Training in cognitive strategies reduces eating and improves food choice

Rebecca G. Boswell[a,1], Wendy Sun[b,1], Shosuke Suzuki[b], and Hedy Kober[a,b,2]

[a]Department of Psychology, Yale University, New Haven, CT 06511; and [b]Department of Psychiatry, Yale University, New Haven, CT 06510

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Obesity rates continue to rise alarmingly, with dire health implications. One contributing factor is that individuals frequently forgo healthy foods in favor of inexpensive, high-calorie, unhealthy foods. One important mechanism underlying these choices is food craving: Craving increases with exposure to unhealthy foods (and food cues, such as advertisements) and prospectively predicts eating and weight. Prior work has shown that cognitive regulation strategies that emphasize the negative consequences of unhealthy foods reduce craving. In Studies 1 and 2, we show that cognitive strategies also increase craving for healthy foods by emphasizing their positive benefits, and change food valuation (willingness to pay) for both healthy and unhealthy foods. In Studies 3 and 4, we demonstrate that brief training in cognitive strategies ("Regulation of Craving Training"; ROC-T) increases subsequent healthy (vs. unhealthy) food choices. This was striking because this change in food choices generalized to nontrained items. Importantly, in Study 5, we show that brief training in cognitive strategies also reduces food consumption by 93–121 calories. Consumed calories correlated with changes in food choice. Finally, in Study 6, we show that the training component of ROC-T is necessary, above and beyond any effect of framing. Across all studies (N_{TOTAL} = 1,528), we find that cognitive strategies substantially change craving and food valuation, and that training in cognitive strategies improves food choices by 5.4–11.2% and reduces unhealthy eating, including in obese individuals. Thus, these findings have important theoretical, public health, and clinical implications for obesity prevention and treatment.

cognitive strategies | craving | food | obesity | self control

Imagine standing in a food court. The smells of French fries, greasy Chinese food, and $2 pizza surround you, and the only available salad costs $10. Would you make the healthy choice?

Food choices like this one are important because they can lead to malnutrition, weight gain, and obesity. Rates of overweight and obesity have risen dramatically in the past 30 y (1, 2). Today, two-thirds of the United States population is overweight, and obesity is the second leading cause of preventable disease and mortality, accounting for one in five deaths (3). Weight gain is caused by caloric imbalance associated with overconsumption of unhealthy foods, such as pizza, and underconsumption of healthy foods, such as salad (1, 4). Caloric imbalance is exacerbated by convenient, inexpensive access to high-calorie/unhealthy foods (1) and pervasive food marketing (5) in the presence of expensive healthy alternatives (6, 7). This underscores the urgent need to develop interventions that could help people make healthier food choices in the face of temptation.

To address this, public-health interventions have attempted to alter the structure of the environment to decrease unhealthy and increase healthy food consumption (5, 8). Examples of these interventions include altering food prices (e.g., soda tax) and reducing the availability of unhealthy foods [e.g., junk food bans (9)]. Other approaches rooted in behavioral economics "nudge" people toward healthy behaviors by changing "choice architecture" [i.e., framing/choice presentation/optimal defaults/"right sizes" (9–12)]. Such interventions do not require cognitive effort on the part of consumers. However, nudges have had limited real-world success since they are restricted in implementation and generalizability to organizations that agree to adopt them (1). Moreover, even if environmental changes were widely implemented, most of us ultimately would still find ourselves staring temptation squarely in the face. Indeed, there may always be nudge-resistant food courts filled with cheap, delicious, unhealthy options.

In tempting situations, we are ultimately left to our own devices. In such cases, we could exert self-control over our thoughts, feelings, and behaviors. As observed in seminal work on delay of gratification (13), self-control can be facilitated through cognitive strategies. Consistently, cognitive strategies for the regulation of craving are included in treatments for obesity and eating disorders (14). Experimentally, we (and others) have shown that these strategies, such as thinking about the negative consequences of consumption, reduce both self-reported craving for unhealthy foods (15, 16) and drugs (16–20) and the neural activity associated with craving (15, 17, 21–23). Cognitive manipulations have also been shown to alter food bidding (24–27). Such effective down-regulation of food craving is important, because several meta-analyses (on prospective data) have shown that craving for unhealthy foods consistently predicts subsequent eating and weight (28, 29).

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Significance

Despite public health interventions, most individuals in the United States are overweight or obese. Here, we provide evidence for a mechanism-based technique to improve food choices in an "obesogenic" environment filled with temptation. Across two studies, we demonstrate that cognitive strategies decrease craving for unhealthy foods, increase craving for healthy foods, and modulate subjective valuation. Importantly, across four additional studies we show that brief training in such cognitive strategies increases subsequent healthy food choices in the presence of unhealthy alternatives, without explicit instructions to use the strategies, and across individual differences in weight. Furthermore, this training significantly reduces food consumption. Thus, training in cognitive strategies might ultimately advance clinical treatment and public health interventions aiming to prevent and reduce obesity.

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Data deposition: The hypotheses and analysis plan for Study 5 are available through Open Science Framework (https://osf.io/qfhe4). The data reported in this paper have been deposited in Open Science Framework (https://osf.io/5fytx/).

[1]R.G.B. and W.S. contributed equally to this work.

[2]To whom correspondence should be addressed. Email: hedy.kober@yale.edu.

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Thus, the critical question is whether preemptive training in cognitive strategies—before temptation—could improve subsequent eating behavior. Unlike externally applied, situation-specific nudges, cognitive strategies are individually generated, adaptable, and flexibly modified based on the situation in which they are applied. Instead of modifying the environment, training in cognitive strategies aims to alter the internal architecture of food choices, including how individuals crave and value foods. This is consistent with the recent suggestion that a key factor in self-control is changing the subjective value of choice options (30–32). As such, training in the regulation of food craving could help individuals nudge themselves toward altered internal valuations of food, could be generalizable and flexible even in tempting situations, and ultimately might reduce the consumption of unhealthy foods. Thus, it could have the potential to serve as an intervention to change eating behavior, with implications for existing clinical and environmental approaches to prevent and reduce obesity.

We conducted six studies to develop an intervention to improve eating behavior: Regulation of Craving Training (ROC-T). First, we developed and tested two cognitive strategy instructions that frame foods as "bad for you" or "good for you": NEGATIVE (think about negative aspects of eating food, e.g., long-term health consequences or disliking the taste), or POSITIVE (think about the positive aspects of eating food, e.g., long-term health benefits or liking the taste). In Studies 1 and 2 we asked three questions about these cognitive strategies: (*i*) Can they increase craving for healthy foods as well as decrease craving for unhealthy foods? (*ii*) Can they influence the subjective value of foods [operationalized as willingness to pay (WTP), a common measure in economics that approximates and predicts consumer behavior (33, 34)]? (*iii*) Are such strategies effective across individual differences in body mass index (BMI)? Then, in Studies 3 and 4, we developed ROC-T as a brief intervention based on the strategies tested in Studies 1 and 2 and asked (*iv*) Can training in these cognitive strategies increase subsequent healthy food choices in the presence of tempting alternatives? Crucially, in Study 5, we asked (*v*) Can training in cognitive strategies reduce food consumption? Finally, in Study 6, we compared ROC-T to a framing-only control condition to ask (*vi*) Is the training component a necessary "active ingredient" of ROC-T?

Results

Studies 1 and 2.

Effect of cognitive strategies on craving and WTP. We used the regulation of craving (ROC) task to test the effects of cognitive strategies on ratings of craving and WTP for healthy and unhealthy foods (Fig. 1). In Study 1 ($N_{PARTICIPANTS} = 28$; mean age (M_{AGE}) = 19.09, $SD_{AGE} = 1.00$; $M_{BMI} = 22.03$, $SD_{BMI} = 2.29$) (*SI Appendix*, Table S1), cognitive strategies influenced craving, such that the POSITIVE strategy increased craving and the NEGATIVE strategy decreased craving for both healthy and unhealthy foods relative to LOOK [$F_{(1,27)} = 54.52$, $P < 0.001$, $\eta^2 = 0.67$; $M_{POSITIVE} = 3.53$; $M_{LOOK} = 3.08$; $M_{NEGATIVE} = 2.47$] (Fig. 2*A* and *SI Appendix*, *SI Results*).

Similarly, cognitive strategies modified the subjective value of foods as measured by WTP such that the POSITIVE strategy increased WTP and the NEGATIVE strategy decreased WTP for both healthy and unhealthy foods compared with LOOK [$F_{(1,27)} = 36.23$, $P < 0.001$, $\eta^2 = 0.57$; $M_{POSITIVE} = \$5.20$; $M_{LOOK} = \$4.51$; $M_{NEGATIVE} = \$3.71$] (Fig. 2*B* and *SI Appendix*, *SI Results*). Notably, WTP changed by 69–80 cents (POSITIVE – LOOK: $M_{DIFFERENCE} = \$0.69$; LOOK – NEGATIVE: $M_{DIFFERENCE} = \$0.80$), which is far greater than typically reported effects [e.g., 8×–10× more than that of the proposed penny-per-ounce soda tax (35)]. There were no significant effects of food healthiness and no interactions between strategy and healthiness (*P*s > 0.06).

Study 2 replicated and extended these results to a large online sample that is representative of the United States population (2, 36, 37) ($N_{PARTICIPANTS} = 242$; $M_{AGE} = 35.78$, $SD_{AGE} = 12.21$) (*SI Appendix*, Table S1). Because we found a wide range of BMI values across participants ($M_{BMI} = 27.92$, $SD_{BMI} = 8.01$; $Range_{BMI} = 16.97–63.89$), we included BMI as a covariate in all subsequent analyses in this study. Cognitive strategies again influenced craving and WTP, such that the POSITIVE strategy increased and the NEGATIVE strategy decreased craving [$F_{(1,240)} = 25.20$, $P < 0.001$, $\eta^2 = 0.10$; $M_{POSITIVE} = 3.34$; $M_{LOOK} = 3.12$; $M_{NEGATIVE} = 2.61$] and WTP [$F_{(1,240)} = 7.78$, $P = 0.006$, $\eta^2 = 0.03$; $M_{POSITIVE} = \$4.24$; $M_{LOOK} = \$4.03$; $M_{NEGATIVE} = \$3.47$]. In this sample, cognitive strategies changed WTP by 21–56 cents (POSITIVE – LOOK: $M_{DIFFERENCE} = \$0.21$; LOOK – NEGATIVE: $M_{DIFFERENCE} = \$0.56$) (Fig. 3 *A* and *B*). Unlike Study 1, we found a main effect of healthiness on craving [$F_{(1,240)} = 4.11$, $P = 0.04$, $\eta^2 = 0.02$], such that participants reported higher craving for unhealthy foods than for healthy foods ($M_{UNHEALTHY} = 3.15$; $M_{HEALTHY} = 2.87$). There were no other effects of healthiness or interactions between strategy and healthiness on craving or WTP (*P*s > 0.11). Craving and WTP were significantly correlated [$r_{(240)} = 0.53$; $P < 0.001$] (*SI Appendix*, *SI Results*).

Individual differences in BMI. In Study 2, we found an interaction between food healthiness and BMI for both craving and WTP [craving: $F_{(1,240)} = 13.13$, $P < 0.001$, $\eta^2 = 0.05$; WTP: $F_{(1,240)} = 14.33$, $P < 0.001$, $\eta^2 = 0.06$]. Individuals with higher BMI reported more craving and WTP for unhealthy foods [craving: $r_{(240)} = 0.17$, $P = 0.01$; WTP: $r_{(240)} = 0.17$, $P = 0.009$] but did not report greater craving or WTP for healthy foods (craving: $P = 0.10$; WTP: $P = 0.64$) (Fig. 3 *C* and *D*). BMI was not significantly associated with regulatory success (i.e., percent change between each strategy and LOOK) (*SI Appendix*, *SI Results*). There were no other interactions or effects with BMI (*P*s > 0.21).

Studies 3 and 4. Studies 1 and 2 showed that cognitive strategies can increase craving for healthy foods, reduce craving for unhealthy foods, and alter subjective valuation of foods (WTP) across BMI.

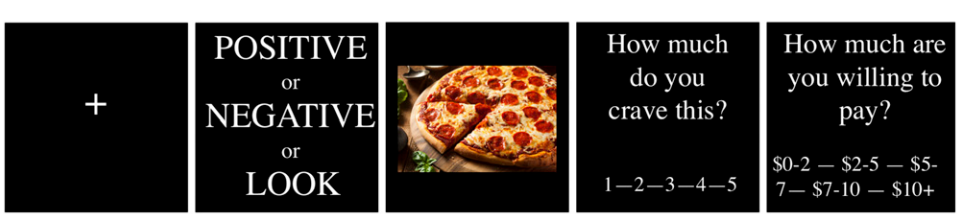

Fig. 1. ROC task (Studies 1 and 2). Schematic representation of the ROC task. Participants first saw a fixation cross (duration 0.5 s), followed by the strategy instruction (duration 2.5 s). Specifically, NEGATIVE instructed participants to think about the negative aspects of eating the pictured food (e.g., long-term health consequences, disliking the taste). POSITIVE indicated that they should think about the positive aspects of eating the food (e.g., long-term health benefits, liking the taste). LOOK (just look at the image) served as a control instruction. Instructions were followed by an image of healthy or unhealthy food (duration 6 s), after which participants rated their craving and WTP (4.5 s each). Pizza image courtesy of iStock.com/bhofack2.

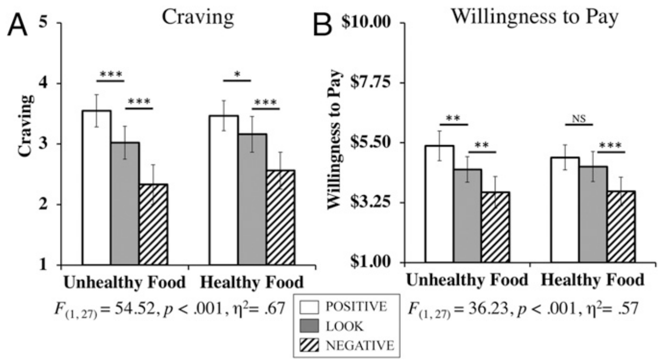

Fig. 2. Changes in craving and WTP (Study 1; $n = 28$). The POSITIVE strategy increased and the NEGATIVE strategy decreased craving (*A*) and WTP (*B*) for both healthy and unhealthy foods in Study 1 (college-aged students). *F* statistics represent the main effects of Instruction. Error bars represent 95% confidence intervals; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$; NS, not significant.

Notably, the POSITIVE and NEGATIVE strategies were both effective compared with LOOK. In Studies 3 and 4, we asked whether training in such strategies could alter subsequent food choices by developing a brief intervention: ROC-T (*Methods*). ROC-T trains participants to use cognitive strategies to either (*i*) increase craving for healthy foods (*POSITIVE* ROC-T) or (*ii*) decrease craving for unhealthy foods (*NEGATIVE* ROC-T; conditions are italicized; strategies are not italicized). Then, we tested whether ROC-T—compared to a *CONTROL* no-training "look-only" condition—can change choices of healthy vs. unhealthy foods. To do this, participants in Studies 3 and 4 completed three tasks: (*i*) the Choice Task, (*ii*) ROC-T, and (*iii*) the Choice Task for a second time (Fig. 4 and *SI Appendix, SI Methods*). During both Choice Tasks, participants chose between pairs of foods, with the critical choices occurring during healthy–unhealthy food pairings (Fig. 4 and *SI Appendix, SI Methods*). Importantly, ROC-T was designed to alter internal representations of food values using cognitive strategies, and participants were not asked to exercise cognitive strategies while making food choices. Rather, they were encouraged to choose the item that they desired most in the moment.

Effect of ROC-T on subsequent healthy food choices. In Study 3, 384 participants chose between healthy and unhealthy foods before and after undergoing ROC-T ($M_{AGE} = 37.25$, $SD_{AGE} = 12.06$; $M_{BMI} = 28.75$, $SD_{BMI} = 7.77$) (*SI Appendix*, Table S2). There were no differences in healthy vs. unhealthy food choices in the first Choice Task between conditions ($P = 0.89$). However, after completing ROC-T, individuals in both the *POSITIVE* and *NEGATIVE* ROC-T training conditions chose significantly more healthy than unhealthy foods [effect of Time: $F_{(1,381)} = 35.25$, $P < 0.001$, $\eta^2 = 0.09$; Condition: $F_{(2,381)} = 3.54$, $P = 0.03$, $\eta^2 = 0.02$; Time × Condition interaction: $F_{(2,381)} = 39.24$, $P < 0.001$, $\eta^2 = 0.17$]. Specifically, healthy food choice increased significantly by 5.9% in the *POSITIVE* ROC-T condition and by 11.2% in the *NEGATIVE* ROC-T condition but decreased significantly by 3.6% in the *CONTROL* condition (Fig. 5*A* and *SI Appendix*, *SI Results*). Study 4 ($N_{PARTICIPANTS} = 370$; $M_{AGE} = 39.21$, $SD_{AGE} = 13.34$; $M_{BMI} = 27.49$, $SD_{BMI} = 7.44$) directly replicated Study 3 [effect of Time: $F_{(1,367)} = 28.44$, $P < 0.001$, $\eta^2 = 0.07$; Condition: $F_{(2,367)} = 3.46$, $P = 0.03$, $\eta^2 = 0.02$; Time × Condition interaction: $F_{(2,367)} = 17.81$, $P < 0.001$, $\eta^2 = 0.09$]. Again, there were no differences in healthy vs. unhealthy food choices in the first Choice Task between conditions ($P = 0.36$). Importantly, healthy food choice increased significantly from pre- to post-training by 5.4% in the *POSITIVE* ROC-T condition and by 7.6% in the *NEGATIVE* ROC-T condition. There was a significant decrease in healthy food choice in the *CONTROL* condition (1.7%). Across both studies, both ROC-T conditions significantly increased healthy food choices and were significantly different from *CONTROL* (*SI Appendix*, *SI Results*). In Study 3, the *NEGATIVE* ROC-T condition led to greater change in healthy food choices than the *POSITIVE* ROC-T condition; in Study 4, ROC-T conditions were equally effective at increasing healthy food choices (Fig. 5*B* and *SI Appendix*, *SI Results*).

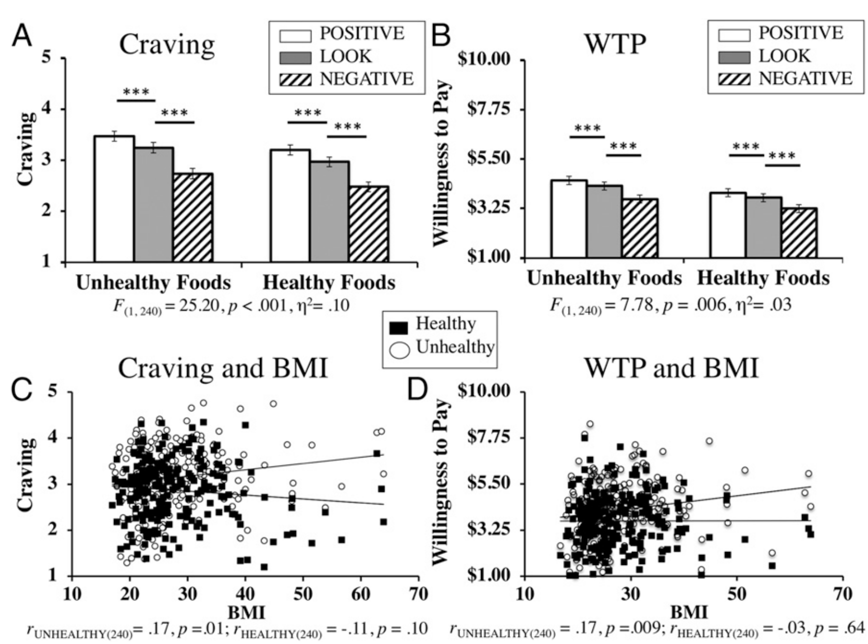

Fig. 3. Changes in craving and WTP in an online sample (Study 2; $n = 242$). (*A* and *B*) The POSITIVE strategy increased and the NEGATIVE strategy decreased craving (*A*) and WTP (*B*) for both healthy and unhealthy foods. (*C* and *D*) Additionally, BMI correlated with craving (*C*) and WTP (*D*) for unhealthy but not for healthy foods. *F* statistics represent the main effects of Instruction. Error bars represent 95% confidence intervals; $^{***}P < 0.001$.

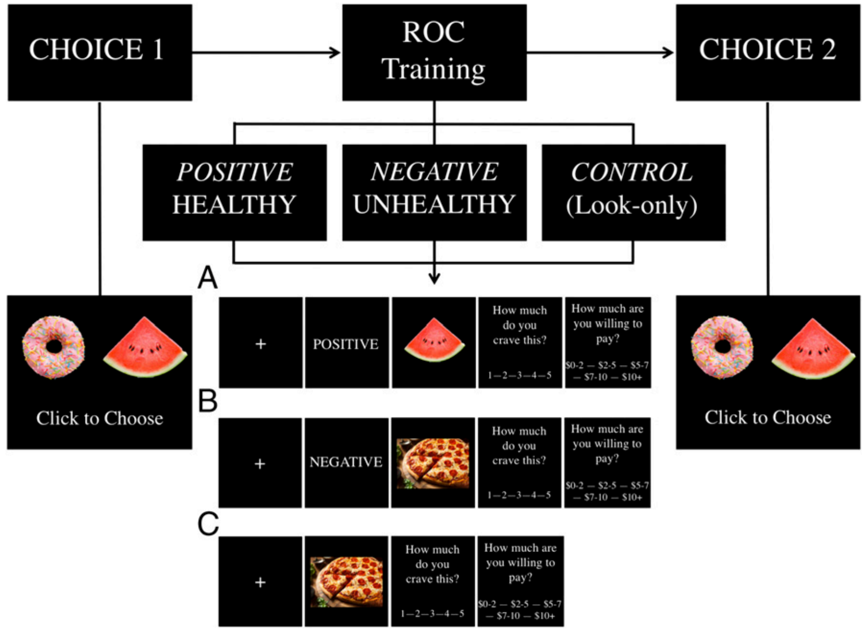

Fig. 4. Food choice and ROC-T procedures (Studies 3 and 4). Schematic representation of the procedures. Before and after ROC-T, participants completed 108 choices, 72 of which were between healthy and unhealthy foods (other choices were between healthy vs. healthy or between unhealthy vs. unhealthy foods). All images were presented evenly within each task. During ROC-T, participants were randomized into one of three possible conditions, following the ROC task in Studies 1 and 2, namely, (*A*) *POSITIVE* ROC-T, (*B*) *NEGATIVE* ROC-T, or (*C*) *CONTROL* (look-only). In the *CONTROL* condition, participants saw the same images shown in either the *POSITIVE* or *NEGATIVE* training conditions (*SI Appendix*, *SI Methods*). Pizza image courtesy of iStock.com/bhofack2. Watermelon image courtesy of iStock.com/Boonchuay1970. Donut image courtesy of iStock.com/Sergey Skleznev.

Food choice reaction times. Individuals who underwent ROC-T could have practiced regulation strategies during the second Choice Task, which would correspond with an increase in reaction time (RT) from the first to the second Choice Task (38, 39). However, participants got faster during the second Choice Task compared with the first across all conditions [effect of Time: Study 3: $F_{(1,381)} = 272.11$, $P < 0.001$, $\eta^2 = 0.42$; $M_{PRE} = 1{,}667.98$, $SD_{PRE} = 592.60$; $M_{POST} = 1{,}274.92$, $SD_{POST} = 404.51$; Study 4: $F_{(1,367)} = 168.96$, $P < 0.001$, $\eta^2 = 0.32$; $M_{PRE} = 1{,}644.10$, $SD_{PRE} = 591.91$; $M_{POST} = 1{,}223.67$, $SD_{POST} = 512.10$]. Critically, RT was not slower in the training conditions than in *CONTROL* (no effect of Condition, *P*s > 0.13), and changes in RT did not differ by condition (no Time × Condition, *P*s > 0.44) (*SI Appendix*, *SI Results*).

Did training generalize? To test whether training effects were specific to images practiced in ROC-T, we compared the change in healthy choices from the first to second Choice Task between trained and untrained items. In Study 3, there was no significant difference between change in choice for items paired with strategy instructions during ROC-T compared with those paired with LOOK ($P = 0.41$), suggesting full generalization of training effects to items unpaired with a strategy, i.e., items that were not trained during ROC-T. In Study 4, there was a greater change in choice for the items paired with the strategy instructions during ROC-T [$t_{(215)} = 3.57$, $P < 0.001$]. Nevertheless, there was a significant increase in healthy choices for items paired with LOOK during ROC-T [5.1%; $t_{(215)} = 4.79$, $P < 0.001$], suggesting generalization of training effects to untrained items.

BMI and choice. In Study 3, we found that individuals with higher BMI chose more unhealthy items during the first Choice Task [$r_{PRE(372)} = 0.12$, $P = 0.02$] but not during the second ($P = 0.27$). While there was a significant interaction between change in choice and BMI [$F_{(1,370)} = 4.82$, $P = 0.03$, $\eta^2 = 0.01$], there was no correlation between BMI and change in choice ($P = 0.08$). That is, training effects in individuals with higher BMI were similar to those in individuals with lower BMI. In Study 4, individuals with higher BMI chose more unhealthy food items overall [$r_{PRE(359)} = 0.12$, $P = 0.02$; $r_{POST(359)} = 0.11$, $P = 0.04$]. There was no interaction or correlation between change in choice and BMI (*P*s > 0.54), indicating that individuals with higher BMI did not exhibit a greater increase in healthy food choices.

Study 5. Importantly, in Study 5 we tested whether ROC-T could reduce food consumption ($N_{PARTICIPANTS} = 64$; $M_{AGE} = 18.81$, $SD_{AGE} = 0.91$; $M_{BMI} = 23.64$, $SD_{BMI} = 5.02$) (*SI Appendix*, Table S4). We used the procedures from Studies 3 and 4 and included a

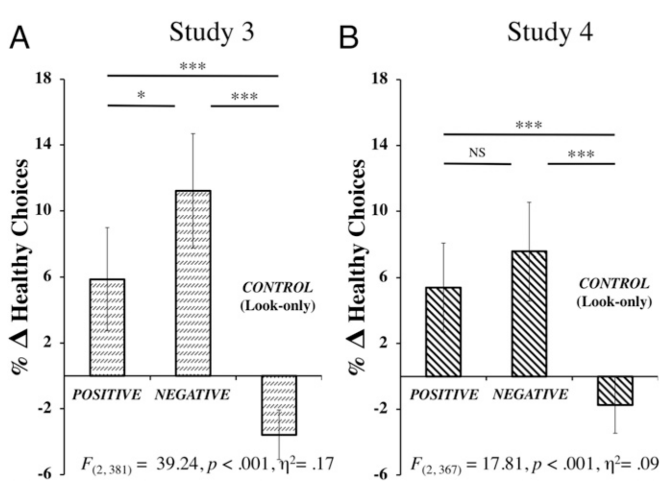

Fig. 5. Percent of change (Δ%) in healthy choices after ROC-T (Studies 3 and 4; $n = 754$). (*A*) Both *POSITIVE* and *NEGATIVE* ROC-T increased healthy food choices compared with *CONTROL* in Study 3. (*B*) Study 4 replicated these findings. *F* statistics represent the Time × Condition interactions. Error bars represent 95% confidence intervals; **P* < 0.05; ****P* < 0.001; NS, not significant.

new and ostensibly unrelated Food Taste Task (FTT). After completing ROC-T and the second Choice Task, participants were asked to taste four foods presented in gallon containers, to consume the foods ad libitum, and to provide taste ratings. Items were secretly weighed in grams before and after the FTT, and the caloric content of the foods was calculated from calorie/gram information. We expected that ROC-T would reduce overall caloric consumption and specifically would reduce caloric consumption of unhealthy foods. A reduction in food consumption would indicate that ROC-T is an efficacious intervention that alters eating behavior, above and beyond food choice. Our hypotheses and analysis plan were registered with Open Science Framework (https://osf.io/qfhe4).

ROC-T increases healthy food choices. Study 5 replicated Studies 3 and 4, such that healthy food choices significantly increased from the first to the second Choice Task by 8.2% in the *POSITIVE* ROC-T condition and by 9.2% in the *NEGATIVE* ROC-T condition, whereas they significantly decreased by 4.1% in the *CONTROL* condition [effect of Time: $F_{(1,61)} = 7.68$, $P = 0.007$, $\eta^2 = 0.11$; Time × Condition interaction: $F_{(2,61)} = 8.00$, $P = 0.001$, $\eta^2 = 0.21$] (Fig. 6*A* and *SI Appendix*, *SI Results*). There was no effect of Condition ($P = 0.83$).

ROC-T effects generalize to untrained foods. Again, there was no significant difference between change in choice of items paired with strategy instructions during ROC-T compared with those paired with LOOK ($P = 0.88$), suggesting full generalization of training effects to items unpaired with a strategy, i.e., items that were not shown during ROC-T.

Food choice RTs. In Study 5, as in Studies 3 and 4, there was a significant reduction in RT between the first and the second Choice Tasks across conditions [effect of Time: $F_{(1,61)} = 8.78$, $P = 0.004$, $\eta^2 = 0.13$] (*SI Appendix*, *SI Results*). Importantly, participants in the training conditions were not slower than those in *CONTROL*, as would be expected if they were exerting additional cognitive effort (no Time × Condition interaction; $P = 0.09$). Rather, participants in the *POSITIVE* ROC-T condition were faster overall [$F_{(2,61)} = 4.00$, $P = 0.02$, $\eta^2 = 0.12$] (*SI Appendix*, *SI Results*). There was no interaction with BMI ($P = 0.62$).

ROC-T reduces caloric consumption. As expected, participants consumed more unhealthy food calories than healthy food calories [Healthiness: $F_{(1,61)} = 26.17$, $P < 0.001$, $\eta^2 = 0.30$]. Importantly, we found an effect of ROC-T on caloric consumption [Condition: $F_{(2,61)} = 4.62$, $P = 0.01$, $\eta^2 = 0.13$], such that individuals who underwent *NEGATIVE* and *POSITIVE* ROC-T consumed 93–121 fewer calories than those in *CONTROL* ($M_{POSITIVE} = 191.59$, $SD_{POSITIVE} = 128.12$; $M_{NEGATIVE} = 219.69$, $SD_{NEGATIVE} = 155.67$; $M_{CONTROL} = 313.02$, $SD_{CONTROL} = 143.66$) (Fig. 6*B*). Further, this was driven by consumption of ∼100 fewer calories of unhealthy foods [Healthiness × Condition: $F_{(2,61)} = 5.24$, $P = 0.008$, $\eta^2 = 0.15$] (Fig. 6*B*). There were no differences between *POSITIVE* and *NEGATIVE* ROC-T ($P = 0.55$) (*SI Appendix*, *SI Results*).

Individual differences in food choice and consumption. The change in healthy food choice negatively correlated with total caloric consumption [$r_{(62)} = -0.28$, $P = 0.02$] and unhealthy caloric consumption [$r_{(62)} = -0.33$, $P = 0.008$], such that greater increases in healthy choice were associated with lower caloric consumption (Fig. 6*C*). However, changes in food choice and total caloric consumption were not related to BMI, self-reported hunger, time since last meal, or frequency of consumption of foods (Ps > 0.16). Self-reported liking of unhealthy foods correlated with unhealthy food consumption [$r_{(62)} = 0.25$, $P = 0.05$].

Study 6. Studies 3 and 4 demonstrated that ROC-T significantly improves food choices, and Study 5 also showed that ROC-T reduces food consumption, compared with the *CONTROL* look-only condition. However, ROC-T includes both an informational framing component (healthy foods are framed as positive and unhealthy foods are framed as negative in an introductory informational essay) and a training component (practicing the strategy while looking at food cues). Therefore, it was unclear whether training was indeed the primary active ingredient of

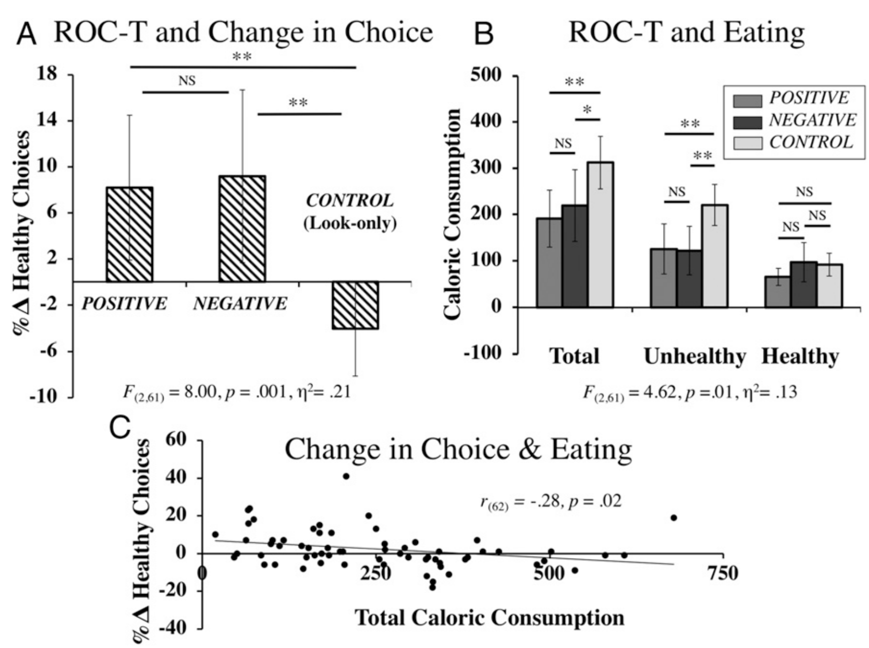

Fig. 6. Change in food choice and caloric consumption after ROC-T (Study 5; $n = 64$). (*A* and *B*) Compared with *CONTROL*, *POSITIVE*, and *NEGATIVE* ROC-T increased healthy food choices (*A*) (*F* statistic represents the Time × Condition interaction) and reduced total and unhealthy caloric consumption (*B*) (*F* statistic represents the main effect of Condition). (*C*) Greater increase in healthy food choice correlated with reduced caloric consumption after ROC-T. Error bars represent 95% confidence intervals; *$P < 0.05$; **$P < 0.01$; NS, not significant.

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ROC-T. To test this, in Study 6 we compared ROC-T with a framing-based no-training control condition to determine whether training in cognitive strategies is necessary—above and beyond the effect of framing—for ROC-T's efficacy (*Methods*). In this framing-based no-training control condition, participants read positive or negative information about foods (as they did in *POSITIVE* and *NEGATIVE* ROC-T) and then simply rated food images (as in the *CONTROL* condition in Studies 3–5).

Effect of ROC-T vs. framing-only on subsequent healthy food choices. In this study, 440 participants were randomized to one of five conditions: *POSITIVE* ROC-T, *NEGATIVE* ROC-T, *CONTROL* look-only, Positive Framing+look-only, and Negative Framing+look-only (M_{AGE} = 35.92, SD_{AGE} = 11.93; M_{BMI} = 28.41, SD_{BMI} = 7.65) (*SI Appendix*, Table S5; see Fig. 7 for a schematic representation of conditions). There were no significant differences in choices of healthy vs. unhealthy foods in the first Choice Task between conditions ($P = 0.67$). Importantly, we found significant differences in the change in healthy choices between conditions [effect of Time: $F_{(1,435)} = 37.93$, $P < 0.001$, $\eta^2 = 0.08$; Time × Condition interaction: $F_{(4,435)} = 9.20$, $P < 0.001$, $\eta^2 = 0.08$; no effect of Condition, $P = 0.29$]. Specifically, replicating Studies 3–5, individuals in the *POSITIVE* and *NEGATIVE* ROC-T conditions exhibited a significant increase in healthy vs. unhealthy food choices from the first to the second Choice Task (*POSITIVE*: 8.1% increase; *NEGATIVE*: 7.8% increase), whereas those in the *CONTROL* condition exhibited a 1.6% decrease. There were no significant differences between the *POSITIVE* and *NEGATIVE* ROC-T conditions ($P = 0.87$).

Crucially, direct comparisons between conditions showed that individuals who completed *POSITIVE* and *NEGATIVE* ROC-T exhibited a significantly greater increase in healthy vs. unhealthy food choices than those in the Positive and Negative Framing conditions: >4× in *POSITIVE* ROC-T and >2.5× in *NEGATIVE* ROC-T. Each condition was greater than *CONTROL* (Fig. 8 and *SI Appendix, SI Results*). Within the framing conditions—that did not include any training—participants in the Positive Framing condition did not choose significantly more healthy foods in the second Choice Task than in the first Choice Task ($P = 0.14$), while participants in the Negative Framing condition did [2.9%; $t_{(76)} = 2.01$, $P = 0.05$]. These two conditions were not different from one another ($P = 0.55$).

Food choice RTs. Participants across conditions got faster in the second Choice Task [effect of Time: $F_{(1,435)} = 268.89$, $P < 0.001$, $\eta^2 = 0.38$; M_{PRE} = 1,657.68, SD_{PRE} = 618.65; M_{POST} = 1,245.36, SD_{POST} = 395.83)]. Changes in RT from the first to the second Choice Task did not differ by condition (no effect of Condition or Time × Condition interaction, *P*s > 0.15) (*SI Appendix, SI Results*).

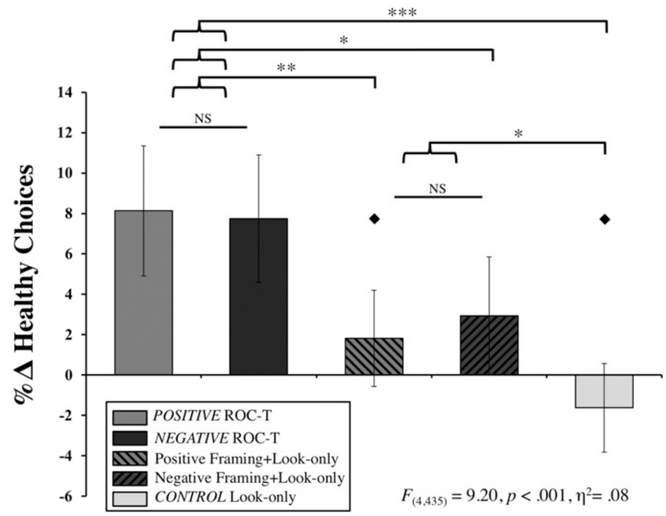

Fig. 8. Percent change in healthy choices (Study 6; $n = 440$). Both *POSITIVE* and *NEGATIVE* ROC-T increased healthy food choices significantly more than Positive or Negative Framing+look-only and *CONTROL*. *F* statistic represents the Time × Condition interaction. Error bars represent 95% confidence intervals; ◆, no significant difference from the first to the second Choice Task; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant.

Did training generalize? Participants in ROC-T conditions were slightly more likely to make healthy choices with items on which they were trained [$t_{(152)} = 2.12$, $P = 0.04$]. Nevertheless, conceptually replicating Studies 3–5 and directly replicating Study 4, there was a significant increase in healthy choices for items paired with LOOK during ROC-T [7.1%; $t_{(152)} = 6.20$, $P < 0.001$], suggesting that training generalized to nontrained items.

BMI and choice. Individuals with higher BMI chose more unhealthy items during the first Choice Task ($r_{PRE(431)} = 0.12$, $P = 0.02$) but not during the second Choice Task ($P = 0.09$). There were neither interactions between BMI and condition or change in choice, nor correlations between BMI and change in choice (*P*s > 0.07).

Discussion

Public-health interventions for obesity modify the framing of food choices to nudge people toward healthier options (8, 9, 12). Despite some efficacy, these interventions are limited in generalizability and flexibility because they depend on externally applied environmental changes. Instead, we tested an internally applied approach using cognitive strategies: thinking about the negative consequences of eating unhealthy foods or the positive benefits of

CONDITION	*NEGATIVE* ROC-T	*POSITIVE* ROC-T	*CONTROL* Look-only	Negative Framing + Look-only	Positive Framing + Look-only
Order of Tasks	Choice Task	Choice Task	Choice Task	Choice Task	Choice Task
	Negative essay	Positive essay	Neutral essay	Negative essay	Positive essay
	NEGATIVE ROC-T	*POSITIVE* ROC-T	Look-only	Look-only	Look-only
	Choice Task	Choice Task	Choice Task	Choice Task	Choice Task
	Surveys	Surveys	Surveys	Surveys	Surveys

Fig. 7. Schematic representation of conditions (Study 6).

healthy foods. We then examined whether training in such strategies could help individuals nudge themselves, improve their food choices, and reduce their consumption of unhealthy foods.

In Studies 1 and 2, cognitive strategies not only decreased craving for unhealthy foods but also increased craving for healthy foods. This finding is especially pertinent, given that craving accounts for as much as 26% of the variance in subsequent eating and weight (28), suggesting that changes in craving may influence eating of both healthy and unhealthy foods. In parallel, cognitive strategies modified WTP for foods; this is important because subjective valuation plays a substantial role in food choices (6), reliably predicts purchasing behavior (33, 34), and may be a key process in self-control (30–32). In Studies 3–6, participants received brief training in one of two cognitive strategies, and we tested whether training changed subsequent food choice. In the absence of intervention, healthy food choices were unchanged (Study 6) or significantly decreased (Studies 3–5). Importantly, training in either cognitive strategy increased healthy food choices in the face of tempting unhealthy options (Studies 3–6). Critically, in Study 5, training in cognitive strategies reduced total caloric consumption, especially of high-caloric/unhealthy foods (e.g., M&Ms, potato chips). These results demonstrate that training-based interventions influence eating behavior—and specifically, that ROC-T can reduce unhealthy eating. Finally, in Study 6, we showed that training in cognitive strategies was necessary to obtain the full effect of ROC-T on food choice, above and beyond the framing of healthy and unhealthy foods.

It is well known that consumption of high-caloric/unhealthy foods increases obesity (1, 6). In Study 5, we found a decrease in caloric consumption ~30–45 min following ROC-T. Indeed, the difference in food consumption between the ROC-T conditions and *CONTROL* was 93–121 calories. Importantly, goals established in some "small changes" weight-loss interventions require a mere 50- to 100-calorie reduction daily (40). Although weight loss is a complicated physiological process (4) made more difficult by environmental challenges (7), some have suggested that such a daily reduction in food consumption could reduce weight by 10–15 lb/y (40). Therefore, because ROC-T was shown to change craving, subjective value, choice, and consumption of food, it should be further tested as an intervention for obesity and related health complications.

Additionally, we found an increase in both self-reported craving and choice for healthy foods following training. Just increasing the consumption of healthy foods protects against malnutrition and disease (41) and increases weight loss (42, 43), which may be due to the substitution of healthy for unhealthy items (43, 44). Although we did not observe an increase in the amount of healthy food consumed post–ROC-T, our data are consistent with individuals substituting healthy for unhealthy foods, thus reducing total calorie consumption.

ROC-T may be effective, because it generalized to items that were not specifically trained and from images to real food. In other words, the observed increase in healthy (vs. unhealthy) food choices was not specific to the items paired with strategies during training but rather extended to items on which participants were not trained. The data also demonstrate generalization across classes of stimuli, from images to real food. This is important because it increases the potential real-world applicability of ROC-T, including to items not trained and to real food.

Importantly, we showed that the training component of ROC-T was necessary for maximal change in food choice to take place, having double to quadruple the effect of framing alone. Just looking at food images (in the *CONTROL* look-only condition) either did not change or decreased healthy food choices in Studies 3–6. Further, in Study 6, we showed that reading an introductory essay that framed healthy foods as positive did not change healthy food choices. Framing unhealthy foods as negative increased healthy food choices but to a significantly lesser extent than ROC-T. In this study, consistent with prior work showing that framing-based nudges have only limited efficacy (45), the framing conditions were different from *CONTROL* (in which healthy choices decreased) but were far less effective than either ROC-T condition. This finding suggests that training in cognitive strategies is an important active ingredient of ROC-T, above and beyond framing information about healthy and unhealthy options. Specifically, ROC-T requires individuals to use and cognitively manipulate framed information about food—and this practice is necessary to maximally change food choices. In turn, this suggests that additional practice using cognitive strategies may be an important addition (e.g., as homework) to existing treatments and public health efforts (e.g., educational campaigns). Future work should determine whether training in cognitive strategies is both necessary and sufficient to improve food choice and whether individual differences in knowledge about food healthiness may moderate the effectiveness of framing and/or training alone.

Additionally, in Studies 3–6, RT in the second Choice Task was not increased in ROC-T conditions. RTs are an often-accepted measure of cognitive effort (e.g., refs. 39 and 46) and have been used as a measure of self-control (38), choice difficulty (46), and information processing (47). Thus, we would expect RT to increase during the second Choice Task, selectively in the training conditions, if participants were actively regulating (38), exerting increased cognitive effort (39, 46), or exhibiting self-control depletion (48, 49). Instead, we found a reduction in RTs in the second Choice Task across both training and no-training conditions. These data may suggest that ROC-T increases healthy choices without effortful regulation during choice. In this way, these findings support the idea that training changed the subjective value of unhealthy and healthy foods, perhaps by altering internal choice architecture that nudges individuals toward more healthy choices. In turn, this might suggest that ROC-T could lead to sustainable change, because it may not require continuous exertion of cognitive effort and potentially limited self-control resources. However, although our data are consistent with this interpretation, RT is only one measure of cognitive effort, and this finding should be tested further (e.g., under cognitive load, stress, and/or time pressure). Furthermore, debate about self-control vs. valuation-based mechanisms is currently ongoing (30–32), and future work should examine whether ROC-T alters the use of cognitive control and/or valuation-based processes. Until then, even if the mechanisms remain unclear, our findings demonstrate that ROC-T increases choices of healthy food and reduces caloric consumption.

In Studies 3, 4, and 6, individuals with higher BMI made fewer healthy food choices before ROC-T. Despite this, these individuals used cognitive strategies to successfully reduce craving and WTP for unhealthy foods and increased their choices of healthy foods as much as leaner individuals following ROC-T. This suggests that ROC-T can be effective despite a greater baseline preference for unhealthy foods. Prior work has shown that higher BMI is associated with greater food cue-reactivity and craving (50), more unhealthy food choices (51), and increased food consumption after depletion (52). However, this work provides additional information about how individuals with high BMI make food choices, and demonstrates no BMI-related differences in the efficacy of cognitive regulation of craving.

These findings have important clinical and public health implications for the prevention and treatment of obesity and eating disorders. Clinically, both POSITIVE and NEGATIVE strategies are part of cognitive-behavioral treatments (CBTs) for overweight, obesity, and eating disorders (14). However, CBTs were developed based on theoretical models, not on experimental tests of their components (14). As such, cognitive strategies to regulate craving were not previously shown to directly affect food consumption, choice behavior, or WTP for food. The current findings provide clinically relevant, experimental evidence that cognitive strategies directly change behavior. Further, this suggests that, outside of CBT, training that targets craving may be sufficient to change eating even in challenging situations. This would be clinically useful even if the effects are short-lived. Additionally, in the future, ROC-T could potentially be applied to improve eating habits, including in individuals with strong cravings, eating pathology, overweight, or increased risk of weight gain (28, 50). Also, ROC-T may be easily disseminated; because we found similar effects across in-laboratory and online samples, ROC-T may be effectively disseminated using Web-based platforms, as are online depression interventions (53). Importantly, because it is easily disseminated, ROC-T could have particularly powerful effects in contexts where nudge-based, framing-based, or environment-based interventions have failed to eliminate temptations. As such, this work could have important future public-health applications for preventing or reducing obesity.

Taken together, these studies present the development of a targeted, mechanism-focused, cognitive strategy-based intervention to prevent and reduce unhealthy eating. This work is theoretically important, given current thinking about self-control, value-based decision-making, and eating behavior, and presents several avenues for future work. For instance, future work should test the enduring effects of ROC-T on eating, including the cumulative effects of repeated sessions, its efficacy for choices of varying difficulty, its ability to supplement existing treatments (e.g., as homework training in CBT), its ability to complement behavioral economics-based interventions or education approaches (e.g., calorie labels, taxation), and its durability under stress, cognitive load, and/or time pressure. Additionally, future work should elucidate the dynamics of valuation-based mechanisms and investigate whether training can influence long-term outcomes (54), including weight. Also, future work should investigate whether, despite similar behavioral effects, POSITIVE and NEGATIVE strategies have different neural mechanisms and whether there are individual differences in strategy choice and efficacy (55).

In sum, across six studies, cognitive strategies beneficially influenced craving, subjective valuation, food choice, and, importantly, eating behavior. Specifically, based on the findings, we propose that training in the regulation of craving may inoculate individuals against future temptation by modifying the affective and economic value of healthy and unhealthy foods. Cognitive strategies could be especially useful when environmental approaches fail and individuals find themselves with a pressing choice between a tempting unhealthy food and an overpriced healthy option. Further, preemptive training in such strategies may allow individuals to nudge themselves toward healthier food consumption.

Methods

Participants.

Studies 1 and 5. College-age students ($N_{STUDY1} = 29$; $N_{STUDY5} = 83$) were recruited through the Yale University Psychology subject pool. For both studies, participants were excluded for missing data. In Study 5, participants were also excluded if they could not complete the Food Taste Task (FTT) (*SI Appendix, SI Methods*).

Studies 2–4 and 6. Across four studies, 1,901 participants were recruited from Amazon Mechanical Turk (M-Turk; $N_{STUDY2} = 366$; $N_{STUDY3} = 499$; $N_{STUDY4} = 471$; $N_{STUDY6} = 565$). Samples recruited via M-Turk are demographically and cognitively representative of the United States population, including a wide range of BMI. Data from such samples were shown to be reliable and comparable to laboratory data (36, 37). Recruitment was limited to the United States, and participation in any study by our group precluded participation in subsequent studies.

Across all studies, 10.9% were excluded for incomplete data reporting, and 12.7% of participants were excluded for failing manipulation checks (*SI Appendix, SI Methods*). Final samples were $N_{STUDY1} = 28$; $N_{STUDY2} = 242$; $N_{STUDY3} = 384$; $N_{STUDY4} = 370$; $N_{STUDY5} = 64$; and $N_{STUDY6} = 440$; $N_{TOTAL} = 1{,}528$.

Food Images. Before Study 1, we pilot-tested food images with an independent sample through M-Turk. Images in the test set ($N_{IMAGES} = 400$) depict frequently consumed and frequently craved foods. The images either had been used in previous research (16, 17) or were found online. Pilot participants ($n = 237$; $M_{AGE} = 35.50$, $SD_{AGE} = 12.02$; $M_{BMI} = 26.97$, $SD_{BMI} = 6.45$) viewed 30 randomly selected images and rated each image on several dimensions, including craving, tastiness, food complexity, number of food items in the image, sweetness, savoriness, image complexity, healthiness, amount of calories, and perceived cost. Such ratings accurately assess healthiness and caloric content (56). We used these ratings to create balanced image sets for subsequent studies.

For Studies 1 and 2, we created two sets of food images using high vs. low ratings of healthiness ($N_{HEALTHY} = 40$; $N_{UNHEALTHY} = 40$). Images in the healthy set included items such as salad, strawberries, and grilled chicken; the unhealthy set included items such as pizza, donuts, and ribs. The image sets did not differ on mean ratings of craving, food tastiness, food complexity, number of food items in each image, sweetness, savoriness, image complexity, or perceived cost ($Ps > 0.09$). As expected, the healthy set was rated as significantly more healthy ($P < 0.001$) and was perceived to have fewer calories ($P < 0.001$) than the unhealthy set.

For Studies 3–6 we created four lists (subsets) of food images to be paired with different strategy instructions (POSITIVE, NEGATIVE, and LOOK instructions; see below). The lists did not differ on mean ratings of craving, food tastiness, food complexity, number of food items, sweetness, savoriness, image complexity, or perceived cost ($Ps > 0.25$) but did differ in food healthiness ($P < 0.001$) and number of perceived calories ($P < 0.001$) (*SI Appendix, SI Methods*).

Procedures.

Studies 1 and 2. Following our prior work (16, 17), we modified the ROC task to investigate whether cognitive strategies can both up- and down-regulate craving [operationalized as "a strong desire" following Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (57)] and subjective value [operationalized as willingness to pay; WTP (33, 34)] for healthy and unhealthy foods ($N_{STUDY1} = 28$; $N_{STUDY2} = 242$). Both studies were identical in procedures, but participants in Study 1 were Yale undergraduates recruited from the Psychology subject pool, whereas those in Study 2 were recruited from M-Turk. Once participants provided informed consent, they received a link to an online platform where they were introduced to the ROC task. Participants were first introduced to three instructions: (*i*) think about negative aspects of eating the food (e.g., long-term health consequences, disliking the taste; "bad for you" framing; indicated by the instruction NEGATIVE), (*ii*) think about the positive aspects of eating the food (e.g., long-term health benefits, liking the taste; "good for you" framing; POSITIVE), or (*iii*) observe the image (LOOK). The task consisted of 80 trials. Each trial included a strategy instruction (NEGATIVE, POSITIVE, or LOOK; 2.5 s), followed by a food image ($N_{HEALTHY} = 40$; $N_{UNHEALTHY} = 40$; 6 s), and a brief delay (500 ms). Then, participants rated their craving (5-point scale: 1 = not at all to 5 = very much; up to 4.5 s) and WTP for each food (5-point scale: 1 = \$0–2 to 5 = \$10+; up to 4.5 s; Fig. 1). Importantly, in a recent meta-analysis including only prospective studies, we showed that single-item estimates of self-reported craving (as used in the current studies) predict subsequent real-world eating and weight (28), as have others (29). Similarly, estimates of WTP are well validated, correspond with choice behavior, and predict real-world consumer behavior, including food purchasing (33, 34). Participants were encouraged to rate craving based on their desire for the food items in the moment and WTP based on their willingness to pay in the moment, not based on how they "ought to" rate it. Instructions and images were randomized across trials. The task was presented using Inquisit (https://www.millisecond.com/) and was ∼25 min long. After completing the ROC task, participants provided demographic information, survey responses, and self-reported height and weight through Qualtrics (https://qualtrics.com/).

Studies 3 and 4.

Choice Task 1. Each choice screen presented two food images, and participants were simply instructed to select the food item they desired more by clicking on it. Participants made 108 choices, 72 of which were the critical choices between healthy and unhealthy items. The other choices were either healthy–healthy or unhealthy–unhealthy pairs.

ROC-Training. Participants were randomized to one of three conditions: the *POSITIVE* training, *NEGATIVE* training, or *CONTROL* no-training (look-only) condition. Those randomized into the *POSITIVE* or *NEGATIVE* conditions read a brief essay about either the benefits of eating healthy foods (POSITIVE) or the risks of eating unhealthy foods (NEGATIVE). The essays were matched on structure, topic, and word count (*SI Appendix, SI Methods*). Then, participants completed six free-response questions to ensure that they understood and encoded the content of the essays. Next, participants were trained to use this information to inform a cognitive strategy (POSITIVE or NEGATIVE) as compared to LOOK, following the ROC task procedures from Studies 1 and 2.

In the *POSITIVE* condition, participants practiced the POSITIVE instruction while looking at a picture of healthy food and rated craving and WTP at the end of each trial. Thus, they were trained to frame healthy foods in terms of their positive qualities. Only half of the healthy images were used during training. The other half of the healthy images, along with the unhealthy images, were paired with the LOOK instruction. Conversely, in the *NEGATIVE* condition, participants practiced the NEGATIVE instruction while looking at a picture of unhealthy food and rated their craving and WTP at the end of each trial. Thus, they were trained to frame unhealthy foods in terms of their negative qualities. Only half of the unhealthy images were used during training; the other half of the unhealthy images, along with the healthy images, were paired with the LOOK instruction. In the *CONTROL* look-only condition, participants simply viewed all the images and rated craving and WTP for each item. This condition was designed to control for effects of image exposure and familiarity with the task experience. Thus, across all conditions, images were presented twice during this phase, which lasted ∼15 min.

Choice Task 2. Again, each choice screen presented two food images, and participants were instructed to select the food they preferred by clicking on it. Each participant was randomly presented with the same 108 choices as in the first Choice Task, 72 of which were between healthy and unhealthy items. Then, participants completed self-report questionnaires. Importantly, to avoid effects of novelty and/or repetition on choice behavior, each image was presented equally frequently in each part of the study, as well as across the entire study.

Analysis. During the Choice Tasks, 72 of 108 choices compared healthy vs. unhealthy foods and thus were considered the critical choices indexing food-choice behavior. The main tests were 2 (Time: pre- and posttraining) × 3 (Condition: *POSITIVE* ROC-T, *NEGATIVE* ROC-T, *CONTROL*) ANOVAs on those critical healthy choices with Time as a repeated measure and Condition as a between-subjects factor. Another dependent measure was the percent change from pre- to posttraining in the number of healthy items chosen during these critical choices.

Study 5. This study was registered with Open Science Framework (https://osf.io/qfhe4). Participants in Study 5 were recruited from the Yale Psychology subject pool and completed all measures in our laboratory. Following procedures from Studies 3 and 4, participants completed the Choice Task, followed by ROC-T (*POSITIVE*, *NEGATIVE*) or *CONTROL* (no training), and the Choice Task for a second time. Choice and ROC-T procedures and analysis methods were identical to Studies 3 and 4, with six exceptions. (*i*) We used E-Prime 2.0 instead of Inquisit software to present images. (*ii*) We added a neutral essay for the control training condition (to account for reading time), which was matched for word count with the essays in the ROC-T positive and negative conditions and pertained to the biological processes involved in food consumption and metabolism. (*iii*) Importantly, all the food images shown during the Choice Tasks were snack foods because (*iv*) participants were explicitly told that some choices were going to be selected at random and that they would have to eat some of the food items that they picked. Thus, following prior work (24, 25, 51), we reinforced the instruction that they should choose only the foods they truly preferred (*SI Appendix*, *SI Methods*). Finally, (*v*) participants only rated craving (to save time), and (*vi*) during the Choice Tasks, each image was paired with every other image, which resulted in 153 choices, of which 72 compared healthy vs. unhealthy foods, similar to Studies 3 and 4.

Finally, after the second Choice Task, we administered the ostensibly unrelated Food Taste Task (FTT). Participants were presented with unhealthy and healthy foods in gallon containers: M&Ms, Lay's potato chips, apple slices, and baby carrots. Participants were left alone with the food and were asked to taste each item and provide ratings of the tastiness, healthiness, and characteristics (e.g., crunchiness) of the foods. They were encouraged to consume the foods ad libitum, consistent with prior work (24). Food items were weighed surreptitiously in grams before and after the FTT. The FTT took place ∼30–45 min after the completion of ROC-T; during the interval, participants completed self-report measures. During debriefing, no participants reported awareness that food items in FTT were weighed.

Choice Task data were analyzed as in Studies 3 and 4, following our registered analytic plan. For FTT data, the amount of food consumed was calculated by subtracting the pre-FTT weight from the post-FTT weight. The caloric content of the foods was calculated from calorie/gram information.

Study 6. As in Studies 3–5, participants first completed a Choice Task. Next, they were randomized to one of five conditions: *POSITIVE* ROC-T, *NEGATIVE* ROC-T, *CONTROL* look-only, Positive Framing+look-only, and Negative Framing+look-only (Fig. 7). In the Positive and Negative Framing+look-only conditions, participants read the same brief essays as in the ROC-T conditions and then viewed and rated all the images from the Choice Tasks (as in the *CONTROL* no-training, look-only condition in Studies 3–5). These additional conditions were designed to control for the informational/framing component of ROC-T and to examine the specific effects of training using cognitive strategies. Finally, participants completed a second Choice Task and self-report measures.

Choice data were analyzed as in Studies 3–5, except with five conditions.

Institutional Approval. All studies were approved by the Yale University Institutional Review Board. All participants provided informed consent.

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1. Swinburn BA, et al. (2011) The global obesity pandemic: Shaped by global drivers and local environments. *Lancet* 378:804–814.
2. Flegal KM, Kruszon-Moran D, Carroll MD, Fryar CD, Ogden CL (2016) Trends in obesity among adults in the United States, 2005 to 2014. *JAMA* 315:2284–2291.
3. Masters RK, Powers DA, Link BG (2013) Obesity and US mortality risk over the adult life course. *Am J Epidemiol* 177:431–442.
4. Hall KD, et al. (2011) Quantification of the effect of energy imbalance on bodyweight. *Lancet* 378:826–837.
5. Gearhardt AN, et al. (2012) Obesity and public policy. *Annu Rev Clin Psychol* 8:405–430.
6. Drewnowski A, Darmon N (2005) The economics of obesity: Dietary energy density and energy cost. *Am J Clin Nutr* 82(Suppl 1):265S–273S.
7. Brownell KD, Horgen KB (2004) *Food Fight: The Inside Story of the Food Industry, America's Obesity Crisis, and What We Can Do About It* (McGraw Hill, Contemporary Books, New York).
8. Wilson AL, Buckley E, Buckley J, Bogomolova S (2016) Nudging healthier food and beverage choices through salience and priming: Evidence from a systematic review. *Food Qual Prefer* 51:47–64.
9. Liu PJ, Wisdom J, Roberto CA, Liu LJ, Ubel PA (2014) Using behavioral economics to design more effective food policies to address obesity. *Appl Econ Perspect Policy* 36:6–24.
10. Johnson EJ, et al. (2012) Beyond nudges: Tools of a choice architecture. *Mark Lett* 23: 487–504.
11. Loewenstein G, Brennan T, Volpp KG (2007) Asymmetric paternalism to improve health behaviors. *JAMA* 298:2415–2417.
12. Thaler RH, Sunstein CR (2008) *Nudge: Improving Decisions About Health, Wealth, and Happiness* (Penguin Books, New York).
13. Mischel W, Baker N (1975) Cognitive appraisals and transformations in delay behavior. *J Pers Soc Psychol* 31:254–261.
14. Wilson GT, Grilo CM, Vitousek KM (2007) Psychological treatment of eating disorders. *Am Psychol* 62:199–216.
15. Giuliani NR, Mann T, Tomiyama AJ, Berkman ET (2014) Neural systems underlying the reappraisal of personally craved foods. *J Cogn Neurosci* 26:1390–1402.
16. Kober H, Kross EF, Mischel W, Hart CL, Ochsner KN (2010) Regulation of craving by cognitive strategies in cigarette smokers. *Drug Alcohol Depend* 106:52–55.
17. Kober H, et al. (2010) Prefrontal-striatal pathway underlies cognitive regulation of craving. *Proc Natl Acad Sci USA* 107:14811–14816.
18. Naqvi NH, et al. (2015) Cognitive regulation of craving in alcohol-dependent and social drinkers. *Alcohol Clin Exp Res* 39:343–349.
19. Volkow ND, et al. (2010) Cognitive control of drug craving inhibits brain reward regions in cocaine abusers. *Neuroimage* 49:2536–2543.
20. Lopez RB, Onyemekwu C, Hart CL, Ochsner KN, Kober H (2015) Boundary conditions of methamphetamine craving. *Exp Clin Psychopharmacol* 23:436–444.
21. Siep N, et al. (2012) Fighting food temptations: The modulating effects of short-term cognitive reappraisal, suppression and up-regulation on mesocorticolimbic activity related to appetitive motivation. *Neuroimage* 60:213–220.
22. Yokum S, Stice E (2013) Cognitive regulation of food craving: Effects of three cognitive reappraisal strategies on neural response to palatable foods. *Int J Obes* 37:1565–1570.
23. Silvers JA, et al. (2014) Curbing craving: Behavioral and brain evidence that children regulate craving when instructed to do so but have higher baseline craving than adults. *Psychol Sci* 25:1932–1942.
24. Hutcherson CA, Plassmann H, Gross JJ, Rangel A (2012) Cognitive regulation during decision making shifts behavioral control between ventromedial and dorsolateral prefrontal value systems. *J Neurosci* 32:13543–13554.
25. Hare TA, Camerer CF, Rangel A (2009) Self-control in decision-making involves modulation of the vmPFC valuation system. *Science* 324:646–648.
26. Hare TA, Malmaud J, Rangel A (2011) Focusing attention on the health aspects of foods changes value signals in vmPFC and improves dietary choice. *J Neurosci* 31:11077–11087.
27. Harris A, Hare T, Rangel A (2013) Temporally dissociable mechanisms of self-control: Early attentional filtering versus late value modulation. *J Neurosci* 33:18917–18931.
28. Boswell RG, Kober H (2016) Food cue reactivity and craving predict eating and weight gain: A meta-analytic review. *Obes Rev* 17:159–177.

29. Boyland EJ, et al. (2016) Advertising as a cue to consume: A systematic review and meta-analysis of the effects of acute exposure to unhealthy food and nonalcoholic beverage advertising on intake in children and adults. *Am J Clin Nutr* 103:519–533.
30. Berkman ET, Hutcherson CA, Livingston JL, Kahn LE, Inzlicht M (2017) Self-control as value-based choice. *Curr Dir Psychol Sci* 26:422–428.
31. Shenhav A (2017) The perils of losing control: Why self-control is not just another value-based decision. *Psychol Inq* 28:148–152.
32. Buckholtz JW (2015) Social norms, self-control, and the value of antisocial behavior. *Curr Opin Behav Sci* 3:122–129.
33. Carson RT, Flores NE, Martin KM, Wright JL (1996) Contingent valuation and revealed preference methodologies: Comparing the estimates for quasi-public goods. *Land Econ* 72:80–99.
34. Vohs KD, Faber RJ (2007) Spent resources: Self-regulatory resource availability affects impulse buying. *J Consum Res* 33:537–547.
35. Brownell KD, Frieden TR (2009) Ounces of prevention–The public policy case for taxes on sugared beverages. *N Engl J Med* 360:1805–1808.
36. Buhrmester M, Kwang T, Gosling SD (2011) Amazon's Mechanical Turk: A new source of inexpensive, yet high-quality, data? *Perspect Psychol Sci* 6:3–5.
37. Mason W, Suri S (2012) Conducting behavioral research on Amazon's Mechanical Turk. *Behav Res Methods* 44:1–23.
38. Sheppes G, Meiran N (2007) Better late than never? On the dynamics of online regulation of sadness using distraction and cognitive reappraisal. *Pers Soc Psychol Bull* 33:1518–1532.
39. Kerr B (1973) Processing demands during mental operations. *Mem Cognit* 1:401–412.
40. Hill JO (2009) Can a small-changes approach help address the obesity epidemic? A report of the joint task force of the American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. *Am J Clin Nutr* 89:477–484.
41. Aune D, et al. (2017) Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality-a systematic review and dose-response meta-analysis of prospective studies. *Int J Epidemiol* 46:1029–1056.
42. Ledoux TA, Hingle MD, Baranowski T (2011) Relationship of fruit and vegetable intake with adiposity: A systematic review. *Obes Rev* 12:e143–e150.
43. Epstein LH, et al. (2001) Increasing fruit and vegetable intake and decreasing fat and sugar intake in families at risk for childhood obesity. *Obes Res* 9:171–178.
44. Ledikwe JH, et al. (2006) Dietary energy density is associated with energy intake and weight status in US adults. *Am J Clin Nutr* 83:1362–1368.
45. Arno A, Thomas S (2016) The efficacy of nudge theory strategies in influencing adult dietary behaviour: A systematic review and meta-analysis. *BMC Public Health* 16:676.
46. Bettman JR, Johnson EJ, Payne JW (1990) A componential analysis of cognitive effort in choice. *Organ Behav Hum Decis Process* 45:111–139.
47. Tuch DS, et al. (2005) Choice reaction time performance correlates with diffusion anisotropy in white matter pathways supporting visuospatial attention. *Proc Natl Acad Sci USA* 102:12212–12217.
48. Baumeister RF (2014) Self-regulation, ego depletion, and inhibition. *Neuropsychologia* 65:313–319.
49. Grillon C, Quispe-Escudero D, Mathur A, Ernst M (2015) Mental fatigue impairs emotion regulation. *Emotion* 15:383–389.
50. Ferriday D, Brunstrom JM (2011) 'I just can't help myself': Effects of food-cue exposure in overweight and lean individuals. *Int J Obes* 35:142–149.
51. Demos KE, et al. (2017) Identifying the mechanisms through which behavioral weight-loss treatment improves food decision-making in obesity. *Appetite* 114:93–100.
52. Hagger MS, et al. (2013) Chronic inhibition, self-control and eating behavior: Test of a 'resource depletion' model. *PLoS One* 8:e76888.
53. Andersson G, Cuijpers P (2009) Internet-based and other computerized psychological treatments for adult depression: A meta-analysis. *Cogn Behav Ther* 38:196–205.
54. Jamieson JP, Mendes WB, Blackstock E, Schmader T (2010) Turning the knots in your stomach into bows: Reappraising arousal improves performance on the GRE. *J Exp Soc Psychol* 46:208–212.
55. Sheppes G, Scheibe S, Suri G, Gross JJ (2011) Emotion-regulation choice. *Psychol Sci* 22: 1391–1396.
56. Miyazaki T, de Silva GC, Aizawa K (2011) Image-based calorie content estimation for dietary assessment. *2011 IEEE International Symposium on Multimedia* (Dana Point, CA), pp 363–368.
57. APA (2013) *Diagnostic and Statistical Manual of Mental Disorders* (Am Psychiatr Assoc, Washington, DC), 5th Ed.