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Generalization of food devaluation following food-specific go/no-go training

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ABSTRACT

The benefit of food-specific inhibition training on modulating food valuation and eating behaviors has been established, but generalization to untrained foods is seldomly examined. This study investigated whether stimulus variability and practice order, found to effect generalization in motor learning, can improve generalization following food-specific inhibition training. Ninety-three young adults practiced the Go/No-Go task online in three training conditions: 1) Constant ($N = 30$): inhibition practiced on one food stimulus; 2) Variable-Blocked ($N = 32$): inhibition practiced on 6 food stimuli, each in a separate block; and 3) Variable-Random ($N = 31$): inhibition practiced on 6 food stimuli in random order. Consistent with our hypothesis, the Variable-Random group showed better generalization of inhibition to untrained foods than the Constant and the Variable-Blocked groups immediately after training, demonstrating the benefit of stimulus variability and random practice order. This effect was not present 24 h after training. The Variable-Random group also showed decreased desire to eat untrained foods, exhibiting generalization of food devaluation. However, this effect was only present 24 h after training. The Constant group showed increased desire to eat untrained foods immediately and 24 h after training. The Variable-Blocked group did not differ from either group in the desire to eat to untrained foods, suggesting that random order is important for exposing the benefit of variability. The findings illustrate that presenting various training items in random order can improve generalization of food-specific inhibition training. However, inconsistencies found in the timing of generalization effects and modest effect sizes warrant additional investigation into generalization principles of food-specific inhibition training.

1. Introduction

Response inhibition represents the ability to withhold automatic responses for engaging in goal-directed behavior (Friedman & Miyake, 2017; Miyake et al., 2000). Multiple studies delineated links between response inhibition and eating behaviors (see Dohle et al., 2018 for review). Inefficient response inhibition has been associated with dysregulated eating behaviors such as overeating (Guerrieri et al., 2007; Jasinska et al., 2012) and consumption of high-calorie foods (Allom & Mullan, 2014) while efficient response inhibition has been associated with lower consumption of high-calorie foods (Hall, 2012; Hofmann et al., 2014).

Throughout the past decade, studies have assessed whether designated response inhibition training can modulate eating behaviors (see McGreen et al., 2024; Yang et al., 2019 for reviews). These studies utilize food-specific response inhibition tasks such as the Go/No-Go task (GNG; Donders, 1969) which requires initiating a response to ‘go’ stimuli (e.g., a non-food item or low-calorie foods) and withholding a response when presented with ‘no-go’ stimuli (e.g., high-calorie foods). In other versions of this training task, ‘no-go’ trials consist of a neutral cue (e.g., a colored frame) which is then paired with high-calorie food stimuli (e.g., Lawrence et al., 2015).

Training using the GNG has shown generalization to eating behaviors such as reduced food intake (Houben & Jansen, 2011, 2015; Veling et al., 2013a), reduced snacking consumption (Lawrence et al., 2015), weight loss (e.g., Yang et al., 2019), and lower desire to eat trained food items (Veling et al., 2013b). Despite these promising findings, other studies have shown inconsistencies in generalization to eating behaviors

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(e.g., Adams et al., 2021; Najberg et al., 2021) emphasizing the need for a better understanding of ways to improve generalization of such training procedures.

One of the proposed mechanisms through which generalization effects after training occur is through the *food devaluation effect* (Veling et al., 2013b), namely, the assessment of no-go foods as less attractive or desirable after consistently stopping a response to these stimuli. Despite the food devaluation effect being replicated across many studies (see Yang et al., 2022 for review) generalization of food devaluation to untrained foods remains unclear. Although some have shown generalization of the devaluation effect to untrained items (Camp & Lawrence, 2019), most studies either did not examine it (e.g., Houben & Jansen, 2015; Najberg et al., 2021) or showed food devaluation after response inhibition training occurs more strongly for trained than untrained items (e.g., Chen et al., 2016; Chen, Veling, De Vries, et al., 2018). Given that food-specific response inhibition training procedures are often examined as potential intervention techniques (Oomen et al., 2018), it is important to gain a deeper understanding of the methodologies that promote generalization of the food devaluation effect.

Harnessing knowledge of factors that promote generalization from motor learning and other cognitive domains has the potential to refine GNG training to improve generalization conditions. Two well-established principles which influence generalization are stimulus variability and practice order. *Stimulus variability* refers to the benefit of using variety and heterogeneity in stimuli during training (Schmidt, 1975; see Raviv et al., 2022 for review). Benefits of stimulus variability have been demonstrated in research on motor learning (e.g., Maas et al., 2008; Wulf & Schmidt, 1997), language (e.g., Adwan-Mansour & Bitan, 2017), and categorization (e.g., Perry et al., 2010). Variability is suggested to increase generalization by strengthening task and category relevant distinctions (Raviv et al., 2022). Learning a novel category using a larger number or more heterogenous exemplars assists in identifying critical aspects of the category and ignoring irrelevant within-category variability, thus facilitating generalization.

Practice order refers to beneficial effects of presenting stimuli in mixed random order as opposed to one at a time for generalization (Battig, 1966), which has been shown extensively in motor learning (e.g., Shea & Morgan, 1979; Travlos, 2010), as well as other domains (e.g., categorization; Kornell & Bjork, 2008). When tasks or stimuli are practiced in random order the learner is required to hold different exemplars in working memory simultaneously, and switch between them, thus enhancing the salience of their commonalities, and facilitating generalization (Lee & Magill, 1983, 1985; Shea & Zimny, 1988). It was also suggested that the added cognitive effort in random practice order amplifies learning and enhances generalization (Lee, 2012).

We recently examined the principles of stimulus variability and practice order on GNG training using neutral stimuli and showed that using variable stimuli presented in random order increased generalization of stopping responses to untrained no-go items from the same category (Moshon-Cohen et al., 2024). The goal of the current study was to assess if applying principles of stimulus variability and practice order to a food-specific GNG training paradigm can a) improve motor response inhibition to untrained foods and b) improve generalization of food devaluation to untrained foods. In the current study, participants performed one of three GNG training conditions. The ‘constant’ group practiced inhibition on one food stimulus repetitively. This group can be considered a control group because practicing on one stimulus does not involve stimulus variability. The ‘variable-blocked’ group practiced inhibition on 6 food stimuli, one at a time. This group involves stimulus variability because it requires inhibition to multiple food items. However, it does not involve a random practice order. The ‘variable-random’ group practiced inhibition on 6 food stimuli, presented in a random order. This group involves both stimulus variability and random practice order. Comparing results of the ‘variable-blocked’ and the ‘variable-random’ groups to the ‘constant’ group should reflect the impact of stimulus variability, while comparing the variable-random group to the variable-blocked group should reflect the impact of practice order. Task performance and desire to eat trained and untrained foods were measured immediately after training, and the stability of these effects was measured again 24 h after training. We hypothesized that: 1) practicing stopping to variable food stimuli in random order (variable-random group) will contribute to generalization of stopping to untrained stimuli compared to repetitive practice on constant stimuli (constant group) or training in a blocked order (variable-blocked group). 2) Practicing stopping to variable food stimuli in random order (variable-random group) will contribute to generalization of the food devaluation effect to untrained stimuli compared to repetitive practice on constant stimuli (constant group) or training in a blocked order (variable-blocked group).

2. Materials and methods

2.1. Participants

We recruited 103 healthy young adult participants through social media and university resources. Participants were women ($N = 69$) and men ($N = 34$) between the ages of 18–40 ($M = 26.40$, $SD = 4.59$) Inclusion criteria included: Hebrew mother tongue, right hand dominance, intact or corrected vision, intact hearing, no special dietary preferences (i.e., vegan), absence of past or current eating disorder and any psychiatric or neurological disorder. Participants were assigned to one of three training groups (constant, C; variable-blocked, VB; variable-random, VR) based on stimulus variability and practice order. Participants were asked to refrain from eating 2 h prior to each session. Participants received monetary compensation or course credit for their participation. The sample size was determined a-priori via a power analysis that was conducted using G*Power 3.1 (Faul et al., 2007). The analysis indicated that the sample size is sufficient for detecting a medium-sized within-between interaction effect ($\eta_p^2 = 0.06$) between Group (C, VB, VR) and Stimulus type (Ice Cream, Untrained Foods), at a power of >80 % and an alpha of 0.05.

2.2. Pretest task descriptions

2.2.1. Stroop Color-Word Test: (Golden, 1978; Stroop, 1935)

A-priori group differences in inhibitory control could jeopardize interpretation of group differences. Therefore, the Stroop Color-Word Test was administered as a standardized neuropsychological test of inhibitory control to ensure no baseline differences between the groups. The Stroop Interference Score was calculated by subtracting the sum and product of the color and word components from the color-word score (as described by Golden, 1978).

2.2.2. Dutch Eating Behavior Questionnaire (DEBQ; van Strien, Frijters, et al., 1986)

The DEBQ was administered to ensure no baseline differences in participants eating behaviors and used in a moderation analysis. The questionnaire consists of 33 self-report items on a scale of 1 (never) to 5 (very often) and includes three subscales, each measuring the extent of engagement in a different eating behavior: emotional eating (13 items; Cronbach $\alpha = 0.95$), external eating (10 items; Cronbach $\alpha = 0.76$), and restrained eating (10 items; Cronbach $\alpha = 0.90$). The DEBQ has shown good predictive validity (van Strien, R Frijters, et al., 1986).

2.2.3. Demographic questionnaire

Participants were asked to fill in demographic and personal information including: height, weight, sex, age and years of education to ensure no baseline differences. Body Mass Index was calculated as weight/height^2.

2.2.4. State hunger rating

Participants were asked hunger ratings in the beginning of Session 1

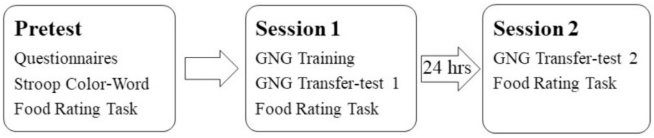

Fig. 1. Study timeline.

and the beginning of Session 2 to ensure no baseline differences between groups. Participants were asked to report hunger levels on a visual analogue scale with a slider ranging from 0 (not hungry at all) to 100 (extremely hungry).

2.3. Measures

2.3.1. Go/No-Go (GNG) training task

A modified version of the GNG task (Donders, 1969) was used as a response inhibition training task. Training consisted of 6 blocks of 120 trials each. During each block, participants were presented with picture stimuli and instructed to press the space bar when a non-food object (‘go’ stimuli) is displayed, and to refrain from responding when a food (‘no-go’ stimuli) is displayed. The instructions were identical across training groups. Participants were instructed: “In the following task pictures will appear in the center of the screen. If a picture of food appears, do not press any key and wait for the next picture. If the picture presented is not a food picture, press the space bar as fast as you can”. Trials consisted of a fixation cross (750 ms), stimulus presentation (200 ms) and a response window consisting of a plain white screen (400 ms). Go and no-go trials were presented in random order, with a proportion of 70 % and 30 %, respectively. Feedback on reaction time to go stimuli and accuracy to no-go stimuli was presented at the end of each block during training. During training, the constant (C) training group was presented with only 1 no-go stimulus – a picture of ice cream. The variable-blocked (VB) and variable-random (VR) training groups practiced on 6 no-go stimuli including the ice cream stimulus and 5 pictures of other high-calorie sweet foods. In Group VB, each of the 6 no-go stimuli were presented in separate blocks, in counterbalanced order across participants, whereas in Group VR the 6 no-go stimuli were all presented together, mixed in random order, across all blocks. The food and object stimuli used in the study were taken from the food-pics database (Blechert et al., 2014). Full details on the stimuli used can be found in supplementary materials S1.

2.3.2. GNG Transfer-test 1 & 2

Generalization of stopping to untrained no-go items was examined using transfer tests immediately following training (Transfer-test 1), as well as after a 24 h interval (Transfer-test 2), and included a short version of the modified GNG task (2 blocks of 120 trials). The transfer tests included a Go/No-go proportion of 50 %/50 % to ensure a sufficient number of no-go trials for analysis of each of the no-go categories separately; ice cream and untrained foods. Food stimuli included the ice cream stimulus, trained by all groups, and 5 pictures of untrained foods. The ice cream stimulus was presented on 50 % of no-go trials and the 5 untrained foods were presented on the remaining 50 %. Transfer-test 2 used different untrained food stimuli than the Transfer-test 1 to control for familiarity with specific items. The 6 non-food object stimuli used in both transfer tasks were identical to those in the Training task.

2.3.3. Food rating task

To measure the effects of training on the desire to eat, participants were presented with food stimuli and asked to rate their desire to eat the depicted food on a scale from 1 (not at all) to 10 (very much). Two categories of stimuli were included: 1) ice cream; 1 picture of the ice cream stimulus presented during training to all groups and 2) untrained foods; 12 pictures of novel high-calorie sweet and salty foods that were not used in the training or transfer tests. The 5 items trained by the variable groups and 6 pictures of low-calorie foods were used as filler items. The task was administered at baseline (Pretest), immediately after training (Session 1), and 24 h after training (Session 2).

2.4. Procedure

The study was approved by the Institutional Review Board of the University of Haifa (075/22). After obtaining consent, a Pretest session was conducted via video conference with the experimenter (see timeline in Fig. 1) which began with completing a digital consent form. The demographic questionnaire, DEBQ, Stroop Color-Word Test, DEBQ and the first Food Rating Task, respectively, were administered at pretest. Between-group comparisons for baseline differences are presented in Table 1. The first experimental session was conducted at least 24 h after the pretest and included the Training task, Transfer-test 1 and the second Food Rating task. A 3-min break was given following block 2, block 4, and between Training and Transfer-test 1. To examine the stability of these effects and offline effects of consolidation, participants completed the second session 24 h after training, during which they completed Transfer-test 2 and the third Food Rating Task. To enhance motivation, participants were told that they would receive monetary compensation based on their performance. All participants received equal bonus compensation at the end of the experiment.

2.5. Statistical analysis

Outliers for analysis included participants with 3 or more blocks (across Training and Transfer tasks) with mean response time (RT) and/or mean accuracy measures that were above or below 3.5 standard deviations from the group mean. Four participants were excluded from the analysis after meeting this criterion. Three additional participants were removed for failing to complete Session 2 and three due to corrupted data. Hence, 93 participants were included in the final analysis, 30 in Group C, 32 in Group VB, and 31 in Group VR. 1.64 % of trials across

Table 1
Between-group comparisons of baseline demographic variables, state hunger ratings, Stroop Color-Word and DEBQ scores. Mean scores are presented with standard deviation in parenthesis.

Measure		Group C (N = 30)	Group VB (N = 32)	Group VR (N = 31)	Group comparison
Sex	Female	70.0 %	71.9 %	74.2 %	$\chi^2 (2) = 0.134, p = .935,$ V = 0.039
Age		25.97 (5.11)	26.75 (3.94)	26.30 (4.56)	$F(2,90) = 0.25, p = .780, \eta_p^2 = 0.006$
Years of Education		14.10 (2.27)	14.84 (2.36)	14.53 (2.27)	$F(2,90) = 0.83, p = .438, \eta_p^2 = 0.018$
State Hunger Ratings	Session 1	64.69 (16.02)	55.45 (23.50)	52.50 (24.06)	$F(2,90) = 2.72, p = .071, \eta_p^2 = 0.055$
	Session 2	66.50 (13.90)	58.75 (25.37)	55.32 (23.41)	$F(2,90) = 2.14, p = .124, \eta_p^2 = 0.045$
Body Mass Index		23.57 (4.34)	23.62 (3.45)	25.07 (8.72)	$F(2,90) = 0.64, p = .531, \eta_p^2 = 0.014$
Stroop Interference		5.36 (6.31)	7.61 (7.99)	6.50 (9.28)	$F(2,90) = 0.62, p = .542, \eta_p^2 = 0.014$
DEBQ: Restraint		2.63 (0.89)	2.47 (0.78)	2.41 (0.79)	$F(2,90) = 0.59, p = .559, \eta_p^2 = 0.013$
DEBQ: Emotional Eating		2.61 (1.05)	2.72 (1.05)	2.84 (0.92)	$F(2,90) = 0.38, p = .684, \eta_p^2 = 0.008$
DEBQ: External Eating		3.40 (0.46)	3.51 (0.56)	3.44 (0.58)	$F(2,90) = 0.349, p = .706, \eta_p^2 = 0.008$

Note: DEBQ refers to the Dutch Eating Behavior Questionnaire.

tasks were excluded because RT was below 200 ms. In the Food Rating Task, 0.6 % of trials with RT above 3.5 standard deviations from the total mean were also excluded.

Baseline characteristics between groups were assessed using a one-way analysis of variance (ANOVA) for age, years of education, Body Mass Index and Stroop Color-Word test. A Chi-square test was used for sex.

In order to examine our primary hypotheses, analysis of Transfer-tests 1 and 2 utilized a repeated measures ANOVA with Group (C, VB, VR) as the between-subject variable and Stimulus type (ice cream, untrained foods) as the within-subject independent variable. No-go accuracy was used as the dependent measure. As a result of the main study hypotheses for Transfer-test 1 and potential influence of being exposed to untrained stimuli in Transfer-test 1 on performance in Transfer-test 2, we analyzed each time point separately.

We used the Food Rating task to examine our hypothesis regarding changes over time in the desire to eat trained and untrained foods. A repeated measures ANOVA was used with Group (C, VB, VR) and Time (Pretest: before training, Session 1: immediately after training, Session 2; 24 h after training) as the independent measures with average rating as the dependent measure calculated for each category; ice cream and untrained foods.

Across all analyses, in cases when sphericity could not be assumed we used the Greenhouse-Geisser correction when $\varepsilon < 75$ and Huynd-Feldt when $\varepsilon > 0.75$. In cases when equality of variances could not be assumed corrected measures were used.

3. Results

For results of training, see supplementary materials S2.

3.1. *Demographic variables, Stroop color-word and questionnaires*

No differences between groups were found in participants' sex, age, years of education, state hunger ratings, Body Mass Index, Stroop Interference and the DEBQ eating behavior styles (see Table 1).

3.2. *Transfer-test 1 & 2*

To assess generalization in no-go accuracy (see Table 2 for raw data) to untrained stimuli we examined the differences between ice cream and untrained foods in Transfer-tests 1 and 2 as a function of Group. *Transfer-test 1* (see Fig. 2a): The analysis revealed a significant main effect of stimulus type ($F(1,90) = 90.75$, $p < .001$, $\eta_p^2 = 0.502$) with higher accuracy for the ice cream stimulus, and a significant effect of group ($F(2,90) = 3.42$, $p = .037$, $\eta_p^2 = 0.071$) with Group VR having higher accuracy than Group C ($t(90) = -2.06$, $p = .042$ $\eta_p^2 = 0.045$) or Group VB ($t(90) = -2.43$, $p = .017$, $\eta_p^2 = 0.062$) with no difference between C and VB ($t(90) = 0.33$, $p = .740$, $\eta_p^2 = 0.001$). The analysis also revealed a significant Group by Stimulus Type interaction ($F(2,90) = 3.16$, $p = .047$, $\eta_p^2 = 0.066$). This interaction resulted from a simple effect of Group for untrained foods ($F(2,90) = 3.91$, $p = .023$, $\eta_p^2 = 0.080$), but not for ice cream ($F(2,90) = 2.32$, $p = .103$, $\eta_p^2 = 0.049$). To understand how no-go accuracy for untrained foods changes as a function of Group we carried out contrast analyses. In line with the hypothesis, Group VR had significantly higher no-go accuracy to untrained foods compared to Group C ($t(133.11) = -2.59$, $p = .004$, $\eta_p^2 = 0.061$), indicating an effect of stimulus variability, and compared to Group VB ($t(133.11) = -2.55$, $p = .012$, $\eta_p^2 = 0.047$), indicating an effect of practice order. Group VB did not significantly differ from Group C ($t(133.11) = -0.445$, $p = .657$, $\eta_p^2 = 0.001$). *Transfer-test 2* (see Fig. 2b): The analysis revealed a significant main effect of stimulus type ($F(1,90) = 95.95$, $p < .001$, $\eta_p^2 = 0.516$) with higher accuracy for the ice cream stimulus. No main effect of Group was found ($F(2,90) = 0.11$, $p = .901$, $\eta_p^2 = 0.002$). The Group by Stimulus Type interaction was significant ($F(2,90) = 3.45$, $p = .036$, $\eta_p^2 = 0.071$), however no simple effect of Group for untrained foods ($F(2,90) = 0.11$ $p = .896$, $\eta_p^2 = 0.002$) or ice cream ($F(2,90) = 0.52$ $p = .595$, $\eta_p^2 = 0.011$) were evident. These results indicate that the effect of stimulus variability and practice order dissipated 24 h later.

Table 2
No-go accuracy (%) in Transfer-tests 1 and 2 for ice cream and untrained foods. Mean scores are presented with standard deviation in parenthesis.

	Stimulus type	Group C (N = 30)	Group VB (N = 32)	Group VR (N = 31)
Transfer-test 1	Ice cream	92.5 (6.92)	90.3 (7.43)	94.0 (6.22)
	Untrained foods	82.5 (9.68)	83.4 (10.48)	88.8 (8.11)
Transfer-test 2	Ice cream	95.2 (4.86)	93.6 (5.20)	92.4 (17.14)
	Untrained foods	88.3 (7.30)	87.6 (7.91)	88.9 (17.03)

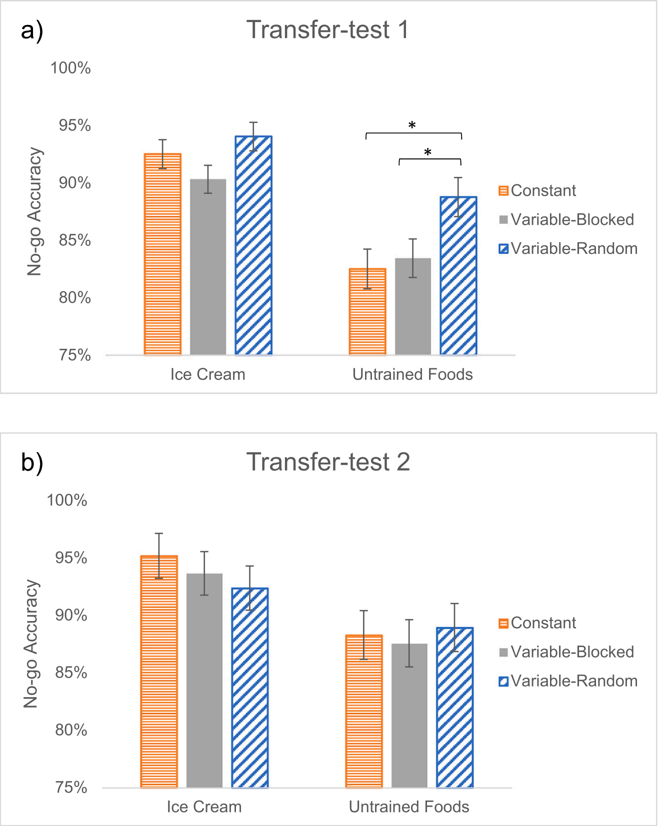

Fig. 2. Performance in Transfer-tests 1 and 2. Illustrated by no-go Accuracy to the ice cream and untrained foods for each group in a) Session 1: administered immediately after training and b) Session 2: administered 24 h after training. Error bars indicate standard error. $^*p < .05$.

3.3. *Food rating task*

For untrained foods, the analysis did not reveal a main effect of time ($F(1.43,128.47) = 0.46$ $p = .630$, $\eta_p^2 = 0.005$) or group ($F(2,90) = 0.72$ $p = .490$, $\eta_p^2 = 0.016$). However, a significant interaction of Time by Group ($F(2.85,128.47) = 5.18$, $p = .002$, $\eta_p^2 = 0.103$) was found, illustrated in Fig. 3a. Contrast analysis found that Group VR had a significant decrease in desire to eat average ratings between Pretest and Session 2($t(180) = 2.71$, $p = .007$, $\eta_p^2 = 0.039$), but not between Pretest and Session 1 ($t(180) = 0.81$, $p = .422$, $\eta_p^2 = 0.004$), or between Session 1 and Session 2 ($t(180) = 1.91$, $p = .058$, $\eta_p^2 = 0.020$). Group C had a significant increase in average ratings between Pretest and Session 1 ($t(180) = -2.51$, $p = .013$, $\eta_p^2 = 0.034$) and between Pretest and Session 2 ($t(180) = -3.28$, $p = .001$, $\eta_p^2 = 0.056$), but not between Session 1 and Session 2 ($t(180) = -0.76$, $p = .456$, $\eta_p^2 = 0.003$). No differences in average ratings across

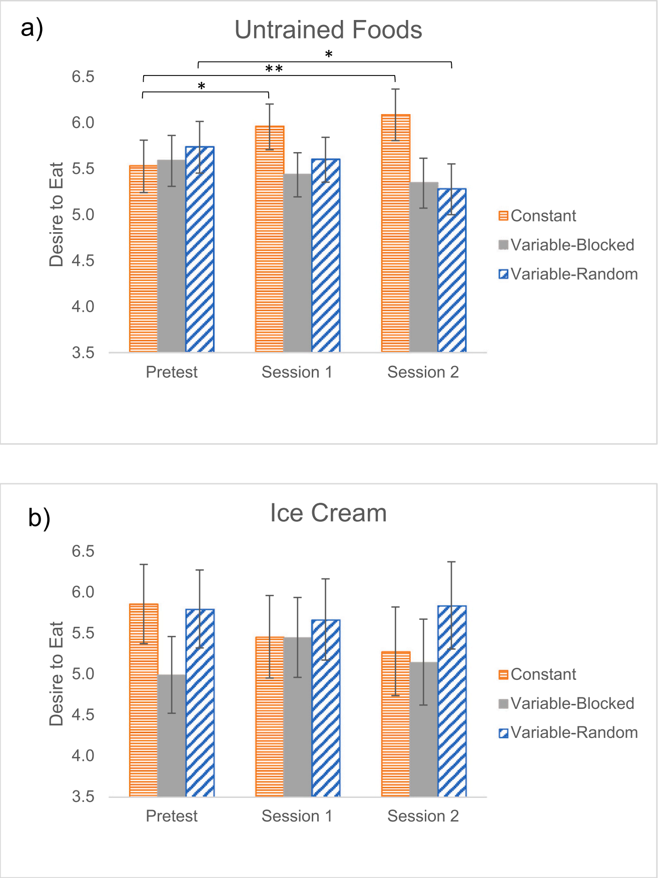

Fig. 3. Performance on Food Rating Task tasks. Illustrated by average ratings between groups on a) Untrained Foods b) Ice cream. Error bars indicate standard error. $^*p < .05$, $^{**}p < .01$.

time points were found in Group VB (Pretest to Session 1: $t(180) = -1.22$, $p = .225$, $\eta_p^2 = 0.008$, Session 1 to Session 2: $t(180) = 0.55$, $p = .586$, $\eta_p^2 = 0.002$). No significant Time by Group interaction was found within the ice cream category ($F(2.48,111.37) = 0.934$, $p = .413$, $\eta_p^2 = 0.020$) (see Fig. 3b). Taken together, these results indicate no effect of stimulus variability or practice order on the devaluation to eat untrained foods immediately after training. However, 24 h later a significant effect of variability and practice order is apparent.

4. Discussion

This study examined the effects of stimulus variability and practice order on generalization of food-specific response inhibition and food devaluation in the framework of a food-specific GNG training. In accordance with the hypotheses, more efficient response inhibition to untrained foods appeared in a group that trained on variable food stimuli in random order (i.e., variable-random group) compared to a group that trained on variable food stimuli presented in a blocked order (i.e., variable-blocked group), and a group that trained on a single food item repetitively (i.e., constant group). However, these effects were not sustained 24 h after training. In contrast, the devaluation of untrained foods was absent immediately after training, but emerged 24 h after training as reduced desire to eat those foods in the variable-random group. In contrast, the constant group showed increased desire to eat untrained foods after training and 24 h later. The variable-blocked group did not differ from either group in the desire to eat untrained foods. Unexpectedly, the desire to eat the trained food (i.e., ice cream) did not change over time in any group.

Although the timeline of effects in the two tasks was inconsistent, this study is the first to demonstrate the benefits of stimulus variability and random practice order on generalization of response inhibition to untrained food items as well as for devaluation of untrained foods. This is in accordance with recent findings showing enhanced generalization of response inhibition following training with high stimulus variability in the GNG task using neutral stimuli (Moshon-Cohen et al., 2024). These results suggest that by including more items and increasing heterogeneity of exemplars during practice, inhibition becomes associated with the larger category of “high-calorie foods” and this enhances generalization of stopping to untrained foods and devaluation of untrained foods. The results also highlight the importance of presenting variable stimuli in random order during training as indicated by superior generalization to untrained foods in the variable-random compared to the variable-blocked group. The elimination of these group differences 24 h later (in Transfer-test 2) could be the result of exposure to a variety of foods in random order during the first transfer test. For the desire to eat untrained foods, the findings show food devaluation as a result of training in the variable-random group, up-valuation in the constant group and lack of change in the variable-blocked group. Together, these findings imply that presentation of variable stimuli in random order is critical for devaluation generalization. The results are consistent with findings from perceptual and motor learning about the effects of high practice variability and random practice order (e.g., Raviv et al., 2022; Travlos, 2010) and suggest that the same principles can be applied to paradigms aimed to increase inhibition of appetitive foods.

The study results also shed light on potential differences between the time course of behavioral and attitudinal generalization after GNG training. While the benefit of training on response inhibition performance was evident immediately after training and dissipated after 24 h, the effect of training on the desire to eat was only evident 24 h after training and not immediately after training. This may suggest that generalization of behavioral performance and attitudinal factors involve a different time course. It could be that generalization of devaluation may take more time to evolve after training. This notion is in line with previous results from other domains showing that offline consolidation processes improve generalization (Fenn et al., 2003; Gómez, 2011). Additionally, these results highlight the importance of attempting to better characterize the time course through which devaluation occurs after food GNG training.

It is noteworthy that the methodology in this study differs from previous studies on food-specific response inhibition. This study provided explicit instructions prior to training not to respond when encountering food stimuli. A similar procedure yielded robust group differences in generalization in our previous study (Moshon-Cohen et al., 2024). Nevertheless, most studies on food devaluation after GNG training utilize more implicit learning of food-stop associations by presenting food stimuli that are paired with go or no-go instruction cues (i.e., cued-GNG; see Veling et al., 2022). It is unclear whether the mechanisms through which cued-GNG training operate are similar to those which label specific stimuli as go or no-go. For example, it has been proposed that when a no-go cue appears after an appetitive food stimulus, this causes updating of the value of that stimulus in order to align behavior with task requirements (Veling et al., 2022). As such, within cued-GNG, presentation of the no-go cue after the appetitive food stimulus is important for the process of devaluation (Liu et al., 2023). In contrast, in non-cued-GNG tasks, as used in the current study, devaluation cannot occur through a similar process as there are no cues presented. Alternatively, it could be that devaluation occurred through a more proactive process involving a-priori negative inferences regarding food items (Van Dessel et al., 2019) that had impact on both behavioral performance (i.e., improved response inhibition to food) and devaluation of untrained food items.

An unexpected finding in the current study was that devaluation did not occur for the trained item (i.e., ice cream). Lack of devaluation of trained items is not consistent with common results in food-specific GNG training studies (see Veling et al., 2022). A possible reason for the absent devaluation of the trained food item is that after the training and before the food rating task, participants were administered with an additional GNG task (i.e., Transfer test 1) to assess the impact of training on response inhibition. Within this test, there were equal proportions of go and no-go items (i.e., in contrast to the training which involved 25 % no-go trials). The change in proportion may have retrained participants with a reduced effort to stop responses to the ice cream (presented in Transfer-test 1). It has been previously shown that administering measures similar to training may interfere with subsequent tests (Chen et al., 2021). Note that this may explain why devaluation effects occurred only for untrained stimuli in the desire to eat task, as these were different than the untrained stimuli presented in Transfer-test 1.

An alternative explanation for the lack of devaluation of trained foods may be related to the large number of training trials. Previous studies on one-session food-specific GNG training utilized far less training trials which led to devaluation of trained items but did not induce generalization (Adams et al., 2021; Chen et al., 2016; Chen, Veling, De Vries, et al., 2018; Chen, Veling, Dijksterhuis, & Holland, 2018; Lawrence et al., 2015; Masterton et al., 2021). Researchers have proposed that the continuous efforts to inhibit a response to food may have paradoxically resulted in disinhibition (Jansen & van den Hout, 1991; Weinbach et al., 2020), similar to the mechanisms that occur in restrained eaters after exposure to palatable foods (Jansen & van den Hout, 1991). This would have essentially balanced out the devaluation effects and ultimately led to no change in evaluation of the trained ice cream stimulus. The up-valuation of untrained foods that we found in the constant group after training supports this claim; the constant and repetitive inhibition towards only the ice cream stimulus may have resulted in greater disinhibition which generalized towards other palatable foods.

Limitations of the study include running the study remotely, thus, limiting the ability to control the environment in which the training was performed. Additionally, fixed food items were used for all participants. Variability in food preference likely exists among participants that could impact response inhibition to different food items as well as food devaluation. Future studies could benefit from using a personalized food selection approach based on each participants' personal preferences.

Despite these limitations, the current study has theoretical and applied implications. This study demonstrated that stimulus variability and random order of items during food-specific GNG training improves generalization of response inhibition to novel untrained foods and leads to devaluation of untrained foods. Notably, due to modest effect sizes and inconsistencies in the timeline of the two effects, further exploration is required before practical recommendations for GNG training can be established. Future studies are encouraged to assess the impact of additional parameters (e.g., number of trials, stimuli, breaks) on generalization effects of response inhibition trainings. Establishing empirically based principles of training characteristics that facilitate generalization will allow maximizing their utility.

Author agreement

All authors, Tamara E. Moshon-Cohen, Tali Bitan and Noam Weinbach have seen and approved the final, submitted version of this manuscript.

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CRediT authorship contribution statement

Tamara E. Moshon-Cohen: Writing – original draft, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tali Bitan:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Noam Weinbach:** Writing – review & editing, Validation, Supervision, Software, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

FoodDevaluation_Dataset_OSF (Original Data).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eatbeh.2024.101902.

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