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The 'Go's and the 'No-Go's of response-inhibition training to food: lessons learned from trials

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High food-reward sensitivity and low inhibitory control are modifiable targets for overeating interventions. Our review of 16 food-related response-inhibition training (RIT) trials identified key elements linked to effectiveness, including recruiting from at-risk populations (i.e. those with overweight or heightened snacking behaviour), and designing intervention tasks to support bottom-up, associative (food-inhibition) learning. The optimal comparison condition depends on the research question, but the most consistent training effects have been seen relative to generalised (non-food) RIT. Trial outcomes should prioritise objective and validated measures (e.g. weight loss and explicit food devaluation). Future trials should consider unanswered questions such as training schedules and timing, and whether training people to 'go' to healthy foods can increase their appeal.

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Introduction

Poor diet is one of the leading causes of premature mortality [1]. Many people know they should eat more fruits, vegetables and wholegrains and fewer foods high in fat, sugar and salt (HFSS), but struggle to translate their intentions into behaviour. This is partly because HFSS foods are highly rewarding, and rapidly attract attention and elicit motor excitation and approach responses, resulting in cravings and impulses that can be hard to control [2]. Those at particular risk of overeating have strong automatic reward responses to HFSS food and ineffective response inhibition [3]. Recent interventions for overeating target these automatic responses to food, for example, by training people to attend away from HFSS foods or by repeatedly avoiding or inhibiting their motor responses to them [4].

In this narrative review, we focus on identifying the key features of 16 trials of food-specific response-inhibition training (RIT) [5•–19], which are associated with the most positive outcomes. In doing so, we identify the most suitable participants, intervention components, comparison condition, and outcomes (PICO) from real-world trials to guide the design of future food RIT interventions and evaluations.

Background summary

Food RIT adapts Go/No-go (GNG) or stop-signal tasks (SSTs) to require participants to respond (Go) to neutral items or healthy foods, and to inhibit responding (No-go) to HFSS foods [20]. Specific stimuli (e.g. images of sweet snacks) are consistently paired with a stop or no-go signal, such as an auditory tone or a coloured frame around the image. This signal is presented simultaneously with HFSS food in GNG tasks, making motor inhibition easy, but is presented after a delay in SSTs, making inhibition more difficult (see [21] for differences between GNG and SST). Over the past decade, approximately 36 studies have examined food RIT, and several meta-analyses report robust medium effects (d = 0.4–0.5) on reducing food intake and choice [4,22–25] (for relevant p-curve analyses see [26,27]). Stronger effects result from tasks that train more associative 'bottom-up' forms of inhibition, such as the GNG, relative to tasks that place greater demands on 'top-down' forms of inhibition, such as the SST [23,28].

The mechanisms underlying food-RIT effects on intake and choice are unclear, but evidence indicates a role for learnt (automatic) stimulus-inhibition associations [29,30] and reduced liking (devaluation) of inhibited food stimuli, another consistently observed effect of food RIT (e.g. [31,32•]), which is theorised to resolve conflict between 'go' and 'inhibit' response tendencies [33]. In contrast, there is scant evidence for training-related

improvements in top-down inhibitory control as measured on separate GNG or SSTs, which generally show negative results [8,16,17]. Neuroimaging data support the devaluation and automatic motor- inhibition (reduced motor excitation) accounts, rather than improvements in top-down inhibitory control; studies show training-related reductions in activation in reward, attention and motor-related brain regions, but no increases in activation in prefrontal brain circuits associated with inhibitory control [9•,19], see also [34].

Whilst the laboratory evidence that food RIT modifies eating behaviour is robust [4,22–24], it is unclear how well intervention effects translate to the real world and over the longer term. This review considers 16 trials examining the effects of multiple sessions of food RIT (see Table 1). Trials are identified based on the 'trial' (vs. lab study) inclusion criteria recommended by Wiers et al [35].[1] The majority (12 out of 16) of these trials reported positive effects on at least one outcome related to eating behaviour (weight, food intake or liking, see Table 1). We have identified common features of these trials, and using the PICO framework, we provide a current guide to developing an effective food-RIT intervention and appropriate evaluation. These include the need to recruit at-risk populations, to employ tasks that train associative inhibition effectively (and show evidence of this) and to include both validated and objective outcome measures, for example, stimulus devaluation and weight loss.

Population

Both common sense and evidence suggest that trial participants should be those who like/are frequent consumers of the trained no-go foods (i.e. those for whom training-induced devaluation and inhibition could have the greatest impacts on energy intake and weight loss). Indeed, food RIT facilitates weight loss among participants with a higher body mass index (BMI) [14,18] or with greater baseline food intake or liking [11••,14]. Null effects on these outcomes have been observed in healthy-weight, unselected (e.g. low snacking) samples [5•], see also [36•] for similar findings using combined food GNG/cue-approach training. More proximal outcomes (such as devaluation) *can* be impacted in healthy populations [5•,36•], however, evidence indicates that food RIT brings the greatest behaviour change and weight-loss benefits to 'at risk' or overweight populations.

[1] We included studies that aimed to test the efficacy of RIT (as a stand-alone or adjunct intervention to treatment as usual), and that included participants who were aware that they may receive an intervention, and were motivated to change their behaviour. We have not included lab studies or trials that combined RIT with other cognitive interventions, such as training attention, approach responses, working memory or if-then plans [34,36•–40].

Intervention

RIT task parameters should be carefully designed to support bottom-up associative (HFSS food-inhibition) learning. This includes facilitating high accuracy on HFSS food–No-go trials, which is linked to RIT effects [23] (Box 1, Figure 1). Inhibition accuracy tends to be higher (see Table 1) in GNG tasks, likely because the task is easier than the SST. However, this needs to be complemented with ensuring the task remains challenging and engaging. RIT tasks should include at least 50% Go trials (to place some demands on inhibition, [31]) and include filler items that have 50% Go and 50% No-go response mappings [14], which also enables a direct measurement of stimulus-response (S-R) learning during training (e.g. greater No-go accuracy and faster Go reaction times to consistently paired foods vs. inconsistently paired fillers indicate associative learning). It is notable that all six trials showing evidence of such S-R learning in their training tasks reported significant effects on at least one of weight loss, food intake or devaluation [5•,7,13,14,16,19]. The remaining trials either did not measure or report RIT task performance data, but it is possible to estimate task potential for training related associative-inhibition at the HFSS food stimulus or category level by examining task parameters (see Box 1). We suggest that all of the trials reporting positive findings are likely to have trained associative inhibition to HFSS foods (Table 1), with the exception of one ([6] study 1), whose BMI findings were based on self-report and failed to replicate using objective measures ([6] study 2). In contrast, it is doubtful whether the four food-RIT trials reporting null effects effectively trained associative inhibition to HFSS foods, for example, because they used a SST or included diverse Go and No-go foods, which may compromise category-level learning and generalisation ([6] study 2 [8,10,17]; see Table 1. See also [40] for a lengthier discussion of this point).

Interventions are only effective if the target audience engages with them. Lab studies have shown that the amount of attention paid to stimuli during RIT can determine the strength of effects on subsequent outcomes [41,42] and testing in busy/distracting environments can sometimes lead to null effects (e.g. [43]). Manipulating the GNG cues may help to boost attention to food stimuli, for example, by having a short delay between the presentation of the food and No-go cue, or by using the foods themselves as a stop cue (Box 1). Gamification to increase short- and long-term engagement is a potential solution (see [36•] for an excellent example of a trial testing food GNG with state-of-the-art game design principles). However, gamification should be executed carefully as it can weaken or obliterate training effects, for example, if complex visuals and mechanics interfere with attention to food stimuli and S-R learning [11••,17]. Gamification may be more

Table 1

Summary table of key elements in trials of food-specific RIT describing the PICO. Trials with an asterisk showed positive findings for at least one eating-related outcome (weight loss, food intake or food valuation). The Intervention column includes (in italics) evidence for, or an estimate of, associative S-R learning. FFQ = food frequency questionnaire, VAS = Visual Analogue Scale. L/R = left/right response, EEG = electroencephalography, fMRI = functional magnetic resonance imaging, EMA = ecological momentary assessment, EDE-Q = Eating Disorders Examination questionnaire.

Study	Population	Intervention *Estimate of potential for associative inhibition*	Comparison	Outcomes	Findings
*Adams et al., 2021 [5•]	308 healthy, 78% female BMI *M*=23.7, age *M*=24.5	100% No-go to 9 HFSS snack foods (cakes, biscuits, crisps, chocolate), 100% Go to 9 healthy foods (fruits, vegetables, crispbreads). 50% Go and No-go to non-food Filler items (clothing). L/R response on Go trials. (N=167) 96% HFSS-No-go accuracy 1/day for 4 days (4 trainings) *Good category-level learning (specific S-R associations for Go and No-go stimuli shown)*	Non-food GNG (N=141)	After 2 weeks: Liking (VAS) Food Intake (FFQ) Weight	 Positive: Reduced more in active Null: Reduced in both Null: Reduced in both
*Allom & Mullan, 2015 [6] study 1	72 healthy students, 80% female BMI *M*=22.6, age *M*=20.4	SST with 50% stop to 8 HFSS-foods (e.g. chips, chocolate) and 100% Go to 8 healthy foods (fruits and vegetables). Stop-signal delay calibrated for 50% stop accuracy. Healthy/unhealthy food categorisation on Go trials. 50% stop accuracy for HFSS foods (N=26) 1/day for 10 days (10 trainings) *No S-R learning data but would expect weak HFSS-food inhibition learning due to lack of consistent inhibition (on 25% of HFSS food trials)*	Food SST (both HFSS and healthy foods 25% associated with stop signal) (N=21) Food Go (no stop signals) (N=25)	After 12 days: Fat intake (FFQ) BMI (self-reported)	 Null: No changes in fat intake Positive: Reduced more in active
Allom & Mullan, 2015 [6] study 2	70 healthy students, 78% female BMI *M*=23, age *M*=23 years	As above (N=24 to food SST)	As above (N=23)	After 12 & 18 days: Fat intake (FFQ) BMI (measured)	 Null: No changes in fat intake Null: No changes in BMI
*Camp & Lawrence, 2019 [7]	81 meat eaters interested in meat reduction, 84% female Age *M*= 24.5	100% No-go to 8 meats, 100% Go to 8 healthy foods (fruits, vegetables, crispbreads). 50% Go and No-go to 8 Filler items (clothing). L/R response on Go trials. (N=48) 94% meat-No-go accuracy 1/day for 4 days (4 trainings) *Good category-level learning (specific S-R associations for Go and No-go stimuli shown)*	Non-food GNG (N=33)	After 4 weeks: FFQ Liking (VAS) Meat diary (during training week)	 Positive: Reduced more in active Positive: Reduced more in active Null: No group differences
Carbine et al., 2021 [8]		100% No-go to 10 high-calorie foods, 100% Go to 10 healthy foods (fruits,	Non-food GNG (N=48)	After 4 & 12 weeks:	

Table 1 (*continued*)

Study	Population	Intervention *Estimate of potential for associative inhibition*	Comparison	Outcomes	Findings
	100 with overweight/obesity, 53% female BMI *M*=32.5, age *M*=28.05	vegetables,). 50% Go and No-go to 20 non-food Filler items (diverse). Different images in each training session (selected from 100 high-calorie, 100 healthy and 200 non-foods). L/R response on Go trials. ? % HFSS-no-go accuracy (not reported) (N=52) 4/week for 4 weeks (16 trainings) *No S-R learning data but would expect weak/moderate HFSS-food inhibition learning due to the diverse range of foods and filler items included and lack of repetition (expected to lead to weak learning at category-level)*		Weight Food intake (24 hour recall) EEG (N2 component) Food inhibitory control (GNG with different food images to training) Power of Food scale	Null: No weight loss Null: No changes in food intake Null: No differences in EEG Mixed: Active group more accurate than controls at 4 but not 12 weeks but due to decreased accuracy in controls. Null: Both groups reduced
*Chen et al., 2019 [9•]	36 chronic dieters, 100% female BMI *M*= 22.5, age *M*=19.1	SST with 8 HFSS-foods as stop cues (100% associated) and left/right arrows as targets. Stop-signal delay calibrated for 50% stop accuracy. 8 different HFSS foods per training (x 10 trainings = 80 foods). L/R response on Go trials. (N=18) 50% stop accuracy (for arrow targets) 10 trainings over 12 days *No S-R learning data but would expect good learning due to HFSS foods constituting the stop cues (i.e. 100% associated with need to stop, even if arrows only successfully stopped to on 50% of trials). No foods were presented on Go trials so task trains a consistent "food-stop" association*	Non-food SST (arrows with auditory stop cue) (N=18)	After 2-3 weeks: fMRI reward and control system responses EMA food desires (7 days)	Positive: Reduced more in active in reward (VS, OFC ROIs and network) and frontoparietal control system Positive: Reduced more in active
Forman et al., 2016 [10]	119 students with habitual intake of salty snack foods, 62% female BMI *M*=24.5, age *M*=22.7	SST with 50% stop to 12 salty snack foods and 100% Go to 12 non-foods (chairs). Stop-signal delay calibrated for 50% stop accuracy. Food/chairs categorisation on Go trials. 50% stop accuracy for foods (N=27) 1/day for 4 days (4 trainings but on average 2 completed) *No S-R learning data but would expect weak food-inhibition learning due to lack of consistent inhibition (on 25% of food trials)*	60 minute psycho-education on reducing salty snacks (N=27)	After 1 week: Intake of salty snack foods (EMA 3 x day for 7 days pre and post-training)	Null: Both groups reduced

Table 1 (*continued*)

Study	Population	Intervention *Estimate of potential for associative inhibition*	Comparison	Outcomes	Findings
*Forman et al., 2019 [11••]	106 with high sweet food intake and overweight, 91.5% female BMI *M*=33.5, age *M*=47.3 years	100% No-go to 35 sweet energy-dense foods, 100% Go to healthy foods (fruits, vegetables,). 50% Go and No-go to 8 non-food Filler items (e.g. toothpaste). L/R response on Go trials. ? % HFSS-no-go accuracy (go response latency reduced with increasing accuracy so N/A) (N=29) 44 trainings over 8 weeks *No S-R learning data but would expect good learning due to clear delineation of Go and No-Go categories with repetition of personalised No-go items*	Food Go (L/R response to foods and fillers) (N=23)	After 6 & 8 weeks: Weight Associations with sweet foods (Implicit Association Test)	 Null: Both groups lost weight but Positive: Moderation - reduced more in active with implicit preference for sweet foods Null: Implicit Association test sweet liking not changed
*Forman et al., 2021 [12]	20 with high sweet food intake and overweight, 100% male (new participants added to above 2019 study) BMI *M*=33.4, age *M*=46.7	Training as above Study compared gamified vs. non-gamified RIT (N=76) in men (n=25) and women (n=51). Data combined with active participants from above study.	N/A	After 8 weeks: Weight	 Positive: Moderation – Reduced more with gamified training in men but not women
*Keeler et al. 2021 [13]	80 with bulimia nervosa or binge eating disorder, 96% female BMI *M*= 29.2, age *M*= 31.8	100% No-go to 8-24 (personalised) HFSS snack foods, 100% Go to 24 healthy foods. 50% Go and No-go to 24 filler items (clothing, stationery, flowers). Tap Go image on Go trials. (N=40) 99.92% HFSS-no-go accuracy 1/day for 28 days (median 21 trainings) *Decent category-level learning (specific S-R associations shown) – significant for Go trials but not for No-go (but >99% accuracy so ceiling effects)*	Treatment as usual (no training) (N=40)	After 4 weeks: Binge frequency EDE-Q (symptoms) Liking	 Null: Both groups reduced Positive: Reduced more in active Positive: Reduced more in active
*Lawrence et al 2015 [14]	83 selected for frequent HFSS-food intake and disinhibition, most with overweight/obesity, 74% female BMI *M* = 29, age *M* = 50.5	100% No-go to 9 HFSS snack foods (cakes, biscuits, crisps, chocolate), 100% Go to 9 healthy foods (fruits, vegetables, crispbreads). 50% Go and No-go to Filler items (clothing). L/R response on Go trials. (N=41) 98% HFSS-no-go accuracy 1/day for 4 days (4 trainings) *Good category-level learning (specific S-R associations for Go and No-go stimuli shown)*	Non-food GNG (N=42)	After 2 weeks: Weight Kcal (24hr diary) Food Intake (FFQ) Liking (VAS) Food Intake (taste test)	 Positive: Reduced more in active Positive: Reduced more in active Null: Reduced in both Positive: Reduced more in active Null: No difference between groups but poorly controlled

Table 1 (*continued*)

Study	Population	Intervention *Estimate of potential for associative inhibition*	Comparison	Outcomes	Findings
*Memarian et al., 2021 [15••]	46 children with overweight or obesity and high sugar cravings, 47.5% female Age *M* =9.2 (range 7-11)	100% No-go to 10 (personalised) energy-dense sweet foods, 100% Go to 10 (personalised) healthy foods. 50% Go and No-go to 10 filler items (stationery). Progressively harder each day, e.g. shorter trials and faint or missing No-Go signals. Select the Go image on Go trials (out of 2 images). (N=23) Over 80% accuracy 1/two days for 2 weeks (7 trainings) *No S-R learning data but would expect good learning as on day 6 and 7 there were no No-go signals but participants had to respond with at least 80% accuracy, suggesting they had learnt S-R associations (Go to healthy foods)*	Non-food GNG (N=23)	After 2 weeks and 3 months: Food Intake (taste test) Sweet food choice BMI	 Positive: Reduced more in active, maintained at 3 months Positive: Reduced more in active, not maintained at 3 months Null: Both groups increased BMI (normal in children)
*Oomen et al., 2018 [16]	41 healthy but scored high on uncontrolled eating, 76% female BMI *M*= 22.5, age *M*=22.6	100% No-go to 8 HFSS snack foods (cakes, biscuits, crisps, chocolate), 100% Go to 8 healthy foods (fruits, vegetables, rice-cakes). 50% Go and No-go to Filler items (clothing). L/R response on Go trials. (N=21) 97% accuracy 1/day for 6 days (6 trainings) *Good category-level learning (specific S-R associations for Go and No-go stimuli shown)*	Non-food GNG (N=20)	After 1 week: Food Intake (taste test) Food No-go (different images) Cue induced craving (video)	 Positive: Reduced in active Null: Both groups improved Null: Both groups reduced
Poppelaars et al., 2018 [17]	104 young adults, 89% female BMI *M*= 24.07, age *M*=20.95	100% No-go to 40 high-calorie foods, 100% Go to 120 non-foods (household items). Simple button press on Go trials. Gamified "infinite runner" task. ? % food-no-go accuracy (adaptive task - go response latency reduced with increasing accuracy) (N=51) 1/day for 1 week (7 trainings) *No S-R learning data but there may have been weak food-inhibition learning due to increased task difficulty (adaptive speeding) compromising inhibition success, and the option to execute "avoid" responses (switching lanes) rather than inhibit responding on No-Go trials.*	No training (healthy eating brochure and website). (N=53)	After 1 week: Liking (VAS) Food-specific inhibitory control (in a separate, modified GNG task). Food Intake (taste test) (N=64)	 Null: Both groups reduced Null: No change in either group. Null: No change in either group.

Table 1 (*continued*)

Study	Population	Intervention *Estimate of potential for associative inhibition*	Comparison	Outcomes	Findings
Veling et al., 2014 [18]	55 healthy, 91% female BMI *M*=24, age *M*=22.3	100% No-go to 100 HFSS foods, 100% Go to 100 non-foods. Space-bar on Go trials. (N=29) 98.4% accuracy 1/week for 4 weeks (4 trainings) *No S-R learning data but would expect good learning due to clear delineation of Go and No-Go categories and images appearing 100 ms before Go or No-Go signals so attracting attention*	Non-food GNG (N=26)	After 4 weeks: Weight Food Intake (24 hour FFQ)	 Positive: Reduced more in active Null/Mixed: Main (pre-post) analysis showed no difference between groups but data per week suggested greater reduction in active than control group.
Yang et al., 2021 [19]	51 overweight (in Asia BMI 23+), 93% female BMI *M* = 25.6, age *M*= 19.5	100% No-go to 80 HFSS foods, 100% Go to 80 healthy foods. 50% Go and No-go to Filler items (glasses of water). Same items repeated in each training. L/R response on Go trials. (N=24) 99% HFSS-no-go accuracy 1/week for 5 weeks (5 trainings) *Good category-level learning (specific S-R associations for Go and No-go stimuli shown)*	Non-food GNG (N=27)	After 5 weeks: Attractive (VAS) fMRI Weight	 Positive: Reduced more in active Positive: Reduced more in active (inhibition/craving/reward) Null: No change in either group

Box 1 Recommendations of the key elements for training associative ('bottom up') inhibition. ***See*** **Figure 1** ***for an example of recommended methods.***

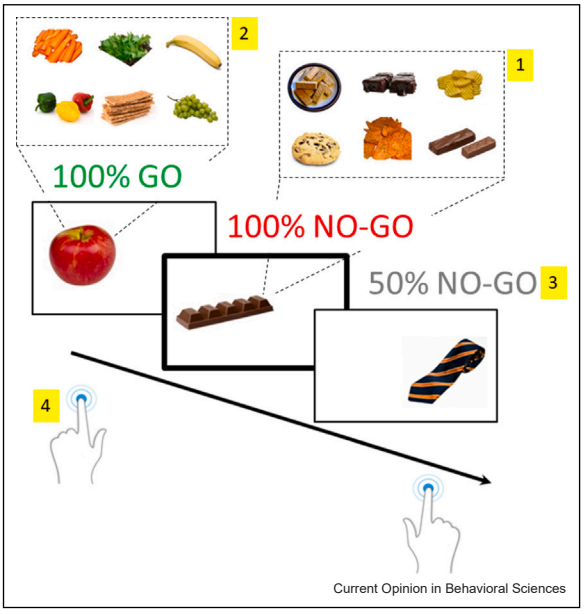
Aim	Rationale and evidence	Recommended methods (see figure 1 for example)	Other methods
1. Establish S-R inhibition learning	Create direct associations between HFSS foods and the inhibition of a motor response. (Differs from *indirect* associations between HFSS foods and a stop signal, which may not be consistently followed by response inhibition, [30])	Specific HFSS foods are repeatedly associated with the successful inhibition of a response. For example, GNG task where HFSS foods are 100% associated with a No-go cue (Figure 1, 1) and inhibition is easy resulting in high rates of successful inhibition (e.g. above 95% [13])	HFSS foods are inconsistently associated with response inhibition. For example, SSTs where HFSS foods are equally presented on Go and stop trials and the stop-signal delay is calibrated to maintain stopping accuracy at ~50% (i.e. participants would inhibit responding to HFSS foods on ~25% of HFSS trials) [6,10]
2. Establish category-response inhibition learning	Encourage associative inhibition to generalise from the item to the category level (i.e. to HFSS foods other than the precise items presented during training)	Several exemplars from a clear and meaningful category of HFSS food [47] or a small number of categories [13] are consistently paired with response inhibition (Figure 1, 1). A clearly delineated category of healthy food such as fruits and vegetables, for example, [14] or non-food items, for example, [18] is paired with Go responses (Figure 1, 2). Task may also include a third clearly delineated category of filler items such as clothing (Figure 1, 3 [14]).	No clear HFSS-food category is associated with response inhibition. For example, a wide range of healthy and unhealthy foods are paired with Go and No-go trials respectively and/or food items are not repeated between training sessions (e.g. [8]). This could lead to participants learning inconsistent associations at the level of a general food category, which would not be helpful, i.e. they may learn a 'food = 50% Go, 50% No-go' association, similar to some 'sham' training tasks.
3. Maximise Attention to HFSS food cues	Increase attention to HFSS food cues to enhance learning of stimulus-inhibit associations	Participants attend to all images either because they need to respond to some aspects such as item location (Figure. 1, 4; [14]), or they act as the stop cues (e.g. [9•]), or they appear shortly (100 ms) before the No-go signal (e.g. [18]). Unpredictable (50% Go and No-go) filler items (Figure 1, 3) may also help to maintain challenge and attention.	There is no need to attend to the food images, for example, the no-go cue is a simultaneously presented letter and Go trials only require a simple (e.g. space bar) response rather than indicating the item location (e.g. [48]). Note — there are no published real-world trials of this precise form of RIT for food but there are some null findings for trials for alcohol [49] or combined RIT/attention training for food [38].

beneficial for some populations such as children [43] and men, but not women [12]. We recommend implementing simple gamification strategies that enhance user engagement (such as point scoring) without compromising GNG training [44]. In sum, we recommend (i) designing tasks that challenge inhibition while allowing high accuracy, (ii) ensuring Go and No-go food categories are clearly defined, (iii) including measures of S-R learning in trial reports (e.g. by comparing accuracy and response times to foods vs. fillers), as without these data, null effects of RIT interventions are difficult to interpret and (iv) implementing simple gamification strategies to enhance engagement.

Comparison

The comparison conditions used in food-RIT trials have included active control training tasks, and no-training 'treatment as usual' conditions, sometimes involving psychoeducation [10,13,17]. The choice of comparison condition partly depends on the research question, for example, trying to isolate the specific active ingredient of training in more fundamental studies versus trying to understand efficacy in a real-world setting. Most studies have used a neutral (non-food) inhibition training task in the control condition [5•,7–9•,14–16,18,19] but a few have used a condition where HFSS foods are associated with Go responses only [6,11••], or a 'sham' training where HFSS foods are equally associated with Go and No-go responses [6]. Whilst including food items in control tasks can control for stimulus exposure and participant-expectation effects [36•], training Go responses to HFSS foods may have adverse effects on eating behaviour [5•], and partial inhibition ('sham') training may still result in some stimulus-inhibition learning (see discussion in [36•,45]). Most trials therefore opt for a non-food control training (e.g. [18]) and these have generally shown positive effects (with the exception of [8]) but participant blinding may not be optimal [5•]. One might expect the strongest effects in trials using a no-training control condition but this has not been the case so far, with only one of three such trials showing positive effects [13], although the other two trials [10,17] did not use optimal interventions, making interpretation difficult. We recommend that future trials continue to

Figure 1



Example of a RIT task containing key elements to encourage associative learning of HFSS-food inhibition (see Box 1 table above). Taken from [14] . Task adapted for use in several trials reporting positive results [5•,7,13,16,19]. It includes 1) a limited number of items/categories of HFSS food that are consistently and repeatedly paired with No-go cues. 2) A distinct category of healthy foods is always paired with Go cues and 3) a third distinct category of fillers (e.g. clothing items) is equally paired with Go and No-go cues. The fillers provide a baseline for measuring associative responses to food items, keep the task challenging and help to make the foods relatively more predictive.

explore the optimal control condition, using the other recommendations in this review to design strong trials and facilitate interpretation of findings. Trials should also measure participant blinding and expectations as these may also contribute to RIT effects [5•].

Outcome

Trials of food RIT have examined a range of outcomes (Table 1), including intake (predominantly measured using self-report via food diaries or food frequency questionnaires), weight loss (mainly measured by a researcher, but sometimes self-report) and tasks measuring putative mechanisms (e.g. devaluation, improved inhibitory control).

A limitation in the field is the over-reliance on self-reported intake as an outcome, which has generally not shown positive effects of RIT (i.e. positive in two out of eight trials [7,14]). Of note, four of the trials reporting null or mixed effects on self-reported intake showed positive effects on other outcomes [5•,7,14,18]. Reductions in self-reported intake are often observed in both the intervention and control groups, likely due to non-specific trial effects such as the recruitment of motivated participants, placebo effects and engagement in self-monitoring. Self-reported intake, particularly when measured using simple instruments such as food frequency questionnaires, is likely to be less accurate, sensitive and reliable than objectively measured intake, which has shown more consistent and robust effects of RIT in many lab studies (e.g. see [23]). In line with this, of the three trials that included an objective measure of food intake under controlled conditions, two reported positive effects of food RIT [15••,16] and one was negative [17], although the latter used an intervention that may not have trained associative inhibition (Table 1).

An advantage of RIT for food (over alcohol and smoking) is the relative ease of measuring weight loss objectively, and this has been done in eight trials. Three of these found greater weight loss in active versus control groups, at least in more at-risk populations [11••,14,18] and five reported null effects. As discussed above, most of the null trials used an intervention that may not have effectively trained associative inhibition [6,8] or recruited a suboptimal population (i.e. those who may not frequently consume the trained no-go foods [5•,19]). Memarian and colleagues [15••] attributed their null effects on BMI in children to a lack of dieting motivation or the sweets-specific nature of their training. In order to draw clearer conclusions about RIT effects on weight loss, we need more well-designed trials in at-risk individuals.

Outcomes related to mechanisms

Several studies have reported significant devaluation of inhibited foods, measured using subjective ratings of liking, attractiveness or daily cravings [5•,7,9•,13,14,19] and fMRI cue reactivity in brain-reward systems [9•,19]. In contrast, two trials reported null findings for devaluation measured using explicit ratings [17] or an implicit association test [11••]. Explicit measures have greater sensitivity for detecting training-related devaluation [19] and the null result reported by Poppelaars and colleagues [17] may have been due to a suboptimal intervention.

In terms of improvements in inhibitory control to trained stimuli, it is important to distinguish between automatic, associative inhibition and more 'top-down' forms of inhibition (see [30]). Trials measuring top-down inhibitory control (i.e. in a separate SST or GNG, given before and after training and using different stimuli to those in the training task) have shown negative or unclear RIT effects [8,16,17]. In contrast, as described above, trials that have measured stimulus inhibition or stimulus-Go associations within the training task itself have all shown evidence of S-R learning [5•,7,13,14,16,19]. This

discrepancy between different measures of stimulus-related inhibition (measured within the training task vs. using a separate task with different stimuli) has even been demonstrated within a single study [16]. This underscores the importance of integrating and reporting measures of S-R associative learning within the training itself. Finally, the fact that those studies that did not show evidence of devaluation or improved associative inhibition also failed to find training effects on more distal outcomes further lends support to these as potential mechanisms of RIT (see also [40]).

Conclusions and future directions

This review of 16 trials of food RIT argues that positive findings are related to the use of tasks that train more associative forms of inhibition in more at-risk populations, and measure effects on more objective outcomes. It encourages researchers to measure S-R learning within their training tasks and to include simple standard outcomes (such as explicit devaluation of HFSS foods measured using visual analogue scales [32•]) to facilitate comparison between trials. Such comparison would help to address important unanswered questions such as the most effective amount and timing of RIT [46], whether training people to Go to healthy foods (in addition to No-go to HFSS foods) can increase their valuation and intake (e.g. [5•,46]) and whether training is best completed on a static computer or a mobile device [46]. By implementing the current recommendations in adequately powered, pre-registered trials, future research will be able to clarify whether, and how, food RIT translates into real-world changes in eating behaviour.

CRediT authorship contribution statement

Natalia Lawrence: Conceptualisation, Methodology, Investigation, Writing – original draft, Visualization; **Lucy Porter:** Conceptualisation, Investigation, Writing – original draft; **Petra Staiger:** Conceptualisation, Writing – review & editing.

Conflict of interest statement

None

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Roth GA, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N, Abbastabar H, Abd-Allah F, Abdela J, Abdelalim A: **Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017**. *Lancet* 2018, **392**:1736-1788.

2. Stice E, Lawrence NS, Kemps E, Veling H: **Training motor responses to food: a novel treatment for obesity targeting implicit processes**. *Clin Psychol Rev* 2016, **49**:16-27.

3. Nederkoorn C, Houben K, Hofmann W, Roefs A, Jansen A: **Control yourself or just eat what you like? Weight gain over a year is predicted by an interactive effect of response inhibition and implicit preference for snack foods**. *Health Psychol* 2010, **29**:389.

4. Aulbach MB, Knittle K, Haukkala A: **Implicit process interventions in eating behaviour: a meta-analysis examining mediators and moderators**. *Health Psychol Rev* 2019, **13**:179-208.

5. • Adams RC, Button KS, Hickey L, Morrison S, Smith A, Bolus W, Coombs E, Randolph S, Hunt R, Kim D: **Food-related inhibitory control training reduces food liking but not snacking frequency or weight in a large healthy adult sample**. *Appetite* 2021, **167**:105601.

The largest pre-registered trial of food RIT involving 308 participants. This trial used a previously validated active (vs. non-food control) intervention and demonstrated significant S-R learning and devaluation of HFSS foods. Null effects on weight loss were attributed to the population being predominantly young, healthy-weight adults who were not frequent consumers of the trained HFSS foods.

6. Allom V, Mullan B: **Two inhibitory control training interventions designed to improve eating behaviour and determine mechanisms of change**. *Appetite* 2015, **89**:282-290.

7. Camp B, Lawrence NS: **Giving pork the chop: response inhibition training to reduce meat intake**. *Appetite* 2019, **141**:104315.

8. Carbine KA, Muir AM, Allen WD, LeCheminant JD, Baldwin SA, Jensen CD, Kirwan CB, Larson MJ: **Does inhibitory control training reduce weight and caloric intake in adults with overweight and obesity? A pre-registered, randomized controlled event-related potential (ERP) study**. *Behav Res Ther* 2021, **136**:103784.

9. • Chen P-HA, Kelley WM, Lopez RB, Heatherton TF: **Reducing reward responsivity and daily food desires in female dieters through domain-specific training**. *Soc Neurosci* 2019, **14**:470-483.

One of the only studies that has used HFSS foods as stop cues and has demonstrated that RIT decreases food cue-reactivity (a form of food reward value) measured using fMRI, and real world food desires measured using ecological momentary assessments over 7 days.

10. Forman EM, Shaw JA, Goldstein SP, Butryn ML, Martin LM, Meiran N, Crosby RD, Manasse SM: **Mindful decision making and inhibitory control training as complementary means to decrease snack consumption**. *Appetite* 2016, **103**:176-183.

11. •• Forman EM, Manasse SM, Dallal DH, Crochiere R, Loyka CM, Butryn ML, Juarascio AS, Houben K: **Computerized neurocognitive training for improving dietary health and facilitating weight loss**. *J Behav Med* 2019, **42**:1029-1040.

The only trial of food RIT that has compared gamified and non-gamified versions of active (sweet food no-go) vs. control (sweet food-go) training. Strengths were the recruitment of participants with high sweet food intake, the large amount of training (44 sessions over 8 weeks) and the optimisation of training (foods were personalised and go trials became more challenging over time). Significantly greater weight loss was seen in active participants with an implicit preference for sweet foods but gamification was not beneficial.

12. Forman EM, Manasse SM, Dallal DH, Crochiere RJ, Berry MP, Butryn ML, Juarascio AS: **Gender differences in the effect of gamification on weight loss during a daily, neurocognitive training program**. *Transl Behav Med* 2021, **11**:1015-1022.

13. Keeler JL, Chami R, Cardi V, Hodsoll J, Bonin E, MacDonald P, Treasure J, Lawrence N: **App-based food-specific inhibitory control training as an adjunct to treatment as usual in binge-type eating disorders: a feasibility trial**. *Appetite* 2022, **168**:105788.

14. Lawrence NS, O'Sullivan J, Parslow D, Javaid M, Adams RC, Chambers CD, Kos K, Verbruggen F: **Training response inhibition to food is associated with weight loss and reduced energy intake**. *Appetite* 2015, **95**:17-28.

15. •• Memarian S, Moradi A, Hasani J, Mullan B: **Can sweet food-specific inhibitory control training via a mobile application improve eating behavior in children with obesity?** *Br J Health Psychol* 2022, **27**:645-665.
Interesting trial of app-based RIT to sweet foods in children with high sugar cravings. Active vs. control training resulted in reduced choice and objectively-measured intake of sweet foods, with the latter persisting over 3 months follow-up. There were no significant effects on BMI.

16. Oomen D, Grol M, Spronk D, Booth C, Fox E: **Beating uncontrolled eating: training inhibitory control to reduce food intake and food cue sensitivity**. *Appetite* 2018, **131**:73-83.

17. Poppelaars A, Scholten H, Granic I, Veling H, Johnson-Glenberg MC, Luijten M: **When winning is losing: a randomized controlled trial testing a video game to train food-specific inhibitory control**. *Appetite* 2018, **129**:143-154.

18. Veling H, van Koningsbruggen GM, Aarts H, Stroebe W: **Targeting impulsive processes of eating behavior via the internet. Effects on body weight**. *Appetite* 2014, **78**:102-109.

19. Yang Y, Morys F, Wu Q, Li J, Chen H: **Pilot study of food-specific go/no-go training for overweight individuals: brain imaging data suggest inhibition shapes food evaluation**. *Soc Cogn Affect Neurosci* 2021, https://doi.org/10.1093/scan/nsab137.

20. Veling H, Lawrence NS, Chen Z, van Koningsbruggen GM, Holland RW: **What is trained during food go/no-go training? A review focusing on mechanisms and a research agenda**. *Curr Addict Rep* 2017, **4**:35-41.

21. Schachar R, Logan GD, Robaey P, Chen S, Ickowicz A, Barr C: **Restraint and cancellation: multiple inhibition deficits in attention deficit hyperactivity disorder**. *J Abnorm Child Psychol* 2007, **35**:229-238.

22. Allom V, Mullan B, Hagger M: **Does inhibitory control training improve health behaviour? A meta-analysis**. *Health Psychol Rev* 2016, **10**:168-186.

23. Jones A, Di Lemma LC, Robinson E, Christiansen P, Nolan S, Tudur-Smith C, Field M: **Inhibitory control training for appetitive behaviour change: a meta-analytic investigation of mechanisms of action and moderators of effectiveness**. *Appetite* 2016, **97**:16-28.

24. Turton R, Bruidegom K, Cardi V, Hirsch CR, Treasure J: **Novel methods to help develop healthier eating habits for eating and weight disorders: a systematic review and meta-analysis**. *Neurosci Biobehav Rev* 2016, **61**:132-155.

25. Yang Y, Shields GS, Wu Q, Liu Y, Chen H, Guo C: **Cognitive training on eating behaviour and weight loss: a meta-analysis and systematic review**. *Obes Rev* 2019, **20**:1628-1641.

26. Carbine KA, Larson MJ: **Quantifying the presence of evidential value and selective reporting in food-related inhibitory control training: a p-curve analysis**. *Health Psychol Rev* 2019, **13**:318-343.

27. Veling H, Chen Z, Liu H, Quandt J, Holland RW: **Updating the p-curve analysis of Carbine and Larson with results from preregistered experiments**. *Health Psychol Rev* 2020, **14**:215-219.

28. Adams RC, Lawrence NS, Verbruggen F, Chambers CD: **Training response inhibition to reduce food consumption: mechanisms, stimulus specificity and appropriate training protocols**. *Appetite* 2017, **109**:11-23.

29. Verbruggen F, Logan GD: **Automatic and controlled response inhibition: associative learning in the go/no-go and stop-signal paradigms**. *J Exp Psychol: Gen* 2008, **137**:649.

30. Verbruggen F, Best M, Bowditch WA, Stevens T, McLaren IP: **The inhibitory control reflex**. *Neuropsychologia* 2014, **65**:263-278.

31. Chen Z, Veling H, Dijksterhuis A, Holland RW: **How does not responding to appetitive stimuli cause devaluation: evaluative conditioning or response inhibition?** *J Exp Psychol: Gen* 2016, **145**:1687.

32. • Yang Y, Qi L, Morys F, Wu Q, Chen H: **Food-specific inhibition training for food devaluation: a meta-analysis**. *Nutrients* 2022, **14**:1363.
The first quantitative meta-analysis of the effects of food response inhibition training on food devaluation. Analysis of 36 independent samples (77 effects) demonstrated significant effects on food devaluation measured using explicit but not more implicit (e.g. implicit association test) evaluations.

33. Veling H, Holland RW, van Knippenberg A: **When approach motivation and behavioral inhibition collide: behavior regulation through stimulus devaluation**. *J Exp Soc Psychol* 2008, **44**:1013-1019.

34. Stice E, Yokum S, Veling H, Kemps E, Lawrence NS: **Pilot test of a novel food response and attention training treatment for obesity: brain imaging data suggest actions shape valuation**. *Behav Res Ther* 2017, **94**:60-70.

35. Wiers RW, Boffo M, Field M: **What's in a trial? On the importance of distinguishing between experimental lab studies and randomized controlled trials: the case of cognitive bias modification and alcohol use disorders**. *J Stud Alcohol Drugs* 2018, **79**:333-343.

36. • Najberg H, Rigamonti M, Mouthon M, Spierer L: **Modifying food items valuation and weight with gamified executive control training**. *R Soc Open Sci* 2021, **8**:191288.
Rigorous, tightly-controlled trial of an impressive gamified (combined GNG and cue-approach) training to food showing significantly greater devaluation in the active relative to a 'sham' (Go and No-go) training control condition.

37. Chami R, Cardi V, Lawrence N, MacDonald P, Rowlands K, Hodsoll J, Treasure J: **Targeting binge eating in bulimia nervosa and binge eating disorder using inhibitory control training and implementation intentions: a feasibility trial**. *Psychol Med* (5) 2022, **52**:874-883.

38. Verbeken S, Braet C, Naets T, Houben K, Boendermaker W: **Computer training of attention and inhibition for youngsters with obesity: a pilot study**. *Appetite* 2018, **123**:439-447.

39. Vermeiren E, Naets T, Van Eyck A, Vervoort L, Ysebaert M, Baeck N, De Guchtenaere A, Van Helvoirt M, Tanghe A, Bruyndonckx L: **Improving treatment outcome in children with obesity by an online self-control training: a randomized controlled trial**. *Front Pediatr* 2021, **9**:794256, https://doi.org/10.3389/fped.2021.794256

40. Stice E, Yokum S, Gau J, Veling H, Lawrence N, Kemps E: **Efficacy of a food response and attention training treatment for obesity: a randomized placebo controlled trial**. *Behav Res Ther* 2022, **158**:104183.

41. Chen Z, Veling H, de Vries SP, Bijvank BO, Janssen I, Dijksterhuis A, Holland RW: **Go/no-go training changes food evaluation in both morbidly obese and normal-weight individuals**. *J Consult Clin Psychol* 2018, **86**:980.

42. Quandt J, Holland RW, Chen Z, Veling H: **The role of attention in explaining the no-go devaluation effect: effects on appetitive food items**. *J Exp Psychol: Hum Percept Perform* 2019, **45**:1119.

43. Porter L, Gillison FB, Wright KA, Verbruggen F, Lawrence NS: **Exploring strategies to optimise the impact of food-specific inhibition training on children's food choices**. *Front Psychol* 2021, **12**:1656.

44. Lumsden J, Skinner A, Woods AT, Lawrence NS, Munafò M: **The effects of gamelike features and test location on cognitive test performance and participant enjoyment**. *PeerJ* 2016, **4**:e2184.

45. Porter L, Bailey-Jones C, Priudokaite G, Allen S, Wood K, Stiles K, Parvin O, Javaid M, Verbruggen F, Lawrence N: **From cookies to carrots; the effect of inhibitory control training on children's snack selections**. *Appetite* 2018, **124**:111-123.

46. Aulbach MB, Knittle K, van Beurden SB, Haukkala A, Lawrence NS: **App-based food Go/No-Go training: user engagement and dietary intake in an opportunistic observational study**. *Appetite* 2021, **165**:105315.

47. Serfas BG, Florack A, Büttner OB, Voegeding T: **What does it take for sour grapes to remain sour? Persistent effects of behavioral**

inhibition in go/no-go tasks on the evaluation of appetitive stimuli. *Motiv Sci* 2017, **3**:1.

48. Houben K, Jansen A: **Training inhibitory control: a recipe for resisting sweet temptations**. *Appetite* 2011, **56**:345-349.

49. Jones A, McGrath E, Robinson E, Houben K, Nederkoorn C, Field M: **A randomized controlled trial of inhibitory control training for the reduction of alcohol consumption in problem drinkers**. *J Consult Clin Psychol* 2018, **86**:991-1004.