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Current Opinion in Behavioral Sciences

How go/no-go training changes behavior: A value-based decision-making perspective

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Inhibitory-control training can change food consumption. Here, we review work on one specific inhibitory-control training, namely go/no-go training (GNG), with the aim of clarifying how this training changes behavior. Recent work suggests it is unlikely that GNG trains general inhibitory control or even food-specific inhibition. Instead, recent research suggests GNG changes the value of food items. These findings call for theorizing on how a training task in which people merely respond or not respond to food items without any external reinforcement can impact the value of these items. We propose the value of trained food items is updated during GNG by action and inaction *decisions*. This value-updating account is descriptively accurate and generates new research questions and testable hypotheses to better understand the underlying mechanisms of GNG. The account also prompts questions about how everyday NoGo decisions can stimulate moderate consumption patterns.

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Current Opinion in Behavioral Sciences 2022, **47**:101206

This review comes from a themed issue on **Executive Control of Eating**

Edited by **Géraldine Coppin** and **Lucas Spierer**

For complete overview of the section, please refer to the article collection, "Executive Control of Eating"

Available online 19th August 2022

https://doi.org/10.1016/j.cobeha.2022.101206

Introduction

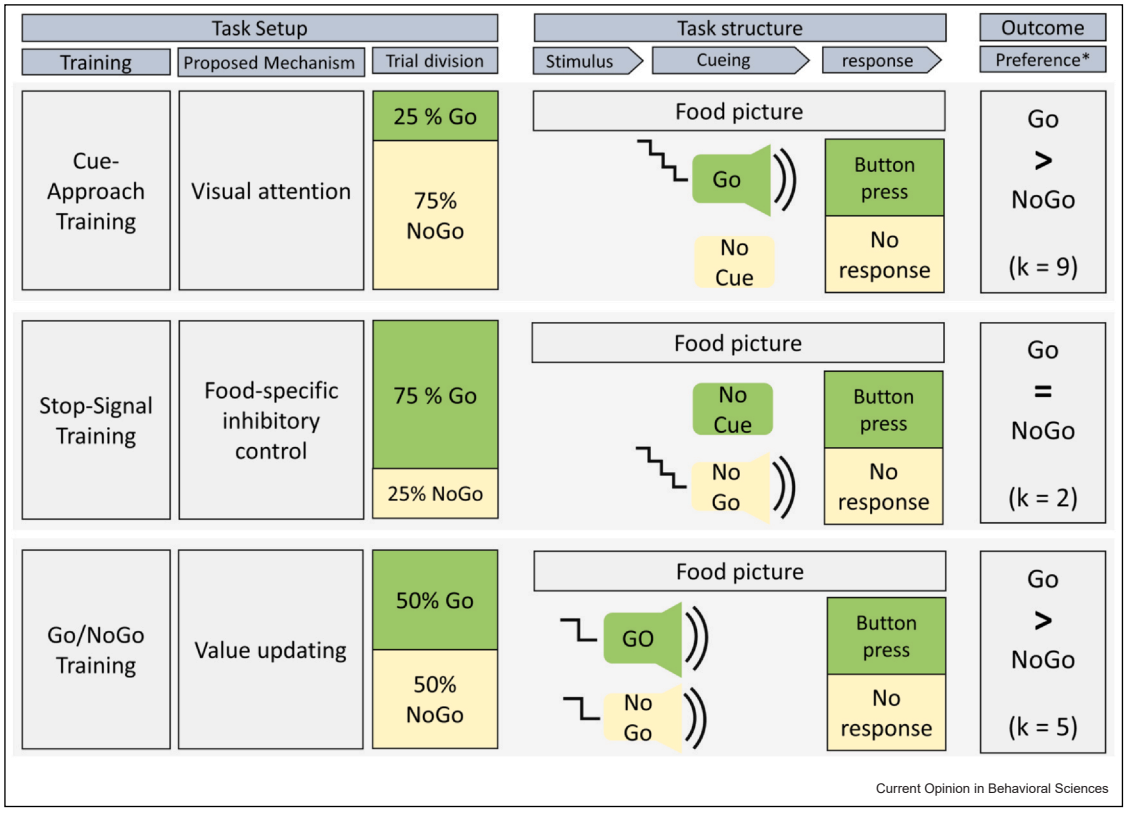
The ability to resist temptations is considered a core feature of self-control [1,2]. This conceptualization of self-control is consistent with empirical approaches to improve self-control by increasing people's ability to resist temptations by some kind of inhibition training [3]. Here, we review recent research on a training toward food items that is often presented as a means to strengthen inhibition: Go/no-go training (GNG). Based on recent insights from research in this domain, we argue GNG may be a way to change the value of tempting objects [4••], such as appetitive foods, rather than a way to strengthen people's inhibition ability [3,5]. Interestingly, GNG may still be viewed as a training to facilitate self-control from the perspective that self-control is a specific instance of value-based decision-making [4••]. Below, we review and connect these recent developments in the literature. The aim is to gain a better understanding of how GNG changes responses to food items, and facilitates self-control.

During GNG, participants are presented with a series of appetitive stimuli, such as images of palatable foods, and consistently respond to some appetitive stimuli by pressing a button (Go items) and withhold responding to other stimuli (NoGo items), depending on the presentation of a go or no-go cue (e.g. a high or low tone), which is presented after a small delay during presentation of the image [6••]. This training influences eating behavior outside the laboratory (e.g. [7]; but see Refs. [8,9]. for some cautionary comments), and in laboratory experiments [6••,10•]. A smartphone-app version of GNG for the general public showed a small association between the number of completed training trials and reductions in unhealthy food intake [11], and GNG is acceptable to people suffering from eating disorders [12].

Go/no-go training does not train inhibitory control

Because people consistently do not respond to food items, GNG is often presented as an inhibitory-control training (e.g. [8,13]). The conceptualization of GNG as an inhibitory-control training appears inadequate, however [14]. First, it has been proposed that GNG should be considered a decision-making training instead of an inhibitory-control training [15], as the fixed interval between stimulus onset (e.g. a food item) and cue onset (e.g. the no-go cue) in combination with 50% no-go trials does not elicit prepotent go responses that need to be inhibited on no-go trials [16]. Indeed, experiments employing food-specific GNG failed to establish any training-induced inhibitory-control responses as measured with event-related potentials (N2 amplitude) to trained food after a single session in a

Figure 1



A comparison of three tasks that train go and no-go responses to food stimuli. *Note. Three training tasks to modify responses to food that differ in the probability of go and no-go trials and the presence and timing of the cue. In all training tasks, a stimulus, such as a food image, is presented for around* 1 s. *During stimulus presentation, a cue that signals whether a response should be emitted (creating Go stimuli, green boxes) or withheld (creating NoGo stimuli, yellow boxes) is presented after a short delay. The (non)responses are often not incentivized. In CAT and Stop-Signal training, the timing of respectively the go or no-go cue is adapted (see staircases) based on participants' performance to make it hard to respond (CAT), or stop a response (Stop-Signal), before the stimulus disappears from screen. This is done by presenting the cue later in a trail after a successful response (CAT) or stop (Stop-Signal)* [21] *In GNG, both go and no-go cues are presented with an equal probability after fixed delay after stimulus onset (often* 200 ms*)* [6••] *Using a nearly identical procedure to measure effects of each training (*i.e. *matching Go and NoGo items on value before the training, measuring probability of choosing Go over NoGo items in repeated binary-choice trials under some time constraint immediately after the training), CAT* [21,22,50,51] *and GNG* [6••,20,33] *increased the probability to choose Go over NoGo food items, whereas the Stop-Signal training did not* [21]**CAT, k = 9, Experiments1–4* [21] *and* [22] *and Experiments 1 and 4* [50] *and Experiments 5 and 6* [51] *Stop Signal, k = 2, Experiments 5 and 6* [21]*; GNG, k = 5, Experiments 4–6* [6••] *and* [20], and *Experiment 1* [33]

student sample [17], and not even after multiple training sessions among overweight and obese individuals [3]. Second, a gamified GNG did not improve inhibitory control on neither an established measure of general inhibitory control, the stop-signal task, nor on food-specific inhibitory control among a mostly healthy-weight sample (e.g. [18]). Third, multiple sessions of food-specific GNG *decreased* (!) inhibitory-control responses (inferior frontal gyrus) to high-calorie foods as assessed with fMRI among overweight participants in a pilot experiment [19]. Fourth, controlled experiments with mostly students found effects of GNG and cued-approach training (CAT) on preferences for Go over NoGo food items [6••,20–22], but this effect was not present when the training was modified to become a food-specific inhibition training (i.e. a stop-signal training where people need to inhibit a prepotent response upon the presentation of a stop signal [21], see Figure 1). This latter finding is consistent with findings in the applied domain that stop-signal training may be less effective than GNG to influence eating behavior [23].

Below, we review recent evidence primarily in the domain of eating behavior supporting an alternative perspective to explain GNG-induced changes in food consumption: GNG changes the value of Go and NoGo food items. Furthermore, in light of these findings, we explain how GNG may elicit value change, and provide future directions for research.

Go/no-go training influences food value

Three lines of research converge on the idea that GNG can change the value of food items presented during the

training. First, research has examined the effects of GNG on explicit evaluations (i.e. ratings) of the trained and untrained food items, and this work consistently shows that participants evaluate NoGo items less positively after GNG across different research designs. In a between-participant design with overweight participants, high-calorie food NoGo items decreased more in rating after GNG in an intervention group compared with the same food items in a nonfood GNG control group [19]. Comparable results were found in a mostly healthy-weight sample [24], and in two trials where GNG was administered together with other training tasks (e.g. attention training, [25,26••]). In within-participant designs (mostly student samples), explicit evaluations of NoGo food items have been shown to decrease from pre to post GNG compared with both Go items and items not presented during the training (untrained items, [5,27–29]), or compared with control items (items presented with both go and no-go cues [30]). NoGo food items decreased more in value than Go items (but not compared with untrained items) among morbidly obese individuals [31]. Two online-administered GNG experiments reported null findings on explicit evaluation [7,32], and the effects of GNG on implicit measures of evaluation appear less robust [23]. The latter may be because the employed implicit measures relied on repeated speeded responses to the trained stimuli, which may undo the training effect [33], so that no devaluation is detected.

Controlled experiments, including untrained items as a baseline, suggest that for appetitive items, no-go items are devalued, whereas go items are unaffected by GNG (e.g. [5,29]). However, go responses appear to increase value for food items when the food items are not very appetitive, or even for appetitive items when go responses are invigorated by implementing an adaptive cueing procedure promoting quick responding [5]. However, the effects of go responses to increase value appear less consistent than the effects of no-go responses to devalue food items [26••,27].

Second, experiments have shown that GNG increases the probability of choosing Go over NoGo items for consumption in value-based decision-making tasks. In these kinds of tasks, people make actual (e.g. [6••,33]) or hypothetical choices [34] for consumption. A preference for Go over NoGo food items has been shown among children in a between-participant design [34], and among student samples in within-participant designs [6••,20,33] (but see Ref. [30]). These effects cannot be explained by changes in inhibitory control, but appear to reflect value changes. First, general inhibitory-control strengthening could explain between-participant differences in food consumption, but it is not applicable to explain GNG-induced preferences for Go over NoGo appetitive food items that occur in within-participant designs [6••]. Second, as explained earlier, food-specific inhibition training fails to change choices [21]. Third, filler trials in which participants choose between high- and low-value items (both Go or both NoGo items) validate that people respond to the value of the presented food items [6••,20,33]. Finally, a recent experiment with a student sample found that the effect of GNG on value-based decision-making was (partly) mediated by GNG-induced changes in item evaluation [14].

Finally, there is work suggesting that the reinforcing value of appetitive stimuli is reduced by GNG. One pilot experiment examined the sole effect of GNG on brain responses to food items, and showed that multiple sessions of GNG reduced brain reward responses (mid-insula) to high-calorie NoGo food items during a passive viewing (and *decreased* inhibitory-control region activation) compared with a no-food training control group [19]. Similar findings on brain reward regions have been obtained in a trial that included multiple cognitive training tasks including GNG [25]. These changes in brain reward responsiveness converge well with behavioral experiments with student samples, which showed GNG does not in general reduce motor responses to food images [35], or erotic images [36], but selectively when these motor responses are a reflection of motivational strength toward these stimuli.

A value-updating account

The findings reviewed above suggest that GNG should not be presented as an inhibitory-control training, but instead that GNG can be considered a training to change the value of food items. One question is how GNG influences food value. That is, NoGo items are devalued compared with Go or untrained items in experiments where there is no external reinforcement of the responses and even when there is no performance feedback whatsoever during the training (e.g. [5,27]). GNG-induced changes in behavior can thus be conceptualized as a form of nonreinforced or nonincentivized behavior change [37••].

How can we explain that nonincentivized responses change stimulus value? First, theorizing to explain the effects of another nonreinforced GNG on food consumption, CAT (see Figure 1), does not appear suitable to explain GNG effects on value [37••]. Specifically, theorizing in relation to CAT is focused on explaining preferences for Go over NoGo items by increased visual attention to Go items. The logic is that by presenting go cues infrequently during CAT, and by ensuring participants need to respond very quickly, attention is boosted toward the Go items, which in turn increases the probability of choosing these items after the training [21]. GNG does not involve vigorous responses to infrequent Go items, however, and GNG

effects appear to be driven by devaluation of NoGo items [5], and, if anything, NoGo devaluation becomes stronger with more attention to NoGo items during the training (for a trend see Ref. [29]).

Alternatively, according to the devaluation-by-inhibition hypothesis (e.g. [35,38]), not responding to stimuli involves motor inhibition, which is tied to negative effect that may become associated with the stimulus to which the inhibition is directed [39]. Note that the evidence reviewed above against the notion that GNG trains inhibitory control does not rule out that inhibition occurs during no-go trials [38,40]. However, this explanation is not satisfactory for two reasons. First, as explained above, food consumption appears less influenced by stop-signal training than GNG [21,23], whereas stop-signal training should elicit stronger inhibition on no-go trials than GNG [16]. In general, the potential of GNG to elicit inhibition has been questioned [14,16]. It is unclear how the devaluation-by-inhibition hypothesis can explain this seeming inconsistency. Second, the devaluation-by-inhibition hypothesis cannot explain that go responses occasionally increase the value of not so appetitive items [5].

Here, we explain GNG effects on food value as a result of a value-updating process by decisions to act or not act on these foods during GNG. The benefit of this explanation is that it does not rely on motor inhibition, and moves away from the conceptualization of GNG as an inhibitory-control training [16]. Moreover, this account is descriptively accurate, as the value of food items changes from pre to post GNG by performing actions and inactions as reviewed above. This accurate descriptive explanation can provide a solid starting point to further examine how and when go/no-go decisions impact food value. We provide one tentative suggestion.

Exposure to appetitive food stimuli likely prepares a tendency to respond, whereas not very appetitive food stimuli prepare a tendency to not respond, due to a hard-wired Pavlovian bias [41,42]. This argument is consistent with the finding that go responses are sometimes quicker to appetitive compared with less-appetitive stimuli [27,40]. During GNG, action and inaction decisions toward the items can run counter to these response tendencies, resulting in prediction errors, which may instigate updates of the value of Go and NoGo food items to bring the prepared response tendencies in line with the requirements during GNG [43••]. Changing the value to change response tendencies may be the most efficient way to complete the training. This logic can explain unchanged value of appetitive Go items and reduced value of appetitive NoGo items after GNG [5,14,27]. It can also explain increased value for not so appetitive Go items and unchanged value for not so appetitive NoGo items [5]. It can even explain why invigorating go responses can increase the value of Go items [5].

Future directions

The value-updating account calls for a systematic investigation of some of the incidental findings described above (e.g. value change of Go items by invigorating go responses). Moreover, the new account predicts that value updating occurs when this makes GNG execution more efficient, which elicits several new hypotheses. First, devaluation should be weaker or absent when NoGo items occasionally require a Go response (e.g. when there is only 90% consistency), as this task setup decreases the efficiency of reducing the value of NoGo items to facilitate task execution. Second, devaluation should be absent when the go and no-go cues are presented before rather than after presentation of the food items, because this eliminates prediction errors. Third, from the perspective of making decisions during GNG as efficient as possible, generalization of devaluation to new stimuli will occur when training occurs on the category level [28]. For instance, generalization to untrained chocolate items may be likely if the training is constructed, such that chocolate items are always NoGo items, and a bunch of different items are Go items. Generalization may not occur when different chocolate items are on Go and NoGo trials.

The value-updating account also points to new research questions to better understand difficulties with behavior change and restrictive dieting. For instance, restrictive diets may involve some successful NoGo decisions [1], especially at the start of the diet, but these diets are often unsuccessful in the long run [45], which suggests that NoGo decisions may not always lead to devaluation. Decision-making during GNG is specific in the sense that it is cued quickly after stimulus presentation, it is time-pressured, and it is immediately followed by subsequent decisions. An interesting question is whether and how these different components can be translated to instigate devaluation after everyday-life NoGo decisions to facilitate moderate consumption patterns. Conversely, an important unanswered question is how Go and NoGo decisions in daily life update training-induced valuation effects. This question is important to understand the durability of GNG-induced behavior change.

Conclusions

GNG is often presented as an inhibitory-control training that can be used to boost self-control. Here, we have substantiated why GNG can better be presented as a training to update the value of food items, and this logic may be applied to appetitive items more generally [14,40,44]. Importantly, this does not invalidate GNG as a means to promote self-control, because self-control can be conceptualized as a form of value-based decision-

making [4••]. Therefore, the current value-updating perspective connects GNG directly to this emerging literature [46,47,48]. In sum, the value-updating account generates new research questions and hypotheses and calls for an integration of GNG research with recent insights into value-based decision-making. Examining these new directions will contribute to a better understanding of when and how GNG changes eating behavior.

Conflict of interest statement

None.

Data Availability

No data were used for the research described in the article.

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