Go or no-go? An assessment of inhibitory control training using the GO/NO-GO task in adolescents

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Abstract

Objective. Adolescence is a critical period for the onset of unhealthy eating habits. One important contributing factor is poor inhibitory control (IC), a cognitive skill that enables behavior regulation. IC training appears successful in countering unhealthy eating in adults, but evidence in adolescents is scarce. In addition, the mechanism of change from IC training remains unclear. Therefore, the present study aimed to assess changes in IC during a single session of IC training in adolescents. The effectiveness of the training was assessed by comparing the experimental group to a matched control group.

Method. A community sample of 57 adolescents between 10 and 18 years was recruited (M_{age} = 16.61, SD_{age} = 2.52, 73.7% girls, $M_{adj.BMI}$ = 105.17, $SD_{adj.BMI}$ = 18.81). IC was assessed before, during, and after the training using a GO/NO-GO task. Indices of IC were commission errors (CE; incorrectly responding on a no-go trial) and reaction time (RT) on go trials.

Results. CE rates among adolescents who received the IC training were the highest during the training and decreased significantly after the training. However, there were no differences in CE before compared to after the training. No differences were found in RT before, during or after the training. In addition, compared to the control group, the experimental group showed no significant differences in either CE or RT before, during or after the training.

Discussion. To the best of our knowledge, the present study is the first to assess changes in IC after an IC training in a community sample of adolescents. Results of this study further elucidate the complex role of IC in adolescents' unhealthy eating habits. Future studies should seek to corroborate these findings in a larger sample.

Keywords. Adolescents, Inhibitory control training, GO/NO-GO, community sample, mechanism of change

1. Introduction

The current Western society can be described as obesogenic, in which highly palatable food is abundantly available. In Flanders, 27% of adolescents consume unhealthy snacks on a daily basis (Matthys et al., 2003). Resisting temptations to consume unhealthy food and maintaining a healthy lifestyle requires a certain degree of self-regulation, which is often described as 'inhibitory control' (IC; Reyes et al., 2015). IC refers to "the capacity to suppress a dominant response that can be triggered by an external cue, stop an ongoing response or resist distracting stimuli" (Reyes et al., 2015, p. 1230). IC enables individuals to regulate their behavior in line with long-term goals (Allom et al., 2016). Weaker IC is related to unhealthy eating habits, increased food intake, and enhances the risk of overweight and obesity in adults (Appelhans et al., 2011; Houben & Jansen, 2011; Manasse et al., 2016) and adolescents (Ames et al., 2014; Kittel et al., 2017). Adolescents are an important risk group, as their brain is not yet fully matured. Regulatory cognitive systems (e.g., IC) are still developing while automatic systems, which are responsible for impulsive choices, are peaking (Steinberg, 2005). This imbalance makes adolescence a crucial developmental period for studying unhealthy eating habits (Van Malderen et al., 2018).

Although multiple methods can be used to assess an individual's level of IC, the most common and behavioral measurement of IC is the GO/NO-GO (GNG) task (Houben & Jansen, 2011). The GNG task is a computerized task that consists of a large number of trials in which participants are instructed to respond as quickly as possible to a certain target stimulus (i.e., go trials) and to withhold this response for other stimuli (i.e., no-go trials). Although to date, to our knowledge, no studies have investigated the validity and reliability of the GNG task in adolescent samples, nor have they compared their psychometric qualities with those of other behavioral tasks (e.g., stop signal task), the GNG task has been widely used in previous research to capture regulatory and reactive processes (Houben & Jansen, 2011; Veling et al., 2017). Indices of poor IC are the so-called 'commission errors' (CE) (Meule et al., 2014). CE refers to the number of errors participants make on no-go trials. In no-go trials, participants need to be able to successfully withhold their responses, which is an indicator of IC (Aron et al., 2005; Littman & Takács, 2017; Rezvanfard et al., 2016). In addition, IC can also be indexed by reaction time (RT) on go trials (Spierer et al., 2013). In support of the horse-race model (Logan & Cowan, 1984), previous studies have found a decrease in RT on go trials in adults – indicating faster responses – even after a single GNG training session (Benikos et al., 2013; Chavan et al., 2015; Hartmann et al., 2016; Manuel et al., 2010). A decrease in RT indicates an increase in the speed of the inhibition process and reflects an increased IC proficiency (Chavan et al., 2015; Hartmann et al., 2016). Thus, both measures (i.e., CE and RT) need to be taken into account for a comprehensive evaluation of IC (Spierer et al., 2013).

To train IC, a modified food-specific GNG task is often used. In such a food-specific GNG task, food stimuli are accompanied by a no-go cue in 90% of trials and by a go-cue in 10% of trials, and vice versa for non-food stimuli. Consistently pairing no-go responses with target stimuli should result in improved response inhibition for those stimuli (Allom et al., 2016; Jones et al., 2017; Spierer et al., 2013). Previous research has provided evidence that using a food-specific GNG training can reduce the consumption and choice of highly palatable food in adults (Houben & Jansen, 2011, 2015; Jones et al., 2016; Oomen et al., 2018; Veling et al., 2013a; 2013b). Houben and Jansen (2011) examined the effects of a single-session IC training on chocolate consumption in female undergraduate students. The authors found that participants, who were trained to consistently inhibit their responses to chocolate stimuli, consumed less chocolate compared to participants who responded to chocolate stimuli on half of the trials. In a study by Oomen et al. (2018), a six-session IC training led to decreased snack consumption in healthy adults with high scores on uncontrolled eating. The above findings indicate that IC training can be implemented to tackle unhealthy eating behavior in adults.

However, to date, a lacuna remains in the existing literature as the results remain inconclusive about the purported mechanism of change from IC training. Given the aim of the training, strengthening top-down inhibitory control appears to be the most obvious mechanism of change, as postulated by Houben and Jansen (2011). To the best of our knowledge, thus far only two studies have examined whether top-down IC itself improved using a food-specific GNG task, one of which was conducted in adolescents. In particular, Oomen et al. (2018) found no significant improvement in IC after a six-session IC training in healthy adults who scored high on uncontrolled eating. Beauchamp et al. (2019) assessed whether IC improved after a 10-session IC training specifically in adolescents from low-income families. They found no significant differences in behavioral measures of IC (i.e., GNG-task) between adolescents who received IC training and a control group. They did, nevertheless, find significant differences in neural activation in IC-related brain regions, with the experimental group showing increased activity and the control group showing decreased activity (Beauchamp et al., 2019).

As research on strengthening IC as the proposed mechanism of change is scarce, it cannot be ruled out as a potential underlying mechanism. Thus, there is a clear need for further research, particularly as to date only one study has focused on whether a food-specific GNG training unequivocally strengthens top-down IC in adolescents (Beauchamp et al., 2019). Adolescence is a time of heightened neural plasticity in which brain development is sensitive to environmental influences (Beauchamp et al., 2019; Gogtay et al., 2004). Therefore, it could be a critical developmental period for improving cognitive skills, such as IC. Elucidating this underlying mechanism of change is an important first step in the development of effective training protocols to tackle unhealthy eating habits.

1.1. Present study

To address the aforementioned gaps in the literature, the present study aimed to investigate changes in IC throughout a single-session IC training in a community sample of adolescents. In addition, the overall effectiveness of the IC training was examined by comparing adolescents who received the training with a group of matched adolescents who did not (i.e., control group). Specifically, the study addressed the following two research questions:

First, research question 1 examined whether changes could be detected in IC before, during, and after the training using a modified GNG task. Based on previous research in adults (e.g., Chavan et al., 2015; Hartmann et al., 2016; Houben & Jansen, 2011; Jones et al., 2017), *it was expected that there would be an increase in IC after the training, indicated by a reduced number of incorrect responses on no-go trials (CE) and a decrease in RT on go trials compared to before and during the training (Hypothesis 1).*

Second, it was examined whether there would be differences in change in IC between the experimental group (active IC training) and the control group (sham training) (research question 2). Specifically, *it was expected that there would be a greater increase in IC, indicated by a reduced number of incorrect responses on no-go trials (CE) and a decrease in RT on go trials in the experimental group compared to the control group after the training (Hypothesis 2)* (Chavan et al., 2015; Houben & Jansen, 2011).

2. Method

2.1. Participants

A community sample of 57 adolescents between 10 and 18 years was recruited. This age range is based on the commonly used definition of adolescence in the literature (Sawyer et al., 2018). The sample consisting of all adolescents from the experimental group was used to address research question 1 (Sample 1: N = 36, 80.60% girls, M_{age} = 13.89, SD_{age} = 2.52, $M_{adj.BMI}$ = 100.92, $SD_{adj.BMI}$ = 13.16). To address research question 2, a matched control sample was created to ensure a balanced dataset (Sample 2: N = 42, 64.3% girls, M_{age} = 13.07, SD_{age} = 2.55, $M_{adj.BMI}$ = 106.33, $SD_{adj.BMI}$ = 20.24). To this end, each adolescent in the control group (N = 21) was matched with the most similar adolescent from the experimental group. The matching criteria in order of importance were sex, age, and adjusted BMI.

2.2. Procedure

Participants and their parents signed an active informed consent. Data collection occurred in two parts. First, participants filled out several online questionnaires at home regarding demographic information, eating behavior, self-regulatory, and IC capacities. The second part involved an experimental protocol that took place in the laboratory at Ghent University. Participants completed a food-specific GNG task, consisting of four blocks, and were randomly assigned to an experimental or control group. Both groups were presented with a pre-training and post-training block and two training blocks. The experimental group received active IC training, while the control group received passive IC training (i.e., sham training) (see ‘Materials – Inhibition and training’ for a detailed description of the GNG protocol). Following the GNG task, the researcher measured participants’ height and weight. All participants received a debriefing flyer regarding the general aim of the study. In addition, participants were thanked for their participation and received two movie tickets or a 20€ voucher. The

Medical Ethics Committee of Ghent University Hospital approved the study procedure (reference number 2019/0801BC-05372).

2.3. Materials

2.3.1. Demographic variables. Participants reported their age and sex. From the objective measurements of height and weight, an adjusted body mass index (BMI) was calculated. The BMI for adults was adapted for adolescents based on Flemish normative data, taking into account age and sex [(actual body mass index [kg/m2]/percentile 50 of body mass index for age and sex) × 100] (Roelants & Hauspie, 2004; Rolland-Cachera et al., 2015).

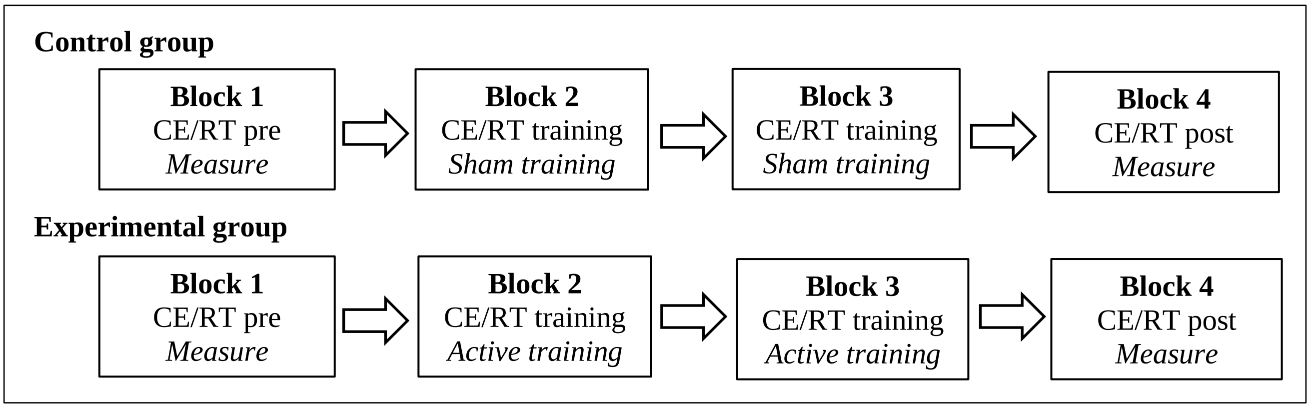
2.3.2. Inhibition and training. The GNG was used both as a behavioral measure of inhibition (control group) and for inhibition training (experimental group). In each case, a food-specific GNG version was used, consisting of 20 pictures of food items that are high in sugar, salt, and/or fat (e.g., chips, chocolate) and 20 pictures of familiar animals not commonly consumed in Western cultures (e.g., giraffe, butterfly). The choice of animal pictures as non-food control stimuli was because animals, like food, are overall appealing stimuli. All pictures were selected from the food-pics database (Blechert et al., 2014), which comprises a wide selection of validated food and non-food images.

In both the control and experimental group, each of the four blocks of the GNG task consisted of 160 trials. In each trial, participants were presented with a picture and a 'go' cue (e.g., the letter 'p'; instruction was to press the space bar) or a 'no-go' cue (e.g., the letter 'f'; instruction was to withhold pressing the space bar) for 1500 milliseconds. The 'go' and 'no-go' cues were presented randomly in one of the four corners of the picture and were counterbalanced across participants (i.e., for half of the participants the letter 'p' was the 'go' cue, whereas for the other half it was the letter 'f'). The first block (block 1) and the last block (block 4) served as a measurement of IC before and after the training and were the same for the two groups. In both groups, food and animal stimuli in block 1 and block 4 were accompanied by a 'no-go' cue in 50% of trials and by a 'go'-cue in the other 50% of trials. The two training blocks in the experimental group consisted of a modified version of the GNG. Food stimuli were accompanied by a 'no-go' cue in 90% of trials and by a 'go'-cue in 10% of trials, and the reverse for the animal stimuli. In the control group, the two training blocks consisted of sham training. In line with the measurement versions used in blocks 1 and 4, food and animal stimuli were accompanied by a 'no-go' cue in 50% of trials and by a 'go'-cue in the other 50% of trials.

Following previous studies (e.g., Meule & Kübler, 2014), the primary outcome measure was the number of CE (i.e., incorrectly responding on no-go trials), with a higher number of errors indicative of poorer IC. In particular, the CE on food pictures and RT on go trials were the outcome variables of interest. Accordingly, CE on food pictures and RT in block 1 will be referred to as 'CE Pre' and 'RT Pre', CE on food pictures and RT in block 2 and block 3 as 'CE Training' and 'RT Training', and CE on food pictures and RT in block 4 as 'CE Post' and 'RT Post'. A visual representation of the four blocks of the GNG task in both groups can be found in Figure 1.

Figure 1

Visual representation of the GNG task in the control and experimental group



2.4. Data analysis

IBM SPSS 25 was used for the statistical analysis of the data. Preliminary analyses were performed separately for research question 1 and research question 2, due to the use of different samples. First, outliers for the dependent variables CE Pre, CE Training, CE Post, RT Pre, RT Training and RT Post were assessed. In accordance with previous studies (e.g., Kemps et al., 2016; Meule & Platte, 2016), trials in the GNG task were considered outliers if the number of CE or RT was more than 2.5 standard deviations from the mean. Second, correlations were calculated between the study variables. Third, normality checks were performed for the variables CE Pre, CE Training, CE Post, RT Pre, RT Training and RT Post as they serve as dependent variables in the analysis. With regard to Sample 2, normality checks were done for the control and experimental group separately. As the normality assumption was violated (see the 'Preliminary analysis' section), non-parametric techniques were used. Separate analyses were performed for CE and RT. The Pre, Training, and Post measurements were included as test variables. To assess the change in IC throughout the experimental protocol (research question 1), a Friedmans' two-way analysis of variance by ranks was carried out. To test whether the IC training improved IC in adolescents in the experimental group compared to the control group (research question 2), an Independent Samples Mann-Whitney U test was performed with the Pre, Training, and Post measurements as the test variables and group as the grouping variable.

3. Results

3.1. Preliminary analysis

3.1.1. Research question 1. CE (i.e., incorrectly responding on no-go trials) and RT on go trials served as dependent variables. Two outliers were found; however, due to the relatively small sample size, these were not excluded from the analyses. To minimize their effects, Spearman Rank Correlations and medians were calculated, as these are more robust against outliers (Kim et al., 2015). The normality distributions of the Pre, Training, and Post measurement of CE and RT were assessed. A Shapiro-Wilk test showed a significant departure from normality for all three CE variables (CE Pre ($W(36) = .853$, $p < .001$), CE Training ($W(36) = .813$, $p < .001$), CE Post ($W(36) = .621$, $p < .001$)) and

RT Post ($W(36) = .933$, $p = .030$)). As the assumption of normality was not met, non-parametric techniques were used for subsequent analyses regarding CE and RT in Sample 1. Descriptive statistics of the RT on go trials, incorrect responses on go trials (i.e., not pressing when a go-cue was presented; omission error; OE) and incorrect responses on no-go trials (i.e., pressing when a no-go-cue was presented; CE) are presented in Table 1. Table 2 provides an overview of the correlations between the study variables for Sample 1. Accuracy on no-go trials was 99.2% ($SD = .80$) for the Pre-measurement, 99% ($SD = .96$) for the Training-measurement, and 99.4% ($SD = .93$) for the Post-measurement.

3.1.2. Research question 2. One participant in the control group had substantial missing data on RT (50%) and was excluded from the analysis, together with the matched participant of the experimental group. Therefore, the sample size was reduced to 40 participants (20 pairs). Next, five outliers were found, but again due to the small sample size, these were not excluded from the analyses. To minimize their effects, Spearman Rank Correlations and medians were calculated between the study variables within each group (i.e., experimental and control group) separately. Subsequently, the normality distributions of the variables CE Pre, CE Training, CE Post, RT Pre, RT Training and RT Post were assessed, for the control and experimental groups separately. A Shapiro-Wilk test showed a significant departure from normality in both the control group (CE Pre $W(21) = .803$, $p = .001$; CE Training $W(21) = .851$, $p = .004$; CE Post $W(21) = .718$, $p < .001$) and the experimental group (CE Pre $W(21) = .897$, $p = .031$; CE Training $W(21) = .746$, $p < .001$; CE Post $W(21) = .652$, $p < .001$). Regarding RT, the Shapiro-Wilk test showed no departure from normality neither in the control nor in the experimental group. As the assumption of normality was not met for CE, and to facilitate comparison between the results, non-parametric techniques were used for subsequent analyses regarding CE and RT in sample 2. Descriptive statistics of the variables RT, OE and CE in Sample 2 are shown in Table 3. Table 4 provides an overview of the correlations between the study variables for Sample 2 in the experimental and control group. Accuracy on no-go trials was 98.2% ($SD = 2.60$) for the Pre-measurement, 98.8% ($SD = 1.14$) for the Training-measurement, and 99.1% ($SD = 1.33$) for the Post-measurement.

Table 1

Descriptive statistics for Sample 1 (N = 36)

	Median	***Range***	***SD***	***SEM***	***95% CI***
CE					
Pre	1.00	0 – 4	1.28	.21	0.87 – 1.74
Training	1.00	0 – 7	1.53	.26	1.11 – 2.14
Post	1.00	0 – 8	1.48	.25	.47 – 1.47
OE					
Pre	0	0 – 2	.465	.08	-.05 - .27
Training	0	0 – 2	.393	.07	.02 - .29
Post	0	0 – 2	.593	.10	.16 - .56
RT					
Pre	631.95	486.63 – 839.39	85.99	14.33	606.51 – 664.69
Training	607.47	458.56 – 897.55	105.76	17.63	601.61 – 673.17
Post	612.80	483.15 – 854.64	98.83	16.47	604.36 – 671.24

Note. CE = commission error; OE = omission error; RT = reaction time

Table 2

Spearman rank correlations between study variables for Sample 1 (N = 36)

	1	2	3	4	5	6
1. CE Pre	-					
2. CE Training	.46***	-				
3. CE Post	.40**	.38**	-			
4. RT Pre	.19	-.01	.15	-		
5. RT Training	.16	-.07	.11	.85***	-	
6. RT Post	.11	-.09	.12	.88***	.83***	-

Note. CE = commission error; RT = reaction time; *$p < .05$, **$p < .01$, ***$p < .001$

Table 3

Descriptive statistics for Sample 2 (N = 40)

	Median	***Range***	***SD***	***SEM***	***95% CI***
CE					
Pre	C: 2.00	C: 0 – 19	C: 5.40	C: 1.21	C: 1.67 – 6.73
	E: 1.50	E: 0 – 4	E: 1.23	E: .28	E: 1.02 – 2.18
Training	C: 1.00	C: 0 – 6	C: 1.97	C: .44	C: 1.10 – 2.95
	E: 1.50	E: 0 – 7	E: 1.70	E: .38	E: 1.03 – 2.62
Post	C: 1.00	C: 0 – 10	C: 2.46	C: .55	C: .65 – 2.95
	E: 1.00	E: 0 – 8	E: 1.84	E: .41	E: .44 – 2.16
OE					
Pre	C: 0	C: 0 – 5	C: 1.32	C: .30	C: .18 – 1.42
	E: 0	E: 0 – 2	E: .45	E: .10	E: -.11 - .31
Training	C: 0	C: 0 – 3	C: .74	C: .17	C: .03 - .72
	E: 0	E: 0 – 2	E: .47	E: .11	E: -.02 - .42
Post	C: 0	C: 0 – 13	C: 2.90	C: .65	C: -55 – 2.15
	E: 0	E: 0 – 3	E: .88	E: .20	E: .19 – 1.01
RT					
Pre	C: 672.68	C: 527.95 – 787.89	C: 65.08	C: 14.55	C: 643.67 – 704.59
	E: 643.31	E: 486.63 – 773.74	E: 82.01	E: 18.34	E: 616.76 – 693.52
Training	C: 653.60	C: 516.19 – 794.44	C: 62.43	C: 13.96	C: 615.24 – 673.68
	E: 627.74	E: 500.44 – 897.55	E: 109.72	E: 24.53	E: 613.61 – 716.30
Post	C: 639.08	C: 356.89 – 827.03	C: 96.92	C: 21.67	C: 594.18 – 684.90
	E: 637.38	E: 515.48 – 854.64	E: 100.14	E: 22.39	E: 610.35 – 704.08

Note. CE = commission error; OE = omission error; RT = reaction time; C = control group; E = experimental group.

Table 4

Spearman rank correlations between study variables for Sample 2 (N = 40)

	1	2	3	4	5	6
1. CE Pre	-					
2. CE Training	C: .70*** E: .43	-				
3. CE Post	C: .71*** E: .38	C: .72*** E: .36	-			
4. RT pre	C: -.60** E: .61**	C: -.35 E: .13	C: -.23 E: .35	-		
5. RT Training	C: -.17 E: .43	C: -.06 E: .10	C: .14 E: .25	C: .70** E: .75***	-	
6. RT Post	C: -.45* E: .44	C: -.27 E: .36	C: -.28 E: .36	C: .40 E: .84***	C: .47* E: .74***	-

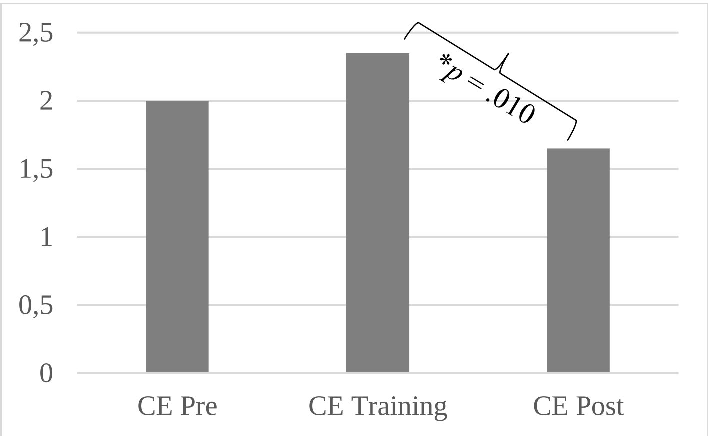
Note. $N_{control\ group}$ = 20, $N_{experimental\ group}$ = 20; C = control group, E = experimental group; *p < .05, **p < .01, ***p < .001

3.2. Main analysis

3.2.1. Research question 1. A Friedmans' two-way analysis of variance by ranks revealed a significant difference in CE Pre, CE Training and CE Post ($\chi^2(2)$ =10.78, p = .005, Kendall's W = .60). Pairwise comparisons with Dunn-Bonferroni correction showed a significant difference between CE Training (M_{rank} = 2.35) and CE Post (M_{rank} = *1.65)* (p = .010), indicating that, on average, adolescents make significantly fewer CE after the training compared to during the training. There were no significant differences between CE Pre (M_{rank} = 2.00) and CE Post (p =.422), or between CE Pre and CE Training (p = .422). In addition, there were no significant differences between RT Pre (M_{rank} = 1.83), RT Training (M_{rank} = 2.06) and RT Post (M_{rank} = 2.11) ($\chi^2(2)$ = 1.56, p = .459, Kendall's W = .02). A visual representation of the CE mean rank across the different measurement points is displayed in Figure 2.

Figure 2

CE mean rank distribution across measurement points for Sample 1



3.2.2. Research question 2. Results of an Independent Sample Mann-Whitney U test revealed no significant difference in CE Pre, CE Training, and CE Post, or RT Pre, RT Training, and RT Post between the control and experimental group. Thus, the IC training did not differentially affect CE or RT between the two groups. A summary of the results can be found in Table 5.

Table 5

Results from independent samples Mann-Whitney U test between groups for Sample 2

	CE Pre	**CE Training**	**CE Post**	**RT Pre**	**RT Training**	**RT Post**
***M* rank$_{control}$**	24.21	21.50	22.33	22.10	20.65	20.40
***M* rank$_{experimental}$**	18.79	21.50	20.67	18.90	20.35	20.60
U	163.50	220.50	203.00	168.00	197.00	202.00
p	.144	1.000	.644	.398	.947	.968
Effect size η2	.052	.005	< .001	.02	< .001	< .001

Note. CE = commission error; RT = reaction time

4. Discussion

The current study aimed to investigate the mechanism of change from IC training and its effectiveness in a community sample of adolescents. In particular, we sought to ascertain IC levels before, during, and after the training. It was expected that adolescents who received IC training would show greater IC after the training compared to before or during the training (Hypothesis 1). In addition, we compared IC in adolescents who received the training (i.e., experimental group) with those who did not (i.e., control group). It was predicted that adolescents who received the IC training would have greater IC after the training than the control group (Hypothesis 2).

Results showed no significant differences in IC before versus during the training or before versus after the training, which does not support Hypothesis 1. However, there was a significant difference in IC during versus after the training. In particular, adolescents made on average fewer CE after the training ($M_{rank} = 1.65$) than during the training ($M_{rank} = 2.35$), which partly supports Hypothesis 1. These results are in line with those of Oomen et al. (2018) (adults) and Beauchamp et al. (2019) (adolescents) who also found no significant differences in IC after a six-week or ten-week respectively IC training. However, both studies compared IC before and after the training and did not include a measurement of IC during the training. Furthermore, Oomen et al. (2018) recruited adults with elevated scores on uncontrolled eating, and Beauchamp et al. (2019) recruited adolescents from low-income families who reported IC deficits. Thus, their results cannot be compared directly to our community sample of adolescents. Moreover, as previous studies in adults focused primarily on other outcomes, such as food intake after IC training, more research is needed to determine whether IC training unequivocally strengthens IC in adolescents.

A second potential explanation for the lack of significant differences between the Pre and Post measurement could be the operation of alternative mechanisms of change. Apart from strengthening top-down IC, GNG training could influence individuals' eating behavior by creating associations between a stopping response and no-go food items ('bottom-up' IC), or through the devaluation of the food items which were paired with no-go responses (Veling et al., 2017). Specifically, consistently mapping food items on to no-go responses could create an association that links specific food items with stopping a response (Veling et al., 2013b; Veling et al., 2017). The idea is that the no-go signal becomes attached to the food stimulus. Therefore, when faced with this specific stimulus, an inhibition response is initiated, which leads to a suppression of the impulse towards this food item. Once the association is formed, seeing the food item will automatically lead to a behavioral stop (i.e., automatic response inhibition) (Best et al., 2016; Veling et al., 2017; Verbruggen & Logan, 2008). In the GNG task, no-go stimuli are consistently associated with stopping responses and go-stimuli with go responses. Therefore, automatic inhibition may develop. Using neuroimaging techniques, Manuel et al. (2010) showed that no-go stimuli triggered an automatic inhibition response, which reduces the contribution of top-down IC during the task. In order to study top-down IC, the training needs to use an 'inconsistent mapping' design in which stimuli are mapped onto different responses, which prevents the development of automatic inhibition. This is the case in the stop-signal task. Therefore, assessing IC training using a stop-signal task may provide further insight into the role of top-down IC in behavior responses. Alternatively, consistently pairing food items on to no-go responses could lead to a devaluation of the food items (Veling et al, 2013a). Appetitive stimuli will trigger approach reactions, but presenting a no-go cue will inhibit these reactions. Continuously pairing highly appetitive food items with no-go cues can lead to a reduction in the appetitive value of the food items. Several experimental studies have reported results that are consistent with the devaluation argument (Chen et al., 2016). As the valence of the food items was not accounted for in the present study, future studies could further assess the role of devaluation as a potential mediating mechanism in food-related IC training.

With regard to the effectiveness of IC training (research question 2), there were no differences between adolescents who received the active IC training and those who did not. These findings do not support Hypothesis 2, but they are in line with Beauchamp et al. (2019) who similarly found no differences in behavioral measures of IC between their experimental and control groups. One possible explanation for this lack of significant differences between the experimental and control groups may be the short duration of the training. A single training session may be insufficient to train IC in adolescents. Although the within-subjects comparisons showed a change in IC in the expected direction for the experimental group, a single session may be insufficient to obtain significant between-group differences when compared to a control group. Compared to adults, adolescents' brains are still developing and frontal lobe regions, which are responsible for IC, are maturing at a more moderate pace compared to other regions. This could explain why a single session of IC training is sufficient to detect behavioral training effects in adults, but not in adolescents (Jones et al., 2017).

Another explanation lies in potential beneficial effects for the control group, such as habituation (Giel et al., 2017). Habituation refers to the reduction in response to a frequently repeated stimulus. Adolescents in the control group were presented with the same food-specific stimuli as the experimental group. Mere exposure to pictures of high-calorie food may have led to habituation (Giel et al., 2017). Hence, future studies could consider using neutral (non-food) pictures instead of food pictures in the control group to avoid habituation processes. In support, a within-subjects Dunn-Bonferroni post-hoc comparison revealed a significant decrease ($\chi^2(2)$ =10.78, p = .005, Kendall's W = .64) in CE over time for the control group. Specifically, participants made significantly fewer CE in the last GNG block (M_{rank} = 1.62) compared to the first GNG block (M_{rank} = 2.36) (p = .050). No differences in RT were found in the control group ($\chi^2(2)$ = 3.90, p = .142, Kendall's W = .10). Finally, the experimental group already showed lower levels of CE before the training (M_{rank} = 2.05) compared to the control group (M_{rank} 2.36). Therefore, there was less room for improvement. As both groups showed similar levels of CE at the end of the GNG task (CE Post M_{rank} = 1.62), the higher levels of CE at pre-measurement in the control group may account for the significant pre-post difference in the control group but not the experimental group. Future studies could assess the effect of IC training in adolescents who experience IC deficits, and therefore have higher levels of CE and RT at baseline.

4.1. Implications, strengths, and limitation

To the best of our knowledge, the present study is the first to investigate whether IC training alters the purported mechanism of change (i.e., IC) in a community sample of adolescents. A better understanding of the mechanism of change clearly has clinical benefits, as it furthers the development or adaptation of cognitive training protocols in the context of unhealthy eating behavior (Oomen et al., 2018). However, more studies with large samples of adolescents are needed to substantiate the current findings.

The present study also has a few limitations. First, the current sample size was relatively small, although it was sufficiently large to ensure the study was adequately powered to detect significant results ($N = 36$ according to a post-hoc power analysis with power = .90, $\alpha = .05$, $f = .25$). Nevertheless, future studies should seek to replicate the present results with a larger sample. A larger sample has the advantage that the central limit theorem applies, and consequently, parametric techniques can be used (i.e., Repeated Measures ANOVA) which have greater statistical power compared to their non-parametric alternatives (Kwak & Kim, 2017). Second, the IC training was of relatively short duration. Although some changes in IC were discovered in the experimental group (i.e., significant decrease in CE after the training compared to during the training), compared to a control group, no differences were found. The lack of significant between-group findings suggests that a single training session may be insufficient to make a substantial difference. In addition, the present study recruited a community sample of adolescents who reported no difficulties in IC. Thus, future studies should examine the effect of multiple IC training sessions in specific subgroups of adolescents who experience IC deficits. Fourth, the present study only used a behavioral measure of IC. Beauchamp et al. (2019) found no significant differences in IC using behavioral measures, such as the GNG task, but they did find differences in neural activation. Future studies could combine multiple assessment methods (e.g., self-report questionnaires, fMRI techniques) to provide the most comprehensive assessment of IC improvement (Van Malderen et al., 2018). Lastly, the present study used a limited selection of food pictures and no new stimuli were added during the GNG task. Therefore, no conclusions can be drawn regarding any generalization of a potential effect to new food stimuli, an important avenue for future research.

4.2. Conclusion

The present study aimed to assess the mechanism of change from IC training in adolescents from the general community. Indices of IC were CE (i.e., incorrectly responding on no-go trials) and RT to go trials. CE rates among adolescents who received the IC training appeared to be the highest during the training and decreased significantly after the training. However, there were no differences in CE before compared to after the training. No differences were found in RT before, during or after the training. In addition, compared to the control group, the experimental group showed no significant differences in CE or RT before, during or after the training. Further research in larger samples using multi-method assessment of IC is needed to corroborate these findings in adolescents. To the best of our knowledge, this is the first study to research the purported mechanism of change from IC training in a community sample of adolescents. In so doing, it makes an important contribution to the clinical field through the provision of insights for the development of tailored IC training in adolescents.

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4.4. Declaration of interest

On behalf of all authors, declarations of interest: none.

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4.6. Contribution

LG, EK, SV en EVM designed the study and wrote the study protocol. EVM was responsible for the data collection, under the supervision of LG. AVR and MD conducted the statistical analysis. AVR wrote the first draft of the manuscript. All authors have edited subsequent drafts and have approved the final version. The corresponding author, AVR, can provide all original data upon request.

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