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Cognitive reappraisal of low-calorie food predicts real-world craving
and consumption of high- and low-calorie foods in daily life

Shane W. Reader*, Richard B. Lopez, & Bryan T. Denny
Department of Psychological Sciences, Rice University

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*Corresponding author:

Shane W. Reader, M.A.
Department of Psychology, Rice University
BioScience Research Collaborative, 780L
6500 Main Street, Suite 780L
Houston, TX 77030
Email: shane@shanereader.com

Abstract

In an increasingly obesogenic environment, an individual's regulatory capacity to pursue nutrient-rich, low-calorie foods over palatable, energy-dense items is essential to maintaining a healthy weight and preventing the detrimental health risks of obesity. Cognitive reappraisal, the process by which one changes the meaning of a stimulus by altering its emotional impact (or in this case, its appetitive value) demonstrates promise as a regulatory strategy to decrease obesogenic food consumption, but little research has directly addressed the relationship between cognitive reappraisal of food cravings and real-world eating behaviors. Additionally, research examining self-regulation of eating has typically focused exclusively on diminishing cravings and consumption of unhealthy, high-calorie foods, rather than examining, in tandem, ways to strengthen (or, up-regulate) cravings for healthier, low-calorie alternatives. In the present study, fifty-seven college aged participants first completed a cognitive reappraisal task in the laboratory in which they practiced regulating their craving responses to high- and low-calorie food items by focusing on the long-term health consequences of repeatedly consuming the pictured foods. Next, for a week following the laboratory session, participants reported daily eating behaviors via ecological momentary assessment. Participants who reported greater up-regulatory success during the reappraisal task also reported increased craving strength for low-calorie foods as well as decreased consumption of high-calorie foods in their daily lives. Greater overall regulation success also predicted more frequent consumption of craved low-calorie foods. These findings substantiate the association between cognitive reappraisal ability and real-world appetitive behaviors, and suggest that future interventions may benefit from specifically targeting individuals' evaluations of low-calorie foods.

1 The obesity rate in the United States continues to climb, with 40% of adults and 19% of
2 children categorized as obese (i.e., body mass index > 30; Hales, Carroll, Fryar, & Ogden, 2017).
3 Globally, the World Health Organization estimates 650 million adults are obese, and that being
4 overweight is a greater threat to most of the world's population than being underweight
5 ("Obesity and overweight," 2017). Overweight and obese individuals experience higher rates of a
6 variety of health problems, including heart disease, stroke, cancer, psychopathology, and all-
7 cause mortality (CDC, 2015), and these health issues incur large costs. For example, in the
8 United States, medical spending each year for obese individuals exceeds that for non-obese
9 individuals by \$1900 per capita, or \$149.4 billion total (Kim & Basu, 2016).

10 While a variety of physiological and environmental factors may contribute to an
11 individual's predisposition for obesity (Albuquerque, Nobrega, Manco, & Padez, 2017;
12 Villanueva-Millan, Perez-Matute, & Oteo, 2015; Scott, Tan, & Bloom, 2013), it's increasingly
13 clear that an individual's construal of his or her food cravings is also an important mediator of
14 obesity and eating behavior (Kober, Kross, Mischel, Hart, & Ochsner, 2010). Indeed, obesogenic
15 (i.e., high fat / high-calorie) foods have both intrinsic and learned reinforcement value that
16 contributes to cravings (Boyland & Halford, 2013; Weltens, Zhao, & Van Oudenhove, 2014),
17 and these food cravings can precipitate short-term binge-eating episodes, predict dieting failure,
18 and result in long-term weight gain (Boswell & Kober, 2016; Greeno, Wing, & Shiffman, 2000;
19 Meule, Westenhofer, & Kubler, 2011). Craving-induced consumption, especially excessive
20 consumption of obesogenic foods, can thus be conceptualized as a failure to exercise adequate
21 control in response to acute food cravings. Indeed, poor inhibitory control predicts weight gain
22 among adults one year later (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Self-
23 regulation deficits in individuals as young as two years old can predict the onset of pediatric

1 obesity and subsequent weight gain into adolescence (Francis & Susman, 2009; Graziano,
2 Calkins, & Keane, 2010). Adult inhibitory control predicts acute food consumption and long-
3 term weight gain, as does functional activity in brain regions associated with inhibition, such as
4 the inferior frontal gyrus (Guerrieri, Nederkoorn, Schrooten, Martijn, & Jansen, 2009; Lopez,
5 Hofmann, Wagner, Kelley, & Heatherton, 2014; Nederkoorn et al., 2010). Individuals with
6 disordered eating patterns, including those diagnosed with anorexia nervosa, bulimia nervosa,
7 and binge-eating disorder, exhibit greater emotion dysregulation than healthy controls, as do
8 obese individuals without psychopathology (Gianini, White, & Masheb, 2013; Harrison,
9 Sullivan, Tchanturia, & Treasure, 2010; Leehr et al., 2015; Zijlstra et al., 2012).

10 It thus stands to reason that, if overconsumption of obesogenic food reflects a failure to
11 regulate cravings, then interventions promoting effective craving regulation may attenuate
12 craving and reduce consumption of obesogenic foods. An initial study by Giuliani and colleagues
13 showed that cognitive reappraisal, a flexible emotion regulation strategy involving the meaning
14 of an appetitive stimulus (e.g., by focusing on the long-term consequences of its consumption),
15 was effective in diminishing food cravings and promoting healthier consumptive behavior
16 (Giuliani, Calcott, & Berkman, 2013).

17 According to the process model of Gross (1998), by changing the meaning of an
18 emotional stimulus via cognitive change, individuals may better regulate their affective response.
19 In the appetitive domain, this frequently takes the form of instructing individuals to focus on the
20 nutritional or dietary impact of various foods (versus their palatability), which in turn leads to
21 changes in affect (i.e., cravings) and behavior for food items with negative dietary impacts.
22 Indeed, reappraisal effectively dampens self-reported cravings for obesogenic foods (Giuliani et
23 al., 2013; Kober, Kross, Mischel, Hart, & Ochsner, 2010). Brain imaging studies, including

functional magnetic resonance imaging (fMRI; Hollmann et al., 2012; Kober, Mende-Siedlecki, et al., 2010; Siep et al., 2012; Yokum & Stice, 2013) and EEG (Meule, Kubler, & Blechert, 2013; Sarlo, Ubel, Leutgeb, & Schienle, 2013; Svaldi et al., 2015), also report modulation of physiological indicators of craving, including reduced ventral striatum activity (Kober, Mende-Siedlecki, et al., 2010) and enhanced magnitude of late positive potentials (Sarlo, Ubel, Leutgeb, & Schienle, 2013). To date, there has been some work measuring actual eating behaviors following cognitive reappraisal practice in particular. Giuliani, Tomiyama, Mann, and Berkman (2015) found that participants who reported more effectively dampening their desire for personally-craved foods during a cognitive reappraisal task also reported consuming smaller quantities of that craved food in the subsequent two weeks. Another study by Forman and colleagues (2013) examined efficacy of cognitive-based (vs. acceptance-based) coping strategies on food cravings, as measured by EMA (Forman, Hoffman, Juarascio, Butryn, & Herbert, 2013) but these strategies consisted amalgams of multiple tactics from cognitive therapies, versus reappraisal-based tactics (strictly speaking). Lastly, Stice and colleagues (2015) used regulation training as an intervention, with participants trained to engage in cognitive reappraisal demonstrating greater decreases in body fat compared to controls after seven weeks, as well as decreases in sugar and fat intake. However, effects did not persist at six month follow-up.

Although limiting intake of obesogenic foods, and thus overall energy intake, likely helps to prevent weight gain, individuals may also substitute low-calorie, nutrient-rich foods in their place. Indeed, goals of large-scale health initiatives such as the United States Department of Agriculture's Choose MyPlate campaign (2018) include *both* decreasing consumption of high fat, high-calorie foods *and* simultaneously increasing consumption of low-calorie foods. Promoting consumption of fruits and vegetables, for instance, increases weight loss and

1 decreases consumption of obesogenic foods (Annesi, 2017; Epstein et al., 2001). Regular
2 consumption of fruits and vegetables also correlates with inhibitory control, suggesting that
3 preference for low-calorie foods may be associated with domain-general regulation (Wyckoff,
4 Evans, Manasse, Butryn, & Forman, 2017). Meule and colleagues (2013) applied this logic by
5 comparing reappraisal efficacy for high- and low-calorie foods, and found that participants
6 successfully increased their cravings for low-calorie foods when focusing on the long-term (in
7 this case positive) health consequences of eating such foods (Muele et al., 2013). However, and
8 importantly, this study did not associate measures from the in-lab reappraisal to people's day-to-
9 day eating patterns, so it remains to be seen whether such effects relate to differences in people's
10 actual consumption patterns in daily life.

11 The present study sought to estimate the relative efficacy in reappraising high-calorie
12 foods with reappraisal of low-calorie food items, and to relate reappraisal efficacy measures to
13 real-world consumptive behavior. In order to measure natural consumption, participants
14 completed an ecological momentary assessment (EMA) protocol adapted from previous work
15 (Lopez, Hofmann, Wagner, Kelley, & Heatherton, 2014) in which they reported their eating
16 behaviors for one week following an initial laboratory session. EMA is an ecologically valid way
17 to assess behavior, as it prompts people to report on behaviors as they occur in real world
18 settings. Additionally, EMA protocols are designed to capture thoughts, feelings, and behaviors
19 that are experienced in the moment or very recently (e.g., ≤ 30 minutes ago), thereby minimizing
20 the influence of memory and/or other biases associated with retrospective recall methods (e.g.,
21 Shiffman, Stone, & Hufford, 2008).

22 Prior work has employed designs linking task-based measures of craving regulation to
23 real world eating behaviors, as measured by EMA (Giuliani et al., 2015). However, no prior

studies to date have used this approach to examine, in tandem, the capacity of individuals to decrease craving for high-calorie foods and increase craving for low-calorie foods. In our study sample, we hypothesized that those individuals who more readily implement cognitive reappraisal strategies, as measured by an in-lab food reappraisal task, would show diminished desire for obesogenic foods and healthier eating patterns in their daily lives. Specifically, we hypothesized this would be achieved via decreases in both craving toward and consumption of high-calorie foods, as well as increased craving and consumption of low-calorie foods.

Method

Participants

Fifty-eight Rice University undergraduate students enrolled in the present study in exchange for course credit, with one participant excluded for not providing any responses during the EMA portion of the study. The final sample included 57 participants (41 females), ranging in age from 18 to 22 ($M = 19.2$ years, $SD = 1.3$ years). The sample included 26 Caucasian participants, 25 Asian participants, seven African-American or Black participants, and six participants who identified as multi-racial or an unlisted race. Additionally, 10 of the participants identified as Hispanic or Latino. The recruitment materials instructed participants to refrain from eating immediately prior to arriving for their experimental session, to equalize levels of state hunger across participants. All participants provided informed consent in accordance with guidelines set by the Institutional Review Board at Rice University, and were debriefed at the end of the study.

Procedure

After providing informed consent, participants first completed the scales in random order at a computer. This was intentional, in order to acquire valid baseline individual difference

measures that were unaffected by altered psychological processes engaged by the task. Next, the experimenter instructed the participant in the reappraisal task, which they then completed privately at the computer. Following the task, participants registered and received instructions for the EMA procedure, which started on the following day.

Scales

Participants completed the Three-Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985), measuring cognitive restraint of eating, trait hunger, and disinhibition, as an index of overall appetitive behavior. While researchers continue to debate the merits of competing appetitive restraint scales, factor analyses generally endorse the TFEQ's restraint scale (Karlsson, Persson, Sjostrom, & Sullivan, 2000). Additionally, TFEQ restraint positively correlates with body mass index (Cornelis et al., 2014; Keskitalo et al., 2008; Stunkard & Messick, 1985), so we included it as a proxy for BMI and participants' baseline eating habits. Participants also provided age, gender, and state hunger on a scale from 0 – *Not hungry at all*, to 100 – *Extremely hungry*.

Reappraisal task

In this within-subjects design adapted from Kober and colleagues' (2010) study, an experimenter instructed each participant to either respond naturally to the food stimuli, or implement a cognitive reappraisal strategy to regulate their cravings to the stimuli. Specifically, whenever they saw the cue "LOOK," participants were instructed to respond naturally to the depicted food items. In contrast, whenever they saw the cue "REGULATE," they were instructed to focus on the long-term health consequences of repeatedly consuming the pictured food. Example consequences modeled by the experimenter for obesogenic foods included "eating this frequently would raise my cholesterol and make it more likely I could have heart

problems,” or, for nutritious low-calorie foods, “this could give me a variety of vitamins and minerals that would keep me strong.” Following each food image, participants reported their subjective craving on a scale ranging from 1 to 5, with 1 indicating no craving at all, and 5 representing very strong cravings. The craving screen persisted for four seconds regardless of whether or not participants made a response. Participants completed guided practice (i.e., with an experimenter) of one *LOOK* trial and two *REGULATE* trials, one paired with a high-calorie food picture and the other with a low-calorie food picture. Participants verbalized their responses to the *REGULATE* trials and received feedback from the experimenter. After the guided practice, participants completed four fixed-pace practice trials on their own.

Each trial of the reappraisal task consisted of a cue (*LOOK* or *REGULATE*) presented for two seconds, followed by a high- or low- calorie food picture for six seconds, then the craving rating scale for four seconds, and finally a two second fixation cross serving as the inter-trial interval. The task consisted of 80 trials total, 40 *LOOK* trials and 40 *REGULATE* trials, each of which was composed of 20 high-calorie food trials and 20 low-calorie food trials. As such, participants responded to an even number of trials for each combination of cue and calorie content. Cue-stimulus pairings were counterbalanced across participants. After the first 40 trials, participants took a short break before resuming the latter half of the task. See Figure 1 for a diagram of the reappraisal task.

Stimuli

Images from the previously validated, *food-pics* image database (Blechert, Meule, Busch, & Ohla, 2014) served as the stimuli for the reappraisal task. Each image consists of a food item, with or without a plate, on a blank white background. The 40 high-calorie stimuli (calories per 100g: $M = 359.8$, $SD = 117.9$; fat per 100g: $M = 18.0$, $SD = 10.2$) and 40 low-calorie stimuli

(calories per 100g: $M = 33.9$, $SD = 19.4$; fat per 100g: $M = 0.4$, $SD = 0.4$) differed significantly by calories per 100g portion, $t(78) = 17.25$, $p < .001$, $d = 3.86$, and fat per 100g portion, $t(78) = 10.97$, $p < .001$, $d = 2.45$, but not in terms of total object size, recognizability, or familiarity, all p 's $> .1$. See the appendix for catalog numbers and macronutrient information. Low-calorie stimuli depicted exclusively fruits and vegetables, such as red apples, grapes, steamed broccoli, and mixed salad, selected to represent a diverse portfolio of nutrients, while high-calorie stimuli included sweet desserts and fat-rich snacks from the Yale Food Addiction Scale's categories of foods subject to over-consumption, including donuts, hamburgers, potato chips, and hard candy (YFAS; Gearhardt, Corbin, & Brownell, 2009).

Ecological momentary assessment

Following the reappraisal task, participants enrolled in a weeklong ecological momentary assessment (EMA) procedure, administered via the EMA/survey management platform SurveySignal (Hofmann & Patel, 2015). Starting the day following the experimental session, and for the following seven days, they received four daily text messages to their smartphones between 7am and 10pm, spaced at random intervals at least 90 minutes apart. Each message contained a hyperlink to an online survey. Participants received a reminder message if they failed to click the link within 20 minutes, and the link expired after one hour, such that participants made responses that were always relatively proximate to and reflective of a recent food desire instance.

Each survey began with a scale assessing current hunger, and then asked participants to indicate whether they currently or recently (i.e., within the last 20 minutes) experienced a desire for a particular food. Participants indicating a desire typed the name of the food and identified it as a generally high-calorie or low-calorie food item. Next, they reported the strength of their

1 cravings for the desired food from 0, very weak cravings, to 100, very strong cravings; and
2 whether or not they actually ate any of the desired food (*desire enactment*). If participants
3 indicated they already consumed some of their craved food, they also reported amount eaten,
4 from 0, a very small amount, to 100, a very large amount (*quantity consumed*). Participants
5 endorsing cravings for high-calorie foods also indicated the degree to which they resisted those
6 cravings, from 0, very weakly resisted, to 100, very strongly resisted. Filler questions regarding
7 current environment and current affect ratings, such as self-esteem and stress, took the place of
8 appetite-related questions for participants who did not endorse experiencing any recent food
9 cravings, in order to discourage participants from denying cravings simply to finish the survey
10 sooner.

11 **Analyses**

12 As per the two-by-two design of the reappraisal task, we ran a repeated measures
13 factorial ANOVA to estimate the effects of cue (*LOOK* vs. *REGULATE*) and calorie content
14 (*high-calorie* vs. *low-calorie*) and their interaction, with the expectation that participants would
15 endorse weaker cravings for high-calorie foods when instructed to *REGULATE*, demonstrating
16 successful down-regulation of craving for these items, but simultaneously stronger cravings for
17 low-calorie foods in this condition, as per Meule and colleagues (2013). The difference between
18 each participant's reported cravings during *LOOK* and *REGULATE* trials indicated reappraisal
19 efficacy: the decrease in mean cravings for high-calorie foods will serve as a *down-regulation*
20 score, with greater scores indicating decreased craving for high-calorie foods; while the increase
21 in mean cravings for low-calorie foods will serve as an *up-regulation* score, with greater scores
22 reflecting a more robust increase in craving for these foods. Further, if down- and up-regulation
23 represent two specific instantiations of the same regulatory capacity, then summing up- and

1 down-regulation scores into a single, aggregate regulation score may potentially provide greater
2 predictive power than using these scores as separate predictors; as such, in addition to examining
3 down- and up-regulation separately, we also examined predictiveness of the aggregate regulation
4 score.

5 The multi-level, nested structure of the EMA data (i.e., observations nested within
6 participants) is appropriate for two-level multilevel linear and logistic regressions using
7 Hierarchical Linear Modeling (HLM; Raudenbush, 2004). Thus, planned HLM models tested
8 the hypotheses that either up- and down-regulation efficacy, or aggregate regulation efficacy, can
9 predict craving strength, enactment, and quantity of craved high and low-calorie foods
10 consumed, while dietary restraint (measured by the TFEQ) and EMA state hunger served as
11 covariates. Higher regulation success scores were expected to predict higher levels of craving,
12 enactment, and quantity consumed of craved low-calorie foods, and lower levels of craving,
13 enactment, and quantity of craved high-calorie foods.

14 Results

15 Scales

16 While TFEQ disinhibition and trait hunger were correlated, $r(55) = .37, p < .01$, neither
17 disinhibition nor trait hunger correlated with restraint, consistent with research suggesting that
18 restraint is independent of the other two factors measured by the TFEQ (Karlsson et al., 2000)
19 (see Table 1).

20 Reappraisal efficacy

21 The factorial repeated measures ANOVA comparing calorie content (*high-calorie* vs.
22 *low-calorie* stimuli) and cue (*LOOK* vs. *REGULATE*) demonstrated a significant main effect of
23 calorie content, $F(1, 56) = 13.06, MSE = 9.82, p = .001$, such that participants endorsed lower

1 cravings overall to high-calorie stimuli, although the main effect of cue did not reach
2 significance, $F(1, 56) = 2.45$, $MSE = 0.21$, $p = .12$ (Figure 2). Further, the analysis revealed a
3 significant interaction, $F(1, 56) = 173.03$, $MSE = 35.5$, $p < .001$; when responding to high-calorie
4 foods, participants reported lower cravings following the cue *REGULATE* ($M = 2.18$, $SD = 0.54$)
5 compared to *LOOK* ($M = 3.03$, $SD = 0.78$), $t(56) = 10.86$, $p < .001$, $d = 1.44$; this relationship
6 reversed for low-calorie stimuli, such that participants reported greater cravings for low-calorie
7 foods following *REGULATE* ($M = 3.39$, $SD = 0.67$), compared to *LOOK* ($M = 2.66$, $SD = 0.63$),
8 $t(56) = 11.32$, $p < .001$, $d = 1.50$ (Figure 2).

9 Down-regulation scores, reflecting participants' capacity to decrease their reported
10 craving for high-calorie foods ($M = 0.85$, $SD = 0.59$), and up-regulation scores, indicating
11 increases in craving for low-calorie foods ($M = 0.73$, $SD = 0.49$), were correlated across
12 participants, $r(55) = .41$, $p < .01$. Participants with greater reported state hunger also reported
13 greater craving during LOOK trials, $r(55) = .39$, $p < .01$, and greater up-regulation efficacy, $r(55)$
14 $= .30$, $p < .05$.

15 **EMA results**

16 Participants answered the EMAs frequently, with a total response rate of 58%, similar to
17 compliance rates in other EMA studies (e.g., Lopez et al., 2017). When participants made
18 responses, they endorsed cravings 48% ($SD = 20\%$) of the time, and of these cravings 69% ($SD =$
19 29%) were for high-calorie foods and 31% ($SD = 29\%$) were for low-calorie foods. Examples of
20 craved high-calorie foods included *cookies*, *hot dogs*, *pizza*, brand name candies, and *waffles*,
21 while craved low-calorie foods included *apples*, *salad*, *papaya*, *peas*, and *raspberries*. On the
22 subject level, we first tested whether task-based reappraisal efficacy, as measured by up-
23 regulation to high-calorie foods, down-regulation to low-calorie foods, or aggregate regulation

1 success (i.e., sum of low and high-calorie regulation success), would be associated with the
2 frequency with which people reported craving food (in general) and high- and low-calorie foods
3 (specifically) during the EMA portion of the study. There were no significant correlations
4 between any measures of reappraisal efficacy and percentage of any craving instances, all p 's $\geq$
5 0.253.

6 Next, we examined results from four of the *a priori* multilevel models predicting various
7 aspects of participants' appetitive behaviors—as measured by EMA; in all models, we included
8 TFEQ restraint and EMA state hunger as covariates. First, neither up-regulation efficacy, $b =$
9 2.40, $p = .53$, nor down-regulation efficacy, $b = 3.35$, $p = .42$, predicted high-calorie food craving
10 strength. However, up-regulation efficacy for low-calorie foods, but not down-regulation
11 efficacy for high-calorie foods, reliably predicted craving strength for low-calorie foods, $b =$
12 8.76, $p = .024$ (Table 2; Figure 3).

13 Additionally, up-regulation of low-calorie foods predicted lower consumption quantity of
14 craved high-calorie foods, $b = -8.16$, $p < .026$ (Table 3; Figure 3). Neither up-regulation, $b =$
15 0.04, $p = .99$, nor down-regulation, $b = 3.80$, $p = .37$, predicted consumption quantity of craved
16 low-calorie foods.

17 Up-regulation did not predict enactment of desires to eat low-calorie foods, $b_{log} = 0.44$, p
18 $= .3$, $OR = 1.56$ [95% CI: 0.68, 3.57], nor did down-regulation, $b_{log} = 0.80$, $p = .1$, $OR = 2.22$
19 [95% CI: 0.84, 5.89]; these models also failed to predict enactment of desires to eat high-calorie
20 foods, both for up-regulation, $b_{log} = -0.6$, $p = .1$, $OR = 0.55$ [95% CI: 0.25, 1.29], and down-
21 regulation, $b_{log} = 0.33$, $p = .1$, $OR = 1.39$ [95% CI: 0.92, 2.11].

22 Aggregate regulation (i.e., sum of low and high-calorie regulation success) marginally
23 predicted craving strength for low-calorie foods, $b = 6.70$, $p = .07$, but not craving strength for

high-calorie foods, $b = 2.92$, $p = .26$. Aggregate regulation did not predict low-calorie food consumption quantity, $b = 2.05$, $p = .24$, but did predict high-calorie food consumption, $b = -5.88$, $p < .03$, although not to as great a degree as up- and down-regulation independently. Finally, the multilevel logistic regression using aggregate regulation scores and the same covariates revealed that those with higher aggregate regulation scores enacted desires to eat low-calorie foods more frequently, $b_{log} = 0.65$, $p < .025$, $OR = 1.92$ [95% CI: 1.11, 3.33] (Table 4).

Discussion

The findings of the current study indicate that individual differences in the implementation success of reappraisal strategies to alter construal of high and low-calorie foods predict craving and eating patterns in daily life. Specifically, when considering the long-term health consequences of food images in the laboratory, participants reported not only decreased craving for high-calorie, obesogenic foods, but also robust increases in craving for nutritious fruits and vegetables. Further, the magnitude of this up-regulatory efficacy predicted a diverse array of appetitive behaviors: greater up-regulation scores predicted greater craving strength for low-calorie food; individuals with greater overall regulatory success enacted their cravings for low-calorie foods more often; and greater up-regulation scores were associated with consuming smaller quantities of craved high-calorie foods. Overall, better regulators craved healthy foods more acutely, consumed them more frequently, and, when they did concede to temptation, they ate more modest portions of unhealthy foods. Neither participants' dietary restraint—a proxy for baseline eating habits and BMI (see Method)—nor hunger at the time of craving explained these effects, as both were controlled for in all analyses. And although no measure of reappraisal efficacy was associated with how often people craved high- and low-calorie foods, the observed effects suggest that as soon as people experience a craving, cognitive reappraisal processes can

1 be brought online to modulate craving and alter downstream eating behaviors. These findings,
2 taken together, further highlight the importance of cognitive reappraisal in the regulation of food
3 cravings, and motivate further research targeting cognitive reappraisal of food cravings as an
4 intervention to promote the maintenance of a healthy, nutritionally-diverse diet.

5 While the majority of literature concerning self-regulation of eating has focused on
6 down-regulating cravings to obesogenic foods, up-regulating cravings for low-calorie foods
7 drove the majority of results in the present study. In fact, high-calorie down-regulation efficacy
8 alone did not prove a reliable predictor for any real world eating outcomes, although aggregate
9 regulation to both high and low-calorie stimuli did predict increased consumption of craved low-
10 calorie foods. Together, these results suggest that up-regulation of low-calorie foods may rely on
11 a different cognitive capacity than down-regulation of high-calorie foods. Enhancing craving for
12 nutritious alternatives appears to decrease palatable food consumption more readily than trying
13 to dampen appetite for obesogenic foods. This is consistent with prior research demonstrating
14 that interventions promoting low-calorie, nutrient-dense foods such as fresh fruits and vegetables
15 result in decreased consumption of obesogenic foods and greater weight loss than interventions
16 targeted at obesogenic foods themselves (Epstein et al., 2001). In this manner, changing one's
17 evaluations toward—and motivations to eat—healthy alternatives may be compared to nicotine
18 replacement therapy for cigarette cessation. That is, rather than simply quitting cigarettes,
19 individuals may partake in less harmful alternatives, such as applying a nicotine patch, that
20 simultaneously attenuates the acute cravings without the detrimental health effects (Stead et al.,
21 2012). A peckish individual may eye that extra donut in the break-room, but mustering the
22 regulatory strength to eat an apple instead may dampen the strength of the cravings and keep him
23 or her satisfied, nutritionally and appetitively, until the next proper meal. Focusing on the long-

1 term health consequences of eating healthy foods may not only tap flexible (i.e., bi-directional)
2 regulatory processes, but may also change the subjective valuation of the consequences of
3 making a healthy (versus unhealthy) choice (Giuliani, Merchant, Cosme, & Berkman, 2018).

4 While strong neurobiological evidence demonstrates the ability of individuals to regulate
5 palatable food cravings with cognitive reappraisal in controlled circumstances (Hollmann et al.,
6 2012; Kober, Mende-Siedlecki, et al., 2010; Meule et al., 2013; Siep et al., 2012; Svaldi et al.,
7 2015; Yokum & Stice, 2013), the real-world applicability of this research remains an important
8 growth area for future research that motivated the current study. Only two identified prior studies
9 used behavioral outcomes to measure the efficacy of cognitive reappraisal of appetitive stimuli,
10 with reappraisal training demonstrating decreases in sugar and fat intake (Stice et al., 2015) and
11 diminished consumption of personally craved foods (Giuliani et al., 2015). The results presented
12 here further substantiate the ecological validity of cognitive reappraisal paradigms by
13 demonstrating the ability of reappraisal efficacy for low-calorie foods, in addition to high-calorie
14 foods, to predict real-world consumptive behavior.

15 Several limitations constrain the inferences that can be drawn from the present study.
16 Notably, the within-subjects design precludes making causal attributions about the relationship
17 between reappraisal efficacy in the laboratory and participants' appetitive behaviors in daily life.
18 Future experimental research may examine whether reappraisal training within (or outside) the
19 laboratory leads to attendant changes real-world craving and eating behaviors. Further, other
20 novel methods can be employed that may more thoroughly catalog an individual's daily desires
21 and concessions to temptation. For example, wearable devices that unobtrusively measure and
22 estimate eating (e.g., see Prioleau, Moore, & Ghovanloo, 2017) can provide convergent validity
23 for self-reported EMA measures. And although our EMA response rate (about 60%) is similar to

that of other studies that have employed similar designs (e.g., Lopez et al., 2016), future related work may benefit from further incentivizing participants, without introducing demand effects, to increase compliance and EMA response rates. Lastly, while the present study's findings are promising, future research would benefit from recruiting a more diverse sample of participants (i.e., outside the college aged / college attending population). For example, recruiting individuals across a diverse range of other characteristics, such as socioeconomic strata and BMI categories, would increase the generalizability of the relationships observed in the current sample. Indeed, including measured BMI and/or other valid covariates to index people's baseline regulatory capacity would strengthen inferences about the unique effects of cognitive reappraisal on subsequent eating behaviors.

Individuals who demonstrated greater regulatory capacity when practicing cognitive reappraisal, particularly when up-regulating appetite for nutritious foods, exhibited more healthy patterns of eating in daily life. Considering that other assessments of regulation are associated with both short-term food consumption and long-term weight gain (Guerrieri et al., 2009; Lopez et al., 2014; Nederkoorn et al., 2010), reappraisal success and reappraisal capacity more generally may be key individual difference measures that can be used to index individuals' longer term risks for weight gain and/or obesity. Further, training individuals to consciously reappraise the appetitive value of food choices in daily life constitutes a promising avenue of future study, as this simple technique can easily be integrated into existing cognitive behavioral therapies, or potentially implemented as a scalable, stand-alone intervention.

Conclusion

Cognitive reappraisal of appetitive stimuli represents a promising regulatory strategy. Reappraisal efficacy, particularly up-regulation of craving for low-calorie foods, predicted

1 adaptive food craving and consumption in daily life. The present study further substantiates the
2 relationship between regulatory capacity in controlled studies and real-world appetitive behavior.
3 While cognitive reappraisal has already attracted the attention of health researchers as an inviting
4 avenue of inquiry, the present evidence suggests that interventions enhancing attitudes toward
5 nutritionally-diverse low-calorie foods may warrant greater attention than those attenuating
6 appetite for obesogenic foods.

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Table 1

Means and Standard Deviations of TFEQ Subscales and State Hunger Scale

Scale	<i>Mean</i>	<i>Standard deviation</i>
Three Factor-Eating Questionnaire		
Restraint	10	1.93
Disinhibition	7.84	2.66
Trait hunger	6.81	1.99
State hunger	48.21	25

Table 2

Multilevel Linear Model Predicting Craving Strength for Low-Calorie Foods

Predictor	<i>b</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Level 1				
Intercept	53.42	2.28	23.46	<.001
EMA state hunger	0.6	0.06	2.69	.01
Level 2				
Dietary restraint	0.93	1.10	0.838	.41
Up-regulation efficacy	8.76	3.72	2.353	.02
Down-regulation efficacy	5.08	5.49	0.926	.36

Table 3

Multilevel Linear Model Predicting Consumption Quantity of Craved High-Calorie Foods

Predictor	<i>b</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Level 1				
Intercept	41.18	1.94	21.22	<.001
EMA state hunger	-0.04	0.06	0.64	0.52
Level 2				
Dietary restraint	0.12	0.95	0.126	0.9
Up-regulation efficacy	-8.16	3.52	-2.319	0.03
Down-regulation efficacy	-4.22	3.05	-1.384	0.17

Table 4

Multilevel Logistic Model Predicting Craving Enactment for Low-Calorie Foods

Predictor	b_{log}	Odds Ratio (95% CI)	SE	t	p
Level 1					
Intercept	-0.14	0.87 (0.58, 1.31)	0.2	21.12	0.49
EMA state hunger	-0.04	0.96 (0.93, 0.99)	0.02	0.64	0.01
Level 2					
Dietary restraint	-0.11	0.89 (0.75, 1.07)	0.09	.10	0.22
Aggregate regulation efficacy	0.65	1.92 (1.11, 3.33)	0.27	2.33	0.02

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*Figure 1.*Diagram of the food reappraisal task, adapted from Kober and colleagues (2010).

Participants received instructions to either respond naturally to the pictured food or to focus on the long-term health consequences.

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Figure 2. Average craving scores by calorie content and instruction. Participants reported stronger cravings for high-calorie foods when responding naturally, but stronger cravings for low-calorie foods when considering the long-term health consequences. Error bars represent 95% confidence intervals.

*Figure 3.*Diagram depicting the predictive efficacy of up-regulation success. Participants who demonstrated better efficacy increasing their cravings for low-calorie foods in the reappraisal task also demonstrated greater cravings for low-calorie foods in the following week, and consumed less of craved high-calorie foods after succumbing to their temptations.

Appendix

Food-pics Images

Calorie content	Item number	Item description	Calories per 100g	Fat per 100g	Object size	Recog- nizability	Familiar -ity
Low-calorie	262	celery	11	0.1	0.25	93.60%	89.10%
Low-calorie	260	asparagus	12	0.1	0.16	99.00%	99.70%
Low-calorie	263	mushrooms (brown)	12	0.2	0.26	99.40%	100.00%
Low-calorie	249	cauliflower	14	0.2	0.28	96.30%	98.60%
Low-calorie	448	garden radish	15	0.1	0.33	97.10%	97.60%
Low-calorie	197	tomatoes	16	0.2	0.28	100.00%	100.00%
Low-calorie	253	pickles	16	0.2	0.27	96.40%	98.50%
Low-calorie	199	watermelon	17	0.1	0.22	99.90%	100.00%
Low-calorie	250	broccoli	17	0.1	0.2	100.00%	100.00%
Low-calorie	274	spinach	17	0.3	0.3	88.50%	95.20%
Low-calorie	455	spinach	17	0.3	0.4	83.20%	96.00%
Low-calorie	259	red cabbage	18	0.1	0.45	95.20%	99.50%
Low-calorie	558	asparagus	21	0.7	0.29	96.30%	97.90%
Low-calorie	196	salad plate	25	0.4	0.54	99.20%	99.10%
Low-calorie	334	carrots	26	0.2	0.23	100.00%	100.00%
Low-calorie	431	carrots	26	0.2	0.2	99.80%	100.00%
Low-calorie	255	pomegranate	27	0.2	0.15	83.70%	86.80%
Low-calorie	198	paprika peppers	29	0.4	0.32	100.00%	100.00%
Low-calorie	429	yellow bell pepper	30	0.3	0.38	98.50%	100.00%
Low-calorie	201	salad plate	31	0.3	0.55	97.10%	99.00%
Low-calorie	211	strawberries	31	0.4	0.34	100.80%	100.80%
Low-calorie	256	grapefruit	33	0.1	0.34	100.00%	99.80%
Low-calorie	200	oranges	34	0.1	0.25	100.00%	98.40%
Low-calorie	230	oranges	34	0.1	0.37	99.30%	99.80%
Low-calorie	531	raspberries	34	0.3	0.37	100.10%	99.50%
Low-calorie	435	Brussels sprouts	36	0.3	0.33	94.50%	98.00%
Low-calorie	288	carrots	37	0.2	0.4	94.10%	97.50%
Low-calorie	442	red bell pepper	37	0.5	0.3	100.00%	100.00%
Low-calorie	202	blueberries	41	0.6	0.32	99.90%	99.90%
Low-calorie	248	blueberries	41	0.6	0.23	99.50%	98.80%
Low-calorie	528	peaches	41	0.1	0.47	98.70%	98.70%
Low-calorie	212	veggie mix with dip	42	2.2	0.37	100.00%	99.60%
Low-calorie	417	pea pod	42	0	0.46	97.50%	98.60%
Low-calorie	204	apples	52	0.4	0.34	100.00%	100.00%

Low-calorie	194	kiwi	53	0.6	0.26	100.00%	100.00%
Low-calorie	280	cherries	63	0.3	0.22	100.00%	100.00%
Low-calorie	270	corn (on a cob)	67	1.5	0.27	99.70%	99.70%
Low-calorie	281	grapes	71	0.3	0.17	99.20%	100.00%
Low-calorie	305	peas, corn and potatoes	78	0.5	0.34	94.60%	97.70%
Low-calorie	379	banana	95	0.2	0.33	99.50%	99.60%
High-calorie	32	pizza	165	5.6	0.53	100.00%	100.00%
High-calorie	470	pancakes with blueberries	190	10.7	0.45	89.70%	95.80%
High-calorie	491	sundae	201	8	0.17	99.90%	100.20%
High-calorie	87	cheese burger	214	12	0.38	100.00%	99.50%
High-calorie	53	hot dog	232	9.9	0.4	97.80%	100.00%
High-calorie	471	French Toast	235	8.2	0.5	83.70%	90.40%
High-calorie	89	strawberry cake	236	11.2	0.39	97.50%	100.00%
High-calorie	489	pizza with salami	245	12	0.47	98.50%	100.00%
High-calorie	2	Hamburger with bacon	252	15	0.37	99.70%	99.70%
High-calorie	313	ice cream cone	255	9.8	0.16	100.00%	99.70%
High-calorie	74	chocolate cake	256	12.1	0.39	100.00%	99.80%
High-calorie	23	ham sandwich	265	20.3	0.31	99.50%	100.00%
High-calorie	48	chocolate muffin	286	11.6	0.47	99.20%	100.00%
High-calorie	78	muffins	286	11.6	0.31	98.20%	99.10%
High-calorie	46	french fries	290	14.7	0.34	99.60%	99.60%
High-calorie	22	french fries	295	17	0.37	100.00%	99.30%
High-calorie	1	cheesecake	311	17.1	0.47	98.00%	97.40%
High-calorie	116	chocolate popsicle	314	19.8	0.19	100.00%	97.80%
High-calorie	488	waffle	331	21.4	0.45	99.00%	99.60%
High-calorie	66	croissants	333	18.8	0.39	98.30%	100.00%
High-calorie	387	goose, roasted	338	31	0.47	99.40%	99.30%
High-calorie	157	gummi candy	340	0.1	0.58	98.80%	98.90%
High-calorie	138	muffin with green topping	370	10.9	0.29	96.90%	92.70%
High-calorie	505	cookies	384	10	0.36	88.30%	88.00%
High-calorie	123	lollipops	391	2.7	0.13	97.40%	98.80%
High-calorie	125	hard candies	391	0.3	0.21	87.50%	93.00%
High-calorie	441	chocolate donut	420	27	0.39	94.70%	96.70%
High-calorie	151	lemon cake	435	23	0.59	98.30%	96.90%
High-calorie	41	Donut with sprinkles	454	23	0.44	100.00%	97.60%
High-calorie	9	waffles	470	24	0.28	99.60%	100.00%
High-calorie	289	chocolate cookies	471	21.1	0.33	87.80%	97.60%
High-calorie	31	cookies (mixed)	489	25.6	0.17	97.00%	95.90%
High-calorie	296	colored chocolate beans	501	20.9	0.22	97.40%	98.10%
High-calorie	7	croissants	508	33.6	0.35	99.80%	99.50%

High-calorie	4	chocolate cookie	510	26	0.2	99.60%	99.60%
High-calorie	286	bar of chocolate	530	29.5	0.28	100.00%	100.30%
High-calorie	27	opened chips bag	535	39.4	0.32	97.90%	99.30%
High-calorie	148	round shortbread cookies	536	29	0.37	98.00%	98.00%
High-calorie	499	pieces of chocolate	559	38	0.23	93.00%	99.80%
High-calorie	465	pralines	566	38	0.35	99.90%	99.10%