Two inhibitory control training interventions designed to improve eating behaviour and determine mechanisms of change

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Highlights

- Testing the effect of Stop-Signal training on eating behaviour and self-regulation
- Training did not change eating behaviour outside the laboratory
- Improvements in resistance to depletion and inhibitory contro
- l were not maintained
- This particular training may not be intense enough to influence eating behaviour
- Improvements in self-regulation may only persist insofar as training does

Abstract

Inhibitory control training has been shown to influence eating behaviour in the laboratory; however, the reliability of these effects is not yet established outside the laboratory, nor are the mechanisms responsible for change in behaviour. Two online Stop-Signal Task training interventions were conducted to address these points. In Study 1, 72 participants completed baseline and follow-up measures of inhibitory control, self-regulatory depletion, fat intake and body-mass index. Participants were randomly assigned to complete one of three Stop-Signal Tasks daily for ten days: *food-specific inhibition*- inhibition in response to unhealthy food stimuli only, *general inhibition*- inhibition was not contingent on type of stimuli, and *control*- no inhibition. While fat intake did not decrease, body-mass index decreased in the food-specific condition and change in this outcome was mediated by changes in vulnerability to depletion. In Study 2, the reliability and longevity of these effects were tested by replicating the intervention with a third measurement time-point. Seventy participants completed baseline, post-intervention and follow-up measures. While inhibitory control and vulnerability to depletion improved in both training conditions post-intervention, eating behaviour and body-mass index did not. Further, improvements in self-regulatory outcomes were not maintained at follow-up. It appears that while the training paradigm employed in the current studies may improve self-regulatory outcomes, it may not necessarily improve health outcomes. It is suggested that this may be due to the task parameters, and that a training paradigm that utilises a higher proportion of stop-signals may be necessary to change behaviour. In addition, improvements in self-regulation do not appear to persist over time. These findings further current conceptualisations of the nature of self-regulation and have implications for the efficacy of online interventions designed to improve eating behaviour.

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The prevalence of overweight and obesity is increasing (Colagiuri et al., 2010; Flegal, Carroll, Ogden, & Curtin, 2010). Although the current food-rich environment, in which unhealthy choices are readily available, may make achieving and maintaining the goal of healthy eating difficult (Stroebe, 2008; Wansink, 2004), some individuals are able to resist high calorie foods and maintain a healthy diet and weight. Research suggests that inhibitory control may be one important factor implicated in the regulation of eating behaviour (Hofmann, Friese, & Roefs, 2009; Houben & Wiers, 2009).

Inhibitory control refers to the ability to overrule impulsive reactions in order to regulate behaviour in line with long-term goals (Miyake et al., 2000). In the case of eating behaviour, this may involve resisting the impulse to eat high-calorie food in order to meet the goal of adhering to a healthy diet. Individual differences in measures said to assess inhibitory control such as the Go/No-Go Task (GNG; Miller, Schäffer, & Hackley, 1991) and the Stop-Signal Task (SST; Logan, Schachar, & Tannock, 1997) consistently predict eating behaviours (Allom & Mullan, 2014; Hall, 2012; Hofmann et al., 2009), as well as weight gain (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010), among non-clinical participants. Further, inhibitory control can be undermined leading to greater consumption of high calorie foods (Hofmann, Rauch, & Gawronski, 2007; Vohs & Heatherton, 2000). This effect, termed depletion, derives from the strength model of self-regulation (Baumeister, Vohs, & Tice, 2007), in which self-regulation is assumed to rely on a limited resource. Goal directed behaviours are rarely performed in isolation, or without the influence of external stressors- two factors which lead to depletion and compromise the capacity to enact goal directed behaviour (Hagger, Wood, Stiff, & Chatzisarantis, 2009). Therefore, in order to achieve the goal of healthy eating, both inhibitory control and resistance to depletion are necessary.

Current research suggests that inhibitory control training can influence eating behaviour using both GNG and SST paradigms (Lawrence, Verbruggen, Morrison, Adams, & Chambers, 2015; Veling, van Koningsbruggen, Aarts, & Stroebe, 2014). In GNG training paradigms, participants are required to respond as rapidly as possible to a neutral set of stimuli while always withholding responses to a set of stimuli representing the target behaviour (Veling, Aarts, & Papies, 2011; Veling, Aarts, & Stroebe, 2013). Consistent pairings of the no-go response with target stimuli facilitates the retrieval of no-go-target stimuli associations and results in improved inhibition of responses to target stimuli (Spierer, Chavan, & Manuel, 2013). SST training paradigms differ from GNG as participants are instructed to respond as rapidly as possible to both target stimuli and neutral stimuli and only inhibit responses to target stimuli on a proportion of trials (Jones & Field, 2013; Lawrence et al., 2015). Improvement in behaviour is typically assessed using a between-participants design wherein participants who are randomly assigned to receive inhibitory control training consume or select less unhealthy foods in an immediately administered laboratory-based task, compared to those assigned to an inert or alternative form of training (Houben, 2011; Veling et al., 2011).

To date, only one study has assessed *change* in ecologically valid health outcomes as a result of inhibitory control training (Veling et al., 2014). This study demonstrated that four sessions of GNG training resulted in decreased BMI. However, underlying mechanisms responsible for change in health outcomes were not directly tested. As described above, the two training paradigms differ in that in the GNG, the go response is consistently inhibited for all members of a certain category, while in the SST the ‘go’ response does not need to be inhibited for all members of a certain category, only for a certain proportion. Therefore, it is suggested that the effectiveness of these paradigms may differ, and the mechanisms by which they influence health behaviour may also differ. Preliminary evidence suggests that GNG training results in the devaluation of unhealthy food stimuli and that this is responsible for differences in eating behaviour (van Koningsbruggen, Veling, Stroebe, & Aarts, 2013). While no direct evidence exists as to what mechanism of change underlies SST training, Jones and Field (2013) demonstrated that alcohol-specific SST training led to a reduction in inhibition errors to alcohol stimuli across training blocks, which may suggest that SST training improves health behaviour by increasing inhibitory control. Nevertheless, this assumption was not directly tested as no additional measure of inhibitory control was included, thus this result may have been due to a practice effect. Therefore, not only is there is a need to examine whether SST training produces changes in ecologically valid eating behaviour outcomes, but to also examine the mechanisms that underlie the effect of training.

It is proposed that SST training may not only influence eating behaviour by improving inhibitory control, but also by decreasing vulnerability to depletion. Vulnerability to depletion has been shown to decrease after behaviour regulation training (Muraven, 2010), which involves regulating an element of behaviour that is unrelated to the target behaviour, such as speech, posture, or mood, for a period time in order to improve self-regulation and consequently health behaviour (Muraven, Baumeister, & Tice, 1999; Oaten & Cheng, 2006b). For example, Oaten and Cheng (2006a) demonstrated that reductions in depletion effects after training resulted in improvement in a variety of self-reported health behaviours, including improvements in healthy eating. Therefore, it may be worthwhile to examine whether inhibitory control training not only improves inhibitory control capacity but also decreases vulnerability to depletion, and to examine whether changes in these elements of self-regulation account for changes in eating behaviour.

Present research

Therefore, the aim of the present research was to improve self-reported eating behaviour through online SST training and to test two potential mechanisms by which this particular version of SST training may improve health behaviour, by examining the extent to which training effects can be attributed to improvements in inhibitory control and/or a decreased vulnerability to depletion. In order to achieve these aims a SST with 25% stop-signal trials was employed, and three conditions, each with a different version of the SST, were included: (1) *food-specific inhibition* condition in which the stop-signals were paired only with unhealthy food stimuli, (2) *general inhibition* condition in which the same stimuli and proportion of stop-signals were used; however, the stop-signals were not contingent on a particular category of stimuli, and (3) *control* condition that included the same stimuli as other conditions but without stop-signals. This final condition was included in order to determine whether general inhibition training was sufficient enough to change behaviour. The stop-signal density was kept at 25% of trials in order to ensure that the training was influencing inhibitory control, or the ability to cancel a response, rather than devaluating the stimuli associated with the stop response, as is proposed to be the case with GNG training in which a stop response is always paired with the target stimuli (Schachar et al., 2007).

It was hypothesised that inhibitory control and vulnerability to depletion would improve in both training conditions compared to the control; however, greater improvement in eating behaviour was expected in the food-specific inhibition condition as inhibition training was targeted to this behaviour. Finally, it was expected that changes in inhibitory control and changes in vulnerability to depletion would mediate the effect of food-specific inhibition training on changes in eating behaviour. Study 1 reports a preliminary investigation into the effect of training on health and self-regulatory outcomes, while Study 2 reports a replication of the training intervention with an additional measurement point in order to test the reliability and longevity of any training effects observed in Study 1.

Study 1

Method

Participants

Eighty-two undergraduate students from a variety of disciplines (age = 20.43 years, *SD* = 4.86; BMI = 22.62, *SD* = 2.64; 66 females) were recruited to participate in a study in exchange for course credit. The number of participants recruited was based on an a-prior power analysis using G-Power 3 software (Faul, Erdfelder, Lang, & Buchner, 2007), which indicated that a sample size of 69 would be sufficient to detect a small to medium (0.15) interaction effect between three conditions at two time points with a power of .80 and an alpha of .05.

Inclusion criteria included having the intention to change dietary behaviour, not colour blind, fluent in English, and having access to the internet. Additionally, participants were excluded if they indicated that they had a current or prior eating disorder diagnosis. Participants were randomly allocated to one of three conditions: *food-specific inhibition* (*n* = 29), *general inhibition* (*n* = 25), and *control* (*n* = 28) by clicking a URL, which randomly directed them to one of three pages. The university's human research ethics committee approved the study and participants provided informed consent prior to participation.

Materials and measures

BMI & saturated fat intake. BMI was calculated from participants' self-reported height and weight. Saturated fat intake in grams was calculated from responses on the Block food screener (Block, Gillespie, Rosenbaum, & Jenson, 2000), which has been validated against a 100-item food frequency questionnaire (Block et al., 2000). Participants indicated how often they ate 17 meat and snack items (e.g. bacon, full-fat ice-cream, fried potatoes) on a 5 point scale ranging from: never (0), to 5 or more times per week (4).

Stroop interference task. Change in inhibitory control capacity was assessed using the computerised version of the Stroop, in which participants were required to name the colour in which a written colour word is printed while inhibiting the tendency to read the word itself. For example, when the word ‘red’ is printed in blue, the tendency to respond ‘red’ must be inhibited in order to provide the correct response of ‘blue’. The task consisted of three types of trials presented in three experimental blocks of 60 trials each and one practice block of 20 trials. *Congruent trials* consisted of colour words that were printed in the corresponding colour. In *incongruent trials*, the colour of the colour word was different to the word itself. *Control trials* consisted of strings of letters matched in length to the colour words. Stimuli were displayed until the participant responded, and the response-stimulus interval was 500ms. The Stroop interference score was calculated as the difference between mean response time of correct responses on incongruent trials and control trials (MacLeod, 2005), where a larger score indicated poorer inhibitory control. Response times that fell three standard deviations above or below a participant’s mean reaction time per block were deemed to be outliers and were deleted (MacLeod, 2005).

Depletion task. Participants were asked to write about what they had done over the weekend for five minutes with the instructions not to use two common letters, namely, a or n. This task has been used in previous research to induce depletion (Lewandowski, Ciarocco, Pettenato, & Stephan, 2012; Schmeichel, 2007). Participants also completed a four item questionnaire measuring their perceptions regarding the depletion task (Muraven & Slessareva, 2003), including how difficult and unpleasant (1 = extremely easy/pleasant – 7 = extremely difficult/unpleasant), and frustrating (1 = not at all frustrating – 5 = extremely frustrating), the depletion task had been for them. In addition, participants indicated how much effort the task required: “How much were you fighting against an urge while working on the task?” (1 = not at all – 5 = extremely), and written responses were reviewed to ensure that participants had completed the task correctly. Depletion was calculated as the difference between Stroop interference before and after the depletion task, where a larger score indicated greater vulnerability to depletion.

Stop-signal task. The current study utilised three versions of the SST with cues, which included three experimental blocks of 64 trials and a practice block of 32 trials. In all versions, each trial began with a fixation cross (+) presented in the centre of the screen for 500ms, followed by a picture of either an unhealthy food or a healthy food. All conditions were exposed to the same number of unhealthy and healthy food stimuli (50% unhealthy, 50% healthy). Participants in all conditions were required to categorise the content of the picture by pressing the “D” key for an unhealthy food picture or the “K” key for a healthy food picture, which was counterbalanced across participants. For the two training conditions, on 25% of trials an auditory tone occurred after a delay which signified that participants should inhibit their response on that trial and wait for the next trial. The stop-signal delay (SSD) was initially set at 250ms and was adjusted dynamically according to participants’ responses using a staircase tracking procedure: When inhibition was successful, SSD increased by 50ms; when inhibition was unsuccessful, SSD decreased by 50ms. On stop-signal trials, responses within the 1500ms timeout period were classed as inhibition errors (Verbruggen, Logan, & Stevens, 2008).

For the *food-specific inhibition* condition, the stop-signal was only presented after unhealthy food images. Therefore, each block consisted of 16 unhealthy food-stop trials, 16 unhealthy food go-trials, 0 healthy food-stop trials and 32 healthy food-go trials. For the *general inhibition* condition, the stop-signal was randomly presented either after a healthy or an unhealthy food image. Therefore, each block consisted of 8 unhealthy food-stop trials, 24 unhealthy food-go trials, 8 healthy food-stop trials and 24 healthy food-go trials. For the *control* condition, participants performed the same task as the other conditions; however, no stop-signals were presented. If participants in either training condition inhibited their responses less than 50% of the time on inhibition trials this was an indication that they were not responding to the stop-signal correctly and thus that session was not included as a training session. Similarly, if participants inhibited their responses more than 50% of the time, this was not counted as a training session and was excluded (Verbruggen et al., 2008).

Stimuli consisted of eight colour pictures of both sweet and savoury unhealthy foods (e.g., potato chips, chocolate) and eight colour pictures of fruit and vegetables (e.g., apple, carrot) displayed on a white background and were approximately 450 by 400 pixels in size. The stimuli were comparable to those used in previous research on eating behaviour and impulsive responses (Veling et al., 2013), and those represented in the Block food screener.

Procedure

The study was conducted entirely online over 12 days. Once participants had signed up to the study, and provided informed consent, they completed the pre-intervention measures in the following order: Stroop task, depletion task, Stroop task, the Block food screener, and reported their height and weight. Finally, participants completed demographic measures and the questionnaire measuring their perceptions of the depletion task. On Days 2 – 11, participants completed one of three SST, depending upon the condition to which they had been randomly assigned. Finally, on Day 12 participants completed the same measures as Day 1, with the exception of height, and demographic measures.

Data analyses

In order to confirm that randomisation was successful the three experimental conditions were compared with respect to scores on age, BMI, Stroop interference, vulnerability to depletion, and saturated fat intake using a one-way analysis of variance (ANOVA), while a chi-squared analysis was utilised to assess sex differences between conditions. Similarly, one-way ANOVAs were used to determine differences on all variables, including condition, between those who completed the study and those who dropped out, with the exception of sex where a Fisher's Exact Test was used. To ensure that the depletion task influenced participants' self-regulatory resources, pre-intervention Stroop interference scores were compared pre- to post- depletion across all conditions using a paired samples *t*-test. To assess the effect of training on Stroop performance and vulnerability to depletion two 2(time: pre-intervention; Day 1, post-intervention; Day 12) by 3(condition: food-specific inhibition, general inhibition, control) mixed ANOVAs were conducted. If a significant time by condition interaction was detected, planned contrasts examining whether change in self-regulatory outcomes experienced by the training conditions differed from that experienced by the control, as well as whether the two training conditions differed from each other. Similarly, to assess the effect of training on saturated fat intake, a 2 x 3 mixed ANOVA was conducted; with planned contrasts examining whether change experienced by the food-specific condition differed to that experienced by the general inhibition and control conditions, as well as whether the two training conditions differed from each other. Finally, bootstrapping techniques for simple mediation (Hayes, 2012), were utilised to test whether changes in either inhibitory control or vulnerability to depletion mediated the effect of food-specific training related changes in saturated fat intake.

Results

Randomisation check

There were no significant differences in any tested variables between conditions, all $p > .05$. Additionally, the number of SSTs performed did not differ between conditions, $p > .05$.

Attrition

Ten participants did not complete post-intervention measures (food-specific inhibition: $n = 3$, general inhibition: $n = 4$, control: $n = 3$). Three participants dropped out of the study and seven did not sufficiently engage with all tasks. There were no differences between those who completed the study and those who did not on any tested variables all, $p > .05$.

Depletion

Participants' performance on the Stroop task was significantly poorer following the depletion task, $MD = -107.870$, $SE = 8.531$; $t(81) = -12.644$, $p < .001$. Additionally, on average participants reported the task as difficult, $M = 6.27$, $SD = 0.92$, unpleasant, $M = 5.12$, $SD = 1.29$, frustrating, $M = 3.61$, $SD = 1.24$, and effortful, $M = 3.35$, $SD = 1.07$.

Training effects

Inhibitory control. There was a significant main effect of time indicating that all conditions improved on Stroop performance post-intervention, $F(1, 69) = 4.635$, $p = .035$, partial eta^2 = .063. There was no main effect of condition, nor was the time by condition interaction effect significant, all $p > .05$. See Table 1 for pre- and post- intervention means and standard deviation of all test variables.

INSERT TABLE 1 NEAR HERE

Vulnerability to depletion. A comparison of pre- and post- intervention depletion scores revealed a significant main effect of time such that all conditions were less vulnerable to depletion post-intervention, $F(1, 69) = 15.097$, $p < .001$, partial eta^2 = .180, which was qualified by a significant time by condition interaction effect, $F(2, 69) = 3.781$, $p = .028$, partial eta^2 = .099; see Figure 1. A planned contrast examining the significant interaction revealed that both training conditions experienced improvement in vulnerability to depletion, compared to the control condition, $\psi = 55.146$, $F(1,69) = 6.377$, $p = .014$. Further, improvement in the food-specific inhibition condition did not differ significantly from the general inhibition condition, ψ = 23.953, $F(1,69) = .8599$, $p = .357$. There was no main effect of condition on depletion, $p > .05$.

INSERT FIGURE 1 NEAR HERE

Saturated fat intake. There was no main effect of condition, time, nor was the time by condition interaction effect significant, all $p > .05$.

BMI. There was a significant main effect of time on BMI such that all conditions decreased in BMI post-depletion, $F(1, 69) = 10.048$, $p = .002$, partial $eta^2 = .127$, which was qualified by a significant time by condition interaction effect, $F(2, 69) = 5.086$, $p = .009$, partial $eta^2 = .128$, see Figure 2. A planned contrast examining the significant interaction revealed that BMI decreased in the food-specific inhibition condition post-intervention, while BMI did not change in the general inhibition condition and the control, ψ = .354, $F(1,69) = 10.171$, $p = .002$. Additionally, a contrast comparing change in BMI in the food-specific inhibition condition to the general inhibition condition revealed that BMI decreased more in the food-specific inhibition condition compared to the general inhibition condition, ψ = .365, $F(1,69) = 7.53$, $p = .008$. There was no main effect of condition, $p > .05$.

INSERT FIGURE 2 NEAR HERE

Mediation analysis. As there were no changes in saturated fat intake the original mediation analysis was not conducted. However, the indirect effect of food-specific inhibition training on BMI through vulnerability to depletion was tested. In order to conduct this analysis, the general inhibition condition was grouped with the control condition and compared to the food-specific inhibition condition. Change in vulnerability to depletion and change in BMI variables were created by subtracting post-intervention scores from pre-intervention scores. The significance of the indirect effect was assessed using 95% confidence intervals, calculated using 5000 bootstrap re-samples (Hayes, 2012). The indirect effect from food-specific training, through change in vulnerability to depletion, to change in

BMI was significant, β = 0.071, 95% [CI: 0.01, 0.20]. The R^2 mediation effect size was .0527; *SE* = .0386, indicating that 5.27% of the variance in change in BMI was explained by the mediating effect of change in vulnerability to depletion on the type of training effect, see Figure 3 for standardised coefficients between all variables.

INSERT FIGURE 3 NEAR HERE

Discussion

As expected, both training conditions demonstrated a decrease in vulnerability to depletion, and within the food-specific training condition; changes in vulnerability to depletion mediated changes in BMI. However, food-specific training did not result in changes in saturated fat intake, nor did type of training influence inhibitory control.

It is possible that training did not differentially influence inhibitory control capacity as Stroop interference is not reflecting the same specific inhibitory control mechanism that SST training is influencing. However, given that previous research has shown there to be overlap between the two tasks (Allom & Mullan, 2014; Miyake et al., 2000; Verbruggen, Liefooghe, & Vandierendonck, 2004), it is unlikely that these measures are wholly independent. While the Stroop procedure used in the current study has been frequently used in previous research (Cassiday, McNally, & Zeitlin, 1992; Formea & Burns, 1996; McNally, Riemann, & Kim, 1990), it may be that not enough practice trials were used. A sufficient number of practice trials is essential in order to acclimatise participants to the display and response characteristics of the task so that response times are based on interference rather than the novelty of the task (MacLeod, 2005).

Despite this, the present results indicated a significant change in vulnerability to depletion in the training conditions. These results are similar to Muraven et al. (1999), who found that behavioural regulation training results in reduced depletion. Similarly, Oaten and Cheng (2007) found that after four months of engaging in financial monitoring participants were not only less vulnerable to depletion but also reported engaging in more health enhancing behaviours. In contrast, within the current study this improvement only transferred to change in BMI in the food-specific condition, suggesting that behavioural specificity of the task, coupled with decrease in vulnerability to depletion may be necessary to change behaviour. Alternatively, it may be that more intense training is required for improvements to translate across behavioural domains. Further research is required to determine the optimal intensity and length of training required to achieve such transfer effects.

SST training did not appear to alter self-reported eating behaviour. Previous research using the SST to influence eating behaviour has demonstrated differences between training and control conditions in the amount consumed in a taste test (Lawrence et al., 2015). Future research should compare both laboratory-based measures of eating behaviour and other measures to ascertain the external validity of SST training. Despite the null result for saturated fat intake, SST training did result in a small but significant decrease in BMI amongst the participants in the food-specific condition. This reflects recent findings that GNG task training improves weight loss (Veling et al., 2014) and may indicate that the current training did alter eating behaviour, but the measure used to assess this outcome was not sensitive enough to detect such changes. While food frequency questionnaires in general have been shown to be effective at assessing change in eating behaviour in intervention studies (Kristal, Beresford, & Lazovich, 1994), it is possible that this particular questionnaire was not appropriate. However, it must be noted that the training paradigm used in the current study differed from that used by Houben (2011) and Veling et al. (2014), which may account for the dissimilar results rather than an issue with the instrument used to measure eating behaviour.

Limitations

Insufficient practice trials in the Stroop task may have precluded the observation of changes in inhibitory control. Secondly, using a food frequency questionnaire that does not take into account portion size may not have been sufficient to capture subtle changes in eating behaviour. Finally, these results need to be replicated with objectively measured height and weight, as it may be the case that the change observed in BMI was an artefact of self-report.

Study 2

Study 2 was designed to address these limitations and establish the reliability of the previously observed effects. Namely, by using an objective measure of BMI, increasing the number of practice trials used in the Stroop, and using an alternative measure of eating behaviour. The National Cancer Institute (NCI) percentage energy from fat screener (Thompson et al., 2007) has been validated in intervention studies (Thompson et al., 2008; Williams et al., 2008), finding that the instrument was consistent at two time points with the gold-standard method of assessing dietary behaviour: the 24-hour food recall (Carter, Sharbaugh, & Stapell, 1981). An additional objective was to include follow-up assessments in order to determine whether training gains persist over time.

Method

Participants

Seventy-eight students and staff from a variety of disciplines at an Australian university (age = 22.97 years, *SD* = 5.81; BMI = 23.11, *SD* = 2.56; 61 females) were recruited to participate in a study in exchange for course credit or $20. The number of participants recruited was based on an a-prior power analysis conducted using G-Power software (Faul et al., 2007), which indicated that a sample size of 57 would be sufficient to detect a small to medium (0.15) interaction effect between three conditions at three time points with a power of .80 and an alpha of .05. Inclusion criteria and randomisation did not differ from Study 1. Participants were randomly allocated to the following conditions: *food-specific inhibition* (*n* = 27), *general inhibition* (*n* = 26), and *control* (*n* = 25).

Materials and measures

BMI & fat intake. Participants' height was recorded at Time 1 and weight was measured at each time point on the same set of digital weight scales. Eating behaviour was operationalised as percentage daily fat intake as measured using the 17-item NCI percentage energy from fat screener (Thompson et al., 2007). Participants indicated how often they ate 15 food items (e.g., fruit, sausage or bacon, full fat cheese) on a 6-point scale ranging from 0 to 5: never (0), to 2 or more times per day (5). Additionally, participants were asked to indicate how often they used a reduced-fat butter or margarine when they prepared foods with butter or margarine, on a 6-point scale ranging from 0 to 5: Didn't use butter or margarine (0), to almost always or always (5). Finally, participants were asked to indicate whether they considered their diet to be low, medium, or high in fat. Percentage energy from fat was calculated using scoring algorithms that assign sex- and age- specific median portion sizes in grams to each item and then uses a regression model to estimate the expected intake given the screener responses.

Stroop interference. Inhibitory control capacity was assessed using the same computerised version of the Stroop task as Study 1; however, the number of practice trials was increased from 20 to 50.

Depletion task and Stop-signal task. The depletion task and the three versions of the SST did not differ from Study 1.

Procedure

This was identical to Study 1 with two exceptions. Measurements of all outcomes were conducted in the laboratory and a third measurement time point was included one week after training was completed.

Data analyses

Randomisation checks, drop-out analyses and depletion checks were performed as per Study 1. To assess the effect of training on Stroop performance and vulnerability to depletion two 3(time: pre-intervention, post-intervention, follow-up) by 3(condition: food-specific inhibition, general inhibition, control) mixed ANOVAs were conducted. Overall effects were examined; however, focus was placed on time by condition interactions between two sets of levels of the within-participants factor (pre-intervention versus post-intervention, and pre-intervention versus follow-up). If a significant time by condition interaction was detected for either comparison, planned contrasts examining differences between the two training conditions and the control, and between the two training conditions themselves, were conducted. Similarly, to assess the effect of training on percentage energy from fat and BMI, two 3 x 3 mixed ANOVAs were conducted; with planned contrasts examining pre- to post-intervention, and pre-intervention to follow-up differences between the food-specific inhibition condition and other conditions, and between the training conditions themselves.

Results

Randomisation check

There were no significant differences on measured variables between conditions pre-intervention, all $p > .05$. Additionally, the number of SSTs performed across the training period did not differ between conditions, $p > .05$.

Attrition

Eight participants did not complete post-intervention and follow-up data (food-specific inhibition: *n* = 3, general inhibition: *n* = 3, control: *n* = 2). Five participants dropped out of the study and three did not sufficiently engage with all tasks. All drop-out occurred at the second time point (post-intervention). There were no differences on measures, all $p > .05$, between those who completed the study and those who did not.

Depletion

Participants' performance on the Stroop task was significantly poorer following the depletion task, *MD* = -109.527, *SE* = 15.323; $t(77) = -7.148$, $p < .001$. Additionally, on average participants reported the task as difficult, *M* = 6.28, *SD* = 0.79, unpleasant, *M* = 5.23, *SD* = 1.01, frustrating, *M* = 3.23, *SD* = 0.82, and effortful, *M* = 3.58, *SD* = 0.85.

Training effects

Means and standard deviation of all test variables at pre-intervention, post-intervention, and follow-up are displayed in Table 2.

INSERT TABLE 2 NEAR HERE

Inhibitory control. There was a significant main effect of time indicating that averaged across all conditions, there were differences in Stroop performance according to the three time points, $F(2, 134) = 22.687$, $p < .001$, partial eta^2 = .253. Additionally, there was a significant time by condition interaction, indicating that the differences in Stroop performance according to time were not the same for each condition, $F(4, 134) = 4.489$, $p = .002$, partial eta^2 = .118. There was no main effect of condition, $p > .05$.

A planned contrast examining the significant interaction effect revealed that both training conditions performed better on the Stroop post-intervention compared to the control condition, $\psi = 92.492$, $F(1, 67) = 11.973$, $p = .001$. However, this improvement was not maintained at follow-up as a planned contrast between pre-intervention and follow-up performance did not indicate significant differences between training conditions and the control, $\psi = 9.105$, $F(1,67) = .163$, $p = .688$. Additionally, improvement in performance demonstrated by the food-specific condition from pre- to post- intervention did not differ to that demonstrated by the general training condition, $\psi = 4.358$, $F(1,67) = .020$, $p = .887$, indicating that both forms of SST training improved inhibitory control as measured by the Stroop. The performance of all conditions across all time points is displayed in Figure 4.

INSERT FIGURE 4 NEAR HERE

Vulnerability to depletion. There was a significant main effect of time indicating that averaged across all conditions, there were differences in vulnerability to depletion according to the three time points, $F(2, 134) = 7.765$, $p = .001$, partial eta^2 = .104. Additionally, there was a significant time by condition interaction, indicating that the differences in vulnerability to depletion according to time were not the same for each condition, $F(4, 134) = 2.661$, $p = .035$, partial eta^2 = .074. There was no main effect of condition, $p > .05$.

A planned contrast examining the significant interaction revealed that both training conditions decreased in vulnerability to depletion post-intervention compared to the control condition, $\psi = 76.995$, $F(1, 67) = 8.347$, $p = .001$. However, this improvement was not maintained at follow-up as a planned contrast between pre-intervention and follow-up performance did not indicate significant differences between training conditions and the control, $\psi = 12.181$, $F(1,67) = .195$, $p = .661$. Additionally, the decrease in vulnerability to depletion demonstrated by the food-specific condition from pre- to post- intervention did not differ to that demonstrated by the general training condition, $\psi = .837$, $F(1,67) = .001$, $p = .975$, indicating that both forms of SST training resulted in decreased vulnerability to depletion. The performance of all conditions across all time points is displayed in Figure 5.

INSERT FIGURE 5 NEAR HERE

Percentage energy from fat. There were no effects of time, condition, nor were any time by condition interactions effects significant, all *p* > .05.

BMI. There were no effects of time, condition, nor were any time by condition interactions effects significant, all *p* > .05.

Discussion

The aim of this study was to replicate and address the limitations of Study 1. The results suggested that both forms of training led to improvement in inhibitory control and vulnerability to depletion; however, this improvement did not lead to changes in eating behaviour or BMI. Therefore, the effect of training on vulnerability to depletion was replicated; however, the effect of food-specific training on BMI was not. The results also suggested that these improvements in inhibitory control and vulnerability to depletion did not persist after the training period had ended, suggesting that inhibitory control training may only improve self-regulatory outcomes in the short-term.

The results indicated that both inhibitory control capacity, and vulnerability to depletion improved after both forms of training. This suggests that repeatedly performing a task that requires inhibitory control results in improvements in this capacity and in the ability to exert this capacity after performing another task that requires self-regulation. This is in line with the strength model of self-regulation, which suggests that self-regulation relies on a limited pool of resources that can become depleted in the short-term, but strengthened over time with repeated acts of self-regulation (Baumeister et al., 2007). Additionally, these results reflect previous research that has used self-regulation training to improve self-regulatory outcomes. Specifically, Muraven (2010) demonstrated that participants who were instructed to avoid unhealthy foods for a two week period, or perform a handgrip task daily for two weeks, showed improved performance on an SST compared to control conditions that did not receive training. However, it appears that while modifying eating behaviour leads to improvement in inhibitory control, as measured by the SST, practicing the SST does not lead to changes in eating behaviour. It may be the case that exerting self-regulation in real-life situations requires more control and results in larger effects that are easily detectable on a reaction time measure, whereas practicing an abstract task may be a less intense form of training that does not translate to improvements in everyday behaviour.

The finding that SST training, as employed in the current study, did not result in changes in eating behaviour is unexpected given that research employing other inhibitory control training paradigms has demonstrated an influence on eating behaviour (Houben, 2011; Houben & Jansen, 2011; Veling et al., 2011; Veling et al., 2013). However, the training paradigm adopted in the current studies differs substantially from previous research and therefore may account for the differing results. Firstly, the majority of previous research has utilised a GNG paradigm in which unhealthy food stimuli are always paired with no-go responses, rather than only a proportion of them. Thus, it may be the case that target stimuli have to be consistently paired with a stop response in order to induce change in behaviour. Additionally, Veling et al. (2014) demonstrated weight loss after four 30 minutes sessions of GNG spread across four weeks, using greater variety of stimuli. Thus, training may not have been effective not only due to the low proportion of stop-signals used in the current paradigm, but also the timing of training sessions and lack of variety in the stimuli that were used. It is recommended that future research aiming to replicate these training effects employ a more intense and varied paradigm. Finally, given that the results of Study 2 did not replicate the change in BMI finding of Study 1, we suggest that this finding may have been due to the self-report measurement of BMI.

The observed changes in inhibitory control and vulnerability to depletion in the two training conditions were not maintained at follow-up. Although different training paradigms and behavioural outcomes were measured, these results are similar to that of Verbruggen et al. (2013), who did not find that inhibitory control training produced long-lasting effects. These results appear to indicate that inhibitory control training may only improve self-regulation outcomes in the short-term. While Baumeister and colleagues did not directly hypothesise about the maintenance of improvements in self-regulation (Baumeister et al., 2007; Hagger, Wood, Stiff, & Chatzisarantis, 2010), the muscle metaphor commonly used to conceptualise self-regulation can be extended to account for these effects. Specifically, while exercise can strengthen a muscle, if exercise is not maintained- strength will slowly decline. Similarly, it appears that if training is not continued, self-regulatory capacity may return to initial levels. Future research should attempt to replicate these effects in order to further knowledge regarding the nature of self-regulation.

General Discussion

These studies represent some of the first to assess the efficacy of an SST training paradigm in the improvement of self-reported health behaviour, in order to determine whether training translates into change in everyday behaviour and to directly test potential mechanisms of change. However, there are limitations to these studies that must be acknowledged. Firstly, it may be the case that presenting stop-signals on only 25% of trials with the target stimuli was not intense enough to induce a change in eating behaviour. Research in the field of alcohol consumption demonstrated a change in laboratory based drinking behaviour after SST training with a 50% stop-signal density (Jones & Field, 2013). Further, GNG training, in which all trials that display the target stimuli are ‘no-go’ (i.e. stop) trials, has more consistently resulted in behaviour change (Bowley et al., 2013; Veling et al., 2014). Therefore, a higher density of stop responses associated with the target behaviour may be necessary to induce behaviour change and future research should systematically vary the density of stop-signal trials in order to determine whether this influences the transfer of training to health behaviour. Further, comparing the efficacy of SST training to GNG training, and whether these paradigms influence behaviour via different mechanisms (i.e. inhibitory control versus automatic evaluations) is warranted.

Additionally, previous research has shown that individual difference variables such as dietary restraint (Houben & Jansen, 2011; Veling et al., 2011), and homeostatic variables such as previous food intake and hunger (Loeber, Grosshans, Herpertz, Kiefer, & Herpertz, 2013), influence food cue processing. Future research may benefit from including and controlling for these variables. Additionally, while the stimulus set used in both interventions reflected that used in other inhibitory control training and eating behaviour interventions (Veling et al., 2013), it was not validated for the respective samples. Future research should assess participants' perceptions of the palatability of food items in order to ensure that the selected stimuli are considered palatable by the target sample. Finally, because there was not a control condition in which participants did not receive a depletion task, it is difficult to ascertain whether the vulnerability to depletion measure accurately assessed this construct. However, all participants performed poorer on the Stroop that followed the depletion task, suggesting that this task did in fact induce a depletion effect. Nevertheless, future research attempting to determine whether SST training can improve vulnerability to depletion should include a depletion control condition in order to test this assumption.

Implications

Despite these limitations, the current results have several implications for interventions designed to improve self-regulatory outcomes and eating behaviour. Namely, it appears that this particular inhibitory control training paradigm does not result in changes in everyday eating behaviour. Comparing the current paradigm to that used in previous research, it appears that training needs to be of a certain intensity in order to induce change in health behaviour, such that the proportion of unhealthy food – stop-signal pairings used in the current studies was not intense enough. . Additionally, these results contribute to theoretical explanations regarding the nature of self-regulation. While it has been established that elements of self-regulation can be improved through training (Muraven, 2010), the current results suggest that the benefits of training are only maintained insofar as training is maintained.

Conclusions

The results of two inhibitory control training studies in which the aim was to improve eating behaviour and demonstrate the mechanism by which this improvement occurs were reported. The results of Study 2 did not replicate those of Study 1, such that inhibitory control training in this intervention did not appear to influence health outcomes. However, the results indicated that inhibitory control training does appear to improve inhibitory control, as measured by a related task, and the construct of vulnerability to depletion, but these effects do not appear to persist after training has ceased.

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Table 1

Means and Standard Deviations of All Outcome Variables for Each Condition Pre- and Post- Intervention

	Pre-intervention						Post-intervention					
	Food-specific *n* = 29		General *n* = 25		Control *n* = 28		Food-specific *n* = 26		General *n* = 21		Control *n* = 25	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Inhibitory control	159.06	114.26	151.79	104.05	132.63	63.56	130.82	81.81	118.74	78.48	107.96	84.72
Depletion	124.90	74.93	100.62	84.58	96.71	72.36	57.47	59.88	47.35	59.85	95.53	83.33
Saturated fat intake	23.16	7.49	24.34	7.04	23.06	6.74	22.01	7.14	23.03	6.28	22.02	6.71
BMI	22.21	2.04	22.78	2.43	22.90	3.31	21.96	2.08	22.65	2.51	22.84	2.94

Note. Inhibitory control = Stroop interference score (ms); Depletion = difference in Stroop interference scores pre- to post- depletion task (ms), Saturated fat intake = g/day calculated from dietary fat items of the Block food screener, BMI = body mass index.

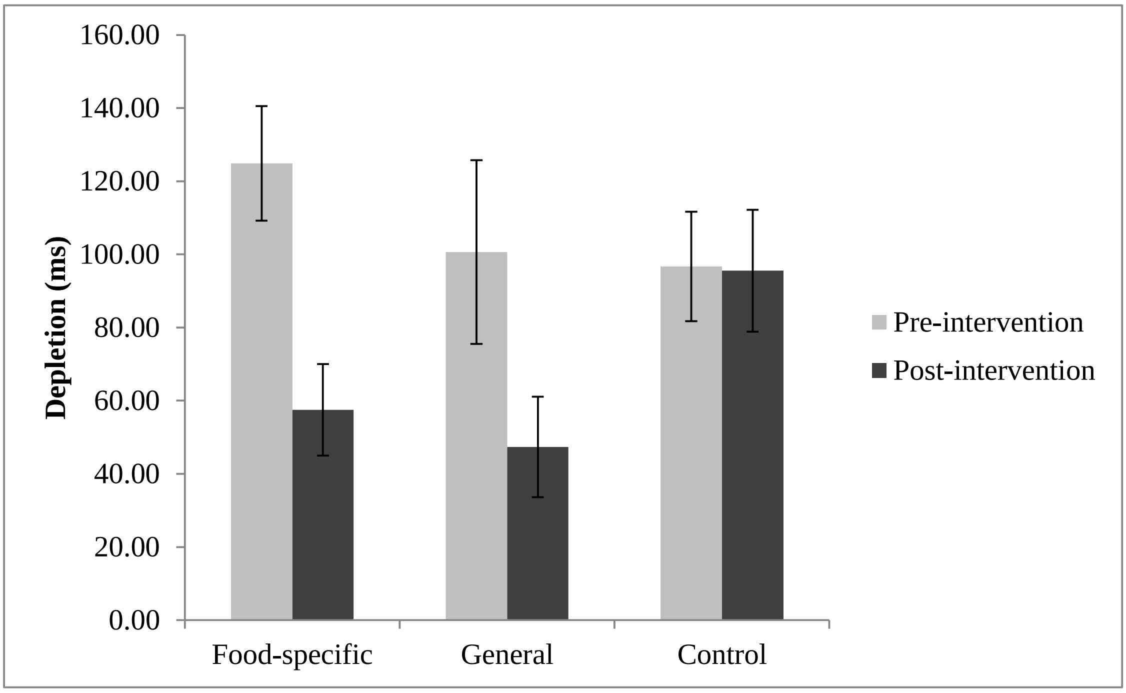
Table 2

Means and Standard Deviations of All Outcome Variables for Each Condition at Pre-Intervention, Post-Intervention, and Follow-Up

	Pre-intervention						Post-intervention						Follow-up					
	Food-specific *n* = 27		General *n* = 26		Control *n* = 25		Food-specific *n* = 24		General *n* = 23		Control *n* = 23		Food-specific *n* = 24		General *n* = 23		Control *n* = 23	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Inhibitory control	138.86	99.62	145.49	89.47	141.62	38.84	32.10	69.64	45.33	35.21	132.45	72.86	108.92	74.55	115.03	84.25	122.33	86.05
Depletion	114.59	165.03	110.57	120.15	120.91	98.87	54.24	70.62	48.68	75.54	129.88	87.45	119.96	111.29	110.04	101.87	128.61	89.33
% energy from fat	34.63	14.36	34.49	14.24	35.95	12.05	34.02	14.83	34.16	14.41	34.65	13.77	34.95	12.67	35.68	14.21	35.09	17.32
BMI	23.11	2.50	23.01	2.73	23.21	2.54	23.18	2.53	23.01	2.89	23.20	2.72	23.14	2.45	22.97	2.93	23.13	2.60

Note. Inhibitory control = Stroop interference score (ms); Depletion = difference in Stroop interference scores pre- to post- depletion task (ms); % energy from fat = fat intake calculated from NCI Percentage Energy from Fat Screener, BMI = body mass index.

Figures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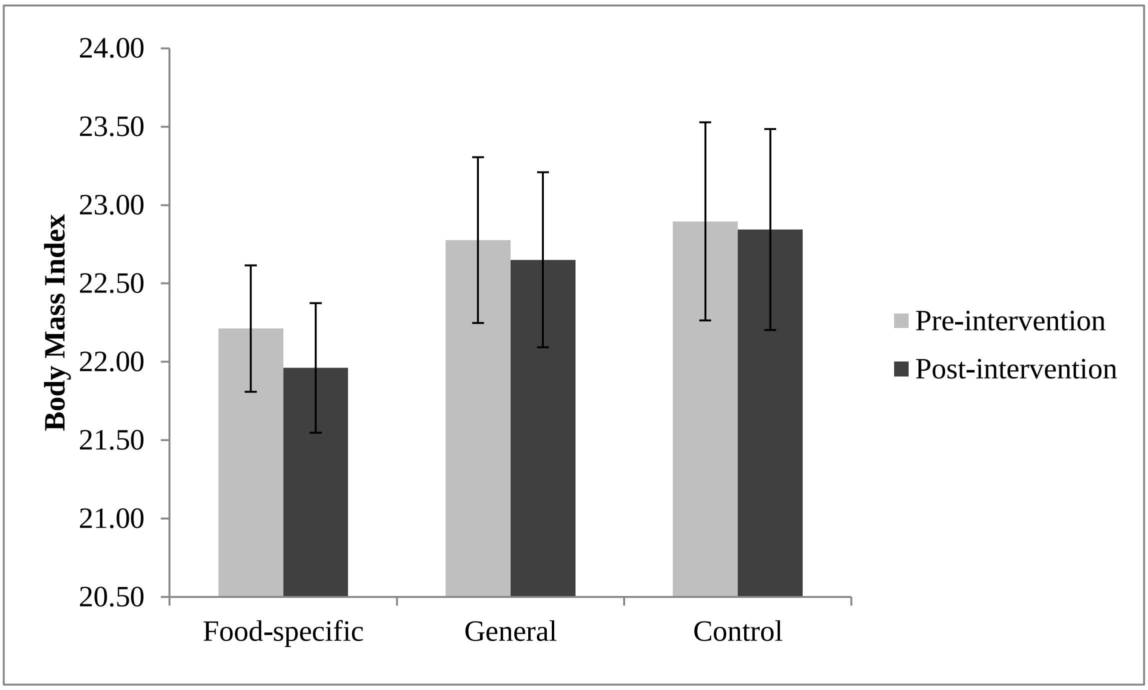
Depletion (ms)
Food-specific
General
Control
Pre-intervention
Post-intervention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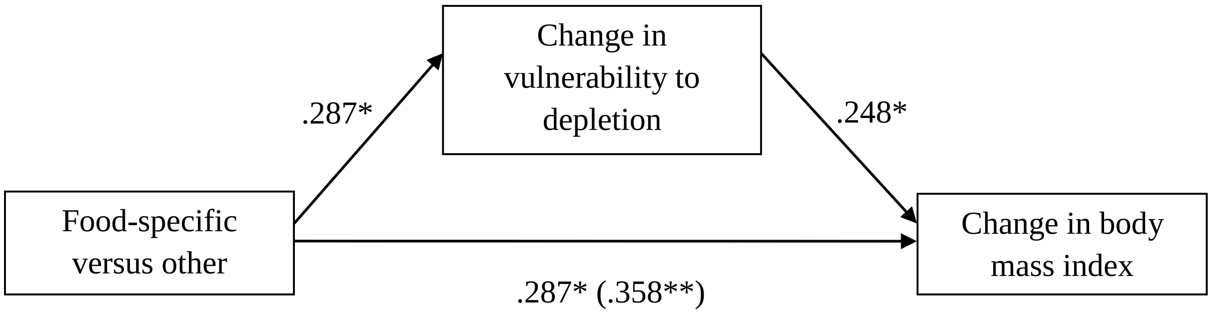
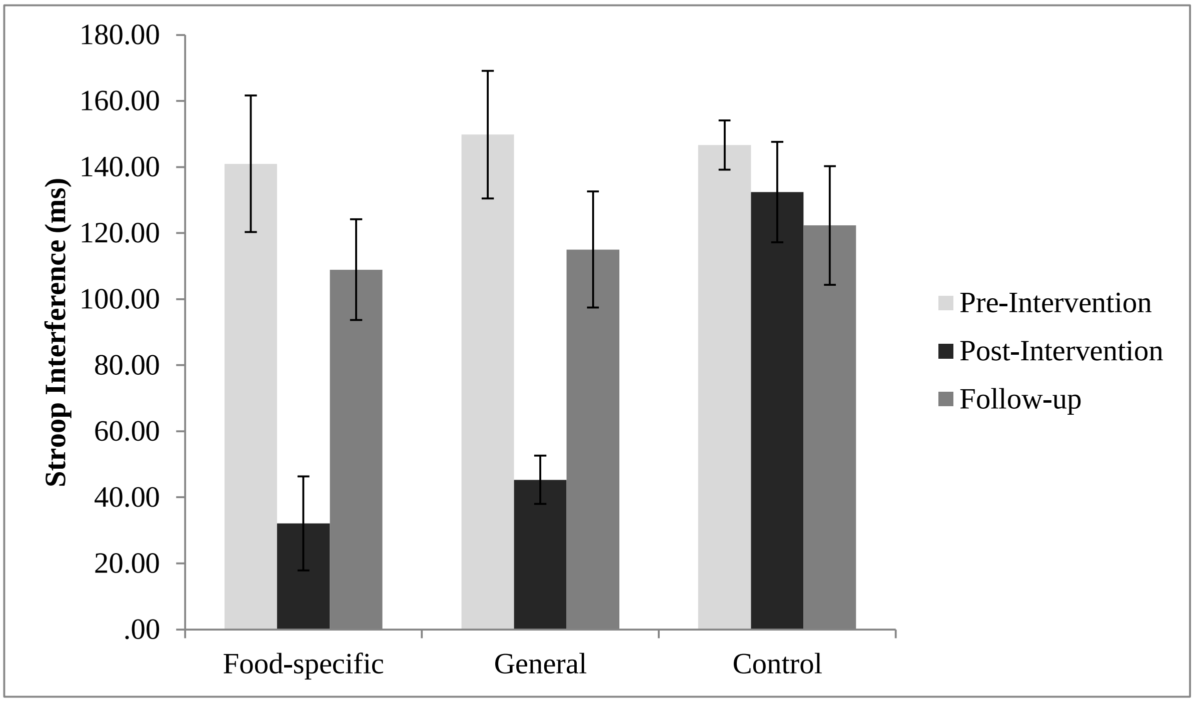
Body Mass Index
Food-specific
General
Control
Pre-intervention
Post-intervention


Change in vulnerability to depletion
.287*
.248*
Food-specific versus other
Change in body mass index
.287* (.358**)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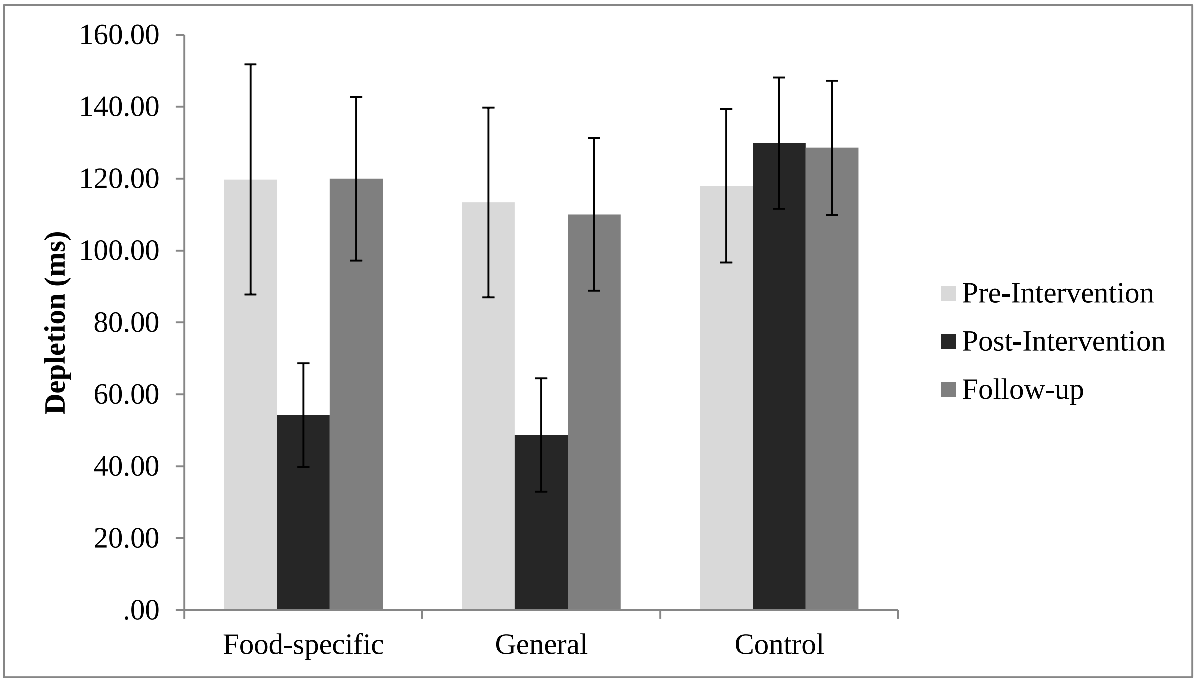
Stroop Interference (ms)
Food-specific
General
Control
Pre-Intervention
Post-Intervention
Follow-up



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Depletion (ms)
Food-specific
General
Control
Pre-Intervention
Post-Intervention
Follow-up

Figure Captions

Figure 1. Amount of depletion (difference in Stroop interference scores pre- to post-depletion task in ms) experienced pre- and post- intervention for each condition. Error bars display standard error.

Figure 2. Body mass index pre- and post- intervention for each condition. Error bars display standard error.

Figure 3. Simple mediation model depicting the indirect effect of type of training on change in body mass index through change in vulnerability to depletion. Standardised beta coefficients are noted in the diagram, $*p < .05$, $**p < .01$.

Figure 4. Inhibitory control performance (Stroop interference scores in ms) pre-intervention, post-intervention and at follow-up for each condition. Error bars display standard error.

Figure 5. Amount of depletion (difference in Stroop interference scores pre- to post-depletion task in ms) experienced pre-intervention, post-intervention and at follow-up for each condition. Error bars display standard error.