THE EFFECT OF GO/NO-GO TRAINING DOSAGE ON WEIGHT LOSS, FOOD EVALUATION, AND DISINHIBITION IN PRIMARILY OVERWEIGHT AND OBESE INDIVIDUALS: A RANDOMIZED CONTROLLED TRIAL

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Dedication

I dedicate this Plan B project to my loving father, for his endless support, jovial spirit, and constant reminders that life is worth living.

Abstract

Response inhibition trainings have recently been studied as innovative approaches to obesity treatment by targeting the impulsive (unconscious) processes that underlie eating behaviors. Specifically, the go/no-go (GNG) task has resulted in reduced food consumption and small, but significant, weight loss in two brief intervention studies. In the current study, participants were randomized to one of three groups: high intensity food-specific GNG (four times per week for 4 weeks; n = 19), low intensity food-specific GNG (one time per week for 4 weeks; n = 22), or nonfood-specific GNG (i.e., control group, one time per week for 4 weeks; n = 23). Pre- and post-intervention measures assessed for changes in body weight, food evaluation, snack consumption, binge eating, and dietary disinhibition. It was hypothesized that those receiving the food-specific GNG training (high intensity and low intensity groups) would experience greater improvement in outcome measures than those in the nonfood GNG group and that a similar pattern would result between the high intensity and low intensity food-specific GNG groups. Moderators (e.g., dietary restraint, disinhibition) were explored, along with the mechanism of food devaluation. Results of repeated measures ANCOVA's (controlling for BMI and dieting status) for all outcome variables revealed there was no significant difference between groups across time. No studied variable was found to moderate the effects of the training, and the devaluation of foods did not mediate the relationship between GNG training and weight loss. Therefore, regardless of dosage, the GNG training did not have a meaningful effect on any of the outcomes assessed. Future research should focus on identifying the underlying mechanism of food-specific GNG training and its interaction with person specific characteristics.

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Within the United States, weight gain has increased substantially, with 70% of the population being either overweight or obese (National Center for Health Statistics, 2019). The rise in overweight and obesity has increased in-step with the development of obesogenic environments, where energy-dense food is both abundant and low in cost (Swinburn et al., 2011). This rise in prevalence is problematic given the association between obesity and the development of severe health conditions, such as cardiovascular diseases, Type II diabetes, and cancers (CDC, 2018). Additionally, the financial impact of obesity is concerning, with obese adults incurring an average of $3,429 in additional medical expenses (Biener et al., 2017) within the United States. This is especially noteworthy given that obesity rates are higher in those of lower income and educational status (Jackson et al., 2020).

Given the negative consequences of obesity, people oftentimes engage in weight loss efforts, though they are often unsuccessful. For example, approximately 44% of Americans have attempted to lose weight in the past five years (Santos et al., 2016), with the most common approaches involving reduced caloric intake through self-control and dieting initiatives (Hollands et al., 2016). Many of these interventions include setting goals, restricting food intake, monitoring food consumption, and making thoughtful food choice decisions daily (Allan et al., 2011). However, most weight loss endeavors result in 70% of lost weight being regained within two years (Purcell et al., 2014).

The low success rate of dieting interventions indicates new and innovative approaches may be required. To establish these, the underlying processes of eating behavior must be further explored. Eating behavior (and its contribution to obesity) can be understood through a dual-process model. According to this model, behavior is guided by two distinct and parallel processes: impulsive and reflective (Strack & Deutsch, 2004). *Impulsive processes* produce automatic behaviors that require no attentional effort, work through associative links, and allow for immediate responses to stimuli in the environment (Strack & Deutsch, 2004). The associative links through which the impulsive system operates are developed through interactions between a presenting stimulus (e.g., chocolate cake), an affective response (e.g., good feelings), and the resulting behavioral action (e.g., eating the cake). These learned associative clusters allow for people to respond to many important environmental stimuli quickly and effortlessly (Hofmann et al., 2009). *Reflective processes*, on the other hand, work through slow, controlled, goal-oriented decision making. It is through these processes that higher order thinking occurs and people can execute control over their actions (e.g., consider all the reasons not to eat the chocolate cake). Therefore, the reflective processes act to balance, or inhibit, the automatic, behavioral responses originating through impulsive processes (Strack & Deutsch, 2004).

To date, most existing weight loss programs have emphasized the use of reflective processes to inhibit urges to eat highly tempting, palatable foods (Rothman et al., 2009). Because such approaches require individuals to consistently exercise a high degree of self-control, they can be difficult to maintain, especially when a person feels stressed, tired, or depleted in some way (Baumeister, 2014). Persistent efforts to self-regulate are difficult for most people, but research suggests that individuals who are overweight or obese may have greater difficulty inhibiting their eating responses than normal weight individuals. This is especially true when faced with highly palatable foods (Lavagnino et al., 2016; Yang et al., 2018), as viewing images of highly palatable foods often leads to more food cravings in those with low inhibitory control

(Meule et al., 2014). In a brain imaging study, obese individuals experienced greater activation of reward regions and reduced activation of inhibitory control regions in response to food stimuli when compared to non-obese participants (Stice et al., 2016). Furthermore, elevated reward responses and reduced inhibitory control to food stimuli was associated with future weight increase (Stice et al., 2016). Similarly, the presence of low inhibitory control along with high impulsive tendencies toward food related stimuli, has previously been noted as a predictor in weight gain (Nederkoorn et al., 2010).

Collectively, these findings suggest that the abilities most necessary to attain weight loss are those that many overweight and obese individuals struggle to utilize. Thus, as an obesogenic environment places nearly constant demands on inhibitory control, without interventions aimed at increasing inhibitory control capacity and/or decreasing automatic preferences, obesity will likely persist. Therefore, it is important to develop novel weight loss interventions that target impulsive processes.

Cognitive Training for Eating Regulation

Over the past several years, researchers have begun investigating the usefulness of computerized cognitive trainings for behavioral health change. The mechanisms through which these interventions work is not clearly understood, but it is generally believed that these training tasks target either top-down or bottom-up processes (Gaspelin & Luke, 2018). *Top-down processing* utilizes one's acquired knowledge and current contextual understanding to appropriately interpret stimuli and guide perception (Anderson, 2004, p. 64). It supports goal-directed intentions and executive functioning through the application of high-level knowledge and visual selection (i.e., requires activation of the prefrontal cortex; Diamond, 2013; Kim & Cave, 1999). *Bottom-up processing*, on the other hand, works through raw sensory input data

(Connor et al., 2004) and associative learning, like a learned reflex (Verbruggen et al., 2014). This processing is based on the stimulus being attended to, regardless of how the stimulus fits into the general context or the goals of an individual and requires less reflective thinking and activation of the prefrontal cortex (Kim & Cave, 1999).

Top-down and bottom-up processing are important in understanding the cognitive training interventions and their underlying mechanisms (Verbruggen & Logan, 2008). Many of the trainings were developed using cognitive tasks initially designed to measure the same construct they are now being used to target as behavioral interventions (Aulbach, 2019). For example, approach avoidance tasks, which were originally designed to measure implicit biases, may be modified to train attention away from an automatic response rather than simply assessing whether an automatic response exists (Aulbach, 2019). Trainings commonly employed to target these processes include working memory training, approach avoidance training, attention bias modification training, and inhibitory control training. Of the trainings studied thus far, inhibitory control training has shown the largest effects on eating behavior change (Aulbach et al., 2019).

Inhibitory Control Training

Inhibitory control is the ability to stop or change an action that may be desired, but not necessarily appropriate (Logan et al., 1984). Inhibitory control trainings (ICT), therefore, consist of repeatedly inhibiting one’s responses to prompted stimuli. ICTs can be either generalized or stimulus-specific, meaning the stimuli presented are either random images (generalized) or they belong to a specific category (stimulus specific; e.g., food, alcohol). Generalized ICT is thought to work by strengthening inhibitory control through top-down processing, whereas stimulus-specific ICT may work by creating associations between automatic inhibition and stimulus-specific cues, which likely occurs through bottom-up processing (Verbruggen & Logan, 2008).

Although generalized and stimulus-specific ICT trainings may occur through different processes, both are primarily conducted through two computerized tasks: stop-signal and go/no-go (GNG). Between these two tasks, recent meta-analyses indicate that the food-specific GNG task most consistently results in positive eating behavior change (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016).

During the computerized GNG task, participants are required to either respond (with a keystroke) or inhibit their response (withhold a keystroke) to stimuli paired with a “no-go” or a “go” cue (e.g., bolded frame vs. not bolded frame respectively; Lawrence et al., 2015). Within the GNG task, both the image and the cue present simultaneously (Verbruggen & Logan, 2008). Generalized GNG utilizes arbitrary images, belonging to no specific category; the overall objective is to increase general inhibitory control capacity through repeated practice of an inhibitory response. Stimulus-specific GNG, on the other hand, trains participants to inhibit responses to particular images belonging to a particular category (e.g., unhealthy food; Jones et al., 2018). In GNG trainings that are food-specific, oftentimes both food images (unhealthy and healthy) and nonfood images (e.g., household items, clothes) are displayed throughout the task. The intention behind the training is to produce an association between unhealthy (high energy density) food images and the inhibition of response. Therefore, unhealthy food images are consistently (90-100%) paired with the no-go cue. Similarly, healthy foods are oftentimes paired consistently with the go cue in efforts to increase associations between the action of responding and healthy food images. When nonfood images are included in food-specific GNG, they are oftentimes paired randomly with no-go and go cues, meaning associations are unlikely to form between a particular response and the randomly paired image (Jones et al., 2018).

The effect of food-specific GNG on health behaviors has been reviewed in meta-analyses alongside other cognitive trainings. Results of these studies indicate that the effect of food-specific GNG training on eating behaviors is small (Aulbach et al., 2019) to moderate (Allom et al., 2016, Jones et al., 2016), showing more promising results than the other cognitive trainings. Therefore, food-specific GNG training was selected for use in the current intervention study.

Food-Specific GNG Training

The effects of food-specific GNG training on eating behavior have primarily been evaluated through studies conducted as single sessions in a laboratory setting. As the main intention of many early laboratory studies was to evaluate whether GNG training would, in fact, result in any eating behavior change, many of the samples within these studies consisted of normal weight, primarily female, undergraduate students (Jones et al., 2016). However, as the results of these studies revealed significant effects of GNG training on subsequent eating behavior, research evaluating GNG training as an intervention increased.

Single Session Laboratory Studies

The majority of experimental laboratory GNG studies have been conducted as between-subject designs, meaning participants were randomly assigned to either a food-specific GNG training group or a control GNG training group (e.g., nonfood-specific GNG training) to complete one session of the training. Each food-specific GNG training utilizes some combination of unhealthy food images (e.g., chips, cake, pizza), healthy food images (e.g., fruits, vegetables), and/or neutral images (e.g., household items, clothes, gardening tools). However, variability exists between studies and between groups within each study on the makeup of the training task used. For example, some food-specific GNG trainings have consisted entirely of food images (e.g., Chen et al., 2018), whereas others have integrated neutral images (e.g., Adams et al., 2017). Similarly, control group trainings have varied from using entirely neutral images (Folkvord et al., 2016) to training participants toward all food images, including those that are unhealthy (Houben & Giesen, 2018).

In food-specific GNG, the consistent pairing of particular unhealthy food images with a no-go cue is central to the training. Within each training session, the trials that consist of this pairing are considered “critical trials” (Jones et al., 2016). Lab studies have had substantial variability in both the duration of the training session and the number of critical trials delivered during the session itself. In their meta-analysis, Jones et al. evaluated the influence of the number of critical trials, the contingency between unhealthy foods and no-go cues (% of times unhealthy food images were paired with no-go cues), and the number of successful inhibitions during the critical trials (i.e., how well the person did on the no-go trials). The results of this analysis revealed that the greater the number of successful inhibitions on critical trials, the larger the effect. However, neither the number of critical trials, nor the contingency between appetitive foods and no-go cues, significantly influenced the effect size of the GNG training within a single session, though the lack of an effect on contingency may be limited by the reduced variability of studies

Most lab GNG studies have assessed food consumption, choice, or evaluation as outcome measures. In these studies, the assessment of food consumption has occurred immediately after the training through either bogus taste tests or free eating scenarios (Folkvord et al., 2016; Houben, 2011; Houben & Jansen, 2011; Veling et al., 2011). Weight, though, has not been assessed through single-session lab GNG studies at follow-up timepoints. Moderating variables of training effect have been assessed (e.g., dietary restraint, BMI, experienced hunger, food novelty), along with potential underlying mechanisms of the training (e.g., general inhibitory control strength, strength of automatic associations, devaluation of unhealthy foods).

Multi-Session Intervention Studies

Although most studies on GNG training have involved single sessions conducted in a laboratory setting, 11 multi-session intervention studies were identified, with six of them being published within the past year, after the initiation of the current study. All of these studies have examined the effects of food-specific GNG training, but have varied in dosage, modalities, study design, and participant makeup. These studies reveal that the effects of GNG training on outcome measures are mixed. Some studies have found GNG training to influence food evaluation, food consumption, and/or body weight, though variability exists across studies.

The first published multi-session GNG training study (Veling et al., 2014) evaluated the effects of combined implementation intentions and GNG training on changes in weight through a randomized 2 (implementation intention condition: dieting versus control) × 2 (go/no-go task condition: food vs. control) design. Participants completed the training once per week for 4 weeks. Weight loss was significant in all conditions except the control. In a more recent study, GNG training was also paired with implementation intentions to evaluate their combined potential in reducing binge eating episodes in participants with bulimia nervosa or binge eating disorder (Chami et al., 2021). Over a 1 month period, participants completed either the food-specific GNG training and implementation intention or the generalized GNG training and implementation intention daily. Reductions in binge eating frequency and eating disorder psychopathology resulted in both groups, with the food-specific training resulting in larger effect sizes.

In a study by Lawrence et al. (2015), food-specific GNG training was found to facilitate weight loss in a sample of primarily overweight participants. Participants were randomized to either a food-specific GNG or a control (nonfood-specific) GNG training, and then asked to complete four sessions of the training over 1 week. The food-specific GNG training group showed significantly greater reductions in weight (1.48 lbs) over 2 weeks, and in self-reported weight from screening to 6-month follow-up (4.85 lbs). This group also reported significantly greater reductions in liking (i.e., stimulus evaluation) of high-energy density foods and in self-reported energy intake from baseline to post-intervention. There was no significant difference in liking of healthy or novel foods between groups, and both groups experienced a reduction in daily snacking frequency from screening to 1-month and 6-month follow-ups. There was no significant difference between groups on the consumption of food during a post-intervention taste test in the laboratory.

Several studies have been conducted since Lawrence et al. (2015), utilizing similar or identical food-specific and control GNG trainings. A replication study by Adams et al. (2021) included 366 healthy weight college-aged participants. Results showed that the food-specific GNG training group experienced greater reductions in their liking of unhealthy foods and increases in their liking of healthy foods compared to the control group. However, consumption of trained foods and weight loss did not differ between groups, though baseline consumption of the trained unhealthy foods was low at approximately once per week. In a sample of primarily healthy weight participants, Oomen et al. (2018) administered the training six times over 6 days and found no significant difference between groups on changes in inhibitory control. However, a small effect of training on snack consumption resulted, with the food-specific GNG training group showing greater reductions in snack consumption, measured through a bogus taste test, relative to the control group. Neither the frequency of consumption nor the evaluation of the trained foods specifically were assessed in this study at either baseline or post-intervention.

Additionally, Carbine et al., (2021) randomized 100 overweight and obese participants to a food-specific or generalized GNG training group and had participants complete the trainings four times per week for 4 weeks. A difference in this study, however, was that the images used from session to session were randomly chosen from a batch of 200 food pictures rather than remaining the same throughout the intervention. Weight, caloric intake, and N2 ERP amplitudes, measured at baseline, 4 weeks, and 12 week follow-up, did not change significantly for either group throughout the training intervention. Neither the frequency of consumption nor the evaluation of the trained foods specifically were assessed in this study at either baseline or post-intervention.

Gamified versions of the GNG task have also been studied (Forman et al., 2019; 2020; Najberg et al., 2021; Poppelaars et al., 2018). One gamified GNG training was evaluated on its effectiveness at reducing sugar intake and weight (Forman et al., 2019). Participants were randomized to one of four conditions: (gamified vs. non-gamified) x (food-specific GNG vs. control training). Each group completed 42 training sessions and two booster sessions over an 8 week period while adhering to sugar-free eating guidelines. Training effects were moderated by implicit liking of sugary foods, with significant weight loss resulting in participants randomized to a food-specific group and who were high in implicit liking for sugary foods. Additionally, in an add on study assessing the moderating role of gender, the gamified GNG had a positive effect on weight loss in men but not women (Forman et al., 2020). In a second gamified GNG intervention (Poppelaars et al., 2018), changes in inhibitory control and food consumption were assessed, with participants randomized to a food-specific gamified GNG training or to reviewing a brochure on healthy eating. Seven sessions were completed over 1 week. There was no significant improvement in food-specific inhibitory control or caloric intake. However, both groups experienced improvement in general inhibitory control and a significant decrease in attractiveness of food images. Lastly, Najberg et al. (2021) evaluated the combined effect of GNG training and cue approach training tasks (CAT), both of which were gamified and included food images to control for participant training expectation. Participants, ranging from healthy to overweight (M_{BMI} = 24.5), were randomized to one of two groups: GNG and CAT with unhealthy foods paired 100% with no-go cues and heathy foods paired 100% with go cues, or GNG and CAT with unhealthy and healthy foods paired equally with no-go and go cues. Participants completed the trainings five times per week for 4 weeks. Those in the intervention group experienced a larger reduction in palatability ratings of unhealthy foods than those in the control, but there was no change in healthy food ratings or body weight. Frequency of consumption of the trained no-go foods prior to the intervention was not assessed in this study.

GNG training has also been studied in combination with other cognitive trainings. Stice et al. (2017) combined GNG with four other cognitive trainings (stop-signal, response-signal, dot-probe, and visual-search) to evaluate the effect of a multifaceted computerized training on weight and food evaluation. Participants were randomized to either a food-specific training or a general training. Training sessions were 50 minutes (10 minutes each task) and were completed one time per week over 4 weeks. Although there was no effect of intervention on body weight, there was a greater reduction in body fat percentage for the food-specific training group after 4 weeks, though it did not persist through the 6-month follow-up. A large reduction in the reward regions of the brain in response to high calorie food images resulted in the food-specific training group. This group also saw greater reductions in monetary valuation and palatability ratings of high calorie food images.

Recently, Lawrence and colleagues (2021) studied food-specific GNG as an app-based intervention that was accessible to the public. The training app was developed at the University of Exeter and is based on the training utilized by Lawrence et al. (2015). In total, 1,234 participants downloaded the GNG food training app (FoodT), completing an average of 10.7 sessions. Participants also completed measures of food intake, weight, and dieting status. Results showed that participants experienced significant reductions in body weight. There was a negative association between the number of completed trials and unhealthy food intake, whereas this was a positive association with healthy food intake (Aulbach et al., 2021). Additionally, results indicated that greater changes in dietary intake were associated with temporally dispersed training completions. Without randomization, however, it is not clear if this finding was related to dosage or motivation.

Together, these more recent studies reveal that the effects of food-specific GNG trainings on eating behaviors are still mixed. Positive results have been found regarding weight loss, food evaluation, food intake, and binge eating frequency in some studies, though the effects have not been supported in others. Variability across studies may account for this, with differences in the number of critical trials offered per session, number of sessions administered, the overall timeframe of the intervention (e.g., seven sessions over 1 week, four sessions over 4 weeks, 42 sessions over 8 weeks), the stimulus categories used, the makeup of participants, and the presence of manipulation checks for the development of stimulus-response associations. Specifically, in studies without manipulation checks of formed associations it is difficult to interpret null findings. However, of the six studies that measured changes in evaluation of the trained foods, all reported significant devaluation of the no-go foods (Adams et al., 2021; Chami et al., 2021; Lawrence et al., 2015; Najberg et al., 2021; Poppelaars et al., 2018; Stice et al., 2017). This supports the idea that devaluation is a more proximal effect of training but that it does not always translate into the more distal effect of weight loss. Therefore, participants may need to consume the trained no-go food for devaluation effects to translate into weight loss. Lastly, when the training is studied alongside other interventions (e.g., implementation intentions, specific food diet, other types of cognitive trainings), or as a gamified version, the isolated effects of repeated GNG trainings may be less clear.

To date, we have not identified any randomized controlled studies assessing the impact of differing dosage levels of the food-specific GNG training on outcome measures. Therefore, additional studies are warranted to systematically test the variability of training dosage.

Moderators of Training Effects

A few individual differences have been noted as possible moderators of the effects of GNG training. In a meta-analysis of laboratory studies using ICT, higher scores on measures of dietary restraint were found to moderate the effects of ICT trainings on amount of food consumed (Jones et al., 2016). This finding aligns well with the notion that individuals who engage in dietary restraint repeatedly restrict food consumption to reduce caloric intake, oftentimes unsuccessfully. These unsuccessful efforts to restrict food intake are frequently accompanied by an undesired overindulgence of highly palatable foods (Polivy & Herman, 1985).

Additionally, evidence for the moderating role of BMI has varied, with studies assessing its effect on different outcome measures of the GNG training (e.g., weight loss, food consumption, food evaluation). In a study by Veling et al. (2011), individuals with a higher BMI

(1 SD above the mean standardized BMI score) consumed less post-training food than those in the control group, whereas those of a lower BMI (1 SD below the mean BMI score), did not differ from the control group on their level of food consumption. Similarly, BMI was found to moderate the effect of GNG training on the reinforcing value of high-caloric food items in a recent study (Houben & Giesen, 2018). The moderating role of BMI is further supported by findings that individuals with an elevated BMI experience decreased inhibition capacity toward highly palatable foods (Batterink et al., 2010). However, BMI was not found to moderate the effects of GNG training on weight loss in a sample of primarily overweight individuals (Lawrence et al., 2015), though this may indicate that when the entire sample has a high BMI, moderating effects are no longer seen. Lastly, in a study directly evaluating the effect of food-specific training in obese compared to non-obese participants, there were no differences between groups on the devaluation of the no-go foods (Chen et al., 2018).

Another potential moderating variable of the GNG training on eating behavior change is hunger level participants experience at the time of the food-specific GNG training (Chen et al., 2018; Veling et al., 2013a; 2013b). In other words, individuals experiencing elevated levels of hunger may experience greater reductions in palatable food choices and greater devaluation effects of the GNG training (Veling et al., 2013a, 2013b), though results were, again, mixed.

Proposed Mechanisms of Training

The mechanism by which food-specific GNG training works is still unclear. However, researchers have noted three different mechanisms(inhibitory control, automatic associations, and food devaluation) that could possibly underpin the training (Veling, 2017).

Inhibitory Control. The first proposed mechanism by which the GNG task may result in eating behavior change is top-down inhibitory control, which entails training generalized inhibition processes (Houben et al., 2011). Most of the studies addressing inhibitory control, however, never specifically measure for it. Rather, strengthened inhibitory control is assumed through reaction time improvement of the inhibition training task itself. However, this improvement could also be explained through automatic inhibition associations (Veling et al., 2017). This is further supported by the lack of effect general ICT has on eating behavior change, as general ICT appears to improve general inhibitory control capacity, not stimulus-specific inhibitory control (Jones et al., 2018). Additionally, Verbruggen and Logan (2008) highlight that inhibitory control as an underlying mechanism in food-specific GNG is not supported. The stop-signal task, a similar inhibitory control training task, requires greater levels of reflective processing to perform, yet results in smaller effects on behavior change than the food-specific GNG training.

Automatic Associations. A second proposed mechanism for the change occurring through the GNG training presents through a bottom-up automatic association (Veling et al., 2017). As inhibiting one's impulses does not necessarily have to be a reflective and effortful process, stimulus-stop associations can be formed through associative learning (Verbruggen & Logan, 2008). Once these associations are formed, the presentation of the stimulus (food item) may create an automatic response inhibition. It has been suggested that this association may originate through top-down inhibitory control, but as the association increases, inhibitory control is less required and utilized (Veling et al., 2017; Verbruggen et al., 2014). Automatic response inhibition has been evaluated in studies that either include filler images in the training that are paired randomly with go and no-go cues, or that present a previously trained no-go image as a go image in a post-training assessment. Automatic inhibition is seen through higher accuracy on images which are 100% paired with a no-go response, or through the slowing of the go response time to these previously trained no-go images compared to novel images (Veling et al., 2011; 2017).

Stimulus Devaluation. The final proposed mechanism works through the devaluation of specific foods and results in the reduction of approach tendencies (Veling et al., 2017). This mechanism is supported by the behavior stimulus interaction (BSI) theory, which postulates that withholding a response to an appetitive stimulus produces a response conflict which may then lead to the devaluation of the stimulus (Chen et al., 2016; Veling et al., 2008). Studies using self-report food evaluation scales have consistently found decreases in food evaluation from pre- to post-intervention, indicating the devaluation effect may be explicit (e.g., Chen et al., 2016; Lawrence et al., 2015; Veling et al., 2013a). Whether there is an implicit devaluation effect of the training is less clear . In their meta-analysis, Jones et al. (2016) foun1qa1`d that studies that measured devaluation through modified implicit association tests, did not show significant results, though significant implicit devaluation effects have resulted when measured through an affective priming paradigm (Tzavella et al., 2020) and a relative reinforcing value task (Houben & Giesen, 2018)

Currently, the devaluation of food items as the underlying mechanism of the GNG training holds the most support, along with the understanding that automatic associations and stimulus devaluation are not necessarily mutually exclusive (Veling et al., 2017). However, there is minimal support for inhibitory control as the underlying mechanism. Given the health behavior changes that have resulted through GNG trainings, more research around its underlying mechanism is needed to support any future integration of the training into clinical populations.

Specific Aims and Hypotheses of the Current Study

There were two primary aims of the current study. The first aim of the current study was to examine the effect of food-specific GNG training on weight and other outcome variables in attempts to replicate findings of weight loss seen in previous studies (Lawrence et al.,2015; Veling et al., 2014). The second aim was to examine the effect of food-specific GNG training dosage on a population of primarily overweight and obese individuals. This study was a near replication of the multi-session intervention study by Lawrence et al. (2015), in which there was a significant effect on weight loss after participants engaged in a food-specific GNG training four times over 1 week. In this study, dosage of the GNG training was varied to assess whether offering a stronger dosage would result in different outcomes than those found by Lawrence et al. (2015). Within the current study, participants were randomly assigned to one of three conditions: low intensity food-specific GNG (one time per week for 4 weeks), high intensity food-specific GNG (four times per week for 4 weeks), or the nonfood-specific GNG control group (one time per week for 4 weeks). The one time per week for 4 weeks dosage was chosen to align with the frequency used by Veling et al. (2014), where weight loss also resulted. Primary outcomes in the current study included body weight, frequency of snack and healthy food consumption, binge eating behavior, and dietary disinhibition.

It was hypothesized that individuals receiving the food-specific GNG training would lose more weight over 4 weeks than individuals in the control condition, and that participants in the high intensity food-specific group would lose more weight than those in the low intensity food-specific group. We hypothesized finding a similar pattern with binge eating frequency, frequency of snack and healthy food consumption, and dietary disinhibition. Dietary restraint was evaluated for its moderating effect on the GNG training outcomes. Additionally, because moderators of the GNG training have not been well-explored, we also evaluated disinhibition (a general difficulty controlling urges to eat highly palatable foods) and self-reported preoccupation with food as potential moderators. It was hypothesized that individuals who received the food-specific GNG training and who were higher in dietary restraint and disinhibition would experience larger effects of the GNG training. Because preoccupation with food as a moderator is more exploratory, no hypotheses regarding this variable were made. The mechanism of food devaluation was also assessed through a pre- and post-intervention measure of food evaluation. It was hypothesized that participants' evaluation of food would decrease more for those in a food-specific GNG training group as compared to those in the control group, and that decreased food evaluation would mediate the relationship between training group and weight loss.

Methods

Design

The current study used a mixed 3 x 2 factorial experimental design with the between-subjects factor being intervention condition (high intensity, low intensity, control) and the within-subjects factor being time (baseline, post-intervention). Participants were randomly assigned to one of the three training groups and were administered pre- and post-intervention assessments and self-report questionnaires. The training intervention (food-specific GNG) was delivered either one time per week for 4 weeks (low intensity) or four times per week for 4 weeks (high intensity). The control training (nonfood-specific GNG) was delivered one time per week for 4 weeks.

This study received approval from the university’s institutional review board (IRB) and was registered with ClinicalTrials.gov. Additionally, the Consolidated Standards of Reporting Trials (CONSORT; Schulz et al., 2010) guidelines were followed in this report of the study.

Participants

This intervention was geared toward individuals who were overweight or obese [body mass index (BMI) ≥ 25 or ≥ 30, respectively], as meta-analyses suggest that this population is the most likely to benefit from GNG interventions for eating regulation (Aulbach et al., 2019; Jones et al., 2016). Therefore, all participants were originally screened for meeting the inclusion criteria of aged 18 or older, a BMI ≥ 25 (based on self-reported height and weight), having a desire to lose weight, and consuming at least one of the no-go training foods used in the food-specific GNG training at least two times per week. To increase sample size, inclusion was expanded to those with a BMI of 24. Therefore, five additional participants were enrolled, with the lowest BMI being 24.3. Exclusion criteria included factors that may affect weight outside of the intervention itself, including the following: medical condition limiting dietary intake or affecting weight (e.g., insulin dependent diabetes mellitus, celiac disease), use of weight loss medication, history of bariatric surgery, current smoker, having quit smoking within the past year, or enrollment in a formal weight loss program in the past 6 months (similar to Lawrence et al., 2015). A current or past diagnosis of an eating disorder was not exclusionary, as anorexia nervosa is naturally excluded given the bounds of BMI inclusion and there is preliminary evidence that people with both bulimia nervosa and binge eating disorder may benefit from inhibition training (Giel et al., 2017).

Recruitment occurred through online newsletter postings and mass emails sent to subscribing faculty and staff at the University of Minnesota Duluth, as well as a newsletter for all students. Faculty and staff were also recruited through smaller liberal arts and community colleges in Minnesota through mass emails. Recruitment statements advertised the opportunity to potentially lose weight through participation in a study examining cognitive training approaches to manage eating and weight. Linked in the recruitment advertisement was an online survey to determine study eligibility. Recruitment occurred between October 15th, 2019 and March 31, 2020.

A total of 263 participants completed the online screening survey. Of these, 126 individuals met the inclusion criteria and were contacted to participate, though 48 individuals did not respond after two contacts. In total, 78 individuals participated in an informed consent meeting, and were randomly assigned to a condition. Three dropped out without completing any sessions, bringing the total to 75 participants (see participant flowchart in Figure 1). Of the 75 participants (M_{age} = 44.37, M_{BMI} = 31.82, 81.3% female; see Table 1 for participants demographics), 100% completed baseline measures and 92% (n = 69) completed at least one follow-up measure (weight or self-report measures).

Procedure

Upon receiving the recruitment information, participants were guided to a screening questionnaire (See Appendix A for all measures used in the study) through a link included in the recruitment materials. If participants met the eligibility criteria for the study, they were e-mailed a link to complete the pre-intervention questionnaire via Qualtrics. This questionnaire included several well-validated self-report measures to assess outcomes, possible mediators and moderators, and additional demographic information. Participants were then prompted to sign-up for a 20-minute session with a researcher via videoconference. During this session, consent was reviewed, the participant was randomly assigned to a condition using a random number generator, and expectations of involvement in the study were outlined. Notably, participants were not originally randomized by block. Therefore, halfway through recruitment, group sample sizes were not even. Adjustments were made to the randomization process, such that participants had a greater chance of being placed in the control group, though it was still possible to be placed in an active intervention group. Specifically, participants had a 1/20 chance of being placed in the high intensity group, a 9/20 chance of being placed in the low intensity food-specific group, and a 11/20 chance of being placed in the control group.

Each participant's training started on the Monday following their videoconference with a researcher. On that Monday morning, participants received an email with instructions for accessing the training and a reminder of how many times to complete the training during the week. They also received instruction on the procedure for sending their weight to the research team. Due to restrictions related to the COVID-19 pandemic, participants could not attend in-person anthropometric measurements in the laboratory. Instead, participants were asked to weigh themselves in the morning before consuming any food or liquids and while wearing light weight clothing. They were then asked to write a "word of the day" on a piece of paper and take a photo of their weight on the scale with the word of the day in the photo to ensure it was taken on the correct day. After weighing themselves, participants emailed the photo of their weight to the research team. Participants were also encouraged to complete the training at a time of day in which they were physically hungry. Additionally, to increase compliance, reminder emails were sent to participants each Monday with a link to the training and instructions to complete the prescribed number of sessions for the week. Those in the low intensity food-specific training group and the control group were sent up to one additional email, whereas those in the high intensity food-specific training group were sent up to two additional emails, depending on rate of completion.

After 4 weeks, participants were sent the post-intervention survey link, which included outcome measures and questions to gauge participant awareness of study intention and possible group differences. Participants were also asked to weigh themselves using the same process as they used at pre-intervention. After completing the post-intervention survey and emailing the research team their weight, participants were e-mailed a $20 e-gift card.

GNG Intervention

The GNG intervention was administered through the web based Inquisit 5.0 (Millisecond software) platform, which allowed participants to complete the training sessions on their personal computers. The GNG training consisted of images that prompted on the computer screen within a rectangular frame. The image and frame would remain on the screen for 1250 ms and were followed by a 1250 ms pause before the next image and frame displayed (based on Lawrence et al., 2015). When an image was presented on the screen, the rectangular frame around the image displayed as either not bold (thin line) for the “go” cue (indicating participants were to press the corresponding key on the keyboard) or bold (thick line) for the “no-go” cue (indicating the participants were to withhold their keystroke; see Appendix B for example GNG training). Reaction times and error rates for each participant were recorded for all trials in each session, to assess changes in performance throughout the training itself.

Consistent with Lawrence et al. (2015), each training session consisted of six blocks with each block displaying 36 images (216 total image promptings). In the food-specific GNG task 18 of these images were food (nine unhealthy, nine healthy), and 18 were household items (clothing). During the training, images presented on either the left or the right side of the screen and were associated with the keys ‘c’ and ‘m,’ respectively. Unhealthy food images were paired with the no-go cue (bold frame) 100% of the time and healthy food images were paired with the go cue (not bold frame) 100% of the time. The clothing images were paired equally with both go and no-go cues. The control group received the same training, with nonfood images exchanged for the food images of the food-specific training groups. The go category for the control group consisted of electrical items, furniture, and buckets, whereas the no-go category consisted of do-it-yourself tools, gardening tools, and stationary. Eleven of the food images and all of the nonfood images utilized in the training were the same as those used by Lawrence et al. (2015). However, given that the Lawrence et al. study was conducted in the U.K., some of the foods were less commonly eaten in the U.S. (e.g., biscuits). Therefore, seven food images were acquired through the extended food-pics database, which is standardized for experimental research around eating and nutrition (Blechert et al., 2019). Food images were chosen based on energy density (greater than 4 kcal/g) and food category (e.g., sweet, savory; Blechert et al., 2019). The images used in the current study can be found in Appendix C.

Outcome Measures

Weight

Weight was the primary outcome in this study. Participants reported their height and their weight, which was measured on their personal scales with a photo for confirmation. Body mass index (BMI) was calculated for each participant based upon these measurements. Participants were asked to weigh themselves in the morning before eating or drinking to get the most accurate representation of their body weight (Loeber et al., 2013).

Snacking Frequency

A food frequency questionnaire (FFQ) was used to evaluate participants' frequency of snacking over the past month. The food categories used were chosen from a pilot study by Churchill and Jessop (2011), during which the eight most cited high calorie snack foods were identified (e.g., chocolate, cakes, chips). In the present study, the category "crisps" was omitted from the FFQ as it is not readily applicable to a U.S. population. Additionally, the questionnaire was modified to include two questions relating to fruit and vegetable intake, raising the total number of items in the FFQ to nine. Participants responded to the prompt “how often have you eaten the following foods in the previous month?” on a scale from 1 (“*less often or never*”) to 8 (“*four or more times a day*”; consistent with Lawrence et al. [2015]). The FFQ was used to evaluate the pre- and post-intervention snacking frequency of the participants for the five trained no-go items included in the FFQ (chips, cake, chocolate, cookies, pastries/donuts).

Disinhibition

The Disinhibition subscale of the Three Factor Eating Questionnaire (TFEQ-D; Stunkard & Messick, 1985) is a 16-item measure used to evaluate levels of disinhibited eating. The measure consists of both true and false questions (e.g., “I usually eat too much at social occasions, like parties and picnics”), and various questions answered on a four-point scale (e.g., “Do you eat sensibly in front of others and splurge alone?”). Each question received either a 1 or a 0, with higher total scores indicative of greater disinhibited eating. The TFEQ has good construct validity with the original three factor structure being maintained in a validation study of female college students (Bond et al., 2001), and is frequently used in dietary research (Bryant et al., 2007). In the current study, internal consistency for this subscale was found to be adequate ($\alpha = 0.72$). The TFEQ-D was used to assess participants’ level of disinhibition both pre- and post-intervention. It was also used to evaluate disinhibition as a moderator for the other outcomes, given that people with higher baseline levels of disinhibition may benefit more from the food-specific GNG training than those with lower levels (Zhou et al., 2017).

Binge Eating Behavior

To assess the presence and level of binge eating behaviors, one binge eating question from the Eating Disorder Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994) was used. Participants were asked to respond to the question “Over the past 28 days, how many times have you eaten what most people would regard as an unusually large amount of food (given the circumstances)?" The binge eating question of the EDE-Q was administered at pre- and post-intervention to assess for possible changes in binge eating behavior throughout the intervention.

Impulsive Food Choices

To measure change in explicit choices of healthy vs. unhealthy foods, an impulsive food choice test was administered at pre-intervention and post-intervention. Like Veling et al. (2013b), the food choice test displayed 16 images to participants (8 healthy, 8 unhealthy) on the computer screen for 15 seconds. Participants were prompted before the task with the following statement: "On the following page there are 16 images of different foods. Please select 8 of your favorites as quickly as possible (within 15 seconds)." Although the images assessed through the impulsive food choice test were not the same as those used in the food-specific GNG training, they did fall into the same food categories (chips, cakes, chocolate, cookies, pastries/donuts). Scoring of responses was the total number of healthy items chosen.

Mechanisms

Food Evaluation

To assess for changes in explicit food ratings, participants were asked at baseline and post-intervention to rate how much they liked 24 food items, which were displayed as images on their computer screens. The items consisted of six trained go foods, six trained no-go foods, two novel healthy foods, two novel unhealthy foods, and eight novel neutral foods, to assess the generalizability of the training (see Appendix D). Food evaluations were assessed through a 100 mm visual analog scale. On this scale, the numbers were hidden and the cursor began at the middle of the scale to avoid demand characteristics. The visual analog scale was used to measure likeness for each presented food image. Participants were asked to respond to the prompt "how much do you like the taste of this?" by moving the cursor toward the left ("*not at all*") or the right ("*very much*").

Moderators

Restraint

Dietary restraint was evaluated as a moderator and assessed through the Restrained Eating subscale of the Dutch Eating Behavior Questionnaire (DEBQ-R;Van Strien et al., 1986) as well as the Revised Restraint Scale (Herman & Polivy, 1980).

The DEBQ-R is a 10-item self-report measure consisting of questions (e.g., "Do you deliberately eat less in order not to become heavier?") with responses ranging from 1 ("*never"*) to 5 *("very often")*. The DEBQ-R has shown good 2 week test-retest reliability (*r* = .92; Allison et al., 1992) in a sample of undergraduate students and 4 week test-retest reliability in a sample of adolescent girls (*r* = .85; Banasiak et al., 2000). Additionally, internal consistency within the current study was good (α = 0.81).

The Restraint Scale is a 10-item self-report questionnaire that assesses dieting concern and weight fluctuations through questions such as "how conscious are you of what you are eating?" Higher scores indicate an increased intention to restrict food intake, with possible total scores ranging from 0 to 35.The validity and reliability of the Restraint Scale has been supported in multiple studies (Heatherton et al., 1988), though the internal consistency within the current study was lower (α = 0.66).

Preoccupation with food

The Power of Food Scale (PFS; Lowe et al., 2009) is a 15-item self-report questionnaire that measures appetite, feelings, and motivations around highly palatable foods in specifically obesogenic environments (Lowe, 2009). The items of the PFS relate to three levels of proximity to food: food is constantly available, but not currently present (e.g., knowing food is readily available in the refrigerator); food is present, but has not yet been tasted (e.g., food out on a platter); and food has been tasted but not fully consumed (e.g., biting an apple, but not yet having swallowed it). Responses to the items are to be considered in relation to the previous month and are measured on a 5-point Likert-type scale ranging from 1 (*don't agree at all*) to 5 (*strongly agree*). The psychometric properties of the PFS are good, with high internal consistency in the current study ($\alpha = 0.96$) and a 4 month test-retest reliability of .77 (Lowe et al., 2009). The PFS was also found to be moderately correlated with the Emotional Eating subscale of the Dutch Eating Behavior Questionnaire and both Disinhibition and Hunger subscales of the Three Factor Eating Questionnaire (Lowe et al., 2009), providing evidence of both convergent and divergent validity. The PFS is uniquely geared toward preoccupation with food in a highly obesogenic environment. Given that a predisposition toward hedonic foods may lead to increased consumption when paired with weaker inhibitory controls (Espel-Huynh et al., 2018), the PFS is likely a useful tool for the current study. The PFS was administered at the pre-intervention session as an exploratory assessment of participants' perception of highly palatable foods as a moderator of the intervention on weight loss.

Statistical Analyses Approach

All data were analyzed using SPSS (v.27). The data were first screened for missing values, outliers, and normality. There were no missing data on completed questionnaires. In cases where entire outcomes were missing (nine participants did not complete some or all the post-intervention measures; 24 participants did not complete all prescribed training sessions), data were left missing. There were no substantial issues with normality (skewness < 1.5 for all variables) and because outliers on questionnaires and BMI were not extreme, their data were not adjusted. Training data (i.e., reaction time and error rates) of two participants were removed from the training-specific analyses because of inconsistent keystroke detection through the training computers. Removing their data corrected for all existing skewness in the training data. Their outcome measure data was retained for analyses, as both participants indicated they completed the trainings as prescribed, despite the lack of detection through the computer.

Groups were compared at baseline using one-way ANOVAs (for continuous variables) and chi-squared tests (for categorical variables). Participants who completed 75% of the prescribed training sessions and at least one of the outcome measures were considered "completers" and were compared to those who did not ("noncompleters"). Independent samples *t*-tests were used for continuous variables and chi-squared tests were used for categorical variables.

Mixed factorial ANCOVAs were used to analyze each outcome variable. These were first conducted to analyze differences between the high intensity food-specific training group and the low intensity food-specific training group. These groups were then combined (high intensity and low intensity) and compared to the control group using mixed factorial ANCOVAs to determine the effect of the food-specific GNG training overall. Any group x time interactions indicated statistically significant differences on changes in outcome variables between the groups across time.

To analyze changes in training performance, mixed factorial ANOVAs were conducted with group (high intensity food-specific, low intensity food-specific, and control) as the between-subjects factor and time (T1, T2) and stimulus category (filler, nonfiller) as the within-subjects factors. The "filler" stimulus category represented the filler images that were paired randomly (50/50) with the go and no-go cues across all three training groups (i.e., the clothing images).

The “nonfiller” stimulus category represented the stimulus-specific images that were paired 100% with a no-go cue (i.e., unhealthy food images and their control group equivalents) or 100% with a go cue (i.e., healthy food images and their control group equivalents). Stimulus category was included as a within subjects factor to test the development of stimulus-specific no-go or go associations. This would be evidenced by greater improvement in accuracy and reaction time to the stimulus-specific images than to the filler images. To explore any significant interaction effects, Bonferroni adjusted post-hoc analyses were conducted. Lastly, to assess for changes in training performance from session 4 (T2) to session 16 (T3) for the high intensity food-specific group, paired samples *t*-tests were conducted.

Across all analyses, effect sizes were calculated. For repeated measures ANCOVAs and one-way ANOVAs, partial eta squared (η_p^2) was calculated (0.01 = small effect, 0.06 = medium effect, 0.13 = large effect). Cohen’s *d* standardized mean difference effect size was calculated when comparing two groups on continuous variables at a single timepoint (0.2 = small, 0.5 = medium, and 0.8 = large) and Cramér’s V was calculated for all chi squared tests (≤ 0.2 = weak association, 0.2 - 0.6 = moderate association, and > 0.6 = strong association).

A sensitivity analysis was conducted to examine whether results would differ if noncompleters were included in the analysis. Intent-to-treat analysis using the Last Observation Carried Forward (LOCF) method was used, replacing participants’ missing data with the value of their last observed response at the point of dropout. This method assumed that participants would have been consistent in treatment and response moving forward from dropout rather than increasing or decreasing any further (Field, 2018). The results were compared to the results of intervention completers only.

Mediation and moderation analyses were conducted using PROCESS v3.4.1 (Hayes, 2018), an SPSS macro. For the moderator analysis examining the effect of disinhibition, restraint, food preoccupation, and BMI on the effectiveness of the intervention for weight loss, the PROCESS simple moderation model (Model 1) was used. Bootstraps was set to 10,0000 iterations to produce a 95% confidence interval. For the mediation analysis, the PROCESS simple mediation model (Model 4) was used to assess the degree to which food devaluation (i.e., change in evaluation of unhealthy food items) accounted for changes in weight by condition.

Power Analysis

For main outcome variables, separate power analyses were conducted for the separate group comparisons, though alpha was set to .05 and a correlation of $r = .5$ between measurement timepoints was used for both analyses. When comparing the high intensity to the low intensity food-specific training group (n =41), the current study had 39% power to detect a small effect ($f = 0.15$) and 87% power to detect a medium effect ($f = 0.25$). When the food-specific groups were combined and compared to the control ($n = 64$), power analyses indicated that the current study had 65% power to detect a small effect and 97% power to detect a medium effect ($f = 0.25$).

Regarding mediation and moderation, this study was quite underpowered to detect a medium interaction effect ($f^2 = 0.06$). For the high intensity vs. the low intensity food-specific group analyses (α =.05), this study had 25% power. For the food-specific training group vs. the control group analyses, (α =.05), this study had a power of 38%. Thus, the mediation and moderation results should be interpreted cautiously.

Results

Baseline Group Comparisons

One-way ANOVAs and Chi squared tests revealed that there were no significant differences ($p > .05$) between groups at baseline for measures of BMI, age, gender, ethnicity, dieting status, weight loss goal, dietary restraint, dietary disinhibition, or preoccupation with food (Table 1). Given the small sample size of this study, effect sizes were also considered in determining differences between groups. Therefore, BMI ($\eta_p^2 = 0.05$) was included as a covariate in the primary analyses and has previously been used as a covariate (Houben & Giesen, 2018) and found to moderate the effects of cognitive trainings in some studies (Veling et al., 2014; Veling et al., 2014). Dieting status was also controlled for because it was nearing significance with a medium effect for between group differences and because it has been studied as a moderator in a previous food-specific GNG study (Veling et al., 2014).

Training Adherence and Retention

In terms of training adherence, 70.6% of participants completed all prescribed trainings, 85.3% completed at least 75% of the prescribed training sessions, and 92% completed at least 50% of the prescribed training sessions. To be considered a treatment completer, participants had to complete at least one follow-up measure and complete at least 75% of all training data (i.e., 3 of 4 sessions for the low intensity training groups, 12 of 16 for the high intensity training group). This 75% cut-off was used because a primary aim of this study was to examine dosage effects, and we considered less than 75% to be inadequate to make group comparisons. Additionally, a 75% completion rate was used as a cut-off for sensitivity analyses in a recent food-specific GNG training study (Carbine et al., 2021). Eleven participants did not complete 75% of the trainings, and thus were considered noncompleters. Of these, six did not complete any of the post-intervention outcome measures, whereas five participants completed at least one outcome measure. Percentage of completers differed significantly by group [χ^2 (2, N = 75) = 11.55, p = .003], with the control group having the highest completer rate (100%), followed by the low intensity food-specific group (91.7%), and the high intensity food-specific group (67.9%).

Completers vs. Noncompleters

A dropout analysis was conducted to compare participants who completed the treatment (n = 64) to those who did not (n = 11: i.e., those who did not complete any outcome measures and/or who had a training compliance rate of less than 75%). No statistically significant differences were found, and effect sizes were small (Table 2).

Measure Correlations

Correlational analyses indicated that some measures were significantly correlated with one another (See Table 3). Disinhibition as measured by the TFEQ-Disinhibition subscale was positively correlated with restraint as measured through the Restraint Scale (r = .47), but not with restraint as measured through the DEBQ-Restraint subscale (r = -.05). The two measures of restraint were only moderately correlated (r = .31). This suggests that dietary restraint, when measured through the DEBQ-Restraint subscale is measuring a construct less closely related to disinhibition than that of the Restraint Scale. Additionally, preoccupation with food, as measured through the Power of Food Scale, was positively correlated with disinhibition (r = .56). This aligns with findings from a recent study that revealed the Restraint Scale is more strongly associated with both dietary disinhibition and external eating than the DEBQ (Adams et al., 2019). Therefore, when analyzing the moderating role of restraint, the DEBQ-Restraint score was used rather than the restraint score acquired through the Restraint Scale.

Primary Outcomes

Means and standard deviations of all outcome measures (body weight, dietary disinhibition, impulsive choices for healthy vs. unhealthy foods, snacking frequency, binge eating behaviors, and food liking) across groups at pre- and post-intervention are reported in Table 4. Analyses were first run with only completers (n = 64), and then again with all 75 participants LOCF as an intent-to-treat approach. The results between the two were compared and no observable differences existed, so the analyses presented here are from the 64 completers.

The first hypothesis tested was that participants in the high intensity food-specific group would experience greater positive change in outcome variables from pre- to post-intervention than those in the low intensity food-specific group. Repeated measures ANCOVAs, with BMI and dieting status included as covariates, found that across all outcomes, the group by time interactions were not significant (*ps* $\geq .11$; see Table 4). Some small effects were found for weight ($\eta_p^2 = .02$), disinhibition ($\eta_p^2 = .03$), frequency of consumption of trained unhealthy foods ($\eta_p^2 = .02$), and liking evaluations of trained healthy foods ($\eta_p^2 = .04$) and a medium effect was found for novel healthy foods ($\eta_p^2 = .07$). Therefore, the hypothesis being tested was not supported overall, and the two food-specific training groups were combined for the remaining analyses.

The second hypothesis was that participants in a food-specific GNG training group (high intensity or low intensity) would experience greater positive change in outcome variables from pre- to post-intervention than those in the control group. Repeated measures ANCOVAs were conducted, again controlling for BMI and dieting status. All group x time interactions were not significant (*ps* $\geq .12$) and are reported in Table 4. Effect sizes between groups for frequency of healthy food consumption ($\eta_p^2 = .02$), liking for trained healthy foods ($\eta_p^2 = .04$), liking for trained unhealthy foods ($\eta_p^2 = .03$), and liking for novel neutral foods ($\eta_p^2 = .02$) were all small. No other effect sizes were meaningful. Therefore, the hypothesis that participants in the food-specific GNG training groups (high intensity or low intensity) would experience greater positive change in outcome variables from pre- to post-intervention than those in the control group was not supported.

There was a main effect of time on impulsive food choices [$F(1,52) = 5.44$, $p = .024$, $\eta_p^2 = .10$], with participants across all groups selecting a greater number of healthy foods at post-intervention than pre- intervention. All other main effects of time were not significant, and all main effects of group were not significant. Results indicate that the GNG training, whether food-specific or non-food specific, did not result in significant changes in weight, dietary disinhibition, frequency of food consumption, binge eating behaviors, or food liking.

Response Inhibition Performance

Means and standard deviations for training error rates and reaction times at the first training session (Time 1), fourth training session (Time 2), and sixteenth training session (Time 3), can be found in Table 5. Carry forward values were used for those participants completing ≥ 75% to <100% of the assigned training sessions. Reaction times are reported for go trials, but not no-go trials (no-go trials requested an inhibition of a response and are captured as no-go errors). As shown, task accuracy was generally high (> 93%) across all groups, and there was improvement in accuracy and rection times throughout the training.

Mixed factorial ANOVAs were conducted (Table 5) to assess for changes in error rates and reaction times from Time 1 to Time 2 across all groups, with group (high intensity food-specific, low intensity food-specific, and control) as the between-subjects factor and time (T1, T2) as a within-subjects factor. Additionally, to test the development of learned stimulus-specific go and no-go associations, stimulus category (nonfiller, filler) was included as a within-subjects factor (Adams et al., 2021; Lawrence et al., 2015).

Total go errors improved over time and showed no difference between groups or a group x time interaction. For no-go error rates, there was a main effect of group, a main effect of time, and a group x time interaction effect. However, there was no main effect of stimulus category

[*F*(1, 59) = 1.42, *p* = .24, η_p^2 = .02] or a stimulus category x group interaction [*F*(1, 59) = 1.06, *p* =.35, η_p^2 = .04]. For the group x time interaction, both the high intensity and the low intensity food-specific training groups improved significantly over time on no-go trials, whereas the control group did not. However, at baseline, the control group performed significantly better than the high intensity food-specific training group, meaning that the control group had less opportunity for improvement.

For reaction time to go items, results showed that all groups improved over time, but improvement did not differ as a function of group or group x time. There was a main effect of stimulus category [*F*(1, 59) = 90.08, *p* < .001, η_p^2 = .60] and a stimulus category x group interaction [*F*(1, 59) = 13.70, *p* < .001, η_p^2 = .24]. For the stimulus category x group interaction, post-hoc analyses revealed that both the high intensity and the low intensity food-specific training groups responded faster to stimulus-specific images (healthy foods) than to filler images, whereas reaction times in the control group did not significantly differ between stimulus and filler images.

For the high intensity food-specific training group, error rates did not change significantly from T2 to T3 for go images *t*(17) = -1.35, *p* = .196, *d* = -0.32, no-go stimulus-specific images, *t*(17) = 0.325, *p* = .749, *d* = 0.08, or no-go filler images, *t*(17) = -1.00, *p* = .331, *d* = -0.24. However, reaction times for both go stimulus-specific images, *t*(17) = 3.05, *p* = .007, *d* = 0.72, and go filler images, *t*(17) = 3.16, *p* = .006, *d* = 0.74 improved from T2 to T3.

Moderation of Training Effects

Moderation analyses were conducted to evaluate the effect of disinhibition, restraint, food preoccupation, and BMI on the effectiveness of the intervention for weight loss. All tested variables (levels of dietary disinhibition, dietary restraint, preoccupation with food, and BMI) did not moderate the relationship between training condition (predictor variable) and weight loss (dependent variable). For dietary disinhibition, there was no significant group x disinhibition interaction, b = .10, t(59) = 0.23, p = .82, 95% CI [-0.78, 0.98] on weight loss. This was similar for group x restraint, b = 2.14, t(59)= 1.05, p = .30, 95% CI [-1.94, 6.21]; group x preoccupation with food, b = .55, t(59) = 0.46, p = .64, 95% CI [-1.81, 2.90]; and group x BMI, b = -.11, t(59) = -0.51, p = .61, 95% CI [-0.03, 0.05]. The hypothesis that individuals who received the food-specific GNG training and who were higher in dietary restraint or dietary disinhibition would experience larger effects of the GNG training, was not supported (See Figure 2 for graphs of moderation interactions).

Mediation Through Changes in Food Liking

A mediation analysis was also conducted to assess the degree to which food devaluation (decrease in liking of no-go foods) mediated the effect of training by condition on weight loss. In the model, training condition (food-specific vs. nonfood-specific) was the independent variable, change in weight (four weeks minus baseline) was the dependent variable, and change in liking score of no-go foods (4 weeks minus baseline) was the mediator variable. Training group was not significantly related to a reduction in weight or to a reduction in food liking. Additionally, the change in liking of no-go foods did not mediate the direct influence of training on weight loss, b = -0.16, 95% CI [-0.60, 0.31] (Figure 3). The hypothesis that decreased food evaluation would mediate the relationship between training condition and weight loss was not supported.

Discussion

There were two primary aims of this study. The first aim was to examine the effectiveness of food-specific GNG training on weight change and other outcome variables (snacking frequency, dietary disinhibition, binge eating behavior, and impulsive food choices), as part of an effort to replicate early findings on weight loss (Lawrence et al., 2015; Veling et al., 2014). A further aim was to assess whether training dosage (frequency and duration) would be related to changes in outcomes, particularly body weight. Possible moderators of the training on weight loss were also analyzed along with the mechanism of food devaluation. Participants, who were primarily overweight or obese ($M_{BMI} =$ 31.82, *SD* = 5.5), were randomly assigned to one of three training groups: high intensity food-specific GNG (four sessions per week for 4 weeks), low intensity food-specific GNG (one session per week for 4 weeks) or low intensity nonfood-specific GNG (one session per week for 4 weeks). Results indicate that none of the proposed hypotheses were supported. Therefore, regardless of dosage, the GNG training did not have an observable effect on any of the outcomes assessed. This result is generally inconsistent with previous food-specific GNG intervention studies, most notably Lawrence et al. (2015).

The primary outcome in the current study was weight loss, which was not significantly different across groups (high intensity food-specific, *M* = 0.71 lbs., *SD* = 1.03; low intensity food-specific, *M* = 0.25 lbs., *SD* = 0.92; control, *M* = 0.28 lbs., *SD* = 0.27). These results differ from early studies of food-specific GNG training on weight loss (Lawrence et al., 2015; Veling et al., 2014), and from a recent GNG gamification study that resulted in significant weight loss in men but not women (Forman et al., 2020). This difference in outcome is especially notable given the level of similarity the current study holds to Lawrence et al. (2015), regarding the specific GNG training used, the dosage prescribed over one week (4 sessions), and the baseline sample characteristics of age, BMI, and disinhibition scores. However, an important difference, which may partly account for the lack of weight loss in the current study, is the different baseline level of trained unhealthy (no-go) food consumption in the current sample (*M* = 2.0) compared to the sample in Lawrence et al. (*M* = 3.8). The lower baseline level of trained unhealthy food consumption in the current study indicates that the sample had less opportunity for the training to have an effect. This offers support for the usefulness of individualized training foods; people could integrate the foods that are most difficult for them to resist and then be trained to inhibit their responses to them (van Beurden et al., 2019).

On the other hand, results of the present study are consistent with the non-significant effects of food-specific GNG training on weight loss found in more recent studies using a similar training (Adams et al., 2021; Carbine et al., 2021; Forman et al., 2019; Najberg et al., 2021), though methodological differences between studies may account for this. For example, Carbine et al. (2021) utilized a GNG training nearly identical to that used in Lawrence et al. (2015) and prescribed it at the same dosage as the high intensity group of the current study (four times per week over 4 weeks). However, the trained food images differed each training session, with 200 total variations of food images across 16 ICT trainings. Given that inhibited responses were not consistently paired with the same no-go food images, associations were less likely to form, making weight loss less likely to occur in that study. In a replication study of Lawrence et al. (2015), by Adams and colleagues (2021), there were also non-significant changes in weight. However, the study sample consisted of primarily normal weight, healthy college students, which supports the notion that food-specific GNG trainings may work better for those with higher BMIs (Veling et al., 2014). However, participants' baseline levels of trained food consumption were lower than in the current study, yet reductions in food evaluation in the intervention group were significant. Similar results were found within a study by Najberg et al. (2021), where food devaluation resulted, but weight loss did not. Baseline levels of food consumption were not measured in that study. Results of these recent GNG intervention studies suggest that, although GNG trainings are generally easy to complete with high compliance rates, individuals may need to experience a combination of 1) high baseline consumption of the trained foods, 2) establishment of learned associations throughout the duration of the training, and 3) a devaluation of the trained items across the intervention timeframe for weight loss to occur. Additionally, personal characteristics may moderate the degree to which each of these requirements must be met, though evidence is still mixed.

Regarding moderation, we evaluated both previously studied variables (dietary restraint, baseline BMI) and those not yet investigated (disinhibition, preoccupation with food). No significant interactions resulted. This aligns with previous studies regarding BMI, where moderation was found in samples with healthy weight participants (Houben et al., 2018; Veling et al., 2014) but not in those with primarily elevated BMIs (Lawrence et al., 2015). The non-significant result of moderation analyses on dietary restraint was inconsistent with those of previous laboratory studies (Jones et al., 2016), though it has not been assessed in any multi-session studies. However, given the small sample size and substantially underpowered nature of the moderation analyses, these results should be interpreted with caution.

We also evaluated the mediating role of food devaluation for training effects on weight loss. The hypothesis that decreased food evaluation would mediate the relationship between training condition and weight loss was not supported. Although previous studies have found similar results regarding mediation effects (Lawrence et al., 2015; Najbeg et al., 2021), the lack of significant changes in measures of food evaluation in the current study is somewhat surprising. A reduction in food evaluation, especially of trained unhealthy foods, is one of the most consistent outcomes across food-specific GNG training studies when assessed through visual analog scales. Additionally, baseline measures of liking of trained unhealthy foods were relatively high (M = 68), meaning that the lack of training effect was not due to low levels of food liking at pre-intervention. A possible reason for this is the lack of formed associations seen through the participants' performance across no-go trials (where associations between the unhealthy foods and an inhibition of response were likely to form). Although trends in mean errors across all groups were in the direction indicating formed associations, there was no significant difference between performance on no-go nonfiller images (stimulus-specific) and the no-go filler images. Additionally, participant liking of trained unhealthy food was not associated with their consumption of those foods, whereas a moderate association between participant liking of healthy foods and their consumption of healthy foods was found (table 3). This may reflect a higher baseline ability within this sample to inhibit responses to the trained unhealthy foods, despite a liking for those foods. (Additionally, on all measures of training performance and task completion from baseline and throughout the study, those in the control group outperformed those in the other two groups. This was an interesting pattern given that generalized ICTs are unlikely to result in significant effects on eating behavior change (Veling et al., 2017).

The main strength of the present study is its use of a randomized controlled design to evaluate the impact of training frequency on changes in eating behaviors. Although a recent study found associations between the number of trainings completed and the frequency of trained food consumption, participants were not randomized to a specific condition (Aulbach et al., 2021). Therefore, it is difficult to determine if effects resulted from the training relative to other variables (e.g., motivation, expectation; Aulbach et al., 2021). Another strength of the current study was its delivery through an entirely remote design, which allowed for individuals (primarily faculty and staff at higher-educational institutions) outside of the University of

Minnesota Duluth vicinity to be recruited and to participate in the randomized controlled trial (RCT) by videoconferencing with a researcher.

There are limitations to consider in the current study. First, the small sample size likely means that it was underpowered to detect small effects for many of the outcomes, along with any moderation and/or mediation effects. Adding to this limitation is the disproportionate rate of compliance between the three groups. Those in the control group were the most compliant, whereas those in the high intensity food-specific training group were the least compliant, with one third of the group being noncompleters. Although the reason for this is unclear, possible explanations include boredom with the training, randomization technique used, and client specific characteristics. It is possible that with an increased number of trainings, participant engagement decreased. Although previous studies of food-specific response inhibition trainings have reported high rates of compliance (Jones et al. 2016), studies that have extended over four or more weeks have either utilized twice daily reminders to encourage compliance (Carbine et al., 2021), or have resulted in reductions in participant compliance across time (Forman et al., 2019). Another potential reason for the difference in drop-out rates between groups is the possible differential impact of factors outside of the training on participants who were randomized within the first three months of recruitment (60% of recruitment timeframe), compared to those who were randomized during the final 2 months. Given the simple randomization technique initially used, a larger percentage of the high-intensity active group participants (96%, n = 29) were enrolled during months 1-3 than participants in the low-intensity active group (73%, n = 19) or the control group (65%, n = 15). Lastly, there may be important person-specific factors contributing to GNG training compliance and effectiveness that have not been explored and were therefore not accounted for in the present study (e.g., expectation, skepticism).

Another limitation of the current study is the lack of a nonfood-specific GNG high intensity control group. Having this control group would better control for the impact of external variables like motivation in the food-specific GNG high intensity group. Additionally, not having personalized images for the food-specific training groups could be a limitation. Although reductions in food evaluation have been noted without personalized images in single-session and multi-session training studies (Aulbach et al., 2019), the personalization of the training would likely have increased the salience of any training effects (Aulbach et al., 2021).

Lastly, the current study took place during the COVID-19 pandemic. It is difficult to know if, or how much, the pandemic impacted the effect of the GNG training on outcomes assessed in this study. To-date, results of studies evaluating the impact of the pandemic on weight status and eating habits are mixed (Bakaloudi et al., 2021) though it is clear that the pandemic impacted the lives of nearly all people in some way (Brodeur et al., 2021). One result of the pandemic, specifically on the design of the current study, was the shift to an entirely online platform. Therefore, all participants were asked to weigh themselves on their personal scales at each timepoint, meaning accuracy of weight may be questionable.

Given that the food-specific GNG training is proposed to work through the impulsive processes (Verbruggen & Logan, 2008), future research might benefit from pairing the food-specific GNG training with more reflective weight loss interventions like mindfulness, goal setting, or structured food plans to target the impulsive and reflective processes simultaneously (Nurmi et al., 2020). Furthermore, consistently utilizing personalized images of foods that participants find difficult to resist, may be helpful for increasing the salience of the effect of the training (Veling et al., 2019). Additionally, to encourage engagement, maintained attention, and associative learning through the GNG training, it may be helpful to further explore difficulty adjustments and gamification elements (Forman et al., 2021). However, given the results of the current study, perhaps future research should focus specifically on identifying the underlying mechanism of the GNG training and how it may be influenced by personal characteristics. Although variation in the delivery format of the training and the addition of gamification elements are aspirational, without knowing the underlying mechanism of the training, results of these studies may continue to vary on meaningful outcomes.

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Table 1.

Means, Standard Deviations, and Test Statistics for Sample Demographics at Baseline Comparisons Across all Groups

Measure	Total (n = 75)	High intensity (n = 28)	Low intensity (n = 24)	Control (n = 23)				Effect size	
	% (n) or M (SD)	*% (n) or M (SD)*	*% (n) or M (SD)*	*% (n) or M (SD)*	F	χ^2	p	η_p^2	V
Age	44.37 (12.52)	44.71 (13.44)	42.79 (9.85)	45.61 (14.12)	0.31		.74	0.01	
Ethnicity (% White)	93.30% (70)	92.90% (26)	91.70% (22)	95.70% (22)		0.32	.70		.07
Gender (% female)	81.30% (61)	82.10% (23)	83.30% (20)	78.30% (18)		0.02	.99		.12
BMI	31.82 (5.5)	32.80 (6.12)	30.14 (5.05)	32.38 (4.88)	1.71		.19	0.05	
Currently dieting (% yes)	29.30% (22)	25.00% (7)	20.80% (5)	43.50% (10)		3.31	.19		.21
Weight loss goal (lbs.)	35.99 (25.62)	43.11 (28.55)	28.89 (20.97)	34.34 (24.83)	2.07		.13	0.06	
DEBQ-Restraint	2.80 (0.54)	2.83 (0.56)	2.79 (0.57)	2.78 (0.51)	0.05		.95	0.00	
Restraint Scale	19.03 (4.25)	19.93 (3.86)	18.13 (4.96)	18.87 (3.85)	1.19		.31	0.03	
Power of Food Scale	2.84 (0.90)	2.85 (0.95)	2.83 (0.82)	2.84 (0.96)	0.00		.99	0.00	
TFEQ-Disinhibition	10.27 (3.20)	10.29 (3.72)	10.29 (2.74)	10.22 (3.09)	0.00		.99	0.00	

Note. BMI = body mass index; DEBQ = Dutch Eating Behavior Questionnaire; TFEQ = Three Factor Eating Questionnaire.

Table 2.

Means, Standard Deviations, and Statistical Comparison of Completers vs. Noncompleters

Measure	Completers (n = 64)	Noncompleters (n = 11)				Effect size	
	% (n) or M (SD)	*% (n) or M (SD)*	t	χ^2	p	d	V
Age	44.83 (12.48)	41.73 (13.02)	-0.76		.67	-0.25	
Ethnicity (% White)	93.80% (60)	90.90% (10)		0.12	.73		.04
Gender (% female)	82.80% (53)	72.70% (8)		0.84	.36		.12
BMI	31.82 (5.25)[1]	30.45 (5.24)	-0.80		.80	-0.26	
Currently dieting (% yes)	29.70% (19)	27.30% (3)		0.03	.87		.02
Weight loss goal (lbs.)	36.05 (25.92)	35.64 (25.06)	0.10		.76	-0.02	
DEBQ-Restraint	2.82 (0.57)	2.71 (0.31)	-0.60		.08	-0.20	
Restraint Scale	18.94 (4.25)	19.55 (4.44)	0.44		.79	0.14	
Power of Food Scale	2.90 (0.91)	2.46 (0.83)	-1.51		.54	-0.49	
TFEQ-Disinhibition	10.44 (3.04)	9.27 (4.01)	-1.12		.22	-0.37	

Note. BMI = body mass index; DEBQ = Dutch Eating Behavior Questionnaire; TFEQ = Three Factor Eating Questionnaire. [1]Data missing from one participant in this cell.

Table 3.

Means, Standard Deviations, and Correlations for Study Variables at Baseline for Whole Sample

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*M (SD)*
1. BMI	-																31.82 (5.50)
2. Restraint Scale	.36**	-															19.03 (4.25)
3. DEBQ-Restraint	-.18	.31**	-														2.80 (0.54)
4. Power of Food Scale	.35**	-.13	-.05	-													2.84 (0.90)
5. TFEQ - Disinhibition	.30**	.47**	-.05	.56**	-												10.27 (3.20)
6. Implicit food choice test	-.15	-.11	.03	-.02	-.17	-											4.23 (1.33)
7. Binge eating behavior	.31**	.29*	-.19	.44**	.57**	-.01	-										5.55 (5.03)
9. FFQ-unhealthy	-.10	-.15	.09	-.02	-.06	-.19	.01	-.08	-								2.01 (0.61)
10. FFQ-trained unhealthy	-.18	-.22	.05	-.05	-.13	-.20	.01	-.04	.91**	-							1.91 (0.61)
11. FFQ-healthy	-.13	-.24*	.07	-.04	-.22	.22	-.29*	.03	.08	.01	-						4.61 (1.46)
12. Liking-trained healthy	-.12	-.26*	.12	-.32**	-.13	.33**	-.24*	-.15	.04	-.04	.49**	-					60.89 (14.26)
13. Liking-trained unhealthy	-.01	.12	-.12	.06	.21	-.45**	.08	-.07	.19	.17	-.09	.25	-				68.38 (12.24)
14. Liking-novel healthy	-.09	-.14	-.06	-.13	.03	.26*	-.08	-.11	.08	.05	.20	.50**	.12	-			74.49 (16.24)
15. Liking-novel neutral	.04	.01	-.14	.07	.13	-.02	.02	.05	.23	.21	.02	.28*	.35**	.29*	-		67.43 (11.10)
16. Liking-novel unhealthy	.08	.37**	-.07	.30**	.39**	-.24*	.21	.02	.05	-.06	.03	.00	.57**	.07	.04	-	65.01 (19.38)

Note. BMI = body mass index; DEBQ = Dutch Eating Behavior Questionnaire; TFEQ = Three Factor Eating Questionnaire; FFQ = food frequency questionnaire. Implicit food choice test is the number of healthy foods chosen out of 16 (8 healthy, 8 unhealthy) foods. Binge eating behavior is the number of overeating episodes in the past 28 days.
$^*p < 0.05$. $^{**}p < .01$.

Table 4.

Means and Standard Deviations at Baseline and Post-Training and Repeated Measures ANCOVA Statistics for Primary Outcome Variables

Measure	High intensity (n = 19)	Low intensity (n = 22)	Control (n = 23)	Group x time interaction					
				High vs. Low intensity			Active vs. Control		
	M (SD)	*M (SD)*	*M (SD)*	F	p	η_p^2	F	p	η_p^2
Weight (lbs.)									
Baseline	206.70 (43.14)	188.47 (35.87)[1]	202.38 (38.79)	0.54	.58	.02	0.04	.85	.00
Post	205.98 (43.72)	188.59 (35.20)[1]	202.10 (39.71)						
BMI									
Baseline	33.70 (6.34)	30.54 (5.23)[1]	32.38 (4.88)	0.54	.47	.01	0.06	.81	.00
Post	33.60 (6.52)	30.60 (6.52)[1]	32.34 (5.07)						
TFEQ-Disinhibition									
Baseline	10.84 (3.69)	10.48 (2.36)[1]	10.22 (3.03)	1.20	.28	.03	0.01	.93	.00
Post	10.74 (3.02)	9.48 (3.60)[1]	9.61 (3.33)						
Implicit food choice test									
Baseline	4.28 (1.32)[1]	4.11 (1.13)[4]	4.55 (1.50)[3]	0.23	.63	.01	0.34	.56	.01
Post	4.83 (1.92)[1]	4.67 (1.41)[4]	5.00 (1.62)[3]						
Binge eating behavior									
Baseline	5.53 (5.90)	6.10 (4.58)[1]	4.91 (4.96)	0.12	.74	.00	0.09	.76	.00
Post	3.32 (4.31)	4.14 (4.51)[1]	2.96 (3.32)						
FFQ-unhealthy									
Baseline	1.92 (0.65)	2.22 (0.54)[1]	1.84 (0.51)	0.37	.55	.01	0.00	.83	.00
Post	1.68 (0.60)	1.78 (0.70)[1]	1.47 (0.66)						
FFQ-trained unhealthy									
Baseline	1.73 (0.68)	2.20 (0.50)[1]	1.77 (0.51)	0.63	.43	.02	0.40	.53	.01
Post	1.60 (0.62)	1.79 (0.80)[1]	1.39 (0.69)						
FFQ-healthy									
Baseline	4.82 (1.44)	4.74 (1.50)[1]	4.54 (1.50)	0.11	.74	.00	1.20	.28	.02
Post	4.87 (1.27)	4.86 (1.42)[1]	4.41 (1.57)						
Liking-trained healthy									
Baseline	65.36 (13.20)	58.66 (16.54)[1]	60.56 (14.41)	1.30	.26	.04	2.49	.12	.04
Post	66.33 (15.10)	62.86 (13.29)[1]	67.46 (14.02)						

Measure	High intensity (*n* = 19)	Low intensity (*n* = 22)	Control (*n* = 23)	Group x time interaction					
				High vs. Low intensity			Active vs. Control		
	M (SD)	*M (SD)*	*M (SD)*	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Liking-trained unhealthy									
Baseline	69.88 (12.72)	70.27 (12.67)[1]	63.46 (12.72)	0.01	.93	.00	1.86	.18	.03
Post	68.43 (15.32)	66.36 (15.17)[1]	65.86 (18.32)						
Liking-novel healthy									
Baseline	80.89 (10.00)	72.71 (17.42)[1]	70.26 (18.87)	2.77	.11	.07	0.08	.77	.00
Post	81.21 (13.71)	79.50 (14.24)[1]	73.89 (19.55)						
Liking-novel unhealthy									
Baseline	65.66 (17.92)	69.88 (23.11)[1]	63.57 (16.28)	0.46	.50	.01	0.62	.44	.01
Post	63.08 (16.60)	63.60 (20.96)[1]	61.20 (24.16)						
Liking-novel neutral									
Baseline	69.26 (9.98)	66.12 (12.91)[1]	66.27 (9.70)	0.45	.51	.01	1.43	.24	.02
Post	68.77 (12.07)	66.68 (12.80)[1]	69.61 (9.37)						

Note. *M* and *SD* are unadjusted. BMI = body mass index; TFEQ = Three Factor Eating Questionnaire; FFQ = Food Frequency Questionnaire. Impulsive food choice test is the number of healthy foods chosen out of 16 (8 healthy, 8 unhealthy) foods. Binge eating behavior is the number of overeating episodes in the past 28 days. Degrees of freedom for high vs. low intensity (1,36) and for food-specific training vs. control (1,59). [1]Data missing from one participant in this cell, [2]Data missing from 2 participants. [3]Data missing from 3 participants, etc. All remaining superscript numbers indicate the number of missing data points for this cell (these range from 1-5).

Table 5.

Means and Standard Deviations for Training Data

Variable	High intensity (*n* = 18)	Low intensity (*n* = 22)	Control (*n* = 22)
	M (SD)	*M (SD)*	*M (SD)*
Go errors (all)			
Time 1	.030 (.031)	.024 (.022)	.017 (.019)
Time 2	.011 (.015)	.013 (.014)	.010 (.010)
Time 3	.018 (.029)		
Go errors (nonfiller)			
Time 1	.028 (.028)	.024 (.026)	.018 (.019)
Time 2	.009 (.016)	.011 (.018)	.013 (.015)
Time 3	.016 (.025)		
Go errors (filler)			
Time 1	.031 (.040)	.024 (.024)	.020 (.023)
Time 2	.012 (.018)	.016 (.018)	.007 (.013)
Time 3	.019 (.035)		
No-Go errors (all)			
Time 1	.028 (.058)	.050 (.054)	.027 (.019)
Time 2	.014 (.019)	.015 (.024)	.009 (.013)
Time 3	.016 (.012)		
No-Go errors (nonfiller)			
Time 1	.069 (.060)	.045 (.056)	.029 (.028)
Time 2	.011 (.016)	.011 (.022)	.008 (.014)
Time 3	.010 (.011)		
No-Go errors (filler)			
Time 1	.067 (.061)	.054 (.056)	.024 (.024)
Time 2	.016 (.027)	.019 (.030)	.011 (.017)
Time 3	.022 (.018)		
Go reaction time ms (all)			
Time 1	644.82 (88.43)	637.88 (93.01)	663.63 (68.09)
Time 2	562.33 (74.99)	569.03 (78.20)	581.89 (61.08)
Time 3	523.99 (73.03)		
Go reaction time ms (nonfiller)			
Time 1	627.97 (86.19)	627.78 (93.12)	661.93 (66.74)
Time 2	546.15 (67.83)	553.58 (81.27)	578.30 (63.42)
Time 3	510.21 (66.06)		
Go reaction time ms (filler)			
Time 1	661.67 (92.43)	647.98 (94.93)	665.33 (71.81)
Time 2	578.50 (84.42)	584.49 (76.61)	585.49 (59.48)
Time 3	537.78 (81.41)		

Note. *M* and *SD* are unadjusted. ms = milliseconds; errors = proportion of incorrect responses; Go (nonfiller) = healthy foods and their control group equivalents (electrical items, furniture, and buckets);.No-Go (nonfiller) = unhealthy foods and their control group equivalents (do-it-yourself tools, gardening tools, and stationary).

Table 6.

Repeated Measures ANOVA Statistics for Training Data

Variable	ANOVA				
	Effect	*F*	*df*	*p*	η_p^2
Go errors (all)					
	G	1.45	2. 59	.243	0.05
	T	12.07	1, 59	<.001	0.17
	T x G	1.00	2, 59	.375	0.03
Go errors (nonfiller)					
	G	.248	2, 59	.781	.01
	T	9.89	1, 59	.003	.14
	T x G	1.23	2, 59	.299	.040
Go errors (filler)					
	G	2.19	2, 59	.121	0.07
	T	7.86	1, 59	.007	0.12
	T x G	0.53	2, 59	.590	0.02
No-Go errors (all)					
	G	3.80	2, 59	.028	0.11
	T	37.57	1, 59	<.001	0.39
	T x G	3.31	2, 59	.043	0.10
No-Go errors (nonfiller)					
	G	2.89	2, 59	.053	0.10
	T	38.29	1, 59	<.001	0.39
	T x G	2.92	2, 59	.059	0.09
No-Go errors (filler)					
	G	3.79	2, 59	.028	0.11
	T	28.07	1, 59	<.001	0.32
	T x G	2.92	2, 59	.062	0.09
Go reaction time ms (all)					
	G	0.51	2, 59	.606	0.02
	T	109.41	1, 59	<.001	0.65
	T x G	0.37	2, 59	.694	0.01
Go reaction time ms (nonfiller)					
	G	1.35	2, 59	.267	0.04
	T	115.69	1, 59	<.001	0.66
	T x G	0.16	2, 59	.852	0.01
Go reaction time ms (filler)					
	G	0.09	2, 59	.918	0.00
	T	87.67	1, 59	<.001	0.60
	T x G	0.58	2, 59	.563	0.02

Note. Go (nonfiller) = healthy foods and their control group equivalents (electrical items, furniture, and buckets); No-Go (nonfiller) = unhealthy foods and their control group equivalents (do-it-yourself tools, gardening tools, and stationary).

Figure 1.

CONSORT Flowchart of Participants

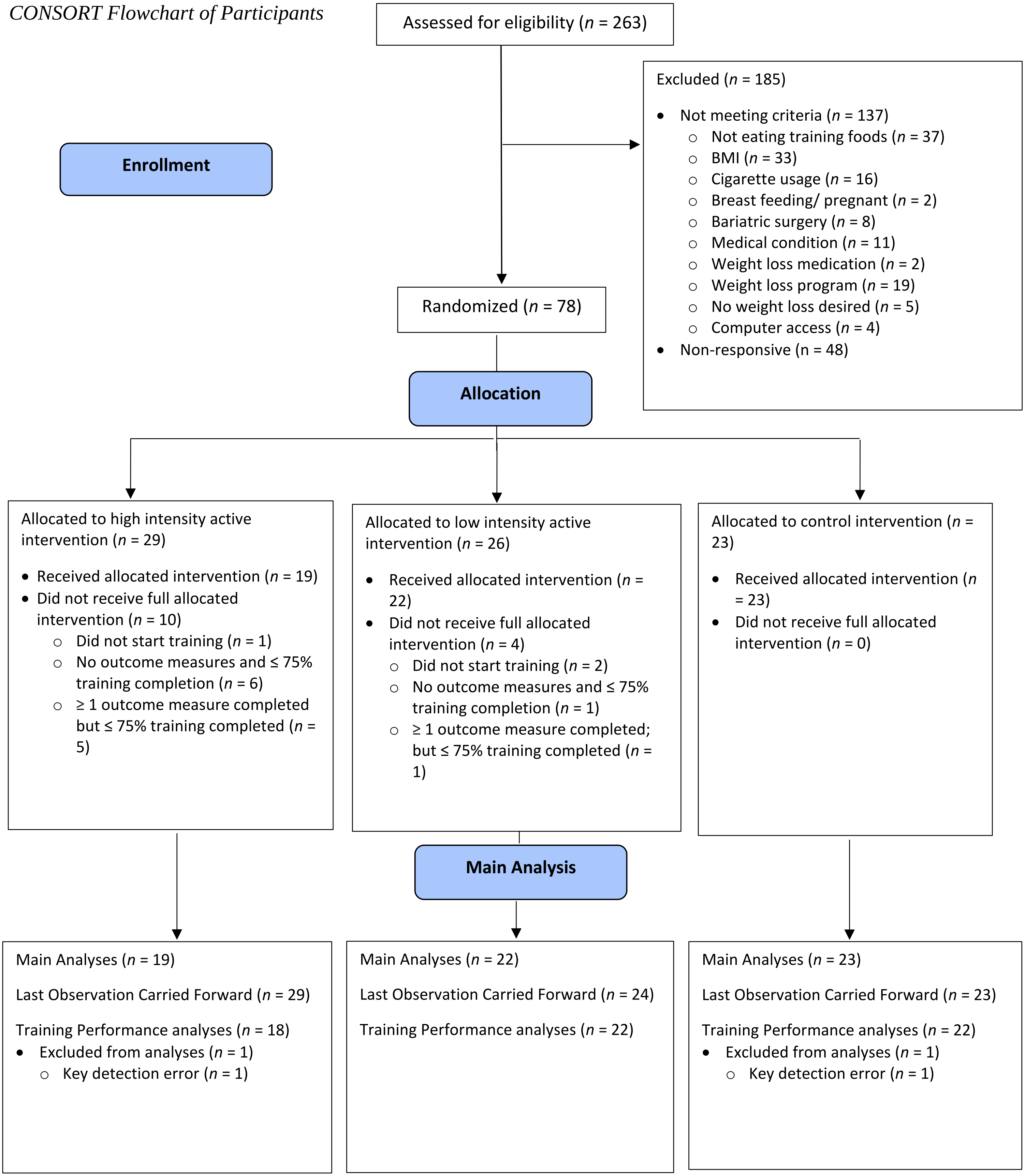
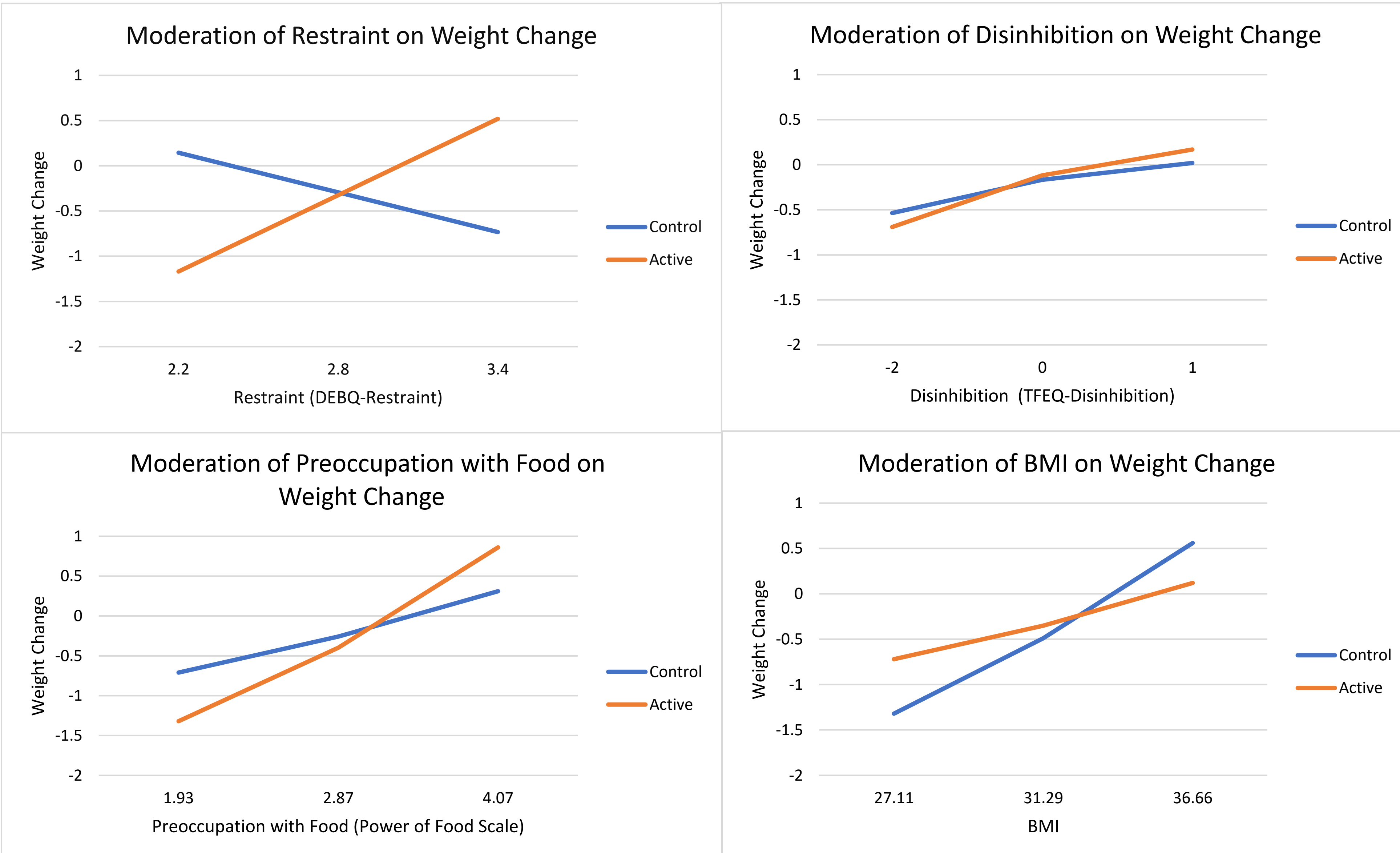


Figure 2.

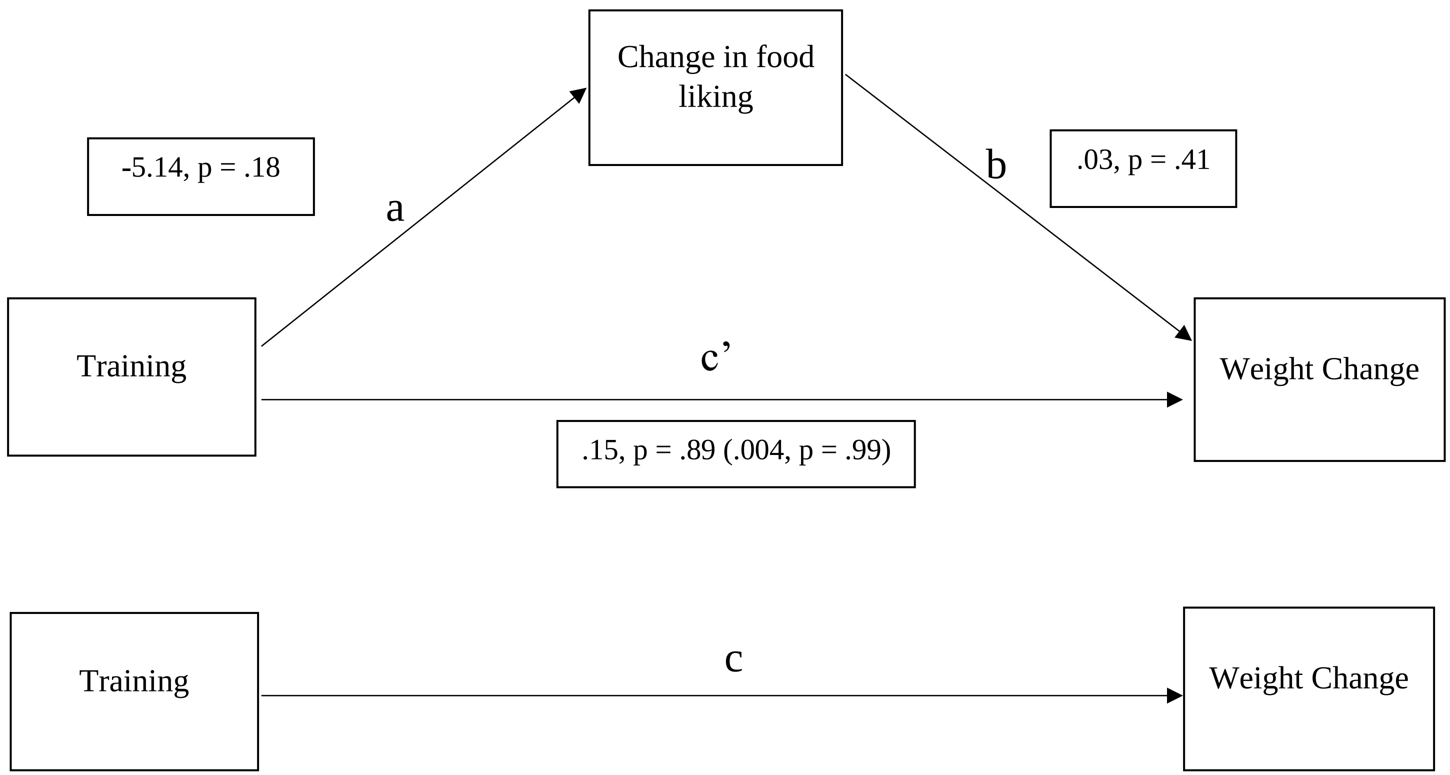
Moderation of Effects on Training Group by Weight Change



Note. BMI = body mass index.

Figure 3.

Mediation Analysis of Food Liking on Weight Change



Note. Standardized regression coefficients for the relationship between training and weight change as mediated by change in food liking. Values within parentheses represent the total effect of training on weight loss. Values outside of parentheses represent the direct effect of bootstrapping analysis.

Appendix A

SCREENER AND QUESTIONNAIRE MEASURE MATERIAL

Screener

Introduction:

This questionnaire contains items that are related to your eating and health habits, and will help to determine your eligibility for this study. All responses are kept confidential and will not be seen by anyone other than the researchers.

If you meet eligibility requirements, you will be sent a link to the consent form and another questionnaire that will take about 15-20 minutes to complete. Following that, you will be contacted by email within 48 hours and be scheduled for a time to meet individually with a research assistant. This meeting will occur remotely via Zoom. During this meeting, the researcher will discuss with you your participation, expectations of the study, and assign you to a group, teach you about the computer intervention, and answer any questions you may have.

Thank you for your time and interest in the study.

1. Gender

   Male
   Female
   Other

2. Current age

   ____

3. Race/ethnicity

   Asian or Pacific Islander
   Black, Non-Hispanic
   Hispanic
   Native American (American Indian)
   White, Non-Hispanic
   Mixed, biracial
   Other ____

4. Current height

   Feet ____
   Inches ____

5. Current weight (estimate if unsure)

Pounds ____

6. Which of the following best reflects your weight goal?

I would like to lose weight (if so, how many lbs?)
____
I would like to gain weight (if so, how many lbs?)
____
I would like to maintain my current weight.

7. Are you currently dieting to lose weight or to avoid gaining weight?

To lose weight
To avoid gaining weight
I am not dieting

8. Which of these statements best describe what has happened to your weight during the past 6 months?

My weight has stayed about the same
I've been losing weight
I've been gaining weight
My weight has fluctuated a lot

9. In the past six months, were you active in a formal weight loss program (e.g., Weight Watchers, Profile by Sanford)?

Yes
No

10. Are you currently using any medication to assist with weight loss?

Yes
No

11. Do you have any medical conditions that affects your weight or dietary intake? Check all that apply:

Thyroid Condition
Insulin dependent diabetes
Non-insulin dependent diabetes
Celiac disease
Other ____
None - I have no medical conditions that affect my weight or diet.

12. Do you have a history of bariatric surgery

Yes
No

13. Are you currently pregnant or did you give birth in the past three months?

Yes
No

14. Are you currently breast feeding?

Yes
No

15. Please list any food allergies or foods you will not eat. Leave blank if there are none.

____

16. Do you currently smoke cigarettes?

Yes
No

17. Have you quit smoking cigarettes within the past year?

Yes
No

18. Do you have daily access to a computer (laptop, desktop, or chromebook) with internet access?

Yes
No

19. Do you have daily access to a body weight scale?

Yes
No

20. If you do not have access to a personal scale, could you find a scale to measure your body weight at three timepoints (this week, in 5 weeks, in 6 months)?

Yes
No

21. If you cannot access a scale, would you use a scale on campus if it was made available to you?

Yes
No

23. How did you learn about this study?

University of Minnesota – Crookston

University of Minnesota – Duluth

University of Minnesota – Mankato

University of Minnesota – Morris

The college of St. Scholastica

Alexandria Technical College

Friend/ Family member

In order for researchers to connect your data with your other measurements and to assign you to an intervention group, you will need to include your name. Your name will later be removed from the database and replaced with a study ID#.

Name (First) ____
Name (Last) ____

Please provide your email address in the space below. If you meet the eligibility criteria for the study, you will be contacted to schedule an appointment with the researcher.

Post-intervention Questions

Introduction:

This questionnaire contains items that are related to your eating and health habits. Please answer all questions as honestly as possible. There are no right or wrong answers.

Thank you for your time and continued interest in the study.

The following questions relate to your experience with the computerized training over the four week intervention period. Please answer each question honestly. There are no right or wrong answers.

1. How did you find the computer training task? (Easy/hard/interesting/boring)?

____

2. In the computer task did you notice anything in particular? For example, did you notice anything about when you had to not press a key?

____

3. Did you think that the stop signals (bold lines) were distributed evenly between all the images? If not, what kind of pictures do you think were associated with the stopping response?

____

4. Do you think that the task influenced your snacking behavior or frequency?

____

5. Did you experience any problems accessing and/or interacting with the training task online?

____

6. Were the instructions clear and easy to follow throughout?

____

7. Would you be prepared to continue doing this kind of computerized training intervention for a longer period of time? (if possible estimate how long for / how frequently would you do it?)

____

8. Did you intentionally alter your eating or exercise routine in anyway (either at the beginning of the training or at some point throughout the training)? If so, please explain.

____

Measures

Introduction:

The following questionnaires contain items that are related to your eating and health habits. Please answer all questions as honestly as possible. There are no right or wrong answers.

Food Frequency Questionnaire

Please indicate how frequently you eat the following foods using the scale below.

	4 times or more 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
Ice-Cream								
Chips								
Candy								
Cakes/pies								
Chocolate								
Cookies								
Pastries/donuts								
Fruits								
Vegetables								

Three Factor Eating Questionnaire - Disinhibition (TFEQ-D)

Please answer the following questions by selecting either True or False.

1. When I smell a sizzling steak or see a juicy piece of meat, I find it very difficult to keep from eating, even if I have just finished a meal.

○ True

○ False

2. I usually eat too much at social occasions, like parties and picnics.

○ True

○ False

3. Sometimes things just taste so good that I keep on eating even when I am no longer hungry.

   ○ True

   ○ False

4. When I feel anxious, I find myself eating.

   ○ True

   ○ False

5. Since my weight goes up and down, I have gone on reducing diets more than once.

   ○ True

   ○ False

6. When I am with someone who is overeating, I usually overeat too.

   ○ True

   ○ False

7. Sometimes when I start eating, I just can't seem to stop.

   ○ True

   ○ False

8. It is not difficult for me to leave something on my plate.

   ○ True

   ○ False

9. When I feel blue, I often overeat.

   ○ True

   ○ False

10. My weight has hardly changed at all in the last ten years.

   ○ True

   ○ False

11. When I feel lonely, I console myself by eating.

   ○ True

   ○ False

12. Without even thinking about it, I take a long time to eat.

- ○ True
- ○ False

13. While on a diet, if I eat a food that is not allowed, I often then splurge and eat other high calorie foods.

- ○ True
- ○ False

Please answer the following questions by selecting the response that is most appropriate to you.

14. Do you eat sensibly in front of others and splurge alone?

- ○ never
- ○ rarely
- ○ often
- ○ always

15. Do you go on eating binges though you are not hungry?

- ○ never
- ○ rarely
- ○ sometimes
- ○ at least once a week

16. To what extent does this statement describe your eating behavior? "I start dieting in the morning, but because of any number of things that happen during the day, by evening I have given up and eat what I want, promising yourself to start dieting again tomorrow."

- ○ not like me
- ○ little like me
- ○ pretty good description of me
- ○ describes me perfectly

EDEQ: Binge Eating

Over the past 28 days, how many times have you eaten what most people would regard as an unusually large amount of food (given the circumstances)? __________

On how many of these times did you have a sense of having lost control over your eating (at the time that you were eating)? __________

Over the past 28 days, on how many days have such episodes of overeating occurred (i.e., you have eaten an unusually large amount of food and have had a sense of loss of control at the time)? __________

Dutch Eating Behavior Questionnaire – Restraint (DEBQ-R)

Please indicate the extent to which you agree that the following items describe you. Use the following 1-5 scale for your responses.

	Never 1	Seldom 2	Sometimes 3	Often 4	Very Often 5
If you have put on weight, do you eat less than you usually do?					
Do you try to eat less at mealtimes than you would like to eat?					
How often do you refuse food or drink offered because you are concerned about your weight?					
Do you watch exactly what you eat?					
Do you deliberately eat foods that are slimming?					
When you have eaten too much, do you eat less than usual the following days?					
Do you deliberately eat less in order not to become heavier?					
How often do you try not to eat between meals because you are watching your weight?					
How often in the evening do you try not to eat because you are watching your weight?					
Do you take into account your weight with what you eat?					

Power of Food Scale

Please indicate the extent to which you agree that the following items describe you. Use the following 1-5 scale for your responses.

	Don't agree at all 1	Agree a little 2	Agree somewhat 3	Agree 4	Strongly agree 5
I find myself thinking about food even when I'm not physically hungry.	○	○	○	○	○
When I'm in a situation where delicious foods are present but I have to wait to eat them, it is very difficult for me to wait.	○	○	○	○	○
I get more pleasure from eating than I do from almost anything else.	○	○	○	○	○
I feel that food is to me like liquor is to an alcoholic.	○	○	○	○	○
If I see or smell a food I like, I get a powerful urge to have some.	○	○	○	○	○
When I'm around a fattening food I love, it's hard to stop myself from at least tasting it.	○	○	○	○	○
I often think about what foods I might eat later in the day.	○	○	○	○	○
It's scary to think of the power that food has over me.	○	○	○	○	○
When I taste a favorite food, I feel intense pleasure.	○	○	○	○	○
When I know a delicious food is available, I can't help myself from thinking about having some.	○	○	○	○	○
I love the taste of certain foods so much that I can't avoid eating them even if they're bad for me.	○	○	○	○	○
When I see delicious foods in advertisements or commercials, it makes me want to eat.	○	○	○	○	○
I feel like food controls me rather than the other way around.	○	○	○	○	○
Just before I taste a favorite food, I feel intense anticipation.	○	○	○	○	○
When I eat delicious food I focus a lot on how good it tastes.	○	○	○	○	○
Sometimes, when I'm doing everyday activities, I get an urge to eat "out of the blue" (for no apparent reason).	○	○	○	○	○
I think I enjoy eating a lot more than most other people.	○	○	○	○	○
Hearing someone describe a great meal makes me really want to have something to eat.	○	○	○	○	○
It seems like I have food on my mind a lot.	○	○	○	○	○
It's very important to me that the foods I eat are as delicious as possible.	○	○	○	○	○
Before I eat a favorite food my mouth tends to flood with saliva.	○	○	○	○	○

Restraint Scale (RS)

1. How often are you dieting?

- never
- rarely
- sometimes
- often
- always

2. What is the maximum amount of weight (in pounds) that you have ever lost within one month?

- 0-4
- 5-9
- 10-14
- 15-19
- 20+

3. What is your maximum weight gain within a week?

- 0-1
- 1.1-2
- 2.1-3
- 3.1-5
- 5.1+

4. In a typical week, how much does your weight fluctuate?

- 0-1
- 1.1-2
- 2.1-3
- 3.1-5
- 5.1+

5. Would a weight fluctuation of 5 pounds affect the way you live your life?

- ○ Not at all
- ○ slightly
- ○ moderate
- ○ very much

6. Do you give too much time and thought to food?

- ○ never
- ○ rarely
- ○ often
- ○ always

7. Do you have feelings of guilt after overeating?

- ○ never
- ○ rarely
- ○ often
- ○ always

8. How conscious are you of what you are eating?

- ○ not at all
- ○ slightly
- ○ moderately
- ○ extremely

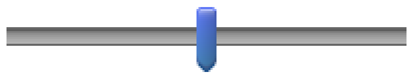
9. How many pounds over your desired weight were you at your maximum weight?

- ○ 0-1
- ○ 1-5
- ○ 6-10
- ○ 11-20
- ○ 20+

Food Evaluation Scale

Please indicate your response to the following questions by moving the cursor on the scale toward the left or the right.

How much do you like the taste of this?

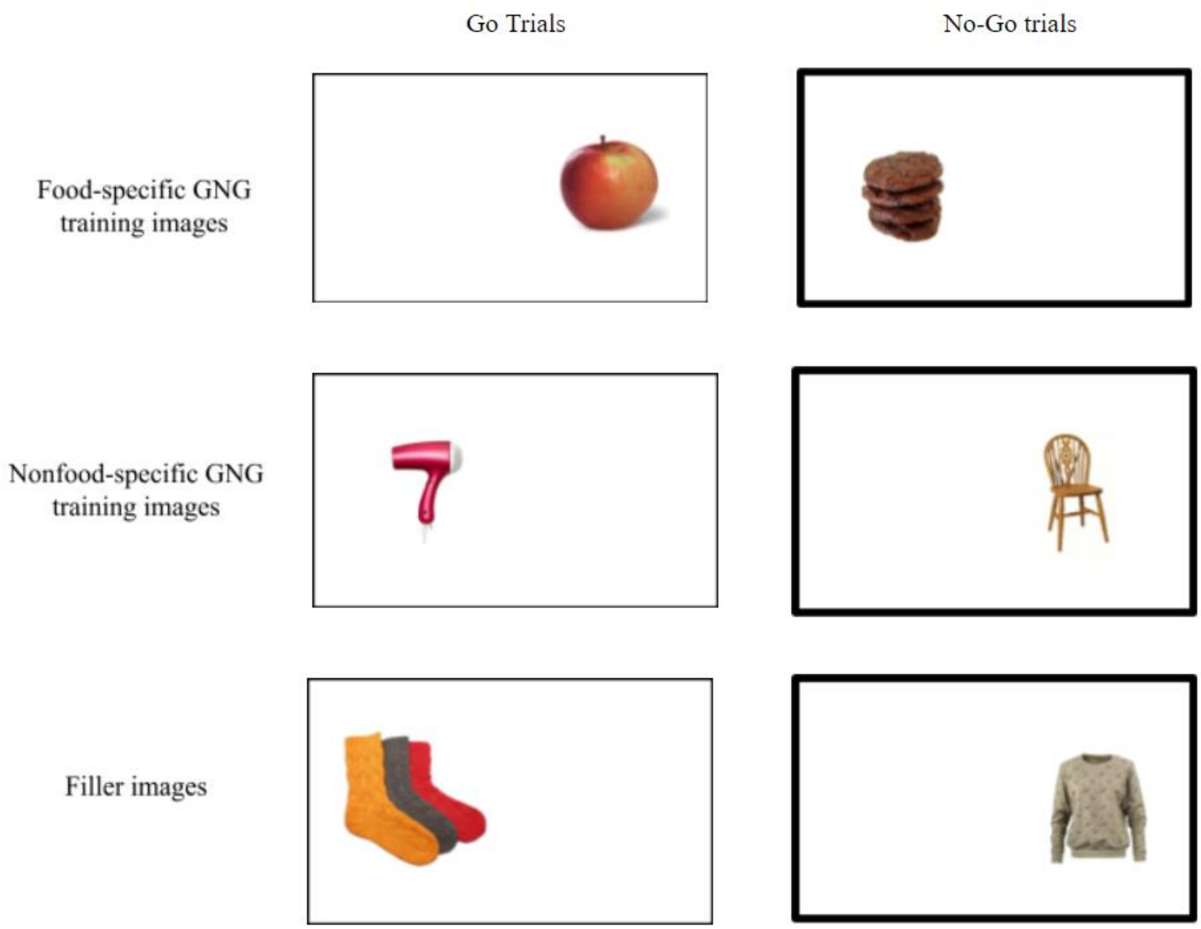


not at all **very much**

*This question presented as an individual question for all of the food evaluation images:

Appendix B

GNG Training Examples

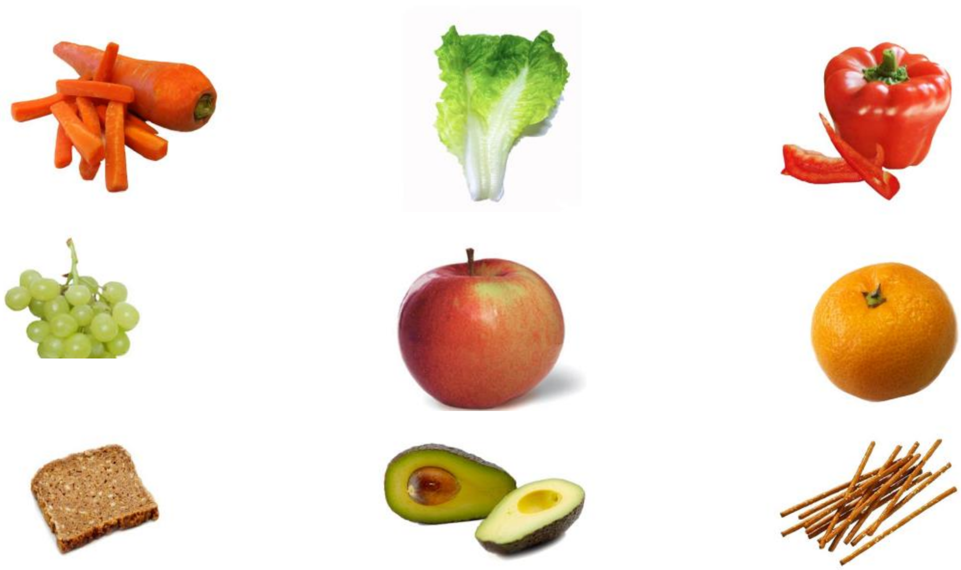


Note. Example "go" (non-bolded frame) and "no-go" (bolded frame) trials of both food and nonfood-specific items. Healthy foods were paired with go 100% of the time, unhealthy foods were paired with no-go 100% of the time, and all filler clothing images were paired with go and no-go cues equally in both GNG trainings.

Appendix C

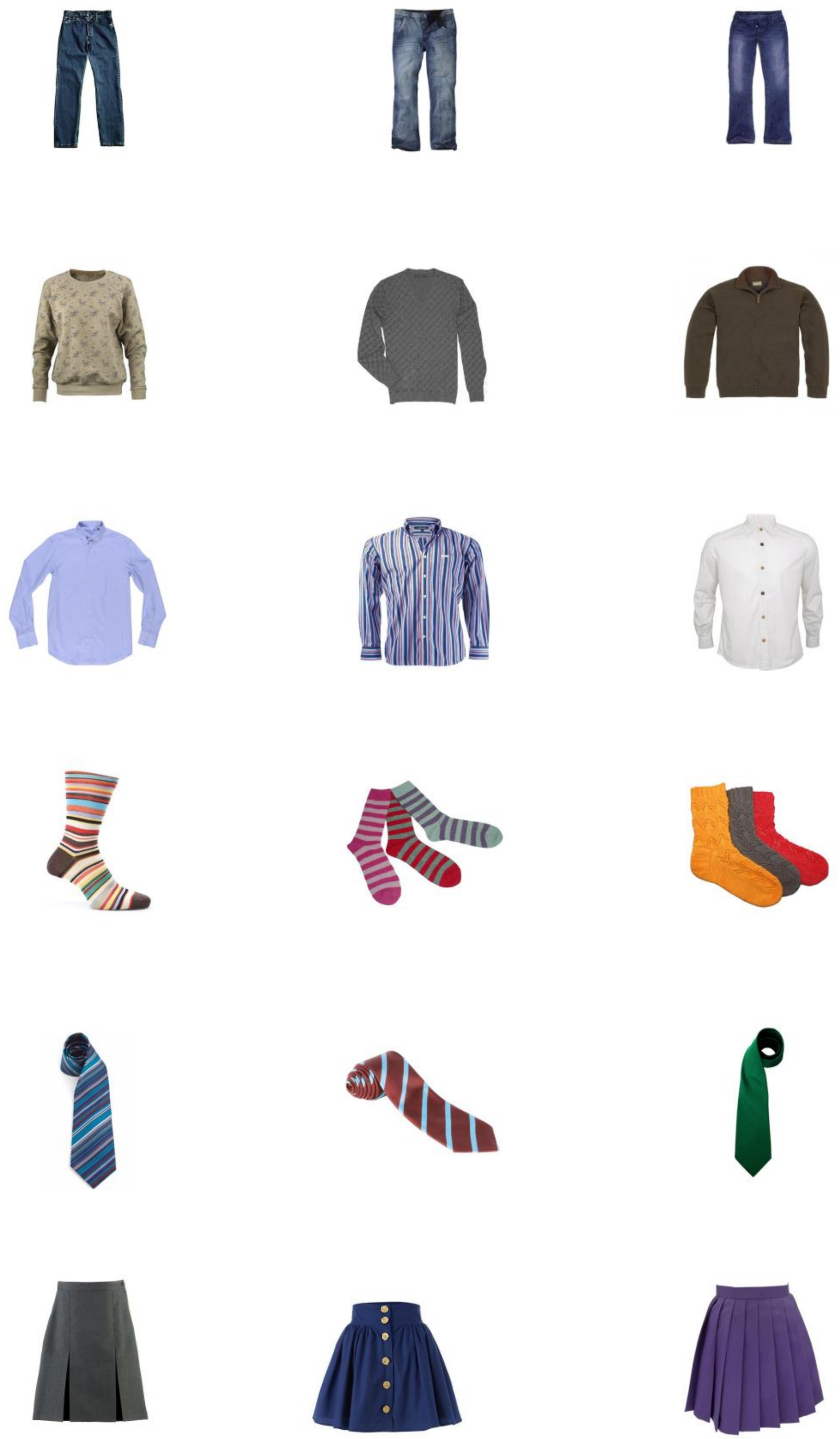
Images

Intervention Group go Healthy Food Images



Intervention Group no-go Unhealthy Food Images

Neutral Images



Control Group go Images

Control Group no-go Images

Appendix D

Food Evaluation Images