

Cognitive control modulates attention to food cues: Support for the control readiness model of self-control



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ABSTRACT

Self-control in one's food choices often depends on the regulation of attention toward healthy choices and away from temptations. We tested whether selective attention to food cues can be modulated by a newly developed proactive self-control mechanism—control readiness—whereby control activated in one domain can facilitate control in another domain. In two studies, we elicited the activation of control using a color-naming Stroop task and tested its effect on attention to food cues in a subsequent, unrelated task. We found that control readiness modulates both overt attention, which involves shifts in eye gaze (Study 1), and covert attention, which involves shift in mental attention without shifting in eye gaze (Study 2). We further demonstrated that individuals for whom tempting food cues signal a self-control problem (operationalized by relatively higher BMI) were especially likely to benefit from control readiness. We discuss the theoretical contributions of the control readiness model and the implications of our findings for enhancing proactive self-control to overcome temptation in food choices.

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1. Introduction

In Walter Mischel's famous "marshmallow test," preschoolers are faced with the impossible challenge of choosing between having one marshmallow now or two later. Some children resolve this dilemma by eating the marshmallow immediately. Others decide to wait. The strategies they use to delay gratification are fascinating: some kids cover the marshmallow with their hands, while others cover their eyes, crawl under the table, or look away, staring at the opposite wall. These children appear to intuit that if they do not see the marshmallow, the temptation will be easier to resist. And they are correct: in the now seminal studies on delay of gratification in children, Mischel and colleagues (Mischel, Ebbesen, and Zeiss (1972) and Mischel, Shoda, and Rodriguez (1989)) found that preschoolers who averted attention away from the single marshmallow were able to wait almost twice as long as those who looked directly at the marshmallow.

Numerous studies over the past decade have corroborated the importance of selective attention for successful self-control in the service of one's long-term goals (Carver & Scheier, 2012). In the present research, we examined a newly-developed procedure for enhancing attentional control in the context of tempting food cues.

1.1. Self-control conflicts

Situations in which an immediate reward conflicts with a preferred, but delayed reward pose a self-control dilemma (e.g., Loewenstein, 1996; Mischel, Ebbesen, & Zeiss, 1972; Mischel, Shoda, & Rodriguez, 1989; Trope & Fishbach, 2004), and in order to protect one's long-term goals from momentary allurements, one often needs to exert self-control (Baumeister, Heatherton, & Tice, 1994; Shah, Friedman, & Kruglanski, 2002).

In the modern world, temptations of various kinds (e.g., tasty foods) become more abundant and more accessible. As a result, self-control dilemmas are more common, and self-control failures are more frequent and begin at an earlier age (Hofmann, Baumeister, Förster, & Vohs, 2012). In turn, self-control failures have detrimental effects on both the individual and society (e.g., Ayduk et al., 2000; Baron, 2003; Baumeister & Tierney, 2011; Mischel, Cantor, & Feldman, 1996; Mischel et al., 1989; Thaler & Shefrin, 1981).

1.2. Facilitating self-control

To date, research on the mechanisms of self-control has focused primarily on *reactive* forms of control, whereby control is engaged only after a temptation begins to bias one's response toward an undesired outcome (Amodio & Devine, 2010). Once a bias is

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detected, reactive control functions to strengthen one's intended response tendency and promote its implementation in behavior. Reactive control is corrective in nature, operating to correct a response only after a bias has begun to emerge. In the context of eating behavior, reactive control would be initiated at the moment a person sees and begins to reach for the cookie, and its function would be to inhibit this behavior and redirect it toward the carrot sticks. This process characterizes dominant models of control in the contemporary self-control literature (see Fujita, 2011 for a review).

Importantly, because reactive control comes online only after the influence of bias occurs, gaining control is often difficult. This difficulty is compounded by factors that mitigate the effectiveness of reactive control processes, such as lack of opportunity, low motivation, or lack of pre-requisite skills. Each of these factors can cause self-control to fail when a temptation arises in the moment (e.g., Amodio, Devine, & Harmon-Jones, 2008; Amodio et al., 2004; Baumeister & Heatherton, 1996; Kross & Mischel, 2010; Trope & Fishbach, 2004). This is especially true when an individual faces an unexpected temptation that catches them off guard, unprepared to exert self-control. In such cases, individuals often fail to react in a way that will enable their higher order goals to prevail over the momentary allurements.

An alternative to reactive self-control is *proactive self-control*: the preemptive engagement of cognitive, affective, and motivational processes to proactively prepare and facilitate self-control (Amodio, 2010; Braver, 2012; Schmid, Kleiman, & Amodio, 2015; Trope & Fishbach, 2000). Various proactive self-control strategies have been proposed in the self-control literature. These include: proactively modifying the situation or the incentive structure (Ainslie, 1975; Becker, 1960; Gross & Thompson, 2007; Trope & Fishbach, 2000), pre-planning goals and intentions (Gollwitzer, 1990; Gollwitzer & Brandstätter, 1997; Mendoza, Gollwitzer, & Amodio, 2010), activating motivations that guide attention and perception to identify an anticipated conflict (Amodio, 2010; Amodio et al., 2008), or increasing goal commitment such that an encounter with a temptation (e.g., a delicious dessert) automatically activates an intended countervailing goal (e.g., a health goal, Fishbach, Friedman, & Kruglanski, 2003). Considered together, this body of research suggests that proactive strategies are more effective than reactive strategies in facilitating self-control. Yet most proactive strategies share a common limitation, which is that the engagement of control typically depends on one's vigilance for a goal-relevant cue and the preplanning of the intended action (e.g., "if I am presented with dessert options, then I will choose fresh fruit"). The use of a highly-specific cue may limit the applicability and flexibility of the self-control process, and its success may be undermined by situational factors that distract an individual from the designated control cue.

These limitations may be especially problematic for individuals who do not have an arsenal of self-control skills and who are especially sensitive to temptation cues in the environment. Moreover, and germane to the present research, it may be particularly difficult for such individuals to selectively modulate attention to overcome distracting, tempting, and/or rewarding stimuli, and such difficulties threaten to perpetuate into a cycle of self-control failures (Fedoroff, Polivy, & Herman, 1997; Papias & Hamstra, 2010). Individuals who have difficulty employing internally-initiated control strategies, then, are the ones who need the most help in regulating their behavior toward achieving the higher order goal. We propose that a mechanism of control that does not rely on the deliberate employment of control may be most beneficial to these individuals.

1.3. Control readiness: Proactive adjustment of cognitive control across domains

Recent research (Kleiman, Hassin, & Trope, 2014) has proposed a general mechanism of control readiness whereby control activated in one domain can facilitate control in another domain. The logic underlying the control readiness mechanism is based on a cognitive model of conflict monitoring and control adjustment (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton, Coles, & Donchin, 1992). Specifically, to account for how the need for control is signaled and how a response is subsequently adjusted, Conflict Monitoring Theory posits that when conflict between one's intentions and current response tendencies is detected by the conflict monitoring system, this system increases the strength of top-down control processes to facilitate the intended responses.

The process of control adjustment can occur "on-line" on a trial-by-trial basis (Botvinick et al., 2001; Kerns et al., 2004). For example, on incongruent Stroop trials (e.g., the word RED displayed in blue), a conflict (between the font color and the word's meaning) is detected, and degree of control is adjusted so that the response to a subsequent incongruent trial (which also requires control) is facilitated. Botvinick et al. (2001) further suggested that the activation of control on the initial trial activates a control process that biases attention toward goal-relevant features and away from goal-irrelevant distractors. In other words, activating control on trial $N - 1$ aids control in trial N via a selective attention mechanism.

The control readiness idea draws inspiration from Conflict Monitoring Theory, and suggests that under certain circumstances control can be adjusted across domains (see discussion of these circumstances in Section 4); that is, it posits that control activated by one task can subsequently facilitate control in another task. In initial tests of the control readiness mechanism, Kleiman et al. (2014) examined the transfer of control across domains in the social psychological context of racial and gender stereotypes, a context in which control is highly prone to failure (Amodio et al., 2004). In line with the control readiness idea, pre-activating control during a standard flanker task, which was unrelated to stereotypes, resulted in the elimination of stereotypically-biased responses on a subsequent implicit bias task. Thus, activating control on trial $N - 1$ facilitated control in a different domain on trial N . This pattern represents the control readiness effect.

1.4. The present research: Control readiness modulates attention to food cues

The aim of the present research was to examine the effects of control readiness on selective attention to food cues in the context of self-control. Attention is critical to response regulation because individuals are less likely to engage with stimuli to which they do not attend (Ainslie, 1992; Thaler & Shefrin, 1981; Wertenbroch, 1998). Research has consistently found that diverting one's attention from temptations or distracting oneself through alternative activities can facilitate self-control across various instances and domains (Feindler, Marriott, & Iwata, 1984; Gross & Thompson, 2007; Mischel, 1974; Mischel & Ayduk, 2004; Mischel et al., 1972; Patterson & Mischel, 1976). Moreover, individuals who are successful at self-control use selective attention strategies effectively to shield their long term goals from temptations (Feindler et al., 1984; Gross & Thompson, 2007; Mischel, 1974; Mischel & Ayduk, 2004; Mischel et al., 1972; Patterson & Mischel, 1976). This suggests that "good self-controllers" may be those who effectively avoid situations where they encounter temptations, thus eliminating temptations from their attentional scope altogether (Hofmann et al., 2012). These findings are in line with Conflict Monitoring

Theory, which stresses the important role of selective attention in the operation of cognitive control (Botvinick et al., 2001; Egner, 2008). Thus, in the present research, we tested whether a control readiness mechanism can aid individuals to achieve their goals by influencing selective attention to food cues.

An important question in this context is whether the transfer of control from one situation to another is more likely to occur for some individuals than for others. Based on our previous research (Kleiman et al., 2014) we reasoned that individuals who are more sensitive to temptation cues and for whom overcoming temptations is a habitual struggle – operationalized in the current study by a measure of Body Mass Index (BMI) – will benefit most from the control readiness mechanism. The reason is two fold: First, motivation stemming from personal relevance can play a significant role in the application of cognitive priming procedures (Eitam & Higgins, 2010; Higgins & Eitam, 2014). Put differently, we propose that control readiness serves as a general priming procedure that can transfer across different contexts and tasks and whose actual application depends on the importance of the goal. Responses to food cues serve this exact function for high BMI individuals. Second, as noted above, individuals who are especially sensitive to temptation cues may lack access to a procedure that will enable them to shift their attention away from temptations and toward healthy alternatives. This lack of an accessible procedure could be domain specific (i.e., related only to food cues) or more general. Indeed, some research suggests that specific self-control functions depend on broader executive function capacity (see Hofmann, Schmeichel, & Baddeley, 2012 for a recent review), and a recent research observed a robust correlation between BMI and temporal discounting rates, such that higher BMI was associated with greater preference for immediate rewards over delayed ones (Jarmolowicz et al., 2014)

Thus, an important prediction of the control readiness framework is that it will affect responses in situations where self-control is personally relevant. And so, in a food choice context, we would expect people with eating concerns to find food choices to be especially self-relevant (Stroebe, Van Koningsbruggen, Papies, & Aarts, 2013). Thus, a consideration of BMI provides a more refined test of our hypothesis, such that the control readiness effect should be more strongly evident among high BMI people than low BMI people (for whom food choices are less of a personal concern). Taken together, we propose that control readiness—that is, the pre-activation of control on a personally irrelevant task—can subsequently enhance goal-directed attention on a personally relevant task. In the domain of food cues, we further predict that individuals who are sensitive to such cues (high BMI individuals) may show the strongest effects of control readiness both because they care about the goal and because they do not have the procedure (attention deployment) readily accessible.

1.5. Overview of studies

In two studies, we investigated the role of selective attention in control readiness. We specifically examined two forms of attention: overt and covert orienting (Neisser & Becklen, 1975; Posner, 1980). Overt orienting involves shifts in eye gaze. Covert orienting, by contrast, refers to a mental shift in one's selective attention that occurs without moving one's eyes. In some situations, averting one's gaze from a temptation might be the most effective strategy—consider the children in Walter Mischel's studies who turned away from the marshmallow and stared at the opposite wall, thus facilitating self-control. However, at times, the tempting stimulus is unavoidable, with no opportunity for overt shifts in attention. In these cases, covert shifts in attention may be necessary. Thus, although both forms of attention orienting may contribute to effective self-control, they involve different strategies, and their

effectiveness may vary by the situation and individual. We therefore tested the implications of the control readiness mechanism on overt orienting, in Study 1, as well as covert orienting, in Study 2. Note that both overt and covert orienting can operate either automatically or intentionally. Importantly, the tasks used in our studies were designed to assess relatively more controlled, intentional orienting responses, as opposed to reflexive (i.e., automatic) orienting.

In both studies, we use a *sequential control adjustment paradigm* (Egner, 2008; Gratton et al., 1992; Kleiman et al., 2014) to examine how the activation of control on trial $N - 1$ affects selective attention to food objects on trial N . That is, we examined how levels of control were adjusted “online,” on a trial-by-trial basis to modulate attention to food cues. Moreover, we tested the differential operation of the control readiness mechanism among individuals for whom personal concerns about food temptations varied. We operationalized this type of personal relevance using BMI. Although BMI may not explain the entire variance of the personal relevance of overcoming temptations, it has been consistently found to correlate with chronic dieting (e.g., Klesges, Isbell, & Klesges, 1992; Lowe, 1984; Ruderman, 1986; Snoek, van Strien, Janssens, & Engels, 2008), and a recent study has found comparable effects of BMI and a more comprehensive assessment of concern for dieting (losing weight importance) on the consumption of tempting food items (Veling, Aarts, & Papies, 2011). Individuals for whom the overcoming of temptations is more personally relevant may be more likely to modulate selective attention to tempting food cues with enhanced cognitive control. We thus expected high BMI participants to show a greater effect of control readiness.

2. Study 1: Overt attention

In Study 1, we tested the impact of control readiness on a form of overt attention that parallels situations in which one has the opportunity to overtly shift his or her attention in order to overcome temptation. We predicted that control readiness (i.e., activating control at time $N - 1$) would enable those for whom overcoming temptations is personally relevant (high BMI individuals) to more effectively shift their attention to attain their goal.

2.1. Method

2.1.1. Participants

Seventy-six undergraduate students (63.2% female, $M_{age} = 19.68$, $SD_{age} = 1.21$) participated in the study for partial course credit.

2.1.2. Experimental tasks

Participants performed alternating trials of two tasks (Fig. 1). The first task, aimed at manipulating control, was a classic color-naming Stroop task (Stroop, 1935), in which the words RED or BLUE appeared in either red or blue color to create congruent and incongruent trials (e.g., the word RED displayed in the color red, or the word BLUE displayed in the color blue, respectively). Because the word meaning is processed and expressed automatically, control is required to respond with the word color when meaning and color conflict. Participants were instructed to indicate the color as quickly and accurately as they could by pressing the D key with their left hand for *red* and the K key with their right hand for *blue*. The stimulus remained onscreen until a response was given.

The second task, designed to assess the spatial deployment of attention, was a dot probe task (MacLeod, Mathews, & Tata, 1986). In this task, pictures of two food items, taken from previous research (Bhanji & Beer, 2012; Hare, Camerer, & Rangel, 2009),

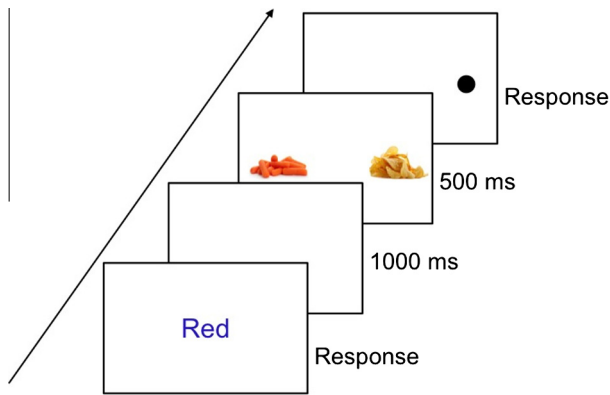


Fig. 1. Schematic of a trial in Study 1, depicting a trial in which an incongruent Stroop trial was followed by a dot probe trial in which the dot replaced the unhealthy snack (chips).

appeared simultaneously on the left and right sides of the computer screen. One picture was always of an unhealthy food item (e.g., brownie), whereas the other was always a picture of a healthy food item (e.g., carrot sticks). Pictures remained onscreen for 500 ms, after which a black dot appeared in the place of either the left or the right side image (centered within the place of the previous image). The duration of image presentation, prior to dot onset, was long enough to permit intentional saccades, such that the response could reflect controlled processing (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007). The left/right positions of the picture types and dots were equally counterbalanced across trials and presented in randomized order, and the dot probe was equally likely to follow each food type. The participants' task was to quickly and accurately indicate the location of the dot probe (left or right side) by pressing the D or K key, respectively. The dot probe remained onscreen until a response was given. In this paradigm, responses to dots that replace the attended stimulus should be faster than responses to dots that replace the unattended stimulus.

Participants performed alternating trials of the Stroop and dot probe tasks, always with a Stroop trial first, followed by a dot probe trial. The trial types in Stroop and dot probe pairings were randomized. The interval between all trial types was 1500 ms. Following four practice trials of each task, participants performed a total of 160 trial pairs (always Stroop followed by dot probe).

2.1.3. BMI

Upon task completion, participants reported their height and weight to permit calculation of BMI ($M = 22.43$, $SD = 3.27$).

2.2. Results

2.2.1. Data preparation

Data from three participants were excluded from analyses because their task error rate exceeded 3 SDs on the Stroop and dot probe tasks combined. Three additional participants failed to report either their height or weight, precluding calculation of BMI. Thus, analyses included 70 participants.

Incorrect dot probe trials, as well as dot probe trials that followed an erroneous Stroop response, were eliminated from analyses (5.28% of the trials), as these responses could not be clearly interpreted in terms of control readiness effects. Responses made faster than 200 ms or slower than 1500 ms on either the Stroop or dot probe task, which reflected action slips or inattention, respectively, were excluded from analyses (0.9% of the trials). Additionally, because participants used the same two keys to

respond to both tasks, analyses included only dot probe trials in which the correct response key differed from that of the previous trial. With this conventional procedure of exclusions, we avoid confounding our predicted control readiness effect with response repetition effects (Mayr, Awh, & Laurey, 2003). To index shifts in selective attention, we computed a *health focus* score for each participant by subtracting response times on trials in which the dot replaced healthy foods from response times on trials in which the dot replaced unhealthy, tempting foods. Higher health focus scores indicate greater relative orienting toward healthy foods and away from temptations—a pattern generally consistent with a health goal.

2.2.2. Main analysis

Health focus scores were submitted to a mixed-model regression (Compound Symmetry), with previous Stroop type (congruent vs. incongruent, effect coded as -1 and 1 respectively), BMI (mean centered), and their interaction included as predictors. This analysis yielded only a significant interaction effect, $B = 1.44$, $SE = 0.60$, $t(68) = 2.39$, $p < .02$, 95% CI [0.24, 2.65] (Fig. 2). Analysis of simple slopes revealed that for relatively low BMI participants (centered at -1 SD), attention was not modulated as a function of previous congruency, $B = -3.40$, $SE = 2.78$, $t(68) = -1.22$, $p > .22$, 95% CI $[-8.95, 2.16]$. However, as predicted, for relatively high BMI participants (centered at $+1$ SD), attention in the service of the health goal was enhanced following incongruent, compared with congruent, Stroop trials, $B = 6.04$, $SE = 2.78$, $t(68) = 2.17$, $p < .04$, 95% CI [0.49, 11.60]. That is, high BMI participants exhibited the control readiness effect, such that it enhanced attention to healthy food cues relative to unhealthy food cues.

2.3. Discussion

In the first test of the role of attention in the control readiness mechanism, we found evidence suggesting that activating control at time $N - 1$ modulated attention to food cues in a manner consistent with individuals' goals at time N . Food cues were presented long enough for participants to consciously process and direct overt attention toward them (i.e., 500 ms, Bar-Haim et al., 2007). Indeed, participants for whom the food cues signaled a personally relevant situation (operationalized in the study using a BMI measure) were the ones who benefited from the pre-activation of control.

It is notable that the stimuli used in the study – both unhealthy and healthy food stimuli – are relevant to high BMI participants' motivational concerns, yet the nature of their relevance differs. Healthy stimuli are goal compatible in the sense that they represent means by which one's target health goal can be achieved

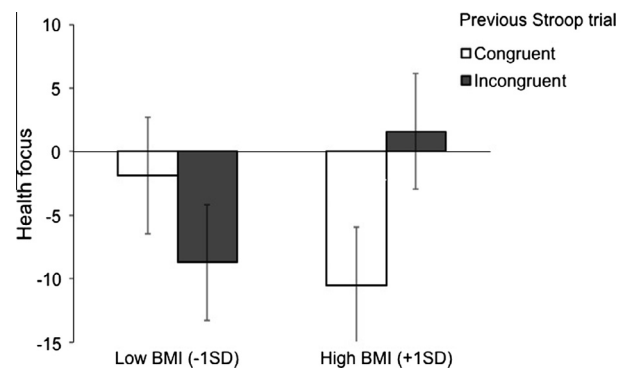


Fig. 2. Health focus score (i.e., relative response speed to dots following unhealthy vs. healthy food pictures) in the dot probe task as a function of previous congruency and BMI in Study 1. Error bars represent ± 1 standard error.

and thus could, if needed, be approached. Unhealthy stimuli, on the other hand, interfere with the attainment of a health goal and thus represent distractors or obstacles that ought to be avoided. In line with the control readiness model, our results suggest that the pre-activation of control modulated the attention pattern to these goal-consistent and goal-inconsistent stimuli.

Study 1 provided evidence that control readiness modulates the spatial deployment of attention to food cues, especially for individuals for whom food choices are personally relevant. In Study 2 we turned to the issue of covert attention, to examine whether the control readiness mechanism might be effective even when averting one's gaze overtly is not possible.

3. Study 2: Covert attention

In many situations, tempting food cues can appear in one's environment, leaving one no choice but to overtly attend to them. The question tested here was whether the control readiness mechanism could help participants shift their *covert* attention despite the inescapable presence of the tempting food cue. In Study 2, we thus used a variation on the emotional Stroop task (Williams, Mathews, & MacLeod, 1996) to examine the effect of control readiness on covert attention. The logic underlying the emotional Stroop task is that performance on the focal task (naming the color in which a word is displayed) will be hindered if the distractors (the meaning of the word) draw attention, for example, because of their emotional content. We adapted the emotional Stroop to create a food Stroop, in which food item words are presented in different color and the task is to indicate the color. The underlying logic is as follows: We claim that control readiness operates via shifts in attention toward goal-relevant cues and away from temptations. To the extent that tempting stimuli (represented by temptation-related words) are excessively activated for high BMI participants, control readiness should reduce this level of activation, resulting in less interference of temptation words on the food Stroop task, relative to healthy food words

3.1. Method

3.1.1. Participants

Eighty undergraduate students (55% female, $M_{\text{age}} = 19.64$, $SD_{\text{age}} = 1.18$) participated in the study for partial course credit.

3.1.2. Experimental task

Participants were instructed to indicate the color of words appearing on the screen. Crucially, and unbeknownst to participants, they performed alternating trials of the classic Stroop task and a food Stroop task (adapted from the emotional Stroop task; Williams et al., 1996). Classic Stroop trials were identical to those in Study 1 and were aimed at manipulating control readiness. On food Stroop trials, words representing unhealthy foods (*fries, pizza, cookies, donut, brownie*) or healthy (*carrots, apple, salad, fruit, cucumber*) foods in either blue or red text were presented, and participants indicated the color via keypress (pressing D for red and K for blue). Stimuli remained onscreen until the participant responded. Each classic Stroop trial was followed by a food Stroop trial, and the pairs of trials were randomized. All intertrial intervals were 1000 ms. Following four practice trials that included two classic Stroop trials and two food Stroop trials, participants performed a total of 160 trial pairs.

3.1.3. BMI

Upon task completion, participants reported their height and weight to permit calculation of BMI ($M = 22.49$, $SD = 2.97$).

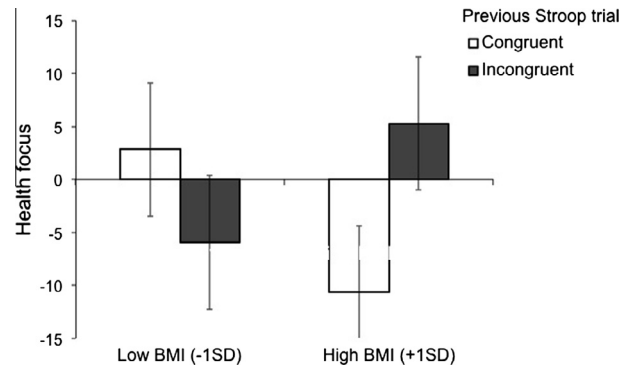


Fig. 3. Health focus score (i.e., relative response speed on trials with unhealthy vs. healthy words) in the food Stroop task as a function of previous congruency and BMI in Study 2. Error bars represent ± 1 standard error.

3.2. Results

3.2.1. Data preparation

Data from one participant were excluded from analyses because her error rate exceeded 3 SDs on the classic and food Stroop tasks combined. Thus, analyses were performed on a sample of 79 participants.

As in Study 1, we eliminated incorrect food Stroop responses and food Stroop trials that followed an erroneous classic Stroop trial from analyses (5.79%); responses shorter than 200 ms or longer than 1500 ms on either the classic or the food Stroop task were eliminated as well (1.13%). Additionally, only food Stroop trials in which the response key was alternated were analyzed, as in Study 1. A *health focus* score was computed for each participant, by subtracting response times to unhealthy foods trials from response times to healthy food trials. Thus, higher scores indicated relatively greater covert attention to healthy than unhealthy food items.

3.2.2. Main analysis

Health focus scores were submitted to a mixed-model regression (Compound Symmetry), with classic Stroop type (congruent vs. incongruent, effect coded as -1 and 1 respectively), BMI (mean centered), and their interaction included as predictors. This analysis produced only the predicted interaction effect, $B = 2.08$, $SE = 0.90$, $t(77) = 2.30$, $p < .03$, 95% CI [0.28, 3.88] (Fig. 3). Simple effects analysis revealed that for low BMI participants (centered at -1 SD), health focus did not differ as a function of previous congruency, $B = -4.38$, $SE = 3.78$, $t(77) = 1.16$, $p > .25$, 95% CI [-11.9, 3.14]. However, as predicted, for high BMI participants (centered at $+1$ SD), health focus improved following incongruent, as compared with congruent, classic Stroop trials, $B = 7.94$, $SE = 3.78$, $t(77) = 2.10$, $p < .04$, 95% CI [0.41, 15.46]. That is, again, high BMI participants exhibited a significant control readiness effect.

3.3. Discussion

The findings of Study 2 suggest that control readiness has beneficial implications for attention, even if it is covert. Participants for whom overcoming temptations is personally relevant were able to mentally shift their attention toward healthy food cues and away from tempting cues following a pre-activation of control. This finding is important because it suggests that control readiness might be effective in modulating attention even if the objective presence of the stimulus is inevitable.

4. General discussion

The successful self-control of eating behavior often requires the regulation of attention, whereby attention is shifted away from a tempting food option and toward a healthier alternative. In two studies, we presented evidence that the control readiness mechanism can facilitate the effective control of attention to food cues. That is, we found that the activation of control in a task unrelated to food can modulate controlled processing on a second, independent task in the food domain, such that relative attention to tempting food cues is decreased. We further showed that this process occurs “online,” on a trial-by-trial basis, such that it is acutely responsive to phasic changes in cognitive control. Importantly, the pre-activation of control reduced relative attention to tempting foods for individuals sensitive to such cues (high-BMI participants).¹ We did not observe a control readiness effect on attention to food cues for relatively low-BMI participants, for whom such cues did not presumably elicit strong self-control motives.

In Study 1, we found that overt attention to temptations was modulated by previously activated control: when control was engaged (compared to when it was not), high BMI participants showed reduced attention to temptation. Put differently, spatial deployment of attention was modulated by the pre-activation of control. In Study 2 we found that covert attention followed the same pattern: previous activation of control led to reduced attention to temptation for high BMI participants, without the need of participants to avert spatial attention. This finding is especially important because it suggests that control readiness can aid in the mental shift of attention.

Our findings, which demonstrate the effect of control readiness on both overt and covert attention, are important for several reasons. First, diverting one’s gaze away from temptations in order to avoid acting upon them is an efficient self control strategy, but one that may be difficult for individuals susceptible to temptation cues to engage. Nevertheless, we demonstrate that this form of attention control can be successfully deployed through control readiness. Second, as noted in the introduction, an even more difficult situation is when the temptation’s presence is unavoidable. This is where covert attentional shifts come to play, and we have shown that control readiness can also effectively enhance covert attention control. Taken together, we have shown that control activated at time $N - 1$ affected a prominent mechanism at time N : selective attention. Our findings thus suggest that control readiness affects a cognitive process that plays a central role in facilitating self-control, rapidly and flexibly.

¹ Indirect evidence that high BMI participants are more sensitive to tempting food cues comes from two additional analyses of the data. Combining the data of the two studies to obtain greater statistical power (Curran & Hussong, 2009) we observed that following congruent Stroop trials (i.e., trials that do not activate control) high BMI participants had higher attention to temptation (i.e., relatively lower health focus) compared to low BMI participants, $B = 1.77$, $SE = 0.90$, $t(273.29) = 1.96$, $p = .051$, 95% CI $[-0.006, 3.54]$, [For both Studies 1 and 2, the effect was in the predicted direction: $B = 1.31$, $SE = 0.99$, $t(127.25) = 1.32$, $p = .19$, 95% CI $[-0.65, 3.28]$, $B = 2.27$, $SE = 1.51$, $t(142.78) = 1.51$, $p = .14$, 95% CI $[-0.71, 5.25]$, for Study 1 and Study 2, respectively]. In addition, for high BMI participants following congruent trials, their attention to temptation (i.e., relatively lower health focus) was significantly greater than zero, $B = 10.47$, $SE = 3.95$, $t(273.29) = 2.65$, $p < .01$, 95% CI $[2.69, 18.25]$, [This effect was significant in Study 1, $B = 10.51$, $SE = 4.58$, $t(127.25) = 2.29$, $p < .03$, 95% CI $[1.44, 19.58]$, and marginally significant in Study 2, $B = 10.62$, $SE = 6.30$, $t(142.78) = 1.69$, $p = .09$, 95% CI $[-1.84, 23.07]$. Taken together these analyses provide empirical support for the idea that high BMI participants are more attracted to tempting food cues in the environment compared to their low BMI counterparts. We thank an anonymous reviewer for suggesting these additional analyses.

4.1. The uniqueness of the control readiness mechanism

In both studies, control readiness lessened attention to temptations only for high BMI participants, presumably because they were more sensitive to tempting food cues and had conflicting approach and avoidance motivations toward these cues. This pattern of results importantly suggests that the operation of control readiness is selective to contexts in which a motivational conflict is detected, assisting in resolving the conflict in favor of the higher-order goal.

As discussed in the introduction, the self-control literature has documented a variety of proactive control strategies. These strategies enable individuals to either avoid self-control dilemmas in the moment (e.g., by changing the route to work so as to not pass by a bakery; Gross & Thompson, 2007), or to be prepared for them in advance when they arise (e.g., by practicing how to respond to a cue in the environment when it appears; Mendoza et al., 2010). However, most of these strategies rely on deliberate intentions to exert control, as one must remain vigilant for cues to exert control. By contrast, the control readiness framework proposes that control can be initiated without the need for cue vigilance. Instead, it requires only a personally-relevant self-control goal. That is, by engaging in a task that is goal-irrelevant, but that nonetheless activates cognitive control (e.g., the color-naming Stroop task), the activation of control transfers to the subsequent task, facilitating the intended response in a personally-relevant choice. Because control readiness does not require prospective cue monitoring, it requires less preplanning, and thus it may be more widely applicable. Furthermore, unlike implementation intention strategies, which involve a specific if-then action plan, the control readiness process engages a flexible form of control that should facilitate any goal-directed response. For these reasons, control readiness may prove especially beneficial to individuals who have difficulty exerting self-control based on specific action cues or who may be vulnerable to factors that undermine reactive forms of control.

4.2. Implications for control adjustment across domains

Our findings support the argument that personal significance plays a crucial role in the adjustment of control across domains. Specifically, an important question raised in the cognitive neuroscience literature on control adjustment is whether control adjustments are *domain general*, as our predictions and findings suggest, or *domain specific*. Past research has examined this question using procedures in which tasks, such as the Stroop (Stroop, 1935) and flanker (Eriksen & Eriksen, 1974), are completed in alternating trials. The typical finding in the literature suggests that control adjustments are domain specific, such that the engagement of control cannot be transferred across different types of tasks (e.g., Funes, Lupiáñez, & Humphreys, 2010a, 2010b; Notebaert & Verguts, 2008; see Egner, 2008 for a review). In recent years, however, accumulating evidence has begun to suggest that control can indeed be adjusted across domains, such that regulatory obstacles on a focal task could be preempted by the activation of control on an immediately preceding task (Freitas, Bahar, Yang, & Banai, 2007; Freitas & Clark, 2014; Kan et al., 2013; Kleiman et al., 2014). Theoretical accounts of these contradictory findings suggest, for example, that the domain generality of control adjustments depends on the similarity of conflict invoked in the two domains (Egner, 2008) or on the degree to which the two tasks rely on the same working memory resources (Braem, Abrahamse, Duthoo, & Notebaert, 2014).

Our theorizing and findings propose another factor: the personal significance of the main task (Kleiman et al., 2014). Specifically, most prior work supporting the domain specific account examined performance on tasks that may be characterized as

having low personal relevance, such as naming word colors or classifying letters. In the context of such tasks, control readiness would be circumscribed to the task because the task does not relate to broader, person-specific concerns that should cut across domains. By contrast, a task that involves highly personally-relevant concerns, such as food choice concerns among high BMI individuals, may induce controlled processing that is more likely to cut across specific responses, thus enabling the adjustment of control across domains. In the present research, we induced personal significance in two ways. First, participants' focal task involved responding to food cues—a domain that is arguably much more personally relevant than that of classifying colors or character strings. Second, we included participants who varied in BMI, reasoning that the personal relevance of the food choice task would be especially strong for high BMI participants. Indeed, in past research, BMI has been consistently linked to dieting concerns (Veling et al., 2011). As expected, control readiness effects on selective attention were observed only for individuals with relatively high BMI.

4.3. Limitations and future directions

We should note that while our predictions and findings are consistent with Conflict Monitoring Theory (Botvinick et al., 2001; see Egner, 2008 for a summary of empirical findings), they may appear to diverge from predictions stemming from ego depletion theory (Muraven & Baumeister, 2000, but see Inzlicht, Schmeichel, & Macrae, 2014; Job, Dweck, & Walton, 2010; Molden et al., 2012, for theoretical and empirical alternatives to the depletion model). Specifically, conflict adaptation theory argues for the on-line adjustment of control, such that the experience of conflict in one trial triggers an increase in control as one approaches a subsequent trial. Ego depletion theory argues that the exertion of control depletes one's limited control resources, resulting in diminished control on a subsequent task. We view ego depletion theory as addressing a different level of psychological processing. Our theoretical focus concerns strategies to engage and enhance control in the first place, in the context of an ongoing task, prior to the potential onset of depletion. By comparison, depletion is typically observed after the central task is completed, and usually on tasks with low personal relevance. Thus, our theoretical focus is not directly contradictory to ego depletion theory; rather, our focus is on a different aspect of controlled processing.

A strength of the present research is its use of an individual difference measure—BMI—to provide a more refined prediction for the control readiness mechanism and, at the same time, to examine the effect of control readiness in a population at greater risk for disease associated with eating behavior. However, it is notable that while BMI offered a reasonable proxy for food relevance, it represents a physical attribute that could reflect a variety of psychological and other processes. Future research will be needed to address the psychological processes linked to BMI that more directly influence the control readiness effect in the context of food choice. For example, the control readiness effects observed among relatively high BMI participants may have reflected concern about one's weight (Veling et al., 2011), importance of the dieting goal (Fishbach, Zhang, & Trope, 2010), or the degree of past success in self-control (Meule, Papies, & Kübler, 2012).

4.4. Concluding remarks

In the present research, we integrated theorizing and findings on the role of selective attention in cognitive and self-control into the framework of our proposed mechanism for proactive self-control: control readiness. As discussed in the introduction, selective attention has been found to play an important role in facilitating self-control, such that individuals are less likely to engage with

stimuli to which they do not attend (e.g., Mischel et al., 1989). Moreover, within the cognitive neuroscience literature on the operation of cognitive control, attention toward the goal and away from distractors is conceptualized as the mechanism underlying the successful exertion of control (Botvinick et al., 2001). The current findings provide evidence for the mechanism underlying behavioral responses in previous research documenting the control readiness process specifically (Kleiman et al., 2014) and the successful adjustment of control across domains more generally (Freitas et al., 2007; Kan et al., 2013).

More broadly, our findings reveal that conflict-induced cognitive control can operate on selective attention, even when the distractor is personally relevant (i.e., tasty foods) and attention must be controlled covertly, without averting one's eyes from the temptation. By examining this mechanism of self-control in the context of food cues, and among individuals varying in BMI, this research integrates research on cognitive control, motivation, and individual differences to make progress toward new interventions to promote healthy eating behavior and personal well being.

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