensitivity to detect such short-term effects. Chen et al. (2016, 2018a) used within-subject designs in which go and no-go foods were carefully matched according to personalised pre-training ratings, reducing sources of noise. Furthermore, ratings of food *attractiveness* were made using a 200-point (rather than our 100-point) scale. It is possible that attractiveness ratings are more sensitive to training as they are more strongly dependent on situational variables such as desire to eat and hunger, whereas liking may be a more stable perception of the food item (Rogers & Hardman, 2015).

In the current study, we believe that the stronger devaluation effect of training at two weeks post-intervention is likely due to distributed practice effects, with multiple training sessions spaced over consecutive days allowing for greater learning of stimulus-response associations (Bakkour et al., 2018; and see evidence for stronger learning over all training sessions compared to one session in the Supplementary Information). This is consistent with previous studies that have shown greater effects of training on devaluation for participants who had improved memory of task contingencies (Camp & Lawrence, 2019; Chen et al., 2018a, 2018b). Another explanation could be the increased amount of training prior to the two-week outcome measure, compared to the immediate one; whilst we found no evidence for a 'dose-response' effect, our study was not designed to manipulate and test dose. Previous studies have indicated that training effects are independent of the number of stimulus pairings within a single session (Jones et al., 2016), suggesting that the best way to maximise training efficacy may be through increased attentional engagement using shorter sessions spread across multiple days (Aulbach et al., 2021; Bakkour et al., 2018; Chen et al., 2019; Veling et al., 2013a). Indeed, several of our active participants commented that the training should be completed over a greater number of days ("I think that any intervention would have to be repeated more frequently than I did this to have significant impact" [11030, active]; "I think it should be longer as 3 days isn't enough to retrain the habits of a lifetime" [11213, active]), but one commented that it may need to be more engaging to support this ("It was not incredibly engaging, so if it was something that you are planning on people doing to loose weight, they may stop after a few times" [sic; 11545, active]). Future research could seek to manipulate training dose, length and overnight spacing to determine optimal parameters.

In addition to exploring the devaluation of energy-dense foods, we also investigated whether repeatedly responding to healthy foods would increase subjective liking. Our results revealed an increase in liking for healthy foods in the active group only; evidence for this group effect was strongest immediately post-training and was borderline-significant after two weeks. These results are consistent with recent studies that have demonstrated increased ratings of attractiveness following go-training (Chen et al., 2016, 2018a, 2018b); however, effects appear to be subject to methodological variations. Previous studies with positive findings have tended to include go cues in the training protocol, which are believed to increase attention towards these foods (Schonberg et al., 2014; Zoltak et al., 2018; but see Zoltak, Holland, Kukken, & Veling, 2020). Furthermore, participants have rated go foods as more attractive than *untrained* foods, but only when go trials were presented frequently (75% of trials) or when the training encouraged rapid responding (using a staircase procedure to delay the cue onset). When Chen et al. (2016) included a training task with 50% go trials, as in the current study, there was no difference in ratings between go foods and untrained foods. Similarly, Lawrence et al. (2015b), found no effects of (go) training on increased liking ratings when training included an equal number of go and no-go trials. Observed effects may be dependent on increased attention or motivational salience of 'go' foods (see Camp & Lawrence, 2019, and discussion about awareness effects below). Research also suggests that the mechanisms involved in increased evaluation of go foods and decreased evaluation of no-go foods differ. Previous studies have found greater go evaluation effects when such trials are frequent, compared to no-go devaluation effects which show the reverse pattern (Chen et al., 2016). Our results also indicate that go effects may be stronger immediately post-training, whereas no-go effects may take longer to develop. A more thorough investigation of long-term training effects on both positive and negative changes in subjective value ratings would be useful.

Our training task used 'meaningful categories' with go-training to healthy foods and no-go training to less-healthy (energy-dense) foods (Serfas et al., 2017), making it hard to separate out training and food-category effects. However, exploratory analyses comparing changes in liking for trained and untrained foods within each category suggested that these changes were due to the trained responses rather than category. These analyses also suggested limited generalisation of training effects to the untrained foods in this study, which may be partly due to the limited similarity between trained and untrained foods (e.g. energy-dense snacks in the trained vs. medium energy-density meals in the untrained category).

In addition to measures of subjective food liking we also explored whether effects of training translated into changes in frequency of consumption and weight loss. We found no reliable evidence of training effects for either of these outcome measures; a finding which is only partially consistent with those of Lawrence et al. (2015b). Similar to the present study, Lawrence et al. found that although both training groups showed a reduction in consumption frequency, there was no group effect, either at one month or six months follow-up (see also Veling et al., 2014). Current and past findings therefore suggest that food frequency measures may detect more general intervention effects, such as increased self-awareness or self-monitoring resulting from taking part in the study and completing the questionnaires. For example, several participants in the control condition referred to general intervention effects ("Even though I think I was in the control condition, I noticed that I was trying to stop myself from snakcing." [sic; 11262, control]; "It was interesting to take part in this training, though I was waiting for any more effective result. but it made me think of the food I eat." [sic; 11382, control]). However, it is important to note that food frequency measures in the current study had a limitation - there was an (unintentional) two-week overlap between our pre- and post-measures (i.e. because participants were asked to report their food consumption over the past month the two weeks immediately preceding the start of training were included in both the pre- and 2 weeks post-training outcome measures), which likely reduced sensitivity to detect changes. However, in the future, researchers may want to employ more sensitive measures of food consumption such as 24-hour food diaries, which Lawrence et al. (2015b) did find to be sensitive to detect training effects.

Lawrence et al. (2015b) also found significant effects of training on weight loss. In the current study we found that although the active group lost more weight than the control group, this difference was not statistically significant. Within-subjects effects suggested less weight loss in the current active group (*M*= -0.47 kg, *SD*= 2.03; d_z= .23), compared to in Lawrence et al. (*M*= -0.67 kg, *SD*= 1.71; d_z= .43), and effects for the control groups were in opposite directions (slight weight loss here [d_z= .13] vs. slight weight gain in Lawrence et al. [d_z= .14]). Without a more sensitive food diary measure, it is difficult to determine whether or not our training affected eating behaviour; however, these results suggest that any changes that did occur were not sufficient to produce significant group differences in weight loss. One potential explanation for the difference across studies is the different samples involved. The current study mainly recruited healthy-weight psychology students (73% had a BMI within the healthy range, with *M*= 23.67, *SD*= 4.29) who participated for course credit, whereas Lawrence et al. selectively recruited a predominantly overweight/obese community sample (78% had a BMI in the overweight and obese range, with *M*= 28.9, *SD*= 5.05) who received no incentive. Participants in the current sample also reported less frequent snacking at baseline, eating each no-go food ~ once/week vs. ~2-4 times/week in Lawrence et al. Training effects on food devaluation/inhibition would be less likely to translate into significant weight-loss in infrequent, compared to more frequent snackers (Veling et al., 2013a). Veling et al. (2014) found that active go/no-go training was only effective, compared to control training, for those with a high BMI (+1 SD; BMI~28). It is possible therefore that we did not see differences in weight loss in the current study due to the already 'healthy' weight and eating behaviour of most of our participants, and their potential lack of motivation to lose weight or their reduced scope to do so (i.e. floor effects). Indeed, several participants made comments along these lines ("I don't snack and I am very disciplined relating to food intake so I was probably not a good candidate for this study." [11348, active]; "I eat very healthy anyway and was in a process of trying to increase my intake of calaroies, which may have affected my results." [sic; 11106, active]). We note that another recent trial of food go/no-go training has also shown significant devaluation of trained no-go foods but no significant weight loss in a predominantly young, healthy-weight sample (Najberg et al., 2021). Future studies interested in investigating effects of cognitive control interventions on weight status would benefit from targeting such interventions at those who need them most and are the most motivated to engage with them. More motivated participants should also find the training more acceptable – participants here gave less positive feedback than in Lawrence et al. (where 89% of participants said they would recommend the training to a friend compared to 51% who said they would or might here).

In addition to the recommendations outlined above, we also advise future researchers to thoroughly consider awareness effects. Previous studies on inhibition training have investigated the role of awareness by assessing participants' knowledge of the contingencies between no-go signals and food categories (stimulus-response associations; Adams et al., 2017; Camp & Lawrence, 2019; Chen et al., 2018a, 2018b; Lawrence et al., 2015b). Findings have been mixed, with some studies reporting no effects of awareness on training outcomes while others have shown that increased awareness is associated with greater changes in food liking. In the current study, however, we asked participants to simply guess whether they were in the active or control group. Results revealed that 87% of participants in the control group were aware of their study condition, compared to 49% of active participants. Furthermore, there was evidence to suggest that aware participants in the active group showed greater effects of training on some outcomes, compared to non-aware participants (although not on our primary outcome of devaluation for energy-dense foods). Previous studies have suggested that the moderating role of awareness can be explained by increased attention, which may have a vital role in learning stimulus-response associations and the subsequent effectiveness of cognitive training interventions (Best, Lawrence, Logan, McLaren, & Verbruggen, 2016; Camp & Lawrence, 2019; Chen et al., 2018b; Quandt, Holland, Chen, & Veling, 2019). It has also been suggested that such interventions may benefit from increasing participants' awareness of such contingencies. However, we add a note of caution due to the additional possibility that awareness of training condition may be associated with expectancy effects and demand characteristics. Differences in expected improvement between intervention groups can undermine interpretations of causality by suggesting that positive training effects are due to factors other than the active intervention (i.e. placebo effects; Boot, Simons, Stothart, & Stutts, 2013; Simons et al., 2016). Future studies should therefore investigate awareness effects alongside expectancy effects to allow firm, causal inferences to be drawn.

Conclusion

The results of the present study are only partially consistent with previous findings investigating the effects of inhibition training on subjective liking, eating behaviour and weight loss (Chen et al., 2016, 2018a, 2018b; Lawrence et al., 2015b; Veling et al., 2013b, 2014). Although we were able to replicate some effects on no-go food devaluation, these effects did not translate into reductions in food consumption frequency or weight in this large, predominantly healthy-weight sample. These findings are consistent with the idea that whilst food-related inhibition training may induce devaluation universally, effects on food intake and weight loss may only be observed in those who overeat, are more overweight and have stronger impulses towards energy-dense foods (Forman et al., 2019; Jones et al., 2016, 2018; Veling et al., 2011, 2013a, 2014). Our findings highlight how differences in study populations and also methodological variations in training and outcome measures may be responsible for differences across studies. We advise future researchers to deliver training in shorter sessions over multiple days, to use more sensitive outcome measures, and to recruit overweight, motivated participants to fully capture training effects. Alongside these recommendations, we encourage future researchers to rule out the possibility that training outcomes are due to differences in outcome expectancy (Boot et al., 2013).

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Contribution Statement

RA, KB, LH, SM, AS, WB, EC, SR, RH, DK, CC, NL contributed to the design and development of the study, LH, SM, AS, WB, EC, SR, RH, DK collected the data, all authors contributed to data processing, analysis and manuscript preparation.

Conflicts of Interest

The authors declare no competing interests.

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Supplementary Information

Compliance with Training Schedule

Of the 366 participants included in the total sample, 189 (51.6%) completed four training sessions as instructed (102 active, 51.5%; 87 control, 51.8%). 137 participants (37.4%) completed between 1 and 3 training sessions (73 active, 36.9%; 64 control, 38.1%) and 40 participants completed more than four training sessions (23 active, 11.6%; 17 control, 10.1%).

Learning Stimulus-response Associations

Training performance was analysed across session one (blocks 1-6) and for overall performance (blocks 1-54) using mixed 2 x 2 ANOVAs (within subjects factor: *stimulus* [consistent, inconsistent]; between subjects factor: *training condition* [active, control]). We analysed no-go errors (commission errors when participants incorrectly made a response on a no-go trial), go errors (a combination of incorrect location responses and omission errors) and go reaction times (GoRT; mean reaction time for all correct go responses).

Session One

For training performance in session one, evidence of learning stimulus-stop associations was found in both the no-go errors and go reaction time. For the no-go errors, the mean proportion of errors was significantly lower for the stimuli consistently associated with stopping (*M*=.08, *SD*=.14), compared to the stimuli that were inconsistently paired with stopping (*M*=.09, *SD*=.14; (F(1, 364)=40.94, p<.001, η_p^2=.1). There was no statistically significant difference between training groups (active: *M*=.08; control: *M* =.09; F(1, 364)=.6, p=.44, η_p^2=.002) and no statistically significant interaction (F(1, 364)=.44, p=.51, η_p^2=.001). For the go reaction time, responses were significantly faster for stimuli that were consistently paired with a go response (*M*=517.84, *SD*=83.41) compared to the stimuli that were inconsistently paired with going and stopping (*M*=539, *SD*=87.19; F(1, 361)=291.59, p<.001, η_p^2=.45). There was also a statistical trend for the main effect of condition (active: *M*=535.54; control: *M*= 519.98; F(1, 361)=3.07, p=.08, η_p^2=.008) and the interaction (F(1, 361)=2.92, p=.09, η_p^2=.008). The interaction suggested that the difference between consistent and inconsistent stimuli was greater for the active group, although pairwise comparisons revealed that the difference was statistically significant for both training groups (both *p*s <.001). There was no evidence of learning, however, in the go error rates, which may have been due to floor effects (consistent stimuli: *M*=.03, *SD*=.1; inconsistent stimuli: *M*=.03, *SD*=.1). There was no main effect of stimulus (F(1, 364)=.15, p=.7, η_p^2<.001), no main effect of condition (F(1, 364)=.34, p=.56, η_p^2=.001), and no statistically significant interaction (F(1, 364)=.31, p=.58, η_p^2=.001).

Overall Performance

For overall training performance, there was also evidence of learning effects in both the no-go errors and go reaction time. For the no-go errors, the mean proportion of errors was significantly lower for the stimuli consistently associated with stopping (*M*=.05, *SD*=.11), compared to the stimuli that were inconsistently paired with stopping (*M*=.07, *SD*=.1; (F(1, 364)=175.52, *p*<.001, η_p^2=.33). There was no statistically significant difference between training groups (active: *M*=.06; control: *M* =.06; F(1, 364)=.03, *p*=.86, η_p^2<.001) and no statistically significant interaction (F(1, 364)=.001, *p*=.98, η_p^2<.001). For the go reaction time, responses were significantly faster for stimuli that were consistently paired with a go response (*M*=501.97, *SD*=74.15) compared to the stimuli that were inconsistently paired with going and stopping (*M*=522.82, *SD*=79.52; F(1, 361)=578.5, *p*<.001, η_p^2=.61). There was also a statistically significant interaction (F(1, 361)=4.2, *p*=.04, η_p^2=.01), with a greater difference in the active group than the control group, although, pairwise comparisons revealed that the difference between consistent and inconsistent stimuli was significant in both groups (both *p*s<.001). The main effect of training condition was not statistically significant (F(1, 361)=1.82, *p*=.18, η_p^2=.005). There was no evidence of learning in the go error rates, which may have been due to floor effects (consistent stimuli: *M*=.02, *SD*=.05; inconsistent stimuli: *M*=.02, *SD*=.05). There was no main effect of stimulus (F(1, 364)=.003, *p*=.96, η_p^2<.001), no main effect of condition (F(1, 364)=.38, *p*=.54, η_p^2=.001), and no statistically significant interaction (F(1, 364)=.3, *p*=.59, η_p^2=.001).

Analysis of Sub-sample for Timepoints 1-3 (N=308)

Group Differences

There were no significant differences between the two groups for sex (χ^2(1)=.002, *p*=.96), age, baseline BMI, baseline consumption of trained energy-dense, foods, BES, TFEQD or DEBQRE (all *t*s <1.3, all *p*s >.2, all *d*s <.15; see Table S1).

Table S1. Group characteristics and training data with between-group significance tests (SD within parentheses).

	Active (n=167)	Control (n=141)	*t*	*p*
Sex (% female)	79.6	79.4		
Age	22.98 (9.51)	23.48 (10.62)	.43	.67
Baseline BMI	23.53 (3.8)	23.51 (4.02)	.03	.98
FCF-energy-dense	3 (0.9)	2.9 (0.84)	1.05	.3
BES	15.32 (5.83)	14.91 (6.28)	.59	.56
TFEQD	7.54 (3.95)	6.99 (3.43)	1.3	.2
DEBQRE	2.73 (0.89)	2.71 (0.87)	.19	.85
# training blocks	22.22 (7.12)	21.23 (6.43)	1.27	.21
Proportion no-go errors	.06 (.08)	.06 (.08)	.1	.92
Proportion go errors	.02 (.06)	.02 (.03)	1.19	.24
GoRT	527.92 (92.61)	512.16 (76.62)	1.61	.11

Note. BMI = body mass index; FCF = Food consumption frequency; BES = Binge Eating Scale; TFEQD = Three Factor Eating Questionnaire – Disinhibition scale; DEBQRE = Dutch Eating Behavior Questionnaire – Restrained Eating scale; GoRT = go reaction time

Training Performance

On average, participants completed 21 out of the requested 24 blocks of training (*M*=21.76, *SD*=6.82, range: 6–54) and 69.5% completed the four training sessions. Importantly, there was no significant difference between groups for the number of completed training blocks ($t(306) = 1.27$, p=.21, d=.15; see Table S1). The proportion of errors for no-go and go errors was low (no-go: *M*=.06, *SD*=.08; go: *M*=.02, *SD*=.05), indicating that participants engaged with the training. Group comparisons showed that there were no significant differences for no-go errors, go errors or GoRT (all *t*s<1.6, all *p*s>.11, all *d*s <.19).

Analysis of Sub-sample for Timepoints 1-2 (N=312)

Group Differences

There were no significant differences between the two groups for sex ($\chi^2(1)$=.56, p=.45), age, baseline BMI, baseline consumption of trained energy-dense foods, BES, TFEQD or DEBQRE (all *t*s <.97, all *p*s >.33, all *d*s<.11; see Table S2).

Table S2. Group characteristics and training data with between-group significance tests (SD within parentheses).

	Active (n=166)	Control (n=146)	*t*	*p*
Sex (% female)	75.9	79.5		
Age	22.9 (8.97)	23.12 (10.15)	.20	.84
Baseline BMI	23.56 (3.8)	23.87 (4.94)	.63	.53
FCF-energy-dense	2.95 (0.9)	2.85 (0.84)	.97	.33
BES	15.1 (5.68)	14.97 (6.67)	.19	.85
TFEQD	7.16 (3.98)	7.05 (3.49)	.26	.8
DEBQRE	2.69 (0.89)	2.72 (0.88)	.24	.81
# training blocks	20.44 (7.55)	20.68 (6.66)	.3	.76
Proportion no-go errors	.06 (.11)	.06 (.11)	.05	.96
Proportion go errors	.02 (.06)	.02 (.03)	1.18	.24
GoRT	522.8 (89.15)	511.97 (78.88)	1.13	.26

Note. BMI = body mass index; FCF = Food consumption frequency; BES = Binge Eating Scale; TFEQD = Three Factor Eating Questionnaire – Disinhibition scale; DEBQRE = Dutch Eating Behavior Questionnaire – Restrained Eating scale; GoRT = go reaction time

Training Performance

On average, 20 out of the requested 24 blocks of training were completed (*M*=20.55, *SD*=7.14, range: 6–54) and 62.8% completed the four training blocks. There was no significant difference between training groups for the number of completed training blocks ($t(310) = .3$, p=.76, d=.03; see Table S2). There were also no significant differences between groups for the proportion of no-go errors, the proportion of go errors or the GoRT (all *t*s <1.18, all *p*s>.24, all *d*s<.001).

Per Protocol Analysis

In accordance with our previous research, participants were excluded based on their training performance (Adams et al., 2017; Lawrence et al., 2015b). Participants were excluded if a) their proportion of errors on no-go trials was > ±3 SDs from the group mean, b) their proportion of errors on go trials was >.15 (including missed responses and incorrect location responses) or c) their reaction time on go trials (GoRT) was > ±3 SDs from the group mean. Performance data was calculated across all training blocks and therefore only changes across timepoints 1-3 are analysed (using sub-sample for timepoints 1-3, N=308). There were 6 exclusions (N=302; 163 active, 139 control); 4 from the active group (1 each for no-go errors, go errors and GoRT and one for both go errors and GoRT) and 2 from the control group (one for GoRT and one for both no-go and go errors).

Group Differences

There were no significant differences between the two groups for sex ($\chi^2(1)<.001$, $p=1$), age, baseline BMI, baseline consumption of trained energy-dense foods, BES, TFEQD or DEBQRE (all *t*s<1.33, all *p*s >.18, all *d*s<.15).

Training Performance

On average, 21 out of the requested 24 blocks of training were completed (*M*=21.88, *SD*=6.72, range: 6–54) and 70.5% completed the four training blocks. There was no significant difference between training groups for the number of completed training blocks ($t(300) = 1.25$, $p=.21$, $d=.14$). There were no significant differences between groups for the proportion of no-go errors, the proportion of go errors or the GoRT (all *t*s<1.55, all *p*s >.12, all *d*s<.18).

Changes in Food Liking

The active group (*M*= -5.17, *SD* = 10.4) showed a significantly greater decrease in energy-dense food liking (devaluation) than the control group (*M*= -2.56, *SD* = 9.48; $r^2=.02$, $F(1, 301) = 5.13$, $p=.02$; B = 2.6, 95% CI [.34, 4.88]). Adding the number of completed training blocks to the regression model revealed that there was no statistically significant dose-response relationship between training and devaluation ($r^2=.03$, $F(3, 301) = 2.7$, $p=.05$; training blocks: B = -.29, 95% CI [-.8, .23], $p=.28$; interaction: B = .26, 95% CI [-.09, .6], $p=.14$).

For healthy food liking, the active group showed an increase in liking (*M*= 1.5, *SD* = 8.9) and the control group showed a decrease (*M*= -.28, *SD* = 7.99). The regression revealed a trend towards significance ($r^2=.01$, $F(1, 301) = 3.3$, $p=.07$; B = -1.78, 95% CI [-3.71, .15]). There was no evidence of a dose-response relationship ($r^2=.02$, $F(3, 301) = 1.83$, $p=.14$; training blocks: B = .33, 95% CI [-.11, .76], $p=.14$; interaction: B = -.2, 95% CI [-.49, .1], $p=.19$).

For the ANOVA, we found a main effect of food type ($F(1.82, 545.06) =31.51$, $p<.001$, $\eta_p^2=.1$, with Huynh-Feldt correction) but not condition ($F(1, 300) =.001$, $p=.98$, $\eta_p^2 < .001$). Importantly, there was a significant interaction between the two ($F(1.82, 545.06) =8.13$, $p=.001$, $\eta_p^2 = .03$, with Huynh-Feldt correction). There was a significant difference between groups for the energy-dense foods ($p=.02$), a statistical trend for the healthy foods ($p=.07$) and no statistically significant difference for the untrained foods ($p=.38$).

Changes in Food Consumption Frequency – Energy-Dense Foods

Both the active group (*M*= -.18, *SD* = .65) and the control group (*M*= -.07, *SD* = .62) showed a reduction in the consumption frequency of energy-dense foods, however, there was no statistically significant difference between groups (r^2 =.01, F(1, 301) = 2.36, *p*=.13; B = .11, 95% CI [-.03, .26]). We also found no evidence of a dose-response relationship when adding the number of completed training blocks (r^2 =.01, F(3, 301) = .86, *p*=.46; training blocks: B= -.01, 95% CI [-.04, .03], *p*=.66; interaction: B= .01, 95% CI [-.02, .03], *p*=.64).

Changes in Weight

Both groups showed a reduction in weight (active: *M*= -.47, *SD* = 2.05; control: *M*= -.27, *SD* = 1.96), but there was no statistically significant difference in weight change between training groups (r^2 =.002, F(1, 282) = .68, *p*=.41; B = .2, 95% CI [-.27, -.67]). Adding the completed number of training blocks also showed that there was no dose-response relationship (r^2 =.003, F(3, 282) = .3, *p*=.83; training blocks: B = -.02, 95% CI [-.13, .08], *p*=.66; interaction: B= .01, 95% CI [-.06, .08], *p*=.71).

Task Feedback and Awareness

The majority of participants answered the debrief questions (83.9%). Of these participants, 7.2% reported that the training did help them to reduce their food intake (active: 7.8%; control: 6.4%), 59% reported that the training did not help (active: 55.4%; control: 63.1%) and 33.9% answered 'not sure' (active: 36.7%; control: 30.5%). 20.2% of participants who responded reported that they would recommend the training to a friend (active: 23.5%; control: 16.3%), 48.9% would not recommend to a friend (active: 44.6%; control: 53.9%) and 30.9% were not sure (active: 31.9%; control: 29.8%). There was no statistically significant difference in responses between training groups for reporting whether the training helped ($\chi^2(2)$=1.87, *p*=.39), or whether they would recommend to a friend ($\chi^2(2)$=3.42, *p*=.18).

The majority of participants responded when asked to guess which training condition they were in (84.7%). Of these participants, 66.1% guessed correctly (active: 49.1%; control: 86.5%) and 33.9% guessed incorrectly (active: 50.9%; control: 13.5%). There was a statistically significant difference between groups ($\chi^2(1)$=48.04, $p<.001$), indicating that participants who responded in the control group were very good at guessing their condition correctly, compared to those in the active group who were at chance.

Effects of Awareness

To explore the role of awareness, awareness of the study condition was entered as a variable for the three main analyses, comparing pre- and two weeks post-training (i.e. timepoints 1 and 3; awareness was measured at the end of session 2). Due to the low sample size for non-aware participants in the control group, awareness was only compared for the active group.

Mixed ANOVAs were performed for food liking and food consumption frequency (between subjects factor: *awareness* [aware or non-aware]; within subjects factor: *food type* [energy-dense, healthy, untrained]), and an independent t-test was used for weight change.

Changes in Food Liking

The main effect of awareness on food liking was non-significant (F(1, 165) =.03, *p*=.87, η_p^2 < .001), however, there was a significant interaction between awareness and food type (F(1.88, 310.68) =3.71, *p*=.03, η_p^2 = .02, with Huynh-Feldt correction). Pairwise comparisons showed a trend towards a difference for healthy foods (*p*=.09). There was no statistically significant difference between aware and non-aware participants for either energy-dense foods (*p*=.27) or untrained foods (*p*=.99).

Changes in Food Consumption Frequency

The main effect of awareness on food consumption frequency was non-significant (F(1, 165) <.001, *p*=1, η_p^2 < .001), however, there was a trend towards significance for the interaction with food type (F(1.95, 321.29) =2.87, *p*=.06, η_p^2 =.02, with Huynh-Feldt correction). This trend is explained by a significant difference between aware and non-aware participants for the change in consumption of energy-dense foods (*p*=.04), with aware participants showing a greater reduction in consumption frequency (*M*= -.29, *SD*=.66) compared to non-aware participants (*M*= -.08, *SD*=.62). The differences for healthy (*p*=.19) and untrained foods (*p*=.73) were both non-significant.

Changes in Weight

There was a significant difference in weight loss between participants in the active group who were aware of the study condition (*M*= -.82, *SD*=2.04) compared to those who were not aware (*M*= -.13, *SD*=1.98; *t*(151)=2.13, *p*=.04, *d*=.34).

Retention Rates Between Online and Lab Testing

There were two arms of the study; one that was completely online and one that involved two lab sessions at the beginning and end of the study. The first lab session included all pre-training outcomes, the first training task and all immediate post-training outcome measures; the second lab session included all two week post-training outcome measures. Both lab sessions also included researcher-recorded weight measurements (see study Procedure). As part of the study we were interested in whether there were any differences in retention between lab versus online participants.

There were 54 exclusions for timepoint 2 due to attrition (14.75%; 54/366); of these 48 were online participants (31.79% attrition; 48/ 151) and 6 were lab-based participants (2.79% attrition; 6/215). Attrition at timepoint 2 was significantly greater for online compared to lab-based participants ($\chi^2(1)$ =59.3, *p*<.001). Greater attrition in the online group was expected, however, the large attrition rate for online participants suggests that instructions may not have been sufficiently clear. For timepoint 3, there were 58 exclusions (15.85% attrition; 58/366);

of these 32 were online participants (21.19%) and 26 were lab-based participants (12.09%). Again, attrition was significantly greater for the online group compared to the lab group ($\chi^2(1)=5.51$, $p=.02$). Together these results suggest that attrition is greater for online studies compared to lab-based studies and this attrition should be accounted for when calculating sample sizes; further, we recommend that instructions and programming (e.g. app reminders) may need to be adapted for online participants to ensure data quality.

We also investigated whether the debrief responses differed for online versus lab-based participants. Importantly, online participants were no less likely to think that the training helped to reduce their food intake ($\chi^2(2)=1.73$, $p=.42$) or to recommend to a friend ($\chi^2(2)=3.26$, $p=.2$). There was also no difference between groups for correctly guessing which training condition they were in ($\chi^2(1)=.55$, $p=.46$).

Comparisons between trained and untrained healthy and energy-dense foods

To explore training effects without the potential confound of (healthy or energy-dense) food category, we compared trained and untrained foods of similar types and examined interactions with group. We split the untrained foods into two categories: healthy (dried fruit, mushrooms, carrot soup, small quiche with salad) and more energy-dense (pizza, pancakes, baked potato with butter, cannelloni, cheese sandwich). Exploratory 2 x 2 ANOVAs were conducted on the mean change in liking for trained and untrained healthy foods, and trained and untrained energy-dense foods (between subjects factor: *condition* [active or control], within subjects factor: *food type* [trained vs. untrained]).

For the time 1-3 changes (pre- to 2 weeks post-training), only the ANOVA for energy-dense foods showed significant effects. There was a main effect of food type ($F(1,306) = 9.83$, $p = .002$, $\eta_p^2 = .031$) with greater devaluation of trained ($M = -3.89$, $SD = 10$) than untrained ($M = -2.08$, $SD = 9.1$) unhealthy foods. There was also a significant group x food type interaction ($F(1,306) = 6.92$, $p = .009$, $\eta_p^2 = .022$), with a significant difference between food types in the active group (M = -3.32, SD = 10.05, $p < .001$), but not in the control group *(*M *= -0.29,* SD *= 10.06, p = .73)*. Consistent with our main analyses, group differences in devaluation were significant for trained ($p = .02$) but not untrained ($p = .73$) energy-dense foods. This suggests that devaluation associated with no-go training was limited to the trained foods.

For the time 1-2 changes (pre- to immediately post-training), there was a main effect of food type for unhealthy foods ($F(1,310) = 20.28$, $p < .001$, $\eta_p^2 = .061$), with greater devaluation of trained ($M = -1.78$, $SD = 6.87$) than untrained ($M = 0.06$, $SD = 5.41$) foods. There was no group x food type interaction. The ANOVA for healthy foods showed no main effect of food type, but a significant group x food type interaction ($F(1,310) = 4.69$, $p = .031$, $\eta_p^2 = .015$), with increased valuation of trained than untrained healthy foods in the active group ($M = 1.35$, $SD = 6.42$, $p = .007$), but not in the control group ($M = -0.23$, $SD = 6.42$, $p = 0.66$). This suggests that increased valuation immediately after active vs. control training was limited to the trained healthy foods.

Table S3. Descriptive statistics for means and change scores (Δ) across timepoints 1–3 (n=308; SD within parentheses).

	Time 1		Time 3		Δ Time 1–3	
	Active	Control	Active	Control	Active	Control
Liking-Energy-dense	68.84 (16.18)	66.11 (16)	63.61 (17.07)	63.56 (16.93)	-5.22 (10.47)	-2.55 (9.42)
Liking-Healthy	58.85 (12.89)	59.69 (13.08)	60.33 (12.81)	59.37 (12.5)	1.48 (8.91)	-0.33 (7.94)
Liking-Untrained-Energy-dense	71.17 (14.03)	71.22 (14.06)	69.27 (14.69)	68.96 (15.13)	-1.91 (8.9)	-2.26 (9.29)
Liking-Untrained-Healthy	52.48 (19.31)	57.58 (16.63)	53.24 (18.73)	56.75 (16.45)	0.76 (10.14)	-0.83 (9.3)

Table S4. Descriptive statistics for means and change scores (Δ) across timepoints 1–2 (n=312; SD within parentheses).

	Time 1		Time 2		Δ Time 1–2	
	Active	Control	Active	Control	Active	Control
Liking-Energy-dense	67.97 (17.17)	65.73 (15.22)	65.95 (17.63)	64.19 (15.8)	-2.02 (7.46)	-1.55 (6.09)
Liking-Healthy	58.18 (12.53)	59.89 (13.08)	59.68 (13.16)	60.18 (13.43)	1.5 (6.12)	0.29 (3.96)
Liking-Untrained-Energy-dense	69.99 (15.1)	71.5 (13.92)	69.76 (15.44)	71.85 (13.6)	-0.23 (5.05)	0.35 (5.75)
Liking-Untrained-Healthy	52.37 (18.29)	57.27 (16.68)	52.52 (19.05)	57.78 (17.07)	0.15 (6.36)	0.52 (6.21)