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THE EFFECTS OF CALORIC EDUCATION, TRIAL-BY-TRIAL FEEDBACK AND
THEIR INTERACTION ON COLLEGE-AGED WOMEN'S ABILITIES TO ESTIMATE
CALORIC CONTENT

by

Marian Tewfik Rizk

A thesis submitted in partial fulfillment
of the requirements for the Doctor of Philosophy
degree in Psychology (Clinical Psychology) in the
Graduate College of
The University of Iowa

August 2018

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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the thesis requirement for the Doctor of Philosophy degree
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ABSTRACT

Many people track the caloric content of food, given its relevance to weight loss, gain, or maintenance. Thus, better understanding the psychological underpinnings of caloric content estimation for unhealthy foods is of significant psychological and public health interest. This study investigated whether college-aged women could be trained to estimate the caloric content of unhealthy foods more accurately via exposure to caloric content education, trial-by-trial feedback, and their combination. Two hundred and thirty-eight college-aged women estimated the caloric content of 84 photographed foods and completed three transfer tasks. Prior to the first task, women were randomly assigned to one of four groups: Education and Feedback; Education only; Feedback only; or Neither Education nor Feedback. Following the first estimation task, participants estimated the caloric content of 24 novel photographed foods without feedback. Second, participants self-served specified caloric amounts of six real foods. Finally, participants were invited to consume as much as they would like of an unhealthy food in a five-minute period. Mixed-effects modeling estimated three aspects of the quadratic function linking true and judged caloric content: threshold (average perceived caloric content), linear sensitivity, and change in sensitivity as caloric content increases. On average, college-aged women underestimated caloric content, demonstrated substantial linear sensitivity to caloric content, and did not show reduced sensitivity as caloric content increased. Trial-by-trial Feedback, but not Caloric Education, reduced bias in caloric estimation and enhanced sensitivity to caloric content on the first two tasks. There were no effects of Feedback, Education, the interaction between Feedback and Education, BMI, or hunger on the distal transfer tasks. Overall, college-aged women showed biased but sensitive judgments of the caloric content of unhealthy food presented in images. Initial evidence suggests trial-by-trial feedback may be an efficacious strategy to enhance the accuracy of caloric content estimation, at least when viewing static images of foods.

PUBLIC ABSTRACT

It is well- established that individuals tend to make errors when estimating the caloric content of food, which may enable excess food intake or facilitate weight gain. Current approaches to improving the accuracy of college-aged women's abilities to estimate caloric content are inadequate. Therefore, a better of understanding of how to improve college-aged women's abilities to estimate caloric content for unhealthy foods is of significant psychological and public health interest.

Two hundred and thirty-eight college-aged women completed three tasks of caloric estimation for photographed, unhealthy foods. For the first task, women were randomly assigned to one of four groups. First, some women received Caloric Education. Second, other women received Feedback, which referred to immediate information on one's accuracy after estimating the caloric content for each food. Third and fourth, some women received both Caloric Education and Feedback, whereas others received neither. On the second task, all participants estimated the caloric content of new, unhealthy foods without Feedback. Third, all participants self-served different specified caloric amounts of six unhealthy foods in a novel assessment of caloric judgment. Finally, participants were invited to consume as much as or as little chocolate as they liked for five minutes.

Overall, across all tasks, college-aged women under-estimated the caloric content of food. Feedback, but not Education, was effective in improving college-aged women's caloric estimation abilities on the first two tasks. Future work should continue to explore how to enhance Feedback, so that it might become an even more useful tool for the improvement of caloric estimation.

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The Effects of Caloric Education, Trial-by-Trial Feedback and their Interaction on College-Aged Women's Abilities to Estimate Caloric Content

Many individuals are concerned about weight loss, weight gain, or weight maintenance (Rodin, Silberstein, & Striegel-Moore, 1984; Tantleff-Dunn, Barnes, & Larose, 2011). Normative concern about weight is not surprising, given the medical and psychological issues related to overweight or obesity. For instance, it is well established that excess weight is associated with several health risks, including coronary artery disease, type 2 diabetes, hypertension, some types of cancer, and sleep apnea (Johnson et al., 2007; Xin, Z., Liu, C., Niu, W.Y., Feng, J.P., Zhao, L., Ma, Y.H., Lin, H., & Yang, 2012), as well as psychological concerns, such as eating disorders, weight-based discrimination, and weight stigma (Mond, Hay, Rodgers, & Owen, 2006; Puhl et al., 2008). Rates of adult obesity increased drastically from 1980 to 2012 and appear to have plateaued at a high rate (Ogden, Carroll, Kit, & Flegal, 2013). The prevalence of adult obesity results from several influences, such as genetics, sedentary behavior, the increased availability of inexpensive foods, the increased frequency of meals consumed outside the home, and food marketing efforts (Chandon & Wansink, 2012; Cohen, 2008; Groop & Pociot, 2014; Maher, Mire, Harrington, Staiano, & Katzmarzyk, 2013; Rolls, 1998). Among these factors is the increased intake of highly caloric food (Ello-Martin, Ledikwe, & Rolls, 2005; Rolls, Morris, & Roe, 2002).

The caloric content of food is relevant to weight loss, gain, and maintenance (Rodin et al., 1984; Tantleff-Dunn et al., 2011). Several diet plans conceptualize the development and maintenance of obesity using a well-established model that states weight gain occurs when caloric intake exceeds caloric expenditure over time (Farias, Cuevas, & Rodriguez, 2011). Additionally, the caloric content of foods has been reported as an important influence on the food selection and consumption process (Carels, Konrad, & Harper, 2007). However, self-reported calorie consumption tends to be inaccurate (Block et al., 2013; Elbel, 2011). Additionally, the US Food Supply has increased its distribution by

500 calories per day since the 1970s (Putnam & Allshouse, 1999; Young & Nestle, 2002).

Unhealthy (i.e., processed) foods tend to have more added fat and more added sugar, relative to non-processed foods (USDA, 2010). As a result, processed foods tend to be more caloric, increasing their potential to contribute to excess weight gain. Therefore, understanding the psychological underpinnings of caloric content estimation for unhealthy foods is of significant psychological and public health interest.

Normative Calorie Estimation: Threshold or Bias

Threshold (i.e., bias), or the extent to which estimated caloric content under- or over-estimates true caloric content, is one of the most frequently examined aspects of calorie estimation. To quantify threshold, many rely on the intercept term in statistical models that predict judged calories from true calories (centered), because this number reflects average caloric-estimation, which could be greater or less than the true average caloric content. More specifically, calorie estimation has primarily been conceptualized in terms of “calorie estimation bias” or a maladaptive “threshold,” which indicates an *underestimate* of the number of calories in a particular amount of food, potentially leading to excess consumption (Lucus, 2008). In other cases, individuals may set an adaptive threshold for caloric content by judging caloric content to be greater than it is (e.g., an estimate of 500 calories when the true caloric content was 350 calories). In either case, individuals tend to misestimate the caloric content of foods, suggesting a biased threshold for caloric perception (Livingstone & Black, 2003).

A Review of Normative Calorie Estimation. Overall, little evidence demonstrates that individuals set an unbiased threshold for caloric content. For instance, only 9 out of 22 licensed nutritionists (41%) were considered accurate in their caloric estimates of consumers’ food choices (Aoki, Nakai, & Yamauchi, 2006). Rather, the majority of this work demonstrates normative calorie estimation bias, though it differs in its direction. Some work reveals caloric underestimation, other

work demonstrates caloric overestimation, and some studies show caloric estimation bias in both directions.

Caloric underestimation has been primarily demonstrated in fast-food restaurants. These studies followed a similar procedure in which participants estimate the caloric content of their meals either directly before or after meal consumption. Across this work, participants underestimated their caloric intake for fast-food meals, making several-hundred calorie errors (Brindal, Wilson, Mohr, & Wittert, 2012; Elbel, 2011; Kiszko, Martinez, Abrams, & Elbel, 2014). Additionally, approximately 2000 fast-food consumers in Australia underestimated the caloric content of purchased meals, and as expected, underestimation errors increased as the portion sizes increased (Block et al., 2013). The aforementioned work was limited because it did not provide participants with standardized meals that varied in caloric content to assess participants' caloric estimations as a function of caloric content. Rather, these studies evaluated caloric estimation of self-selected meals that differed in their food components, a technique that enhances ecological validity but diminishes internal validity. In contrast, Chandon and Wansink (2007) investigated normative caloric estimation for standardized meals. In a series of studies, 358 participants estimated the caloric content of various fast-food meals. Consistent with expectations, participants underestimated calories for these meals (Chandon & Wansink, 2007). Larger meals were underestimated by anywhere from 137 to 198 more calories than the smaller meals. In another of their sub-studies, 405 dieticians underestimated the caloric content of various meals by 8.5 percent.

Caloric mis-estimation may also occur in an adaptive direction, such that individuals are over-estimating caloric content (Geier & Rozin, 2009; Holmstrup, Stearns-Bruening, & Rozelle, 2013). Interestingly, prior to any training, 44 overweight adults overestimated the caloric content of standardized foods by 23% (Martin et al., 2007). When 600 college students were asked to estimate the caloric content of 30 photographed foods, 68.8% overestimated the caloric content of vegetables, and 42.0% underestimated the caloric content of grains and starches (Kim et al., 2014). Moreover,

caloric mis-estimation may be associated with nutritional content of foods. For instance, Patterson and colleagues indicated that consumers reported confusion about the caloric content of added sugar in foods being marketed as “sugar reduced,” subsequently overestimating caloric content (Patterson, Sadler, & Cooper, 2012).

Individuals may set both adaptive and maladaptive thresholds for caloric content depending on the food and its nutritional content. For instance, when 179 clinical staff, non-clinical staff, and healthcare life coaches estimated the caloric content of specified foods, the majority of estimates were inaccurate. On average, across the three groups, the proportion of accurate responses was 27%, 23%, and 44%, respectively. Inaccurate responses were both under and over-estimates of caloric content (Cottrell & Chambers, 2013). A recent review evaluated individuals’ ability to judge estimates of caloric content for foods that vary in their portion size. The review concluded that participants tended to mis-estimate caloric amount, but the error of mis-estimation occurred in both directions (Rizk & Treat, n.d.).

No study has demonstrated that individuals, on average, are adept at caloric estimation. Though caloric content is often underestimated, the aforementioned literature indicates this is not always the case, providing evidence of both under- and over-estimates. Although it is clear that individuals are particularly inaccurate at caloric perception in fast-food restaurants, less work has been conducted to evaluate individuals’ caloric perceptions of more than a few fast foods. Moreover, much work evaluating caloric estimation has relied on non-standardized foods or foods that vary imprecisely in size between subjects. Reliance on non-standardized foods makes it difficult to draw causal inferences about the relationship between caloric content and caloric estimation. In contrast, some work employs the use of standardized stimuli. In this case, participants make caloric judgments of foods that are controlled between subjects, allowing for causal inferences between caloric content and caloric estimation. Caloric mis-estimation for a large number of unhealthy,

standardized foods that vary in their caloric content, for instance, may have serious implications for excess consumption.

A Broader Conceptualization of Caloric Estimation: Threshold and Sensitivity

When characterizing stimulus perception, two parameters typically are estimated: threshold and linear sensitivity (Macmillan & Creelman, 1991). Much extant work evaluating caloric perception focuses only on threshold (i.e., the extent to which estimated caloric content under- or over-estimates true caloric content). However, the current work broadens our understanding of caloric estimation by generalizing our conceptualization, measurement, and analysis of caloric-content perception from a threshold-only model to a model that also includes two less-investigated parameters: linear sensitivity and changes in sensitivity as caloric content increases (Chandon & Wansink, 2007; Rizk & Treat, 2015). Calorie estimation bias, low linear sensitivity, and decreasing sensitivity as caloric content increases all may have implications for excess consumption.

Figure 1 illustrates threshold (or calorie estimation bias), linear sensitivity, and change in sensitivity as calories increase. Actual calories are on the X axis, and judged calories are on the Y axis. The dotted line on the diagonal indicates a perfect, unbiased relationship between actual and judged calories, in which judged calories always equal actual calories. The dark line depicts one observer's judged calories, which are slightly greater than actual calories when calories are low but are substantially less than actual calories when calories are high. The three parameters of this non-linear function indicate the observer's caloric-content threshold, caloric-content sensitivity, and change in sensitivity as caloric content increases, as described below.

Threshold. The first parameter, the intercept of the function, provides an index of the observer's caloric-content threshold, which is marked by a dot on the figure. The intercept indexes the judged caloric content for a food in a set of judged foods that contains an average number of actual calories (i.e., where the vertical, dashed line crosses the X-axis on Figure 1). The depicted threshold is maladaptive – that is, judged calories at the intercept are less than actual calories – which

may support overconsumption, as the observer may believe they are eating fewer calories than they actually are.

Linear Sensitivity. The second parameter, the slope of the observed function at the intercept, provides an index of sensitivity to caloric content. Sensitivity to caloric content refers to one's ability to distinguish between various amounts of calories. Sensitivity can be quantified as the strength of the association between varying amounts and some index of nutritional quality, such as calories. For instance, perfect sensitivity to the caloric information of varying amounts of chicken nuggets would be represented by a maximally steep linear relationship between true and judged calories at the intercept (see the diagonal, dotted line on Figure 1). However, it is likely that most individuals are not able to discriminate perfectly between varying amounts of calories, in which case less steep, but non-zero, slopes indicate varying degrees of caloric-content sensitivity. The observer's sensitivity in Figure 1 might be described as moderate, for example. Lesser sensitivity to caloric content may facilitate excessive consumption, as the observer may not recognize how many calories are in various amounts of food.

Change in Sensitivity as Caloric Content Increases. The third parameter, the reduction in the slope of the observed function as actual calories increase, indexes a decline in sensitivity as the number of true calories increases. In other words, the slope of the function when calories are low is quite steep (high sensitivity), but the slope of the function when calories are high is quite shallow (low sensitivity). Sensitivity to caloric content may increase, decrease, or remain constant as the index of amount or nutritional quality increases. Weaker sensitivity to caloric content as actual caloric content increases may be particularly problematic for excess consumption, as the observer may not realize how many more calories are contained in increasing amounts of food.

Relevant Literature. In a seminal series of studies, Chandon and Wansink (2007) highlighted the potential utility of considering both threshold and sensitivity aspects of caloric perception. In a

series of four studies, including consumers and dieticians, individuals judged the caloric content of fast-food meals. Across studies ($N = 376$), participants not only underestimated the meals' average caloric content, but also made larger underestimation errors as the caloric content increased, consistent with declining sensitivity as calories increased. Chandon and Wansink demonstrated that a compressive power function accounted well for the pattern of declining sensitivity, in which estimates of smaller meals tended to be unbiased, while those of larger meals tended to be significant under-estimates, as depicted in Figure 1.

The work of Rizk and Treat (2015) bolsters these conclusions. 272 college-aged women rated the perceived healthiness of 124 digital food photographs of various portion sizes (extra-small to large) of unhealthy foods. A quadratic function was fit to each participant's healthiness judgments as a function of portion size, which allowed simultaneous estimation of the three parameters of theoretical interest: the intercept (perceived healthiness of the average-sized food), the linear slope (linear sensitivity at the intercept), and the quadratic slope (change in sensitivity as portion sizes increase). Results revealed moderate sensitivity to portions for unhealthy foods, and declining sensitivity as portion sizes increase. More specifically, individuals were generally able to discriminate in their healthiness judgments between foods that were extra-small to medium in size. However, participants' healthiness judgments became less commensurate with the portion presented as the portions increased, which is a maladaptive error in portion-size perception. Notably, when calories were used as a predictor of healthiness ratings, rather than portion size, the analyses revealed highly similar results for the intercept, slope, and acceleration parameters (Rizk & Treat, 2015).

Overall, extant literature suggests that individuals misperceive caloric content and that our conceptualization of caloric content perception usefully could be extended beyond threshold-only models to include parameters that also simultaneously index sensitivity and change in sensitivity as caloric content increases. The conduct of studies and the use of analytic models that distinguish between caloric-content threshold, caloric-content sensitivity, and the change in caloric-sensitivity as

calories increase are warranted. Each of these parameters may have implications for maladaptive consumption. Further, it may prove useful to consider the development and evaluation of training programs designed to address not only maladaptive thresholds but also reduced sensitivity and decelerating sensitivity as caloric content increases.

Calorie Estimation Training Programs

Menu Labeling. Several researchers have investigated the efficacy of attempts to improve normative caloric perception. These efforts include mandatory menu labeling, which is a point-of-purchase intervention that relies on an informational approach to caloric estimation training. Initial work in this area demonstrated that 76% of consumers were inaccurate despite access to menu labels (Elbel, 2011). Taksler and Elbel (2014) investigated the influence of menu labeling on caloric estimation of purchased foods in two cities: one that had already enforced menu labeling and a comparison city that had not yet enforced this law. On average, in both cities, consumers underestimated calories purchased by 216-409 calories, irrespective of access to menu labels. Moreover, accuracy worsened for larger meals (i.e., meals with greater caloric content) (Taksler & Elbel, 2014). Roberto et al. (2013) surveyed 371 individuals who self-reported any eating disorder symptomatology. These participants completed a calorie-estimation quiz after exposure to a labeled menu. On average, 75% of responses were inaccurate (Roberto, Haynos, Schwartz, Brownell, & White, 2013). However, at least one study suggests that providing calorie information may prove beneficial. The presence of calorie ranges on some menu items appeared to improve caloric mis-estimation by 76% in a sample of 306 Mexican fast-food consumers (Liu, Bettman, Uhalde, & Ubel, 2014).

Caloric Education. Some effort has been made to train individuals to improve caloric estimation using relatively more active learning components. Holmstrup and colleagues (2013) trained 15 nutritionists and 15 non-nutritionists to use a “Think Aloud” method to estimate calories in a meal. After listening to a successful demonstration of the “Think Aloud” method, participants were

recorded as they articulated their thoughts. 29% of participants were accurate in their estimates. Though they were not explicitly instructed to do so, accurate estimators were characterized by their ability to convert between common portion size techniques (e.g., “my fist is about the size of 1 cup”), their consideration of energy density, and their accuracy when using basic math skills (Holmstrup et al., 2013). Interestingly, prior nutritional training (i.e., having taken 3 or more college-level nutrition courses) did not impact estimation accuracy during the task. Martin and colleagues (2007) explored the efficacy of The Health Management Resources Calorie System,[®] a method designed to teach caloric content as a function of food amount. A within-subjects design was used, so that participants served as their own control. For each food group, participants memorized the caloric content for anchor foods (e.g., broccoli is 40 kcal/cup) and learned to estimate the caloric content for other foods (e.g., cauliflower). This program decreased caloric overestimates only slightly: from 23% to 19% (Martin et al., 2007). Ayala (2006) randomly assigned participants to a wait-list control or to a single, one-hour session of computer training or group didactic training in the estimation of the portions of 13 real and 14 model foods. Participants in the training conditions learned the same material, which included the relevance of portion size to weight control, recommended portion sizes, and how to use one’s hands or various household items (e.g., a CD) to estimate portion size, using food models. As expected, computer and group training improved estimation, relative to wait-list controls, although this effect was small in magnitude (Ayala, 2006). Broadly, calorie estimation appears to either improve marginally or remain the same when individuals are educated on the caloric content of prototypical foods, energy density (which is directly influenced by a food’s nutritional contents), and portion size. Given the limited work in this area, future work evaluating the efficacy of caloric education on caloric estimation is warranted.

Trial-by-trial Feedback. Limited prior work has relied on trial-by-trial feedback to enhance caloric estimation. Wohldmann (2015) followed a three-step method to evaluate the efficacy of

“feedback” and “view only conditions” in an effort to enhance caloric content estimation. First, all participants saw food photographs on a computer and generated their own estimates of each food’s caloric content. Second, participants were assigned to one of three conditions. Those in the “feedback” condition estimated the caloric content of the foods and received immediate feedback on the actual caloric content, participants in the “view-only” condition viewed each stimulus with its actual caloric content without making caloric estimates, and those in the “control” condition viewed foods without any caloric content and did not make caloric estimates. Third, all participants generated caloric content estimates for the same food stimuli, as well as novel stimuli. Wohldmann demonstrated significant improvement in caloric estimation for participants in both experimental conditions compared to the control condition. Importantly, no significant differences emerged between the “feedback” and “view-only” conditions in accuracy, suggesting that feedback did not enhance caloric estimation more than viewing foods and their caloric content simultaneously (Wohldmann, 2015).

Others have opted to develop and to evaluate the efficacy of portion-size estimation skills training. For instance, three diabetic men were trained to serve themselves portions equivalent to food models, which were later removed. Participants received feedback on their accuracy, as they selected portions for four foods. As expected, exposure to training and feedback improved portion-size accuracy; however, training effects did not generalize to new foods one month later (Rapp, Dubbert, Buttross, & Burkett, 1988). Riley et al.(2007) extended this work by creating a web-based training that allows the participant to control the angle(s) at which each portion is viewed and provides feedback on accuracy. Participants either received this training immediately or after estimating the portion size of their own self-served meal. During the training, participants practiced using this program for at least 30 minutes and then estimated at least 40 portions with feedback. Training shifted accuracy from under-to overestimation (Riley et al., 2007). To date, therefore, the combination of caloric education and feedback training, albeit for portion size estimation, appears to

have little to no effect on portion-size estimation. Notably, training via trial-by-trial feedback has only been applied to calorie estimation in one prior study.

Common features of these training programs appear to be caloric-content education, modeling, feedback, and shaping. Initial work evaluating the informational approach of menu labeling appears inadequate to improve caloric estimation skills. However, the impact of a caloric estimation training program, in contrast to a portion size estimation program, that features an explicit educational component and trial-by-trial feedback is currently unknown. At present, there is also a need to investigate the effect of caloric-content training programs on changes in threshold, linear sensitivity, and change in sensitivity as caloric content increases, as most studies only evaluate estimation accuracy, which collapses across these three parameters. Evaluations of the extent to which these modifications influence consumption also may be a fruitful avenue to explore.

Overview of the Study

The present study examined whether college-aged women could be trained to estimate the caloric content of unhealthy (i.e., processed) foods more accurately via exposure to caloric content education, trial-by-trial feedback, and their combination. A three-parameter model was used to characterize caloric estimation: threshold, linear sensitivity, and change in sensitivity as caloric content increases. The use of this analytic model extends prior work (Chandon & Wansink, 2007; Rizk & Treat, 2015) by characterizing caloric-content judgment with a three-parameter model in a highly standardized and controlled setting using numerous, unhealthy food stimuli. The current study also extended the existing literature by presenting participants with a wide array of unhealthy (i.e., processed) foods that vary by food type (e.g., high added fat, high added sugar, and high added fat and added sugar) and consistency (i.e., solid or amorphous).

Moreover, the current study employed an online, interactive training program that evaluated the effect of a caloric education component and trial-by-trial feedback on the accuracy of caloric judgments. The training program was intentionally developed online, in order to leverage technology,

since a primary criterion of these training strategies are their potential to be easily disseminated. Developing interventions that can be both easily distributed and individually-tailored has been deemed a priority (e.g., Kazdin & Blase, 2011). Though limited, prior work suggests that online intervention strategies may be worthwhile. In the field of disordered eating, for instance, online interventions not only appear efficacious (e.g., Kass et al., 2014), but also highly acceptable and feasible (e.g., Shaw, Stice, & Becker, 2009). Future work evaluating the efficacy of online-based interventions is warranted, however (Bauer & Moessner, 2013; Loucas et al., 2014). Therefore, both modification strategies used in the current study, the Caloric Education Module and trial-by-trial feedback, are computer-based.

The present study further examined whether any improvements in caloric estimation alter performance on two subsequent calorie-estimation tasks (i.e., Proximal Transfer and Distal Transfer Tasks) and one consumption task. The Proximal Transfer Task was highly similar to the training task and assessed participants' estimation of the caloric content of new food stimuli in the absence of feedback. Inclusion of this task allowed quantification of the extent to which caloric content education, trial-by-trial feedback, and their interaction influence threshold, linear sensitivity, and change in sensitivity as caloric content increases in the context of novel food stimuli. Demonstrating that caloric estimation skills can be trained and extended to novel stimuli could have beneficial implications for real-world caloric estimation.

In contrast to the Proximal Transfer Task, the Distal Transfer Task evaluated women's abilities to estimate the caloric content of real foods. Participants were presented with six real, processed foods and asked to self-serve specific calorie amounts of these foods (e.g., given a large bowl of Skittles, put 350 calories of Skittles in a smaller bowl). The Distal Transfer Task was designed to tap whether caloric education, trial-by-trial feedback, or their interaction influences caloric perception in a task that is simultaneously more dissimilar from the original training task and relatively more externally valid. Although the current study was developed with an eye towards

dissemination, two, real-food tasks, which could not be easily disseminated, were also prioritized in the study design. These tasks were included in order to identify the extent to which the trial-by-trial feedback and education procedures influence behavior with real foods in the lab before broadly disseminating these online strategies.

Finally, participants were invited to consume as much of an unhealthy food as they liked in order to explore the effects of caloric education, trial-by-trial feedback, and their interaction on caloric consumption. Examination of the association between caloric consumption and experimental condition is exploratory; given the limited nature of the current training program and that no prior work has investigated the association between any calorie estimation training program and subsequent food consumption.

Summary and Specific Aims

The proposed study addressed three primary objectives. The first aim was to examine the effects of caloric education, trial-by-trial feedback, and their interaction on caloric estimation of photographed food. The second aim was to examine the effects of caloric education, trial-by-trial feedback, and their interaction on a proximal transfer task of caloric estimation of novel, photographed food in the absence of feedback. The third aim was to examine the effects of caloric education, trial-by-trial feedback, and their interaction on a distal transfer task of caloric estimation of real food, as well as consumption of a real, unhealthy food.

Specific aim #1. To examine the effects of caloric education, trial-by-trial feedback, and their interaction on caloric estimation of photographed food. Caloric estimation was characterized using three parameters: threshold, linear sensitivity, and change in sensitivity as calories increase. First, I expected significant main effects of caloric education and trial-by-trial feedback, such that those who receive education or feedback demonstrate less biased threshold, greater linear sensitivity, and a more linear change in sensitivity as caloric content increases, relative to those who do not receive education or feedback. Second, I hypothesized that the interaction between caloric education and

trial-by-trial feedback would be significant. That is, I anticipated that caloric education would potentiate the effect of trial-by-trial feedback.

Specific aim #2. To examine the effects of caloric education, trial-by-trial feedback, and their interaction on a proximal transfer task of caloric estimation of novel, photographed food in the absence of feedback. I hypothesized significant main effects of caloric education and trial-by-trial feedback, such that those who receive education or feedback demonstrate less biased threshold, greater linear sensitivity, and a more linear change in sensitivity as caloric content increases, relative to those who do not receive education or feedback. Second, I expected a significant interaction between caloric education and trial-by-trial feedback, such that the effect of caloric education would be enhanced among those who receive trial-by-trial feedback when estimating calories for novel, photographed food in the absence of feedback.

Specific aim #3. To examine the effects of caloric education, trial-by-trial feedback, and their interaction on a distal transfer task of caloric estimation of real food, as well as consumption of a real, unhealthy food. I hypothesized significant main effects of caloric education and trial-by-trial feedback, such that those who receive education or feedback demonstrate less biased threshold, greater linear sensitivity, and a more linear change in sensitivity as caloric content increases, relative to those who did not receive education or feedback. Second, I hypothesized that the interaction between caloric education and trial-by-trial feedback would be reliable. That is, I anticipated that the effect of caloric education would be greater among those who receive trial-by-trial feedback when estimating calories for novel, real foods. I examined the effects of training, feedback, and their interaction on estimation of ad libitum chocolate consumption on an exploratory basis.

Research Design and Method

Participants

273 undergraduate women were recruited from the Department of Psychological and Brain Sciences Research Pool, which consists of University of Iowa undergraduates enrolled in

introductory psychology classes. To be eligible for participation, women had to be between 18 and 24 years of age and enrolled as an undergraduate student. Only female students were invited to participate because normative concern about weight gain and caloric content is greater in this population. In addition, only those under the age of 24 were eligible to participate because we were interested in the efficacy of a training program for college-aged women.

Sample Characteristics. 273 undergraduate women participated in this study. Data from thirty-five women were not included in the analysis due to food allergies ($n = 9$) and program errors during any task ($n = 26$). Therefore, the final sample included 238 undergraduate women, with an average age of 19.18 ($SD=1.29$). The racial and ethnic composition of this sample was 73.2% White/Caucasian, 11% Asian-American, 6.1% Hispanic/Latina, 4.5% Black/African American, and 5.2% Other. The mean BMI of the sample was 23.76 ($SD= 4.24$), with 74.2% of the participants meeting criteria for normal weight, 17.6% meeting criteria for being overweight, and 8.2% meeting criteria for obesity.

Procedure

Recruitment. Undergraduate females were invited to participate if they were currently participating in the Department of Psychological and Brain Sciences Research Pool. If they were interested in participating, participants registered for a 60-minute session via Sona Systems, a participant registration website administered by the Department of Psychological and Brain Sciences. Participants received 1.0 credit in partial fulfillment of course requirements.

Session Structure. Participants provided informed consent and were seated in front of a computer terminal in a private cubicle. Using a two-by-two, Education-by-Feedback design, participants were randomized into one of four groups: Group 1 = Both Education and Feedback; Group 2 = Education Only; Group 3 = Feedback Only; and Group 4 = Neither Education nor Feedback.

The first half of the session differed by group, as follows. Those randomized to Group 1 completed the caloric education component followed by the Caloric Estimation Task with trial-by-trial feedback. In contrast, those in Group 2 completed the caloric education component, followed by the Caloric Estimation Task without trial-by-trial feedback. Those in Group 3 immediately completed the Caloric Estimation Task with trial-by-trial feedback. Finally, participants in Group 4 immediately completed the Caloric Estimation Task without feedback. The second half of the session was the same for all groups. Following the Caloric Estimation Task, all participants completed the Proximal Transfer Task, the Distal Transfer Task, and the Ad Libitum Chocolate Consumption Task. Regardless of condition, participants rated their current hunger level using a visual analogue scale five times during the study (see description of VAS-H). Current hunger was reported before and after each task. See Appendix A for experimenter instructions.

Stimuli. 132 unique, unhealthy, processed foods that varied in food type (i.e., high added fat, high added sugar, or high added fat and added sugar), consistency (i.e., solid or amorphous), and caloric content were available for inclusion in this study. Rigorous and standardized selection procedures were used to ensure a uniform distribution of stimuli across caloric content, whereas prior work did not present food stimuli that were evenly distributed along caloric content (Chandon & Wansink, 2007). Each food was photographed on a white plate with a 10.25-inch diameter, which was placed on a navy placemat. A metallic fork was to the left of the plate, and a metallic knife and spoon were on the right. The plate, placemat, and utensils were included to serve as sizing guides. See Figure 2 for a sample stimulus.

Examination of Stimuli Recognition. I evaluated whether college-aged women were able to recognize the unhealthy food stimuli included in the Caloric Education Component, Caloric Estimation Task, and the Proximal Transfer Task. Thirty-six undergraduate women viewed 132 photographed food stimuli on a computer screen. For each food stimulus, participants were asked, “Do you recognize this food, even if you cannot name it?” Participants responded by clicking either

“YES” or “NO” for each food stimulus. Participant responses were coded into 1 for “yes” and 0 for “no.” The mean response judgment for each food reflected the percentage of participants who responded “yes” to the food. For example, foods that received a response rate of 1.00 indicated that all 36 participants stated they could recognize this food.

Food stimuli that received a response of less than 0.80 were excluded from the stimulus set used in the primary dissertation study. In other words, at least 80% of this sample had to report that they recognized the food stimulus in order for it to be included in the tasks. Using this criterion, 14 food stimuli were dropped. Therefore, a total of 118 unique food stimuli were available for inclusion in the Caloric Education Module, the Training Task, and the Proximal Task. Stimuli were presented only one time. In other words, after a stimulus was presented in one study component, it was not used again in any other component, including the Caloric Education Module and all tasks.

Caloric Education Component. Prior work suggests that the accuracy of calorie estimation may either improve slightly or remain the same when individuals receive education on the caloric content of prototypical foods, energy density (which is directly influenced by a food’s nutritional contents), and portion size (Holmstrup et al., 2013; Martin et al., 2007). USDA Guidelines suggest that individuals consider how a food is prepared when judging caloric content (USDA, 2010). The Caloric Education Component was divided into seven subsections: Introduction to a Calorie, High Fat Foods, High Sugar Foods, High Added Fat and High Added Sugar Foods, Other Nutrients, How the Food is Prepared, and The Influence of Portion Size on Caloric Content. Participants read about each of these topics and answered several questions throughout the modules to engage their attention, to check their understanding, and to reinforce their understanding of this information. Throughout the module, numeric anchors were provided for the caloric content of some foods (i.e., foods were presented with their caloric content). Provision of numeric anchors is one efficacious strategy for enhancing the expertise of novices and providing guidance when making judgments under uncertainty (Smith, Windschitl, & Bruchmann, 2013; Tversky & Kahneman, 1974). Finally,

participants practiced selecting which of two foods contained more calories and explaining why, highlighting each “caloric content lesson” just learned (see Figure 3). See Appendix B for the complete contents of the Caloric Education Component.

Measures

Calorie Estimation Task. On a computer screen, participants estimated the caloric content of 84 unhealthy foods on a scale that ranged from 0 calories to 1800 calories. Depending on their condition, some participants received trial-by-trial feedback on the accuracy of their responses. In this case, the judged food stimulus appeared on the top of the screen, and the caloric judgment scale appeared below. On the scale, true caloric content was indicated by a dot labeled “TRUE CALORIES” and judged caloric content was indicated by a dot labeled “JUDGED CALORIES.” See Figure 4 for a sample trial.

Proximal Transfer Task. Upon completion of the Caloric Estimation Task, all participants estimated the caloric content of 25 new, unhealthy foods on a scale that ranged from 0 calories to 1800 calories. Participants did not receive trial-by-trial feedback.

Distal Transfer Task. Once participants completed the Proximal Transfer Task, they self-served different caloric amounts of six, real, processed foods. Six foods were chosen, because six data points allowed estimation of the three parameters of interest: calorie threshold, linear sensitivity, and change in sensitivity as calories increase. Since participants were trained to judge the caloric content of foods that were high in added fat, high in added sugar, or both, they were presented with two of each food type. Participants had not seen these foods in any previous task or in the Caloric Education Module. The presented foods were: Nacho Cheese Doritos (high added fat; asked to serve 350 cal), Trail Mix (high added fat; asked to serve 875 cal), Reese’s Pieces (high added fat and high added sugar; asked to serve 525 cal), Buncha Crunch (high added fat and high added sugar; asked to serve 165 cal), Skittles (high added sugar; asked to serve 700 cal), and Sour Patch Kids (high added sugar; asked to serve 1050 cal).

The first 15 participants were asked to serve 165 calories of Powdered Donuts, rather than Buncha Crunch. However, there was little variability in the number of calories of powdered donuts that participants self-served, since individual units of powdered donuts were larger than the units of the other foods, such as individual Reese's Pieces or individual Skittles. After the powdered donuts were replaced with Buncha Crunch, variability in the number of calories self-served increased. Therefore, the remainder of the subjects was asked to serve 165 calories of Buncha Crunch. Caloric estimates for Powdered Donuts for the first 15 participants were dropped from subsequent analyses.

Participants were presented with two trays that contained 6 bowls each. On each tray, three of the bowls contained a high-fat food, a high-sugar food, and a high-fat, high-sugar food. Three bowls were empty and labeled with a specific caloric amount. Participants self-served the requested number of calories from the full bowl to the empty bowl for each food. They completed this task for both trays (see Figure 5). The weight of the bowls was measured before and after the task, so that the caloric content of foods could be computed. The primary dependent variable was the caloric content of the self-served amount.

Each full bowl contained between 25 to 45% more of each food's "correct caloric amount." We did not present participants with exactly 25% more of each food, because we did not want to hold the difference between the presented amount and the "correct" specified caloric amount constant across stimuli. In order to determine the amount presented for each food, we chose a 25% increase for the most expensive food. We also considered how much food could fit into each bowl. For example, we could not fit more than 550 calories of Doritos into the bowl.

Ad Libitum Chocolate Consumption. After the Distal Transfer Task, all participants were presented with an 18-ounce bowl of M&M's. Participants were invited to consume as much or as little as they would like for five minutes. Regardless of how much they consumed, participants waited quietly without distractions until five minutes have passed. The weight of the bowl post-

consumption was measured and recorded, and the number of total calories consumed was calculated. The primary dependent variable was amount consumed.

Visual Analogue Scale- Hunger (VAS-H). The VAS-H (Flint, Raben, Blundell, & Astrup, 2000) asked participants to report their current hunger by drawing a vertical line at any point along a 100 mm horizontal line anchored by “I am not hungry at all” and “I have never been more hungry.” Hunger scores, ranging from 0-100, were calculated by using a ruler to measure the distance from the beginning of the line to the vertical mark. Participants reported their current hunger five times: Hunger 1 was reported prior to the Training task, Hunger 2 was reported prior to the Proximal task, Hunger 3 was reported prior to the Distal task, Hunger 4 was reported prior to the Consumption task, and Hunger 5 was reported following the Consumption task.

Demographics. Participants completed a personal information questionnaire (PIQ). They self-reported their height and weight, from which body mass index (BMI) was computed. They also indicated whether they had any food allergies or dietary restrictions, as well as their age, year in school, race and ethnicity, marital status, et cetera.

Data Analysis

Analysis of Specific Aim #1. Mixed-effects modeling was used to analyze the effects of caloric education, trial-by-trial feedback, and their interaction on the three parameters (intercept, linear slope, quadratic slope) characterizing college-aged women’s caloric estimates during the Caloric Estimation Task. A mixed-effects model was fit to the caloric judgments using the lmer function in the lme4 package (Bates, Maechler, Bolker, Walker, & Christensen, 2014) in R (R Development Core Team, 2008), with p values and degrees of freedom estimated by the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2013). Effect sizes were calculated using recommended procedures for mixed-effects models (Oishi, Lun, & Sherman, 2007). All continuous predictors were standardized, including actual calories, the square of actual calories, BMI, and

Hunger 1. Prior to analyses, BMI was also transformed by taking its natural log. The dichotomous experimental predictors were effect-coded prior to analyses.

Judged calories were modeled as a function of standardized actual calories and the standardized square of actual calories, as shown in the equation below. The three parameters of the model indexed normative caloric estimation ($\beta_0, \beta_1, \beta_2$). The average intercept for the equation, β_0 , reflected participants' average caloric estimate for an unhealthy food with average caloric content. The average linear slope in the equation, β_1 , indexed average linear sensitivity to caloric content at the intercept – that is, the change in judged calories associated with a one standard deviation (SD) increase in the actual caloric content of the average-sized food. The quadratic slope, β_2 , indexed the change in sensitivity as a function of caloric content – that is, the change in the rate of change in judged calories associated with a one SD increase in the food's actual caloric content. A value of zero indicated a linear relationship between actual calories and judged calories, such that there was no change in sensitivity as actual calories increased. A positive value indicated that caloric content sensitivity increased as actual caloric content increased; in other words, the change in the rate of change of judged calories *increased* as actual caloric content increased. Finally, negative values indicated that sensitivity to actual caloric content decreased as caloric content increased; in other words, the change in the rate of change of judged calories *declined* as caloric content increased.

Caloric Estimation Equation without Experimental Predictors:

$$\text{Judged Calories} = \beta_0 + \beta_{01} (\text{Actual Calories (standardized)}) + \beta_{02} (\text{Actual Calories (standardized)})^2 + r$$

The fixed-effects structure in the full model included main effects of and the bivariate interaction between caloric education and trial-by-trial feedback on the intercept, linear slope, and quadratic term in the formula above. This fixed-effects structure allowed evaluation of the effects of these manipulations on the three aspects of caloric estimation. The fixed-effects structure also

included BMI and Hunger 1 (i.e., hunger prior to completion of the Training Task) as predictors of the intercept, linear slope, and quadratic term. The maximal random effects structure supported by the data included random intercepts for subject and food, as well as random subject slopes for actual calories (linear sensitivity) and the square of actual calories (quadratic sensitivity). Note that this data-based random effects structure indicated that there was significant variability across participants in the intercept, linear sensitivity, and quadratic sensitivity parameters.

Analysis of Specific Aim #2. A mixed-effects model was used to analyze the effects of caloric education, trial-by-trial feedback, and their interaction during the Caloric Estimation Task on the three parameters (intercept, linear slope, quadratic slope) characterizing college-aged women's caloric estimates of novel, photographed foods in the absence of feedback on the Proximal Transfer Task. Judged calories were modeled as a function of standardized actual calories and the square of standardized actual calories, as shown in the equation above. This model was identical to that described above for the analysis of Specific Aim #1, except that it included judged calories obtained during the Proximal Transfer Task in place of judged calories obtained during the Caloric Estimation Task. Additionally, the fixed-effects structure included Hunger 2 (i.e., hunger prior to completion of the Proximal Transfer Task), rather than Hunger 1.

Analysis of Specific Aim #3. A mixed-effects model was used to analyze the effects of caloric education, trial-by-trial feedback, and their interaction on the Caloric Estimation task on the three parameters (intercept, linear slope, quadratic slope) characterizing college-aged women's caloric estimates of six, real foods on the Distal Transfer Task. Judged calories (i.e., the number of calories that the participant self-served for each of the six foods) were modeled as a function of standardized actual calories (i.e., the number of calories that the participant was asked to self-serve for each of the six foods) and the square of standardized actual calories, as shown in the equation above. The fixed-effects structure of the model was very similar to that described above for the analysis of Specific Aim #1 and Specific Aim #2, except that the model included Hunger 3 (i.e.,

hunger prior to completion of the Distal Transfer Task). Additionally, the random-effects structure did not include a random intercept for item (i.e., food), as judgments of only six foods are insufficient for estimation of food-related random effects.

A univariate generalized linear model (GLM) was used to examine the effect of caloric education, trial-by-trial feedback, and their interaction on the Caloric Estimation Task on the amount consumed during the Ad Libitum Chocolate Consumption Task. The experimental predictors were effect-coded prior to analyses. BMI and Hunger 4 (i.e., prior to the Consumption Task) were included as covariates. Prior to analyses, BMI was transformed by taking its natural log, and both covariates were standardized.

Power Analysis. Approximately 200 participants, or 50 participants for each of the four cells in the two-by-two design, were necessary to answer the primary questions of interest with .80 power. The main power concerns were power to detect the main effects of caloric education and trial-by-trial feedback, as well as power to detect the interaction between these two manipulations, on the three parameters characterizing caloric judgments. Power estimation followed the procedures outlined by Cohen (1988). Power estimates were the same for the training and transfer tasks. Assuming 200 total participants, power for a conventionally defined medium effect size (i.e., $f = .25$) exceeded .80 for the two main effects and the interaction.

Results

Aim 1: Calorie Estimation Task

Threshold. The true average caloric content of the 84 presented foods in the Calorie Training Task was 757.20. The average caloric rating of the average food was estimated to be 575.26, which was substantially less than the true average caloric content (757.20), $t(117) = -9.566$, $p < 0.001$, $d = -1.77$ (see Table 1). Figures 6a and 6b present model-predicted results for the Calorie Training Task, with actual calories (standardized) on the X-axis, and judged calories on the Y-axis. These figures illustrate participants' thresholds for and sensitivities to caloric content, both on

average (6a) and separately within all four conditions (6b). The average threshold is indicated by the intercept for the participants' regression line (i.e., where the regression line crosses the Y-axis on Figure 6a, at approximately 575.26, given that calories are standardized in the model).

There was a positive, substantial effect of Feedback on the average caloric rating, $p < 0.001$, $d = 1.45$, such that participants who received Feedback rated the average calorie food to be 662.76 calories (i.e., where the long-dash and solid black lines cross the Y-axis on Figure 6b), and participants who did not receive Feedback rated the average caloric food to be 487.76 calories (i.e., where the gray and short-dash lines cross the Y-axis on Figure 6b). Thus, those who received Feedback made estimates that were substantially closer to the true caloric content of the average presented food. There were no main effects of Education, BMI, or Hunger on average caloric ratings, nor an interaction between Education and Feedback on average caloric ratings. Dummy-coding the experimental predictors, Education and Feedback (with values of 1 for Education and Feedback), did not alter the pattern of findings for the intercept, $p = 0.465$. In other words, as illustrated in Figure 6b, whether participants received Feedback was associated with the intercept, not whether participants received the combination of Education and Feedback versus the other three conditions.

Linear Sensitivity to Caloric Content. The average linear sensitivity to caloric content was 220.94, $p < 0.001$, $d = 2.65$, indicating that participants demonstrated substantial linear sensitivity and that caloric ratings increased by 220.94 for each SD increase in the foods' caloric content. Linear sensitivity is illustrated in Figures 6a and 6b by positive linear slopes, and the steepness of the slopes indicates the substantial magnitude of participants' sensitivity.

In Figure 6b, the effects of Education and Feedback on sensitivity to caloric content are plotted. The slope of each line provides an index of linear sensitivity to caloric content in that condition. Participants in all four conditions demonstrated linear sensitivity to caloric content, as evidenced by their positive linear slopes. There was a positive, considerable effect of Feedback on the linear sensitivity to caloric content, $p < 0.001$, $d = 1.29$, however, such that participants who

received Feedback increased their average caloric rating by 260.11 calories for each SD increase in the foods' caloric content (i.e., note the steeper slopes of the solid black and long-dash lines). In contrast, participants who did not receive Feedback increased their average caloric rating by 181.77 calories for each one SD increase in the foods' caloric content (i.e., note the shallower slopes of the gray and short-dash lines). There were no main effects of Education, BMI, or Hunger on linear sensitivity to caloric content, and there was no interaction between Education and Feedback on linear sensitivity to caloric content. Dummy-coding the experimental predictors, Education and Feedback, did not alter the pattern of findings for linear sensitivity, $p = 0.136$. In other words, as illustrated in Figure 6b, whether participants received Feedback was associated with average linear sensitivity, not whether participants received the combination of Education and Feedback versus the other three conditions.

Quadratic Sensitivity to Caloric Content. The average quadratic sensitivity to caloric content was -18.74. The negativity of this value indicated that sensitivity to actual caloric content decreased as caloric content increased; in other words, the change in the rate of change of judged calories *declined* descriptively as caloric content increased, as expected. However, the observed reduction in sensitivity as caloric content increased was not reliably less than zero, $p = 0.238$, $d = -0.24$, contrary to expectations. This finding is illustrated by the largely linear (i.e., minimally quadratic) nature of the trajectories in Figure 6a. In other words, as actual calories increased, participants' judged calories on average did not plateau gradually, suggesting that participants were able to distinguish just as well among foods with greater caloric content as among foods with lesser caloric content.

A trend-level, small effect of Education on quadratic sensitivity to caloric content was revealed, $p = 0.064$, $d = 0.16$, such that participants who did not receive Education showed slopes that decreased more as caloric content increased, relative to participants who did receive Education. More specifically, those who did not receive Education showed slopes that decreased by 22.38

calories for each SD increase in the food's true caloric content, whereas those who did receive Education showed slopes that decreased by 15.09 calories for each SD increase in the food's true caloric content. This trend-level Education effect on quadratic sensitivity is illustrated in Figure 6b by the relatively more linear nature of the solid black and gray lines (i.e., the slopes of the lines are changing little as actual calories increase), as opposed to the more quadratic nature of the long-dash and short-dash lines (i.e., the slopes of the lines are becoming more shallow as actual calories increase). This finding suggests that those who received Education were more able (at a non-significant trend level) to distinguish among large caloric amounts than those who did not receive Education. There were no main effects of Feedback, BMI, or Hunger on quadratic sensitivity to caloric content, and there was not an effect of the interaction between Education and Feedback on quadratic sensitivity to caloric content. Dummy-coding the experimental predictors, Education and Feedback, did not alter the pattern of findings for quadratic sensitivity, $p = 0.352$. In other words, as illustrated in Figure 6b, whether participants received Education was associated with the average quadratic sensitivity, not whether participants received the combination of Education and Feedback versus the other three conditions.

Aim 2: Proximal Transfer Task

Threshold. The true average caloric content of the 24 presented foods in the Proximal Transfer Task was 749.8. The average caloric rating was 641.72, $p < 0.001$, $d = 7.29$, which was substantially less than the true average caloric content of 749.8, $t(25.40) = -3.095$, $p < 0.001$, $d = -1.22$ (see Table 2). Figures 7a and 7b illustrate threshold for and sensitivity to caloric content, on average (7a) and separately for all four conditions (7b). The average threshold is indicated by the intercept for the participants' regression line (i.e., where the regression line crosses the Y-axis on Figure 7a, at approximately 641.72).

There was a positive, large effect of Feedback on the average caloric rating in the Proximal Transfer Task, $p < 0.001$, $d = 0.87$, such that participants who received Feedback rated the average

caloric food to be 705.06 calories (i.e., where the long-dash and solid black lines cross the Y-axis on Figure 7b), whereas those who did not receive Feedback rated the average caloric food to be 578.08 calories (i.e., where the gray and short-dash lines cross the Y-axis on Figure 7b). Thus, those who received Feedback made estimates that were substantially closer to the true caloric content of the average presented food. There were no main effects of Education, BMI, or Hunger on average caloric ratings, nor an interaction of Education and Feedback on average caloric ratings. Dummy-coding the experimental predictors, Education and Feedback, did not change the pattern of results, $p = 0.270$.

Linear Sensitivity to Caloric Content. The average linear sensitivity to caloric content was 288.41, $p < 0.001$, $d = 3.53$, indicating that participants showed considerable linear sensitivity and that caloric ratings increased by 288.41 for each SD increase in the foods' caloric content. Linear sensitivity is illustrated in Figures 7a and 7b by positive linear slopes, and the steepness of the slopes indicates the substantial magnitude of participants' sensitivity. In Figure 7b, the effects of Education and Feedback on sensitivity to caloric content are depicted. There was a positive, large effect of Feedback on linear sensitivity to caloric content, $p < 0.001$, $d = 0.76$, such that participants who received Feedback increased their average caloric rating by 321.16 calories for each SD increase in the foods' caloric content (i.e., note the steeper slopes of the solid, black and black, long-dash lines). In contrast, participants who did not receive Feedback increased their average caloric rating by 224.77 calories for each SD increase in the foods' caloric content (i.e., note the shallower slopes of the gray and short-dash lines). There were no effects of Education, BMI, or Hunger on linear sensitivity to caloric content, nor was there an effect of the interaction between Education and Feedback on linear sensitivity to caloric content. Dummy-coding the experimental predictors, Education and Feedback, did not alter the results, $p = 0.238$.

Quadratic Sensitivity to Caloric Content. The average quadratic sensitivity to caloric content was -35.91. The negative direction of this value indicated that sensitivity to actual caloric content decreased as caloric content increased, as expected. However, reduction in sensitivity as

caloric content increased was not reliably less than zero, $p = 0.300$, $d = -0.45$, contrary to expectations. This finding is illustrated by the largely linear trajectories in Figure 7b.

A trend-level, very small effect of Feedback on quadratic sensitivity to caloric content was revealed, $p = 0.095$, $d = 0.12$, such that participants who did not receive Feedback showed slopes that decreased more as caloric content increased, relative to participants who did receive Feedback. More specifically, those who did not receive Feedback showed slopes that decreased by 41.39 calories for each SD increase in the food's true caloric content, whereas those who did receive Feedback showed slopes that decreased by 30.43 calories for each SD increase in the food's true caloric content. This trend-level Feedback effect on quadratic sensitivity is illustrated in Figure 7b by the relatively more linear nature of the solid, black and long-dash lines (i.e., the slopes of the lines are changing little as actual calories increase), as opposed to the more quadratic nature of the gray and short-dash lines (i.e., the slopes of the linear are becoming more shallow as actual calories increase). This finding suggests that those who received Feedback are more able (at a non-significant trend level) to distinguish among large caloric amounts than those who did not receive Feedback. There were no main effects of Education, BMI, or Hunger on quadratic sensitivity to caloric content, and there was not an effect of the interaction between Education and Feedback on quadratic sensitivity to caloric content. Dummy-coding the experimental predictors did not alter the pattern of findings, $p = 0.275$.

Aim 3: Distal Transfer Tasks

Distal Transfer Task: Threshold. The true average caloric content of the 6 presented foods in the Distal Transfer Task was 610.83. The average served caloric amount was 522.13, $p < 0.001$, $d = 6.64$, indicating that the average college-aged woman served an average amount of food that was significantly less than the true average caloric content, $t(232.34) = -8.60$, $p < 0.001$, $d = -1.13$ (see Table 3). In other words, on average, participants under-served food amount but over-estimated caloric content. Figures 8a and 8b depict threshold for and sensitivity to caloric content on average

(8a) and across all four conditions (8b). The average threshold is illustrated where the regression line crosses the Y-axis on Figure 8a, at approximately 522.13.

There was a trend-level, negative, small effect of Feedback on the average caloric serving, $p = 0.088$, $d = -0.23$, such that participants who received Feedback served 504.42 calories (i.e., where the solid, black line and the long-dash line cross the Y-axis on Figure 8b), while those who did not receive Feedback served 539.84 calories (i.e., where the gray and short-dash lines cross the Y-axis on Figure 8b). There were no main effects of Education, BMI, or Hunger on average caloric servings, and there was no effect of the interaction between Education and Feedback on average caloric servings. Dummy-coding the experimental predictors, Education and Feedback (with values of 1 for Education and Feedback), did not alter the pattern of findings, $p = 0.939$. In other words, as illustrated in Figure 8b, whether participants received Feedback was associated with the intercept, not whether participants received the combination of Education and Feedback versus the other three conditions.

Linear Sensitivity to Caloric Content. The average linear sensitivity to served caloric content was 265.59, $p < 0.001$, $d = 5.04$, indicating that participants showed considerable linear sensitivity and that caloric servings increased by 265.59 for each SD increase in the foods' specified caloric content. Average linear sensitivity is illustrated in Figure 8a by a steep, positive linear slope. Participants in all four conditions demonstrated linear sensitivity to caloric content, as evidenced by their positive linear slopes (see Figure 8b). There were no effects of Education, Feedback, their interaction, BMI, or Hunger on linear sensitivity to self-served caloric amounts. Dummy-coding the experimental predictors did not alter the pattern of findings, $p = 0.975$.

Quadratic Sensitivity to Caloric Content. The average quadratic sensitivity to caloric content was -5.79. The negative direction of this value indicated that sensitivity to actual caloric content decreased as caloric content increased, as expected. Nevertheless, reduction in sensitivity as caloric content increased was not reliably less than zero, $p = 0.182$, $d = -0.16$, which was unexpected.

This finding is illustrated by the largely linear trajectories in Figure 8b. There were no main effects of Education, Feedback, their interaction, BMI, or Hunger on quadratic sensitivity of self-served caloric amounts. Dummy-coding the experimental predictors, Education and Feedback, did not change the pattern of results, $p = 0.536$.¹

Ad Libitum Chocolate Consumption Task. Average chocolate consumption was 11.706 grams (SD = 0.995). A univariate generalized linear model revealed no main effects of Education, Feedback, or their interaction on chocolate consumption (see Figure 9). There was a moderate-to-large, positive effect of Hunger on consumption, such that participants who reported greater hunger ratings were likely to consume more chocolate than their less hungry peers, $F(1, 237) = 53.574$, $p < 0.001$, $\eta^2_p = 0.188$ (see Figure 10). There was no effect of BMI on chocolate consumption.

Discussion

Individuals' abilities to estimate the caloric content of food have been studied previously, but the vast majority of prior investigations of calorie estimation have examined only a single aspect of caloric perception (i.e., threshold), failed to evaluate trial-by-trial feedback, and included relatively few food stimuli. This study investigated whether college-aged women could improve their caloric estimation skills for unhealthy foods via caloric content education, trial-by-trial feedback, and their combination. The present study extends previous work by 1) relying on a more complex conceptual and analytic model to obtain simultaneous estimates of three aspects of caloric judgments; 2) including over one hundred unique, unhealthy food stimuli that vary in their food type and consistency (i.e., solid or amorphous); 3) evaluating whether an interactive caloric education component and trial-by-trial feedback have an immediate effect on caloric estimation (i.e., on the Calorie Estimation Task); and 4) examining whether Education and Feedback affect performance on

¹ Pearson correlations were used to evaluate whether parameter estimates converged across the first three tasks. See Appendix C for more information.

two subsequent calorie-estimation tasks (i.e., on the Proximal Transfer and Distal Transfer Tasks) and one consumption task (i.e., on the Ad Libitum Chocolate Consumption Task).

Calorie Estimation Task

During the Calorie Estimation Task, participants estimated the caloric content of 84 unhealthy foods on a scale that ranged from 0 calories to 1800 calories. Participants were randomly assigned either to complete or not to complete the Caloric Education Module prior to the Calorie Estimation Task. During the Calorie Estimation Task, they were randomly assigned either to receive or not to receive trial-by-trial feedback on the accuracy of their estimates.

Caloric Judgment of the Average Food (Threshold). The current study characterizes college-aged women's abilities to estimate caloric content in terms of three parameters. The first parameter, threshold (i.e., bias or the intercept), refers to the average caloric judgment of the average food. Evidence of underestimation of the true caloric content suggests that college-aged women are setting a low threshold, which may be maladaptive during food consumption, as college-aged women may not recognize how many calories they are consuming.

Participants' average caloric rating of the average food (575.26) was substantially less than the true average caloric content (757.20). College-aged women grossly underestimated the caloric content for the presented foods, as evidenced by the absolute difference between the average caloric rating and the true caloric content (181.94 calories), as well as the magnitude of this effect, $d = 5.59$. In other words, participants set a maladaptive threshold for caloric content, such that judged calories for the average food (i.e., the food at the intercept) were markedly less than actual calories. This result is consistent with prior work in which participants underestimated their caloric intake for fast-food meals, making several-hundred calorie errors (e.g., Brindal, Wilson, Mohr, & Wittert, 2012; Elbel, 2011; Kiszko, Martinez, Abrams, & Elbel, 2014). Moreover, this finding is consistent with the portion distortion hypothesis (Lucus, 2008). This theory states that individuals set too high a threshold for a reasonable portion size, such that the size of a single portion is overestimated, which

in turn represents underestimation of the caloric content of the portion. An analogous expectation could be stated for estimation of caloric content: participants set too low a threshold for estimated caloric content, such that the actual caloric content is underestimated. For example, a person might judge inaccurately that twenty chicken nuggets represent one portion equivalent to 600 calories (an *overestimate* of portion size but an *underestimate* of 350 calories). College-aged women's underestimation of caloric content could facilitate overconsumption, as they may estimate that they are eating fewer calories than they actually are.

Receiving feedback on each trial about the “true” caloric content of the judged food substantially reduced the discrepancy between the true and judged caloric content of the average food, $d = 1.45$. In particular, those who received Feedback judged the average food to be 94 calories lower than its true calories (662.76 vs 747.20), whereas those who did not receive Feedback judged the average food to be 269 calories less than its true calories (487.76 vs 747.20). This encouraging finding suggests that trial-by-trial feedback may be effective for reducing the bias in judges' thresholds when estimating caloric content, at least within a sample of college-aged women during a single training session involving photographed, unhealthy foods.

This effect of feedback on threshold during the Calorie Estimation Task can be contrasted with a parallel effort to use trial-by-trial feedback to enhance caloric estimation accuracy. Wohldmann (2015) relied on a three-step procedure to train participants to estimate caloric content. First, on a computer, all participants viewed photographed foods and estimated their caloric content. Second, participants were assigned to one of three conditions. Those in the “feedback” condition estimated the caloric content of the foods and received immediate feedback on the actual caloric content, participants in the “view-only” condition viewed each stimulus with its actual caloric content but did not make caloric estimates, and those in the “control” condition viewed foods without any caloric content and did not make caloric estimates. Finally, all participants estimated the caloric content for the same food stimuli, as well as new ones. Wohldmann demonstrated significant

improvement in caloric estimation for participants in the two experimental conditions, relative to the control condition. Notably, there were no significant differences between the “feedback” and “view-only” conditions in accuracy, suggesting that feedback did not enhance caloric estimation more than viewing foods and their caloric content simultaneously (Wohldmann, 2015). The present study extends this past work by relying on more complex conceptual and analytic models of caloric judgment, including more participants, presenting significantly more stimuli, and evaluating whether education potentiates the effect of feedback. Moreover, the current work demonstrates a robust effect of feedback from less frequent exposure to the actual caloric content of each stimulus. That is, the current study presented each food’s true caloric content one time, as opposed to once in each of four blocks during the training phase in Wohldmann’s work (2013; 2015). In the future, it will be important to compare the efficacy of our current instantiation of trial-by-trial feedback to that of a “view only” condition, in which participants do not generate caloric estimates but instead view the stimuli and their actual caloric content simultaneously.

The effect of feedback observed in the current study is consistent with the results of a single relevant study on portion-size estimation. Immediate feedback on the accuracy of judgments of the weight of specified portions effectively reduced error (e.g., Arroyo, de la Pera, Ansotegui, & Rocandio, 2007). Over a three-hour period, participants completed three training steps: 1) introduction to standard measurements (e.g., a cup, a slice) without using real foods; 2) direct visual estimation of portion size with real foods placed in containers and labeled with their actual weights; and 3) self-serving food amounts that represented “one portion,” after which the experimenter weighed the served amount and provided feedback on each estimate by comparing the amount served to the food’s actual weight. One week later, participants returned to the lab to assess their ability to estimate portion sizes of new foods. Average percent error of the weight of the self-served “portion” of food decreased by 13% over time, demonstrating that portion size estimation improved (Arroyo et al., 2007). The current work extends this prior work by evaluating an analogous question using

caloric content, presenting significantly more stimuli, and requiring significantly less time. The effect of feedback reported by Arroyo and colleagues (2007) was achieved after three hours, relative to the one-hour duration of this study. Additionally, the current work is much more easily disseminated, as the present study capitalizes on the benefits of relying on an online platform, as opposed to working with participants in person using real foods. Further, Arroyo et al. (2007) investigated the effect of feedback on portion size estimation within a sample of food experts (i.e., dieticians), as opposed to college-aged women, a less expert and presumably more representative sample.

Overall, trial-by-trial feedback may serve as a worthwhile first step to reducing the bias in caloric estimation – or, as it is known more colloquially with respect to portion-size estimation in the literature, portion distortion. Nonetheless, future work remains. Forthcoming research should evaluate whether the magnitude of the feedback effect can be augmented by providing more trials, a greater number of stimuli, and multiple training sessions. Additionally, future work should evaluate the utility of a “view only” condition, in which participants do not generate caloric estimates but instead view the actual caloric content of the stimuli, relative to the current version of trial-by-trial feedback. The duration of the feedback effect also is unknown (e.g., one day, one week, or one month later).

Although the Caloric Education module was designed to be interactive, engaging, and thorough, completion of this module did not significantly reduce the bias in the average threshold for estimated caloric content. This finding is not entirely surprising, since the informational approach of menu labeling appears inadequate to improve caloric estimation skills (Sinclair, Cooper, & Mansfield, 2014). However, other engaging approaches, such as the “think aloud method” investigated by Holmstrup et al. (2013) and The Health Management Resources Calorie System[®] developed by Martin et al. (2007), suggest that explicit education on how to estimate caloric content

can improve caloric estimation abilities. Holmstrup et al. (2013) asked participants to estimate audibly the caloric content of various components of a meal and to add them together to make a total estimate, while Martin et al. (2007) educated participants on the caloric content of specific foods (e.g., apple) and encouraged them to rely on this knowledge to estimate the caloric content of new, similar foods (e.g., banana).

Future versions of the Caloric Education Module might ensure that participants learn the caloric contents for specific foods in specific portion sizes, so that they can apply this information to novel foods, similar to the work of Martin et al. (2007). Alternatively, participants could estimate the caloric content of pieces of food or meals, akin to Holmstrup et al. (2013). For foods that are considered a single unit, participants could be taught to estimate the caloric content of one part of the food (e.g., a quarter of a portion of macaroni and cheese) and multiply by four. This lesson would be well-situated following the lesson about the influence of portion size on caloric content in the current version of the Caloric Education Module. The Education module might also be enhanced by including several more practice trials, in which participants categorize presented foods as high in added fat, high in added sugar, or high in added fat and high added sugar food. Practicing this skill may improve caloric estimation, since the macronutrients contained in food directly influence its caloric content.

BMI was unrelated to threshold during the Calorie Training Task, as expected. Several studies have evaluated the association of BMI and caloric estimation abilities by correlating individuals' BMI with the accuracy of their caloric estimates for self-selected meals. For instance, a previous meta-analysis reported a small-to-moderate association between high BMI and greater under-estimation of the caloric content across various meal sizes (Livingstone & Black, 2003). Concern has been raised about the validity of this non-standardized approach, as it does not control the size of the self-selected meals (Chandon & Wansink, 2007). When standardized stimuli were

presented, more recent work has demonstrated that BMI is unrelated to overall accuracy of calorie estimation (e.g., Speakman, Walker, Walker, & Jackson, 2005).

It was somewhat surprising that hunger was unrelated to caloric content perception, because hunger has been linked to portion size misperception, such that relatively hungrier individuals judged portions to be significantly larger compared to the judgments of their more satiated peers (e.g., Brunstrom, Rogers, Pothos, Calitri, & Tapper, 2008; Ordabayeva & Chandon, 2016). On the basis of this work, we had anticipated that hungrier participants would show more underestimation than their peers (i.e., that they would show greater underestimation of the caloric content of the average food), but this effect did not emerge. Hunger may have been unrelated in the current work, however, because participants were asked to make caloric estimates, as opposed to judgments of portion size.

Linear Sensitivity to Caloric Content. Unlike almost all prior work (with the exception of Chandon and Wansink (2007)), this study broadens our conceptualization of caloric perception to encompass both bias- and sensitivity-like components. Linear sensitivity to caloric content refers to one's ability to distinguish between various amounts of calories and is indicated by the slope of the function linking true and judged calories at the intercept (i.e., at the food with average caloric content). Weak linear sensitivity to caloric content, like underestimation of the caloric content of the average food, could foster excessive food intake.

Participants' average linear sensitivity to caloric content was considerable, $d = 2.65$. For every one SD increase in the foods' true caloric content (equivalent to 435 calories), participants increased their caloric estimates by 220.94 calories, clearly demonstrating their ability to distinguish among various amounts of calories, on average. As an example, college-aged women correctly estimated that three fish filet sandwiches contained fewer calories than six slices of pepperoni pizza, on average. This finding is promising, because being able to distinguish the caloric content of higher- versus lower-calorie foods could curtail excess food consumption.

Receiving feedback on each trial about the true caloric content of the judged food markedly increased linear sensitivity, $d = 1.29$. Those who received Feedback increased their estimates considerably, by 260.11 calories for each SD increase in the foods' actual caloric content, whereas those who did not receive Feedback only increased their estimates by 181.77 calories per SD. In other words, those who received Feedback showed steeper slopes relating true and judged calories, which reflected greater linear sensitivity, than their peers who did not receive Feedback, whose slopes were shallower.

Taken together with the effect of Feedback on threshold, these encouraging findings provide initial evidence that trial-by-trial feedback not only diminishes bias in the average caloric rating for the average food, but also enhances linear sensitivity to caloric content, which may promote less biased and more sensitive judgments of the caloric content for various foods during eating episodes. Future work should evaluate the duration of the feedback effect, as well as the extent to which it could be potentiated by increasing feedback dose (e.g., number of trials, stimuli, or training sessions). Additionally, future work should investigate the impact of a “view only” condition, relative to a trial-by-trial feedback condition, on linear sensitivity to caloric content, given the findings of Wohldmann (2013, 2015). There was neither a main effect of Education, nor a multiplicative effect of Education and Feedback, on linear sensitivity. Given that the effect of Caloric Education on linear sensitivity to caloric content has never been explored, this null finding is neither consistent nor inconsistent with prior work. In the context of the parallel null finding for threshold, however, it is less surprising that Education had no impact on linear sensitivity, as well. Future enhancements to the Caloric Education Module, as described earlier, might change this pattern of results, however.

Moreover, neither BMI nor hunger correlated with average linear sensitivity during the Calorie Estimation Task. This was expected, as past work has demonstrated that BMI was unrelated to average linear sensitivity to portion size when participants judged standardized, rather than self-selected, foods (Chandon & Wansink, 2007; Rizk & Treat, 2015). In combination with the threshold

results, we can conclude that caloric perception more generally appears to be unrelated to BMI and hunger when using more complex conceptual and analytic models that incorporate bias- and sensitivity-like parameters.

Changing Sensitivity as Caloric Content Increases. The final parameter in our three-parameter model of caloric judgments is the change in sensitivity as caloric content increases (or quadratic sensitivity). This parameter indexes the degree of change in the slope of the observed function as actual calories increase. Weaker sensitivity to caloric content as actual caloric content increases may be particularly concerning for excess consumption, as college-aged women may not realize how many more calories are contained in increasing amounts of food.

The average quadratic sensitivity to caloric content was -18.74, which indicated that sensitivity to actual caloric content decreased as caloric content increased. That is, the change in the rate of change of judged calories *declined* as true caloric content increased, as expected. However, the observed reduction in sensitivity as caloric content increased was not significantly less than zero, contrary to expectations (i.e., the average function relating true and judged calories was better described statistically as linear, rather than quadratic). Nonetheless, the quadratic parameter was retained in the model because substantial variability in its estimate emerged across participants, indicating that some participants showed more linear functions, whereas others showed more quadratic functions. The linear nature of the average association between true and judged calories is inconsistent with past work investigating sensitivity to portion size (Chandon & Wansink, 2007; Rizk & Treat, 2015). Chandon and Wansink (2007), for example, found evidence that sensitivity declined as calories increased when using foods that contained a similar range of calories as the stimuli included in the present study. In this sense, the linear nature of the function in this study is a failure to replicate their prior work. Importantly, however, this result is behaviorally adaptive, suggesting that college-aged women were able to perceive the extent to which actual calories increased in the presented foods, even as the number of presented calories grew large.

A trend-level, small effect of Education on quadratic sensitivity to caloric content was observed. Participants who received Education, relative to their peers, showed more linear functions linking true and judged calories (i.e., reduced quadratic sensitivity). This finding suggests that those who received Education were more able (at a non-significant trend level) to distinguish among large caloric amounts than those who did not receive Education. Given that this result is small and unreliable, however, it should be interpreted with caution. Neither BMI nor Hunger was associated with quadratic sensitivity, but future research should re-examine questions regarding predictors of quadratic sensitivity with more caloric foods.

Proximal Transfer Task

During the Proximal Transfer Task, participants estimated the caloric content of 25 novel, unhealthy foods on the same caloric scale that ranged from 0 calories to 1800 calories; no feedback on accuracy estimates was provided.

Caloric Judgment of the Average Food (Threshold). On average, participants' caloric rating of the average food (641.72) was substantially less than the true average caloric content (749.8). College-aged women markedly underestimated the average caloric content for the average presented stimulus, $d = 7.29$, and the absolute difference between the average caloric rating and the true caloric content (127.08) is large. Interestingly, the threshold for caloric content, such that judged calories at the intercept were less than actual calories, exhibited in this task was more maladaptive, $d = 7.29$, than the threshold set during the Calorie Estimation Task, $d = 5.59$, which highlights the robustness of college-aged women's underestimation of caloric content across both tasks. Setting a biased threshold for calorie estimation is also consistent with prior work. For instance, Geier and Rozin (2009) demonstrated that participants grossly underestimated the caloric content of two meals that varied in portion size; participants' underestimates ranged from 262 to 315 calories (Geier & Rozin, 2009). As noted earlier, this finding is also consistent with the portion distortion hypothesis, which predicts underestimation of the caloric content for various portions (Lucus, 2008). Given that

participants showed a biased threshold during the first task (i.e., the Calorie Estimation Task), it is reasonable to expect that this finding would generalize to the following task (i.e., the Proximal Transfer Task).

Participants who received feedback on each trial about the true caloric content of the judged food made less biased caloric estimates, on average. More specifically, participants who received Feedback rated the average caloric food to be 44 calories lower than its true calories (705.36 vs 749.80), whereas those who did not receive Feedback judged the average food to be 171 calories less than its true calories (578.08 vs 749.80). Therefore, those who received Feedback made estimates that were substantially closer to the true caloric content of the average presented food. Notably, the effect of Feedback on threshold during the Proximal Transfer Task, $d = 0.87$, was strong but weaker than during the Calorie Estimation Task, $d = 1.45$, which is not surprising given that the Education and Feedback effects were more distal for this task. The altered replication of the Feedback effect on threshold in the current task is quite promising, however, as it further supports the potential utility of trial-by-trial feedback in reducing caloric estimation bias. Given this, future work should evaluate the effects of feedback dose and duration, as described previously.

As was observed for the Calorie Estimation Task, there were no other effects on participants' caloric rating of the average food during the Proximal Transfer Task. The Proximal Transfer Task was developed to be almost identical to the Calorie Estimation Task, apart from the absence of feedback, the more distal nature of the educational module, and the smaller number of trials and food stimuli presented. Therefore, it is not surprising that a similar pattern of results emerged.

Linear Sensitivity to Caloric Content. On average, participants' linear sensitivity to caloric content was sizeable during the Proximal Transfer Task. For every SD increase in the foods' true caloric content (equivalent to 463 calories), participants' increased their caloric estimates by 288.41 calories. Participants clearly demonstrated their ability to distinguish among various amounts of calories, on average, $d = 3.53$. The substantial size of this effect reflects college-aged women's

abilities to differentiate between varying caloric amounts. Attentiveness to increasing caloric content potentially could reduce unwarranted food consumption, because college-aged women may better note how many calories are in different foods when eating.

Importantly, participants also showed considerable average linear sensitivity to caloric content during the Calorie Estimation Task, $d = 2.65$. Relative to the Calorie Estimation Task, linear sensitivity to caloric content was stronger during the Proximal Task, suggesting increased awareness of varying caloric content in the more distal of the two tasks. This altered replication is encouraging; despite participants' biased threshold on average, they displayed awareness of the actual increasing caloric content per their caloric estimates across more than one task. Overall, the robustness of young women's linear sensitivity across both tasks highlights the utility of characterizing caloric content perception of unhealthy foods using these three parameters, rather than focusing exclusively on threshold-like characterizations of caloric judgments.

Receiving feedback on each trial about the "true" caloric content of the judged food substantially enhanced linear sensitivity, on average, $d = 0.76$. In particular, college-aged women who received Feedback increased their average caloric rating by 321.16 calories per SD, whereas those who did not receive Feedback only increased their average caloric rating by 224.77 calories per SD (a difference of 93.39 calories). In other words, those who received Feedback showed steeper slopes linking true and judged calories, which reflected a greater ability to distinguish among various caloric amounts, relative to their peers who did not receive Feedback, whose slopes were shallower. Once more, this finding increases one's confidence in the potential impact of trial-by-trial feedback, not only on threshold but also on linear sensitivity. Further, the effect of Feedback on average linear sensitivity was also revealed from the Calorie Training Task, $d = 1.29$. It is not surprising that the effect of Feedback on linear sensitivity was weaker during the Proximal Transfer Task, especially given the absence of trial-by-trial feedback during this task. More importantly, the magnitude of the Feedback effect on sensitivity remained large in the Proximal Transfer Task. Consistent with the

pattern of results from the Calorie Training Task, there were no other effects on participants' average linear sensitivity during the Proximal Transfer Task.

Changing Sensitivity as Caloric Content Increases. The average quadratic sensitivity to caloric content was -35.91 , $d = -0.45$. The negative direction of this value indicated that sensitivity to actual caloric content decreased as caloric content increased, as expected. However, reduction in sensitivity as caloric content increased was not reliably less than zero, contrary to expectations. In other words, participants did not demonstrate reduced caloric-content sensitivity as actual caloric content increased. The average lack of reduction in quadratic sensitivity may be helpful in the real world, because college-aged women may be less likely to overeat when confronted with large portion sizes. A similar result, albeit of a weaker magnitude, emerged from the Calorie Estimation Task, $d = -0.24$. An inspection of the observed functions at an individual differences level evidenced clear variability in quadratic sensitivity to caloric content across participants. Such variability supports inclusion of this parameter when estimating caloric perception. Therefore, future work should continue to investigate changes in sensitivity as caloric content increases, especially since the current study used foods that were comparably caloric as the foods used in prior work (Chandon & Wansink, 2007; Rizk & Treat, 2015).

Distal Transfer Tasks

Following the Proximal Transfer Task, participants completed two, more distal tasks that were designed to be increasingly ecologically valid: the Distal Transfer Task and the Ad Libitum Chocolate Consumption Task. During the Distal Transfer Task, participants self-served different caloric amounts of six, real, processed foods. Participants were presented with two trays that contained 6 bowls each. On each tray, three of the bowls contained a high-fat food, a high-sugar food, and a high-fat, high-sugar food. Three bowls were empty and labeled with a specific caloric amount. For both trays, participants self-served the specified number of calories from the full bowl to the empty bowl for each food. During the Ad Libitum Chocolate Consumption Task, participants

were invited to consume as much as or as little chocolate as they liked from a bowl of M&Ms for a five-minute period.

Distal Transfer Task

Average Served Caloric Amount (Threshold). Although the true average caloric content of the six presented foods in the Distal Transfer Task was 610.83, the average served caloric amount was 522.13. That is, the average college-aged woman served an average amount of food that was substantially *less* than the true average caloric content, $d = 6.64$. In this case, participants essentially *overestimated* how many calories they served: they served 522.13 calories believing their servings contained 610 calories (on average). In other words, on average, participants under-served food amount but over-estimated caloric content. Setting a threshold that is too *high* for estimated caloric content, such that the actual caloric content is overestimated, is inconsistent with the results from earlier tasks.

Although this finding is inconsistent with expectations, it is important to note that the current finding is behaviorally adaptive. It suggests that college-aged women may perceive they are serving more calories than they actually are. In contrast, for example, it would have been concerning if college-aged women had served 1000 calories, which would indicate that they perceived what they served to contain 610 calories. In this case, college-aged women would have served too *many* calories, as they would have perceived the caloric content to be *lower* than it actually was, a clearly maladaptive effect.

Aspects of the procedure may have influenced the current findings. For example, it would be of interest to determine whether the same effect emerges if participants are asked to remove food from a full bowl until they reach their estimate of a specified caloric amount, as different processes may underlie filling an empty bowl and emptying a full bowl. The primary dependent variable would remain the caloric content of the self-served amount in this new version of the task, and similar findings would enhance our confidence in the conclusions drawn from the current work. Viewing

stimuli from a single versus multiple perspectives may have differentially influenced threshold estimates across tasks. When the stimuli were presented from a single perspective (as in the prior two tasks), the threshold estimates were maladaptive, whereas when participants were allowed to view the stimuli from multiple perspectives (as in the current task), the threshold estimates were adaptive. To bridge this gap in the current online training program, it may be helpful for participants to view the same photographed food from multiple perspectives on the computer. The training program could present multiple perspectives of the same food with various caloric content using either videos of the stimuli from several angles or multiple photographs of the same food from different perspectives.

There was a trend-level, negative, small effect of Feedback on the average caloric serving, such that participants who received Feedback served 504.42 calories, while those who did not receive Feedback served 539.84 calories. In other words, participants who received Feedback became *more* biased during this task, $d = -0.23$, $p = 0.087$. However, such an effect of Feedback in the real-world would be behaviorally adaptive; it appears that exposure to Feedback may have encouraged participants to become more conservative in their served caloric amounts, which could limit extra caloric intake. Notably, this trend-level effect of trial-by-trial feedback has been demonstrated in the portion size literature, albeit not when participants are judging caloric content and not when viewing photographed foods. Via web-based training, participants controlled the angle(s) at which portions were viewed, estimated portions for specified foods, and were provided immediate feedback on their portion-size estimation accuracy. This viewing experience, in combination with feedback on judgments, shifted accuracy from under- to overestimation (Riley et al., 2007), consistent with the direction of the trend-level effect of Feedback during the Distal Transfer Task. As already noted, it may prove fruitful to allow participants to engage in a similar procedure with multi-perspective photographs of the same amount of food on the computer screen, prior to completing a task in the “real world.”

Linear Sensitivity to Served Caloric Content. The average linear sensitivity to served caloric content on the first Distal Task was considerable. Participants increased their caloric servings by 265.59 for each SD increase in the foods' specified caloric content. Relative to the other two tasks, participants demonstrated stronger linear sensitivity to caloric content. The magnitude of this effect was weakest for the Calorie Estimation Task, $d = 2.65$, and strongest for the Distal Transfer Task, $d = 5.04$. Overall, the substantial linear sensitivity college-aged women demonstrated across tasks is promising, since attentiveness to increasing caloric amounts could reduce excess food consumption.

However, neither Feedback nor Education during or prior to the initial training task influenced linear sensitivity to served caloric content on the first distal task. Thus, the strong effects of Feedback on linear sensitivity in the earlier tasks did not transfer to a more distal task involving judgments about real foods. This poses a significant challenge to the real-world utility of the current online approach. In order to bridge the gap between caloric estimation of photographed foods presented on a computer screen and real-world foods, several avenues should be explored. One possibility, of course, would be to explore the effects of explicitly training participants how to estimate the caloric content of real foods, perhaps using models of real food as examples. Such research could be analogous to the work of Godwin, Chambers, & Cleveland (2004) or Byrd-Bredbenner & Schwartz (2004), as both research teams evaluated the efficacy of food models for improving portion-size perception. However, we are invested in providing all of the training online, to enhance the disseminability of the training procedure. Instead, therefore, we might want to implement online procedures that allow images to be viewed from multiple perspectives. For example, future versions of trial-by-trial feedback could include a feature that allows participants to control the angle(s) at which foods are viewed online, while also providing immediate feedback on their caloric estimation accuracy, analogous to the work of Riley et al. (2007). Alternatively, one could imagine augmenting the Caloric Education Module to include video content that demonstrates multiple perspectives of the same food or uses foods models. This would allow participants to view

foods from multiple perspectives online without necessitating the use of food models or other objects in the “real world”.

Future versions of the Caloric Education Module might include information on the explicit caloric content of certain foods (e.g., donut) and encourage participants to rely on this knowledge to estimate the caloric content of new, similar foods (e.g., pastry), similar to the work of Martin et al. (2007). Along these lines, as already noted, it also may be effective for future Caloric Education Modules to include a feature that allows participants to view several, single-perspective photographs of the same food across various portion sizes along with the foods’ corresponding caloric content. In this way, the influence of amount on caloric content may become more salient. As another example, it may be fruitful to provide an explanation of why each food contains its specified caloric content (e.g., “True Calories = 665 because this food is high in added fat and high in added sugar.”). It may be that combining immediate feedback with simultaneous education enhances caloric estimation, but this question needs to be explored. Capitalizing on video content might also enhance the Caloric Education Module, particularly if the video includes information about the caloric content of foods to which college-aged women are regularly exposed (e.g., foods available to them in campus cafeterias). Using this strategy may enhance participants’ engagement with the material. Given the lack of distal transfer observed in the current work, it will be critical for future work to explore these and other possibilities for enhancing sensitivity to the caloric content of varying amounts of “real” food.

Changing Sensitivity as Caloric Content Increases. The average quadratic sensitivity to caloric content was -5.79, indicating that sensitivity to actual caloric content decreased as caloric content increased, as expected. Nevertheless, reduction in sensitivity as caloric content increased was not reliably less than zero, as in the two prior tasks. The lack of reduction in quadratic sensitivity may be advantageous, because it may promote more accurate caloric perception. Alternatively, it

may reflect the exclusion of foods with more substantial caloric content, as the most-caloric serving requested in the first distal task was 1050 calories.

Overall, the current work extends prior work by investigating the effects of trial-by-trial feedback and caloric education on a more ecologically valid task, while estimating three parameters of caloric perception, rather than only one (i.e., threshold). Moreover, the current work controls the included individual foods (as opposed to presenting few fast-food meals) and the specified caloric amounts across participants, allowing for greater confidence in the results of this work.

Ad Libitum Chocolate Consumption

There were no effects of Education and Feedback on consumption. These null findings imply that at least the current instantiation of these online training strategies is inadequate to modify consumption of a real food. Education and Feedback did not significantly influence caloric perception during the Distal Transfer Task either. In other words, the effectiveness of the current instantiation of the Feedback manipulation may be limited to judgments regarding photographed food stimuli for a brief period of time in the lab, stressing the need to pursue potential augmentations to the training strategies, as described previously.

There was a moderate-to-large, positive effect of Hunger on ad libitum chocolate consumption, such that participants who reported greater hunger consumed more chocolate than their less hungry peers. This finding is not surprising, given that a body of literature establishes hunger as with a positive correlate of consumption (see Herman & Polivy, 2005 for a review; Shimizu, Payne, & Wansink, 2010). Further, there was no effect of BMI on chocolate consumption. There is not compelling evidence relating BMI to chocolate consumption. For instance, via data from the 2003-2006 National Health and Nutrition Examination Survey, increased frequency of “candy consumption,” which was defined as the frequency of the consumption of chocolate and high-added sugar candy over the past 12 months, was not associated with adiposity or cardiovascular risk factors (Murphy, Barraj, Bi, & Stettler, 2013).

Strengths and Limitations

The current work may be most limited by the duration of the training tasks, as participants received Education or Feedback for only one task, which lasted an average of 14 minutes. Receipt of Feedback modified threshold and linear sensitivity for caloric content in adaptive directions only on the training and proximal tasks. Perhaps exposure to more Feedback trials, more lessons in the Education Module, or multiple sessions of caloric estimation training would move performance on the two distal tasks in adaptive directions as well, however. This study is also limited by its use of photographed stimuli, though there were over one hundred stimuli included, and relatively few real foods ($n = 9$). Perhaps Education and Feedback might have exerted more influence on the distal tasks if participants were trained using real foods, although such work would not be easily disseminable, which was a primary criterion when designing our training program. Additionally, the duration of the observed effects on the proximal task (e.g., one day, one week, or one month) and the efficacy of allowing participants to view the same food from multiple perspectives remain unknown.

We intentionally evaluated estimation of caloric content among college-aged women, given that the prevalence of normative concern about weight gain and caloric content is high in college-aged women (e.g., Neighbors & Sobal, 2007). However, caloric estimation is relevant to all people. Thus, the current findings are constrained in their generalizability, as there was no variation in gender (i.e., absence of males) and little variation in age (i.e., only women ages 18-24 years were invited to participate). Although there was some variation in BMI (17.6% overweight and 8.2% obese), future research should investigate the generalizability of the current pattern of results to samples of women with a greater percentage of overweight and obesity, as well as to samples endorsing eating-and weight-related difficulties (e.g., dietary disinhibition and restraint).

Despite these limitations, the current work has several noteworthy strengths. First, this study is the first to evaluate whether college-aged women could be trained to improve their caloric estimation skills for unhealthy foods via online caloric content education, trial-by-trial feedback, and

their combination. Very little prior work has explored the effect of an online caloric education module to enhance caloric estimation or investigated the effect of trial-by-trial feedback on caloric estimation. Finally, this study is the first of its kind to provide trial-by-trial feedback on over 100 unique trials with over 100 hundred subjects.

Second, this is the first study to evaluate these empirical questions using a three-parameter conceptual and analytic model to characterize caloric perception. Traditionally, researchers in this area have focused only on a single threshold-like parameter when characterizing caloric perception. More recently, Chandon and Wansink (2007) demonstrated the utility of distinguishing threshold- and sensitivity-like aspects of caloric perception. Our modeling approach further distinguishes two aspects of sensitivity: linear sensitivity (at the intercept) and quadratic sensitivity. We also rely on mixed-effects modeling techniques to obtain separate, but simultaneous, estimates of the three caloric-perception parameters of interest in our model. Further, we were consistent across our theoretical, analytical, and measurement approaches to this work. That is, we carefully mapped our analytic strategy and study design to the theoretical constructs of interest, three aspects of caloric content perception.

Third, this study utilized a large and rigorously developed stimulus set of unhealthy foods. This set included over 115 foods that were each photographed on the same white plate with utensils on a placement, to provide sizing guides. These stimuli were particularly unique, as they varied in food type (i.e., high added fat, high added sugar, or high added fat and added sugar), consistency (i.e., solid or amorphous), and caloric content.

Fourth, the Caloric Education Module was engaging, interactive, and comprehensive in its content. Each of the seven lessons included in the Caloric Education Module directly informed college-aged women about how to estimate caloric content. Participants read about each of these topics, answered several questions about them, and completed practice trials in order to engage their attention, to check their understanding, and to reinforce their understanding of this information. Fifth,

study tasks were designed to maximize internal validity to the extent possible, while gradually increasing ecological validity in the more distal tasks. Sixth, inclusion of real foods in the Distal Transfer Task extends prior work investigating sensitivity to food characteristics non-negligibly. Prior work has evaluated sensitivity to caloric content using fast-food meals only, as opposed to a variety of foods that vary across added fat and added sugar dimensions. In sum, this work represents a significant step toward better understanding college-aged women's caloric-content perception of unhealthy foods.

Conclusions and Future Directions

Conclusions. Several conclusions about normative caloric-content perception can be drawn from this study, each of which has implications for real-world food consumption. First, college-aged women set too low a threshold for caloric estimates across the first two tasks, the Calorie Estimation Task and the Proximal Transfer Task. College-aged women's underestimation of caloric content could facilitate overconsumption, as they may estimate that they are eating fewer calories than they actually are. Second, college-aged women demonstrated substantial linear sensitivity to caloric content across the first three tasks (i.e., all but the consumption task). This finding is encouraging, because although participants set a biased threshold on average, they displayed awareness of the actual increasing caloric content according to their caloric estimates. Attentiveness to increasing caloric amounts could reduce excess food consumption. Third, college-aged women did not show reduced sensitivity to caloric content as caloric content increased (i.e., quadratic sensitivity to caloric content). This suggests that college-aged women were able to perceive the extent to which actual calories increased in the presented foods, which is behaviorally adaptive. Overall, therefore, college-aged women's normative caloric-content perception demonstrated in the current study is discouraging in terms of their average biased threshold but encouraging in terms of their average marked linear sensitivity and non-biased quadratic sensitivity.

In terms of Feedback, this study demonstrated that trial-by-trial feedback was effective for improving biased threshold and linear sensitivity to caloric content on two tasks (i.e., Calorie Estimation Task and Proximal Transfer Task). The large magnitude of these effects is encouraging, as it suggests that two aspects of caloric content perception can be reduced substantially via a single training session. Further, the altered replicability of the Feedback effect across the two tasks increases one's confidence in the potential efficacy of trial-by-trial feedback, not only for threshold but also for linear sensitivity. The duration of the Feedback effect remains unknown, however, and this effect does not transfer to the two distal tasks. Such an online intervention has the potential to be easily disseminated and implemented across a variety of contexts. For instance, one could imagine a nutritionist or dietician using an online, trial-by-trial feedback program when working with a client. In sum, trial-by-trial feedback appears to be a promising modification strategy.

In contrast, completing the Caloric Education Module did not significantly improve threshold, linear sensitivity, or quadratic sensitivity to caloric content on the Calorie Estimation Task or the Proximal Transfer Task. Several ways to augment the Caloric Education Module have been suggested, such as explicitly juxtaposing different food amounts with their varying caloric content, teaching participants the caloric content of one specific food as a reference for other foods, allowing participants to view multiple perspectives of the same food, and including video content. However, given the lack of significant results in the current work, it seems more advantageous to pursue efforts focused on better understanding the efficacy of trial-by-trial feedback, at least initially.

Finally, Feedback and Education had no effect on both Distal Transfer Tasks. These non-significant findings imply that these particular online strategies were not enough to increase the accuracy of specific caloric servings or to modify consumption of a real food. The effectiveness of Feedback may be limited to an online, computer-based program using photographed food stimuli. It should be emphasized that participants were never explicitly trained on how to estimate the caloric content for real foods that could be viewed from multiple perspectives, only photographed, single-

perspective versions of them. Perhaps this approach could help to bridge the gap between single-perspective and multi-perspective calorie estimation for unhealthy food in future research efforts.

Future Directions. Several directions for future research have already been mentioned. Foremost is the need to determine which modified strategies lead to the most robust effects of enhanced caloric estimation in the lab. Specifically, future work should continue to evaluate the efficacy of trial-by-trial feedback via more trials, a greater number of stimuli, and across multiple training sessions. It is essential to modify or augment the trial-by-trial feedback and education procedures to influence behavior with real foods in the lab before broadly disseminating these online strategies. It may be worthwhile to enhance the Caloric Education Module and trial-by-trial feedback using features that allow participants to vary the size or angle(s) of the presented foods.

In the future, it will be important to evaluate whether engagement and acquired knowledge during the Caloric Education Module are related to calorie estimation performance on subsequent tasks. Since the Education module was self-paced and contained practice trials, it is possible that engagement in the module positively influenced the caloric estimation performance among those who completed the module. It is possible to begin to examine this question in the current work. Two proxies for engagement – average length of time spent on the module and accuracy on the practice trials – were examined as potential predictors of threshold, linear sensitivity, and quadratic sensitivity during the Calorie Estimation Task, as an initial step in this direction. The average reading time ($M = 14.16$ min, $SD = 4.90$ min) was unrelated to threshold ($r = -0.068$, $p = 0.437$), linear sensitivity ($r = -0.053$, $p = 0.575$), or quadratic sensitivity ($r = 0.032$, $p = 0.733$), however. Performance on the six practice trials was near ceiling ($M = 5.64$, $SD = 0.55$), precluding examination of its link with caloric perception performance. Overall, therefore, no evidence emerged that the Education module reduced bias among those who displayed greater engagement with the module. Future work should include more difficult practice trials to ascertain individual differences in acquired knowledge, as well as other direct indicators of active engagement in the module other than average reading time.

It is also critical to consider college-aged women's perceptions of the feasibility and acceptability of these online training strategies. In the current work, college-aged women reported that both the Caloric Education Module and trial-by-trial Feedback were markedly effective and helpful (see Figure 11), with average ratings over 3.7 on a 5.0-point scale. These very preliminary data suggest that this population might be responsive to longer, more intensive online training experiences. Future work should continue to develop and to test enhancements of these training strategies in order to strengthen their effectiveness. Although much remains to be understood, this rigorous work answers several initial empirical questions about the effects of caloric education, trial-by-trial feedback and their interaction on college-aged women's abilities to estimate caloric content.

Table 1. Mixed- Effects Modeling Results for Calorie Estimation Task

Parameter	Estimate	Standard Error	df	t value	p value	d value
Intercept	575.26	19.02	117.00	30.24	<0.001	5.59
TrueCal	220.94	17.71	88.30	12.48	<0.001	2.65
Education	5.88	8.26	218.00	0.71	0.477	0.10
Feedback	87.50	8.19	218.00	10.68	<0.001	1.45
BMI	4.58	8.21	218.10	0.56	0.577	0.08
Hunger	2.22	8.28	218.00	0.27	0.788	0.04
TrueCal_sq	-18.74	17.33	81.30	-1.08	0.283	-0.24
Education*Feedback	-5.99	8.19	218.00	-0.73	0.465	-0.10
TrueCal*Education	0.04	4.12	218.80	0.01	0.992	0.001
TrueCal*Feedback	39.17	4.09	218.80	9.57	<0.001	1.29
TrueCal*BMI	0.91	4.11	219.10	0.22	0.824	0.03
TrueCal*Hunger	0.30	4.14	218.80	0.07	0.942	0.01
Education*TrueCal_sq	3.64	1.96	561.10	1.86	0.064	0.16
Feedback*TrueCal_sq	-3.15	1.94	560.60	-1.62	0.106	-0.14
BMI*TrueCal_sq	1.05	1.95	563.30	0.54	0.593	0.05
Hunger*TrueCal_sq	2.03	1.97	561.40	1.03	0.302	0.09
TrueCal*Edu*Fdbck	-6.13	4.09	218.80	-1.50	0.136	-0.20
TrueCal_sq*Edu*Fdbck	1.81	1.95	560.50	0.93	0.352	0.08

Note. TrueCal = Linear Sensitivity. TrueCal_Sq = Quadratic Sensitivity. BMI = Body Mass Index (standardized). Edu = Education (effect coded). Fdbck = Trial-by-trial feedback (effect coded). Significant effects are bolded.

Table 2. Mixed-Effects Modeling Results for Proximal Transfer Task

Parameter	Estimate	Standard Error	df	t value	p value	d value
Intercept	641.72	34.916	25.40	18.38	<0.001	7.29
TrueCal	288.41	34.145	22.90	8.45	<0.001	3.53
Education	-4.34	9.742	223.10	-0.45	0.657	-0.06
Feedback	63.64	9.764	223.10	6.52	<0.001	0.87
BMI	6.66	9.861	223.10	0.68	0.500	0.09
Hunger	2.40	9.815	223.10	0.25	0.807	0.03
TrueCal_sq	-35.91	33.839	22.00	-1.06	0.300	-0.45
Education*Feedback	-10.80	9.761	223.10	-1.11	0.269	-0.15
TrueCal*Education	-2.38	5.744	226.40	-0.41	0.679	-0.05
TrueCal*Feedback	32.75	5.757	226.40	5.69	<0.001	0.76
TrueCal*BMI	4.54	5.813	226.30	0.78	0.435	0.10
TrueCal*Hunger	6.27	5.787	226.40	1.08	0.279	0.14
Education*TrueCal_sq	-4.45	3.266	738.70	-1.36	0.173	-0.10
Feedback*TrueCal_sq	5.48	3.274	738.60	1.67	0.094	0.12
BMI*TrueCal_sq	-2.59	3.304	737.30	-0.78	0.433	-0.06
Hunger*TrueCal_sq	2.31	3.290	738.30	0.70	0.483	0.05
TrueCal*Edu*Fdbck	-6.82	5.755	226.40	-1.18	0.237	-0.15
TrueCal_sq*Edu*Fdbck	3.57	3.273	738.80	1.09	0.275	0.08

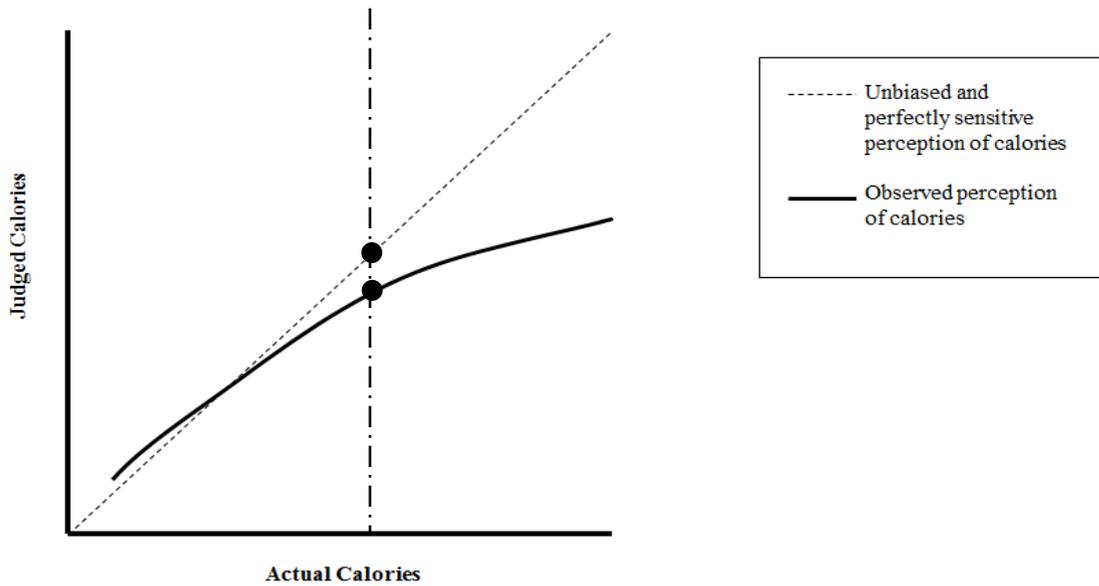
Note. TrueCal = Linear Sensitivity. TrueCal_Sq = Quadratic Sensitivity. BMI = Body Mass Index (standardized). Edu = Education (effect coded). Fdbck = Trial-by-trial feedback (effect coded). Significant effects are bolded.

Table 3. Mixed-Effects Modeling Results for Distal Transfer Task

Parameter	Estimate	Standard Error	df	t value	p value	d value
Intercept	522.13	10.31	232.34	50.637	<0.001	6.64
TrueCal	265.59	6.81	238.47	38.954	<0.001	5.04
Education	14.58	10.34	232.34	1.410	0.159	0.19
Feedback	-17.71	10.32	232.34	-1.715	0.087	-0.23
BMI	8.86	10.43	232.21	0.849	0.396	0.11
Hunger	4.34	10.41	232.42	0.417	0.677	0.05
TrueCal_sq	-5.79	4.32	267.13	-1.338	0.182	-0.16
Education*Feedback	0.79	10.33	232.35	0.077	0.938	0.01
TrueCal*Education	7.71	6.83	238.50	1.128	0.260	0.15
TrueCal*Feedback	-5.64	6.83	238.49	-0.826	0.409	-0.11
TrueCal*BMI	6.16	6.89	237.40	0.895	0.371	0.12
TrueCal*Hunger	-6.29	6.88	239.04	-0.914	0.361	-0.12
Education*TrueCal_sq	-3.65	4.34	267.20	-0.841	0.401	-0.10
Feedback*TrueCal_sq	-4.00	4.33	267.15	-0.925	0.355	-0.11
BMI*TrueCal_sq	-3.94	4.37	265.05	-0.903	0.367	-0.11
Hunger*TrueCal_sq	-5.52	4.37	268.29	-1.264	0.207	-0.15
TrueCal*Edu*Fdbck	0.22	6.83	238.48	0.032	0.974	0.004
TrueCal_sq*Edu*Fdbck	-2.69	4.33	267.19	-0.620	0.535	-0.08

Note. TrueCal = Linear Sensitivity. TrueCal_Sq = Quadratic Sensitivity. BMI = Body Mass Index (standardized). Edu = Education (effect coded). Fdbck = Trial-by-trial feedback (effect coded). Significant effects are bolded.

Figure 1. Caloric Content Perception



Note. Observed perception of caloric content shows underestimation bias at the intercept (i.e., average presented calories), moderate sensitivity to caloric content in the slope at the intercept, and declining sensitivity to caloric content as calories increase. See text for more details.

Figure 2. Sample Stimulus

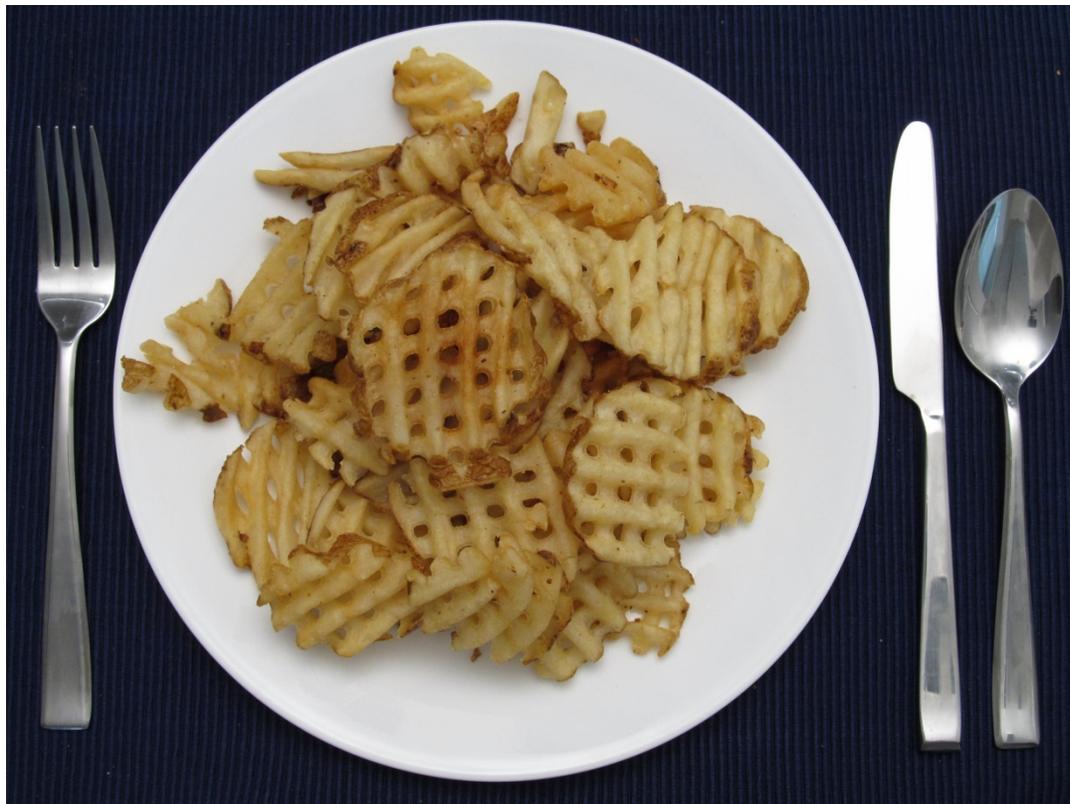
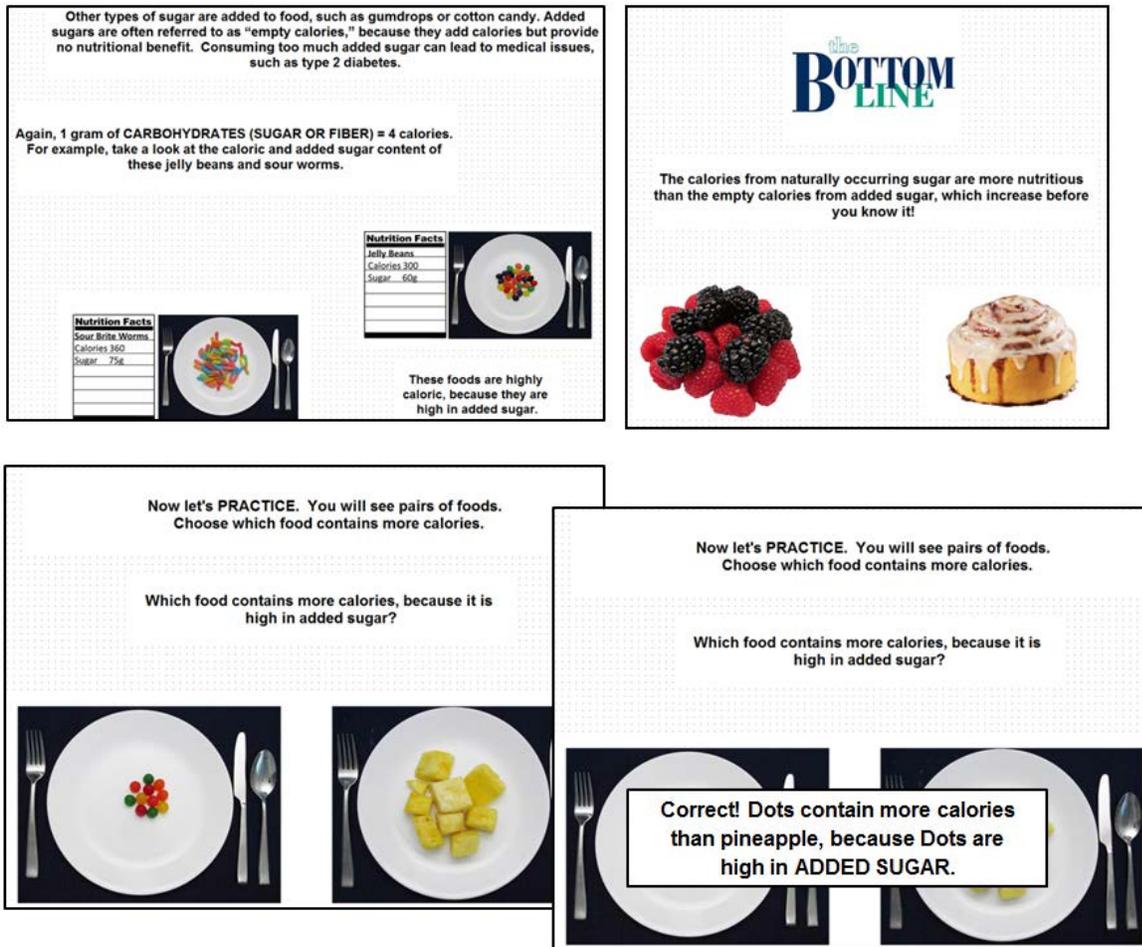
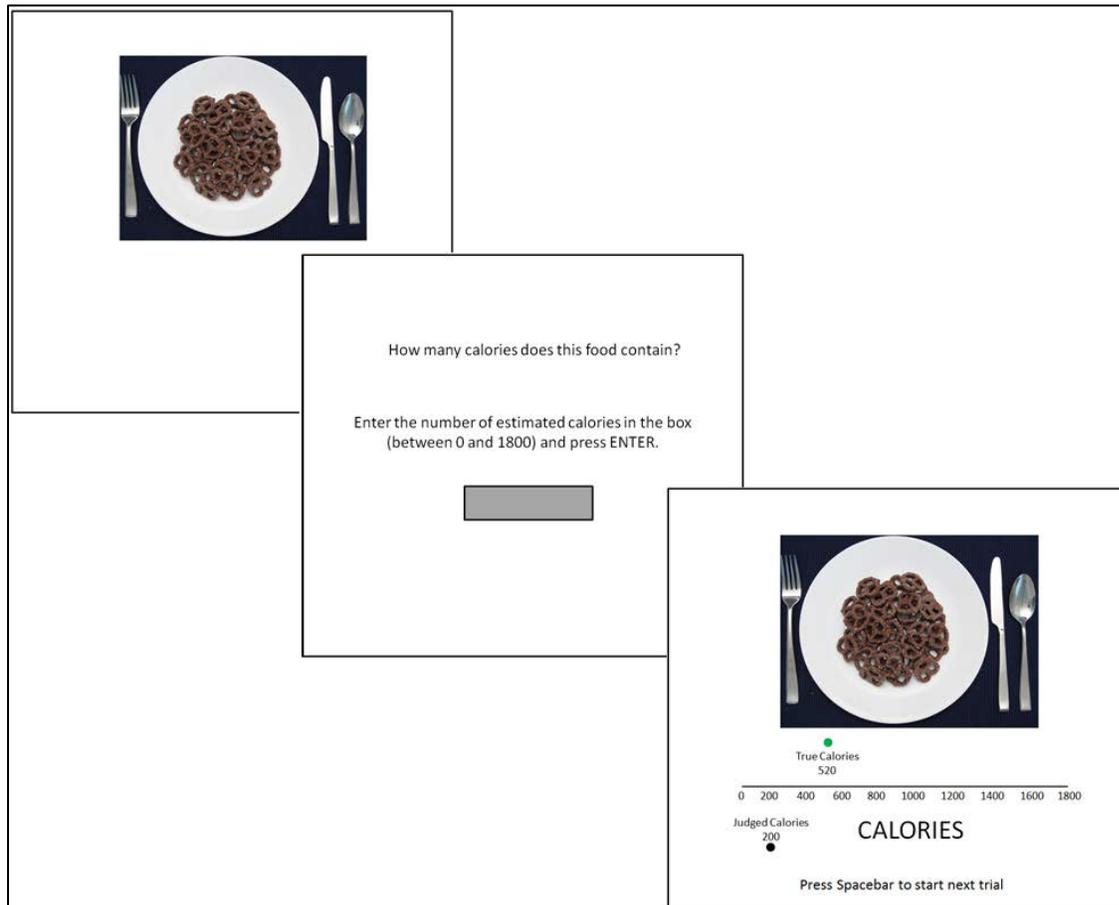


Figure 3. Sample Screenshots from Caloric Education Module



Note. Each screenshot is from a different aspect of the Caloric Education Module. These include: a lesson on high added sugar foods (top left), a summary statement or “Bottom Line” about high added sugar foods (top right), and two practice trials with immediate feedback (bottom left and bottom right).

Figure 4. Sample Caloric Estimation Trial with Feedback



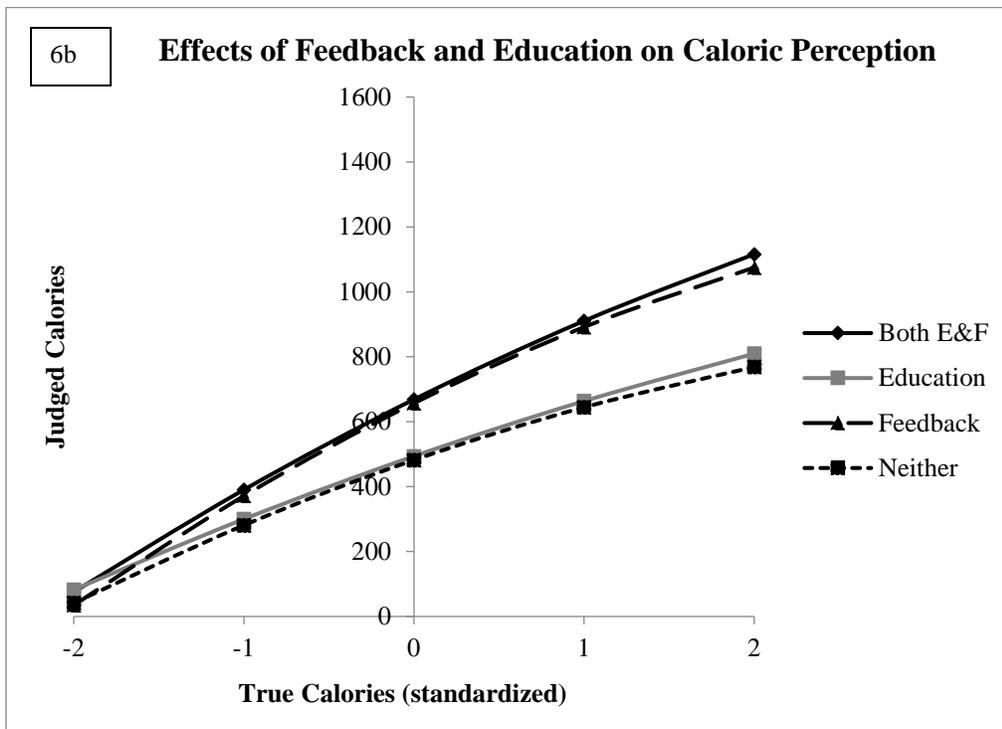
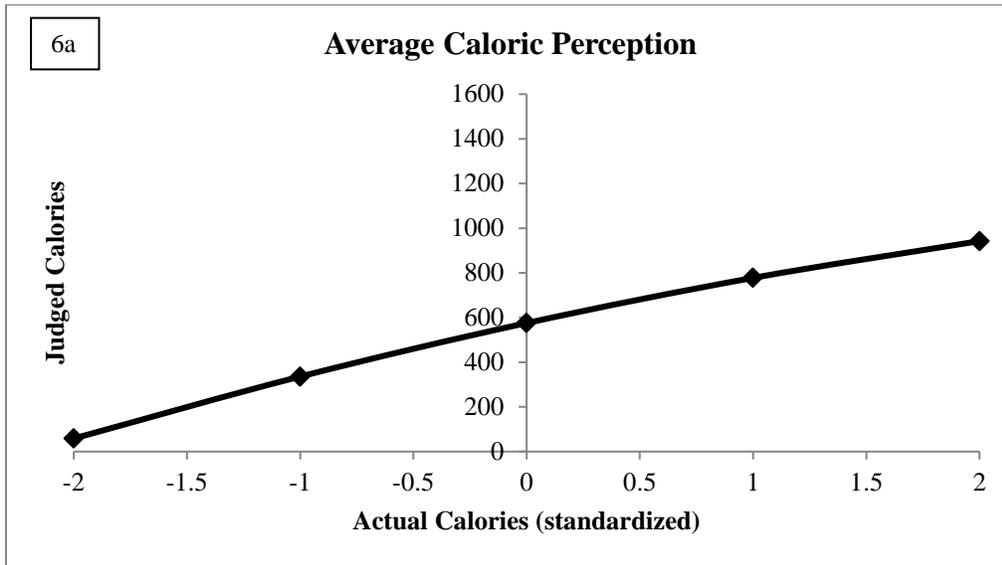
Note. This sequence occurred for each caloric estimation trial with feedback (top left to bottom right). First, the food stimulus appeared on the screen for one second. Second, the response screen appeared and remained until the participant entered a caloric estimate. Third, the feedback screen appeared. The judged food stimulus appeared on the top of the screen, and the caloric judgment scale appeared below. On the scale, true caloric content was indicated by a green dot labeled “True Calories” and judged caloric content was indicated by a black dot labeled “Judged Calories.”

Figure 5. Example of Distal Training Task



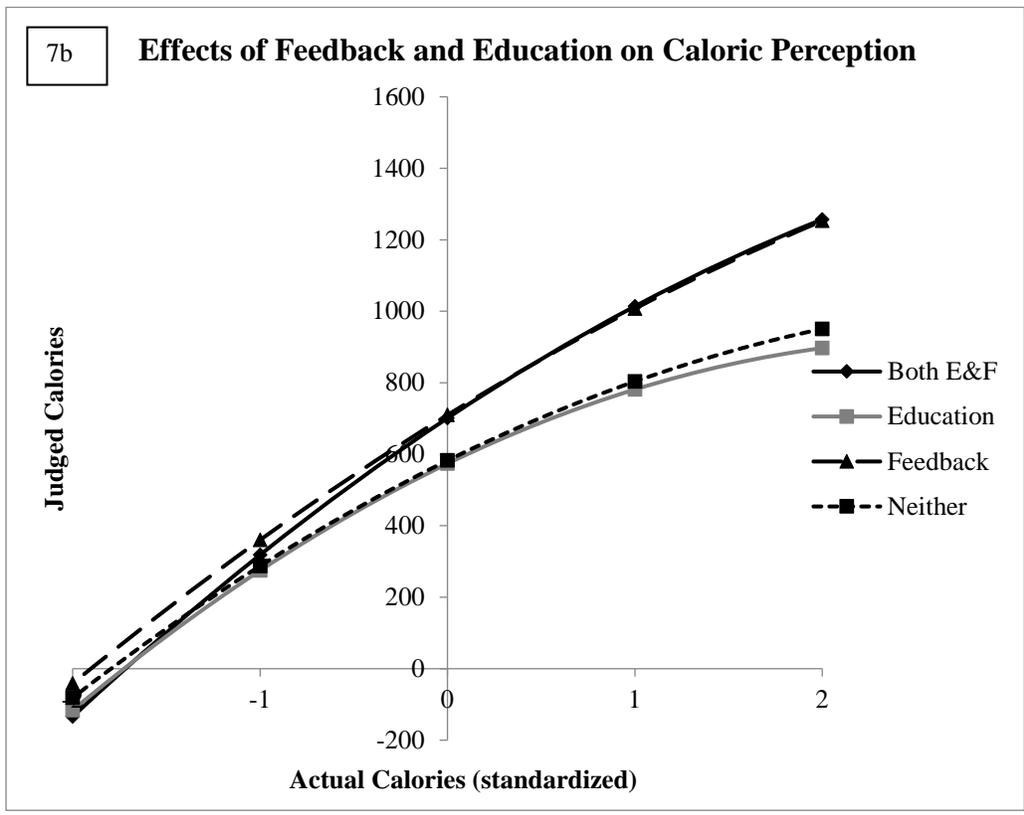
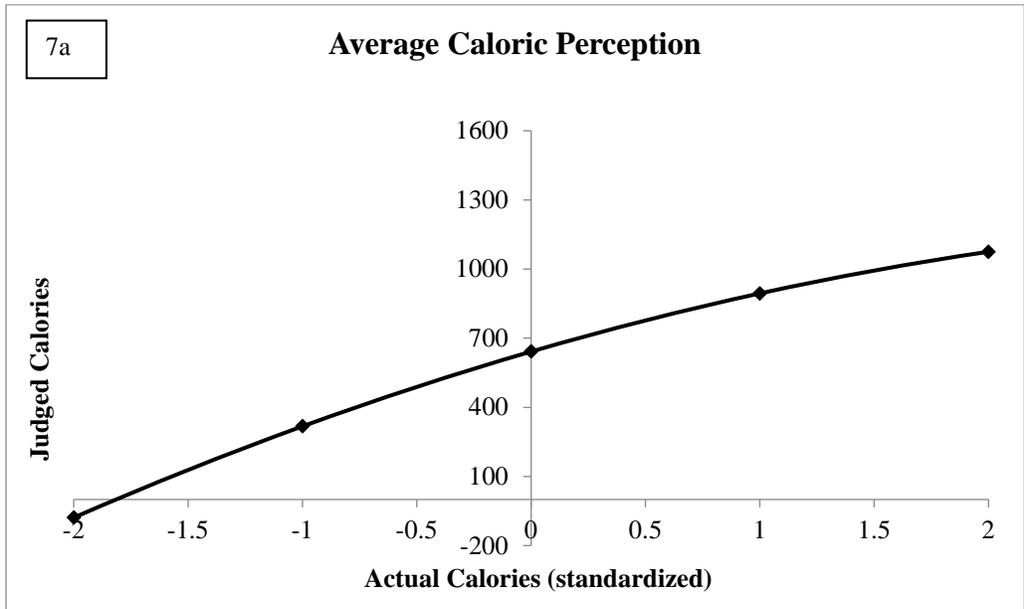
Note. Participants served the specified number of calories from each full bowl to each empty bowl. The presented foods were (from left to right): Buncha Crunch (asked to serve 165 cal); Sour Patch Kids (asked to serve 1050 cal); Trail Mix (asked to serve 875 cal); Skittles (asked to serve 700 cal); Nacho Cheese Doritos (asked to serve 350 cal); and Reese’s Pieces (asked to serve 525 cal).

Figures 6a and 6b. Model-Predicted Results for Caloric Training Task



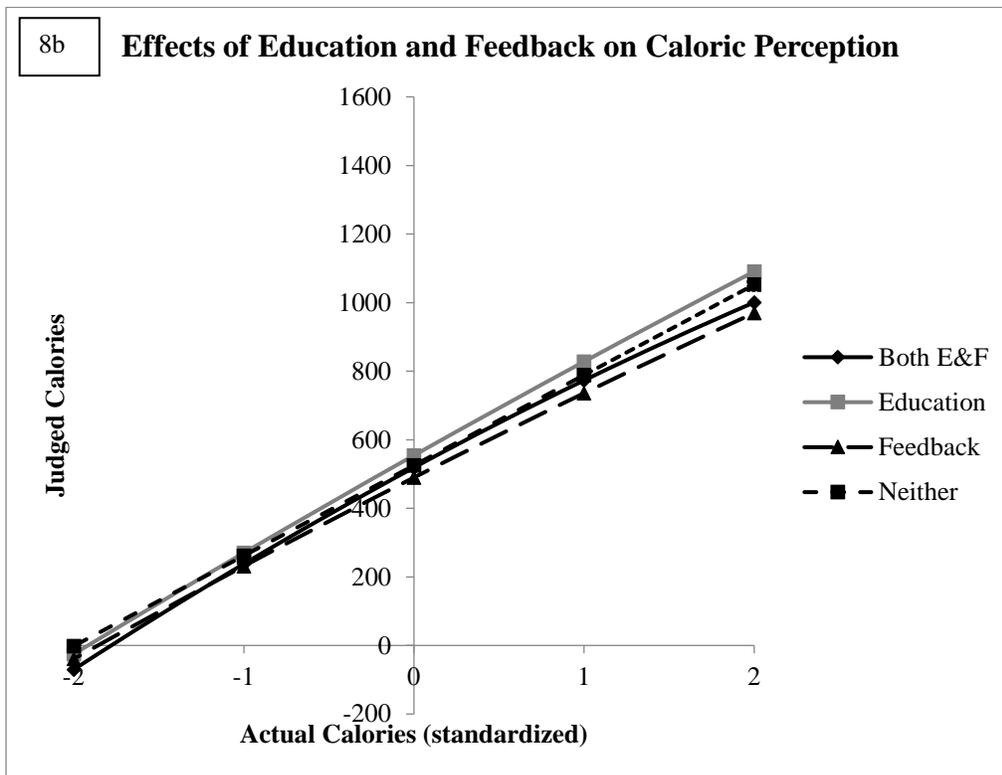
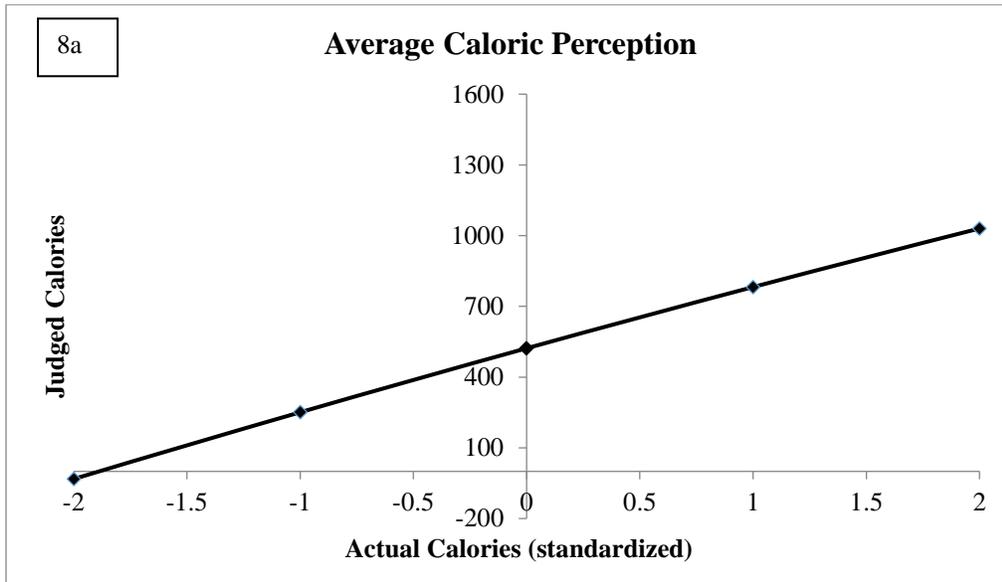
Note. E & F = Education and Feedback.

Figures 7a and 7b. Model-Predicted Results for Proximal Task



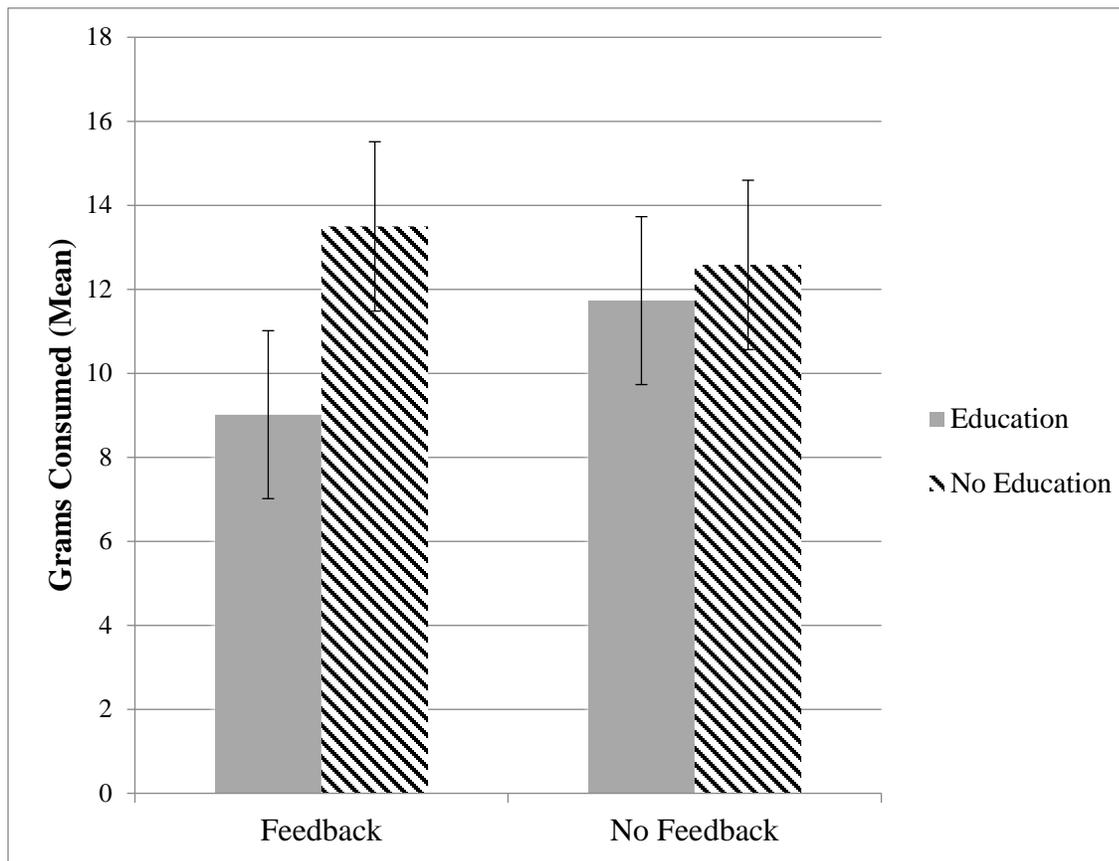
Note. E & F = Education and Feedback.

Figures 8a and 8b. Model-Predicted Results for Distal Task



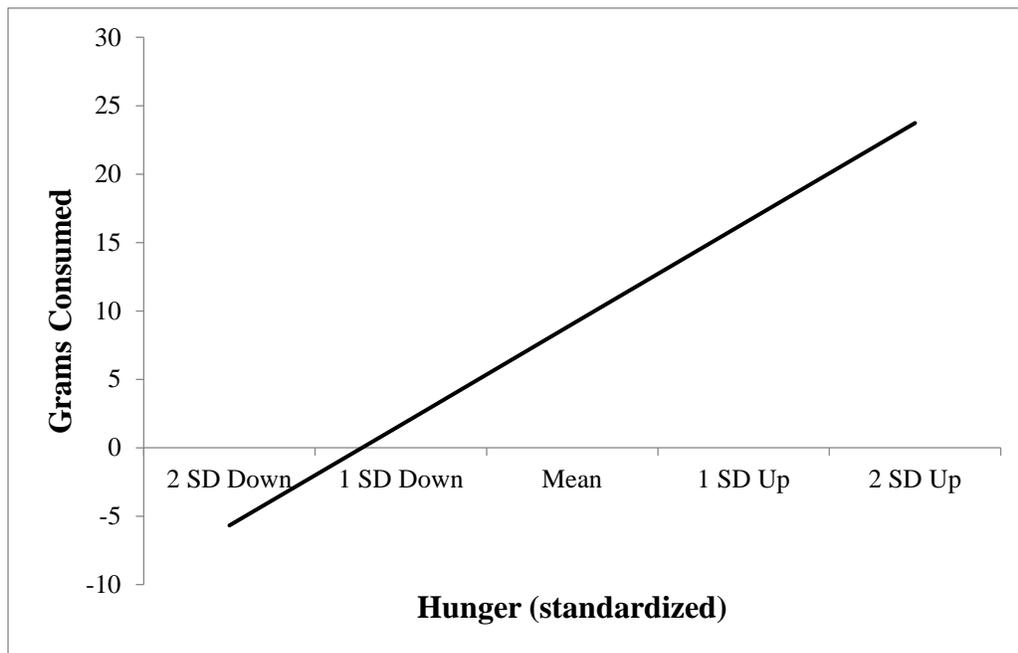
Note. E & F = Education and Feedback.

Figure 9. Ad Libitum Chocolate Consumption as a Function of Education and Feedback



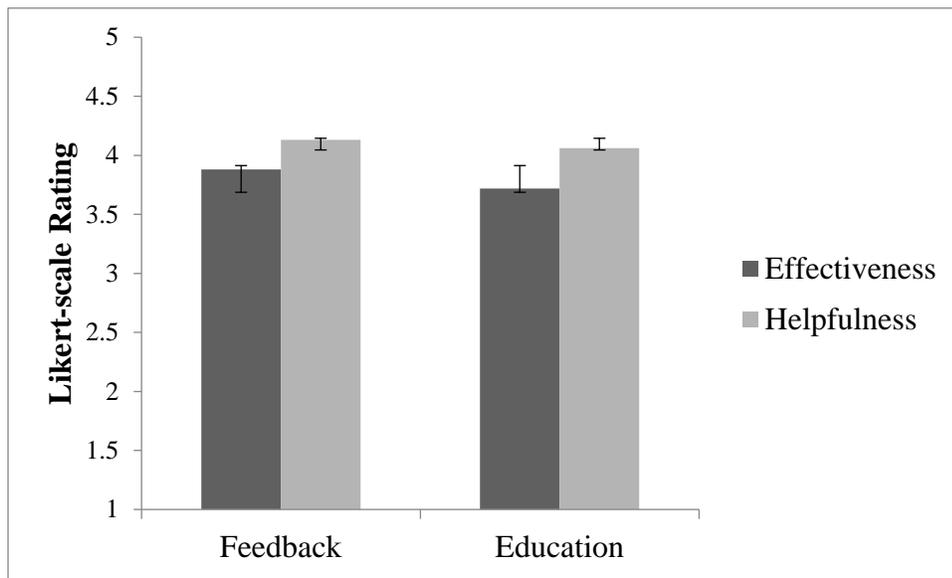
Note. The error bars represent the standard errors.

Figure 10. Model-Predicted Effect of Current Hunger on Ad Libitum Chocolate Consumption



Note. SD = Standard Deviation

Figure 11. Reported Effectiveness and Helpfulness of Feedback and Education



Note. The error bars represent one standard deviation.

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Appendix A. Experimenter Instructions for all Tasks

Prior to any tasks, the experimenter stated:

“There are four parts to today’s experiment. First, you will be asked to estimate the caloric content of photographed foods on the computer. Then, you will be asked to estimate the caloric content of a new set of photographed foods. Then, you will be asked to serve specific caloric amounts for six, real foods. Finally, you will be invited to eat some chocolate and fill out some questionnaires. I will also be asking you to rate how hungry you are several times today. Before I ask you to interact with real foods, I’ll ask you about any allergies you may have to them.”

Participants were then given instructions on how to complete the Visual Analogue Scale for Hunger (VAS-H). While pointing to the form, the experimenter said, *“Place a vertical mark on the line below to indicate how hungry you are right now.”* Participants completed VAS-H 1.

Instructions then varied based on condition:

Condition 1 - Caloric Education and Feedback: *“First, we will provide you with some information on caloric education. Then, you will estimate the number of calories in various photographed foods. You will be given feedback on your accuracy as you complete this task. Please come get me from room 112 when you’re finished.”*

Condition 2 - Feedback Only: *“You will estimate the number of calories in various photographed foods. You will be given feedback on your accuracy as you complete this task. Please come get me from room 112 when you’re finished.”*

Condition 3 - Education Only: *“First, we will provide you with some information on caloric education. Then, you will estimate the number of calories in various photographed foods. Please come get me from room 112 when you’re finished.”*

Condition 4 - Neither: *“You will estimate the number of calories in various photographed foods. Please come get me from room 112 when you’re finished.”*

Participants completed VAS-H 2.

Instructions prior to the Proximal Transfer Task:

“Now, you’ll be judging the caloric content of some more photographed foods.”

Participants completed VAS-H 3.

The experimenter then confirmed that the participant was not allergic to chocolate, peanuts, or any other foods.

Instructions prior to the Distal Transfer Task:

“Now, you will be serving specific caloric amounts for each of these foods. (Pointing to bowl of Buncha Crunch). Fill up this empty bowl with 165 calories of Buncha Crunch. Do the same thing for each food, but be sure to serve the specified number of calories for each food. I’ll stay in this room, but I won’t be watching you, so let me know when you’re done with the first tray.”

When participant indicated they had completed the task for the first tray, the experimenter switched trays and said, *“Please serve the specified caloric amounts for each of these foods.”*

Participants completed VAS-H 4.

Instructions prior to the Ad Libitum Chocolate Consumption Task:

“You are now welcome to eat as much or as little of this bowl of M&Ms as you’d like. I’ll give you five minutes, so I’ll be back when time is up. If you don’t want to eat any of it, that’s fine. Please sit here quietly for five minutes instead.”

Participants completed VAS-H 5.

Instructions prior to the Questionnaires:

“Now you will complete a questionnaire about your demographic information. You may or may not be asked about your experience with the tasks today. As a reminder, this study is completely anonymous, such that we cannot pair participants’ responses with their names or other identifying information. You can skip any question that you likes. Please come find me in room 112 when you are finished. Thank you.”

Appendix B. Complete Caloric Education Module

Participants completed the following Caloric Education Module. Each page represents a single screenshot from the program. For instances in which participants received feedback (i.e., the practice trials), participants would select a food, immediately prompting a text box containing feedback to appear. Thus, for illustrative purposes, some pages contain the exact text provided as feedback.

Sometimes, we don't pay enough attention to how much unhealthy, processed food we eat. Over-eating unhealthy foods can quickly lead to problematic weight gain, because many of these foods are very high in calories.



Please press the space bar to continue.

When selecting and eating food, how often do you consider the food's caloric content?

0	1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	---	----

Never

Always

**Why do YOU think it is important to learn about caloric content?
Press ENTER when you have finished your response.**



The GOAL of this training program is to help you better estimate the number of calories in unhealthy food. Much unhealthy food is high in ADDED FAT and/or high in ADDED SUGAR, so we will focus primarily on those nutrients.

table of contents



To improve your ability to estimate calories in unhealthy food, you will go through several, short modules.

- 1) Categories of Foods
- 2) What is a Calorie?
- 3) High Fat Foods
- 4) High Sugar Foods
- 5) High Fat and Sugar Foods
- 6) Protein and Fiber
- 7) Portion Size
- 8) How the Food is Prepared
- 9) Summary
- 10) Practice

Let's walk through these different categories of foods.

Low Added Fat, High Added Sugar	High Added Fat, High Added Sugar
Low Added Fat, Low Added Sugar	High Added Fat, Low Added Sugar

Some foods are low in added fat and high in added sugar. Sugar-sweetened cereal or gummy worms are examples of this.



Low Added Fat, High Added Sugar	High Added Fat, High Added Sugar
Low Added Fat, Low Added Sugar	High Added Fat, Low Added Sugar

Some foods are high in added fat AND high in added sugar. There are many examples of these foods, such as some types of Chinese food or cake.



Low Added Fat, High Added Sugar	High Added Fat, High Added Sugar
Low Added Fat, Low Added Sugar	High Added Fat, Low Added Sugar

The foods in this group are low in added fat and low in added sugar. Many of these foods are relatively healthy and tend to be low in calories, so we won't be focusing on them today.



Low Added Fat, High Added Sugar	High Added Fat, High Added Sugar
Low Added Fat, Low Added Sugar	High Added Fat, Low Added Sugar

**Some foods are high in added fat and low in added sugar.
French fries and potato chips are examples of this.**



**We all know that in order to maintain weight it is important to eat only as many calories as you burn in a single day.
To lose weight, it is important to eat fewer than the number of calories you burn in a single day.**



**But what is a calorie anyway?
A calorie is the unit used to measure how much energy is in food.**

1 CALORIE
-
THE AMOUNT OF ENERGY REQUIRED
TO RAISE 1 GRAM OF WATER
1 DEGREE CELSIUS

Technically, one calorie is the amount of energy required to raise the temperature of 1 gram of water by 1 degree Celsius (1.8 degrees Fahrenheit).

There are three important macronutrients that contribute to the calories in food: fat, carbohydrates (that is, sugar and fiber), and protein.
Each of these contributes differently to the number of calories in food.

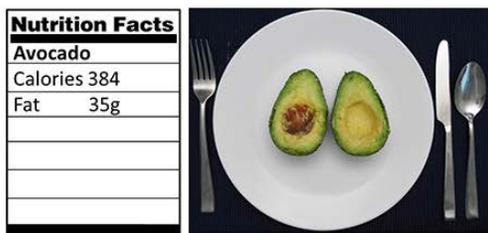


Our bodies use FAT for many health reasons: to give us energy; to protect vital organs; to transport, store and absorb vitamins; and to maintain our skin and hair.



“Good” fat, known as polyunsaturated fat and monounsaturated fat, can be found in nuts, seeds, and fish.

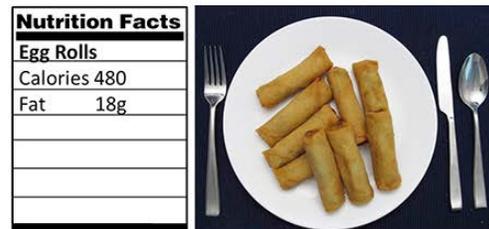
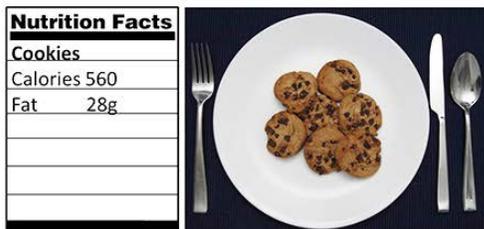
The calories that come from “good fat” help our bodies to function better.
1 GRAM OF FAT = 9 CALORIES.
For instance, take a look at the caloric and fat content for this avocado and nuts.



Notice that since these foods contain a lot of good fat, their caloric content is high.

Eating too much “bad fat,” like trans fat and saturated fat, can lead to major health problems, such as heart disease. “Bad fat” tends to be ADDED to food, so the calories from high added fat foods increase quickly.
Again, 1 GRAM OF FAT = 9 CALORIES.

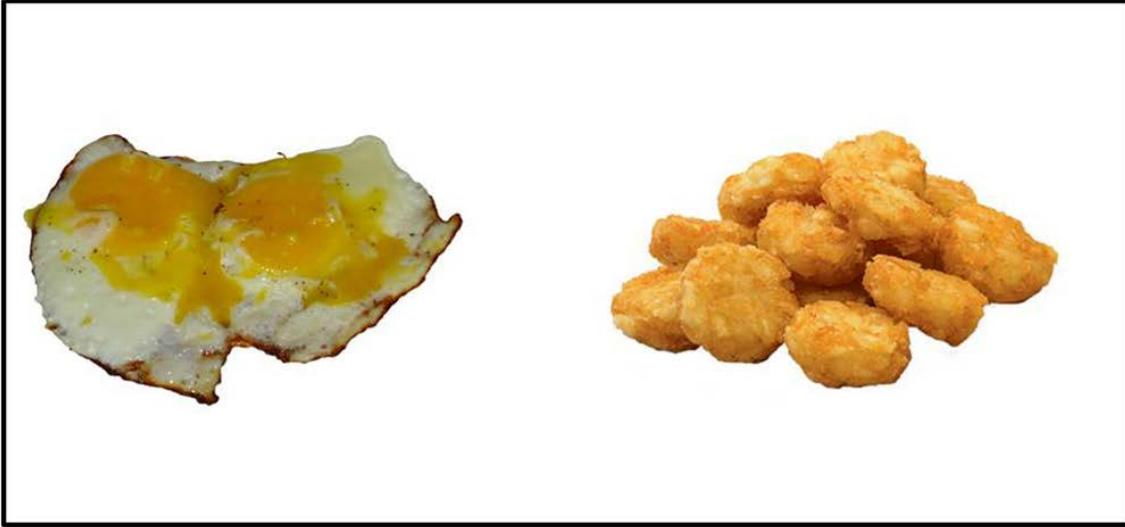
For example, take a look at the caloric and fat content for the chocolate chip cookies and the egg rolls.



These foods are high in bad fat, so their caloric content is high. However, these calories are not nutritious, and they add up before you know it!

Now let's **PRACTICE**. You will see a pair of foods.
Choose which food contains more calories.

Which food contains more calories, because it is high in added fat?



Eggs

Hashbrowns

Correct! Hashbrowns contain more calories than eggs, because hashbrowns are high in **ADDED FAT**.

Many SUGARS are considered simple carbohydrates. This nutrient is quickly digested and used by our bodies, so it doesn't keep you feeling full for long. Some sugar is naturally occurring, like the sugar in fruit or milk.



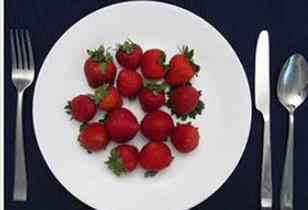
Please press the space bar to continue.

Foods that are high in naturally occurring sugar tend to be low in calories and highly nutritious.

1 GRAM OF CARBOHYDRATES (SUGAR OR FIBER) = 4 CALORIES.

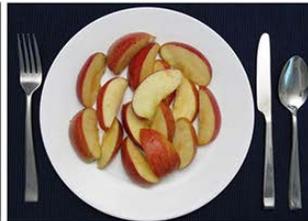
For instance, take a look at the caloric and naturally occurring sugar content for these strawberries and apples.

Nutrition Facts	
Strawberries	
Calories	46
Sugar	7g



Foods that are high in naturally occurring sugar tend to have far fewer sugar grams than foods that contain added sugar. That's why foods that are high in naturally occurring sugar tend to have fewer calories.

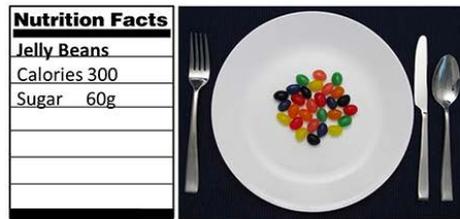
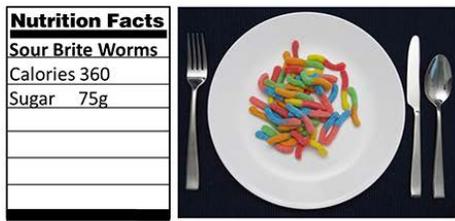
Nutrition Facts	
Apples	
Calories	95
Sugar	19g



Please press the space bar to continue.

Other types of sugar are **ADDED** to food, such as gumdrops or cotton candy. Added sugars are often referred to as “empty calories,” because they add calories but provide no nutritional benefit. Consuming too much added sugar can lead to medical issues, such as type 2 diabetes.

Again, 1 gram of **CARBOHYDRATES (SUGAR OR FIBER) = 4 calories**. For example, take a look at the caloric and added sugar content of these jelly beans and sour worms.



Foods that are high added sugar tend to have far more sugar grams than foods that are high in naturally occurring sugar. That’s why foods that are high in added sugar tend to have more calories.

Please press the space bar to continue.

the BOTTOM LINE

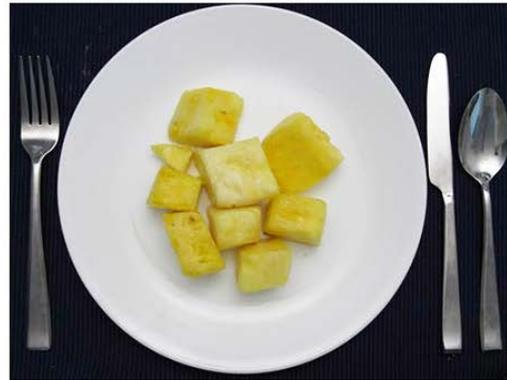
The calories from naturally occurring sugar are more nutritious than the empty calories from added sugar, which increase before you know it!



Please press the space bar to continue.

Now let's PRACTICE. You will see pairs of foods.
Choose which food contains more calories.

Which food contains more calories, because it is
high in added sugar?



Dots

Pineapple

Correct! Dots contain more calories than pineapple,
because Dots are high in ADDED SUGAR.

Some foods are high in added fat AND high in added sugar. We often refer to these foods as sweets, such as cake, pie, or cookies. Other foods that we don't often think of as sweets are also high in fat and high in sugar, such as barbecued fish or sweet and sour chicken.



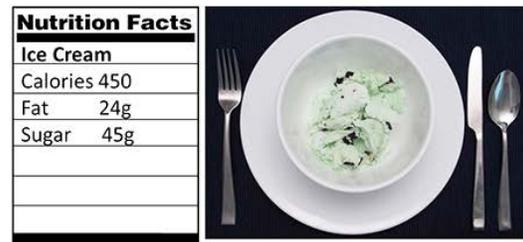
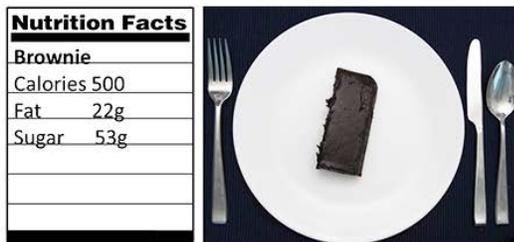
Please press the space bar to continue.

Since these foods are high in both added fat and added sugar, it is easy to see how they tend to be the most caloric.

1 gram of CARBOHYDRATES (SUGAR OR FIBER) = 4 calories

1 GRAM OF FAT = 9 CALORIES

For example, take a look at the calories, fat, and sugar content of this brownie and this scoop of ice cream.

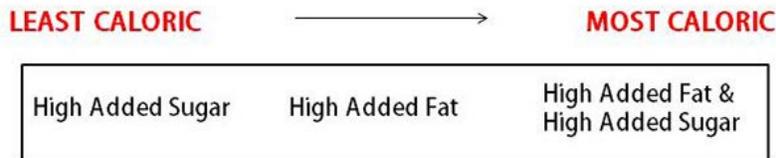


Note the foods' high fat and high sugar content. That's why they're so high in calories!

Please press the space bar to continue.

the BOTTOM LINE

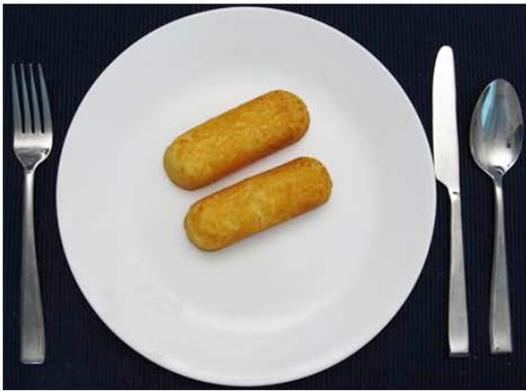
Be on the lookout for added fat, added sugar, or both when estimating caloric content of food. The presence of these nutrients can add numerous calories to the foods we eat, and they don't promote health in any way, unlike natural fat and natural sugar.



Please press the space bar to continue.

Now let's PRACTICE. You will see pairs of foods.
Choose which food contains more calories.

Which food contains more calories, because it is
high in added fat AND added sugar?



Twinkies

Fritos

Correct! Twinkies contain more calories than Fritos,
because they are high in ADDED SUGAR and
ADDED FAT.

Of course, there are other nutrients that contribute to the caloric content of food, especially in combination with fat and sugar. We will focus on PROTEIN and FIBER.

PROTEINS are a part of every cell, tissue, and organ in our bodies. We are constantly breaking down and replacing them. The protein in the food we eat is broken down into amino acids and eventually used to replace the protein in our bodies.

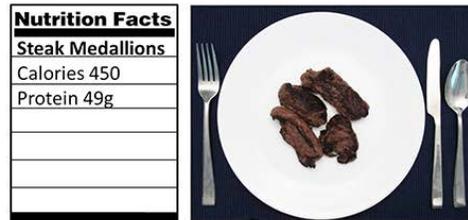
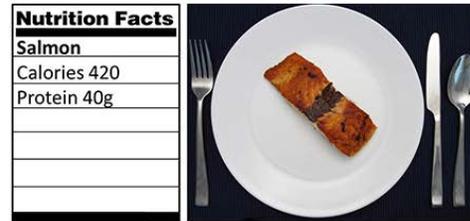
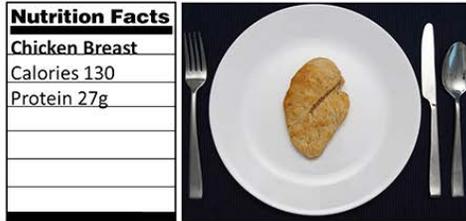


Please press the space bar to continue.

People tend to eat enough protein in a day, and it is important to keep track of how many calories these foods contain.

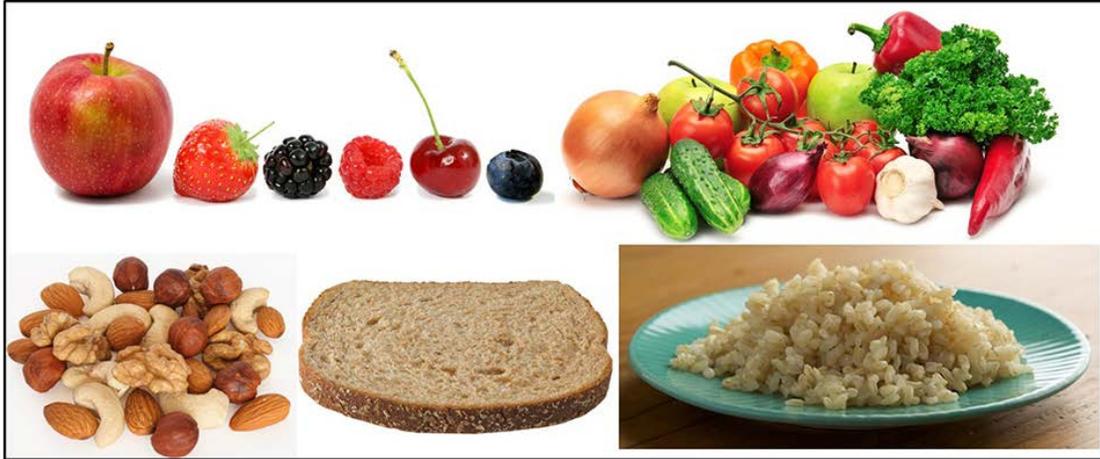
1 GRAM OF PROTEIN = 4 CALORIES

For example, take a look at the caloric and protein content for the chicken breast, grilled salmon, and the steak medallions below.



Please press the space bar to continue.

FIBER is a complex carbohydrate.
These nutrients take longer for your body to digest, so they keep you full longer. Fiber can be found in vegetables, fruits, and whole grains.



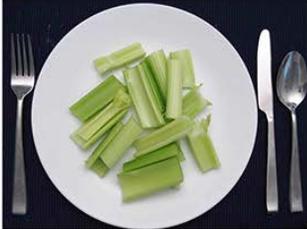
Please press the space bar to continue.

High-fiber foods, to which nothing is added, tend to be lower in calories.

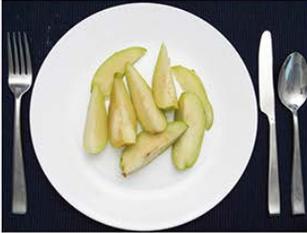
1 GRAM OF CARBOHYDRATES (SUGAR OR FIBER) = 4 CALORIES.

Note how the high-fiber foods below tend to be lower in calories.

Nutrition Facts	
Celery	
Calories	36
Fiber	4g



Nutrition Facts	
Pear	
Calories	103
Fiber	6g

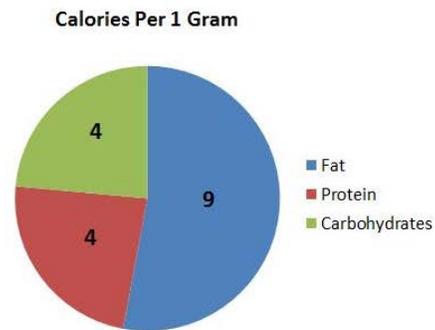


Please press the space bar to continue.



Each of these macronutrients is converted to usable energy, which is measured in calories. For overall health, you should eat carbohydrates (sugar and fiber), proteins, and fats in the right proportions. The guideline is 60% of your calories from carbohydrates, 30% of your calories from fats, and 10% of your calories from proteins.

Remember, every...
1 gram of FAT = 9 calories
1 gram of PROTEIN = 4 calories
1 gram of CARBOHYDRATES (SUGAR OR FIBER) = 4 calories



This means that, everything else being equal, one gram of fat is more caloric than one gram of other nutrients.

That is one reason why foods that are high in added fat tend to be more caloric than high-added sugar foods.

Please press the space bar to continue.

Other Considerations

Now that we've discussed how the nutrients in food influence the number of calories they contain, let's think about what else influences how many calories are in a food.

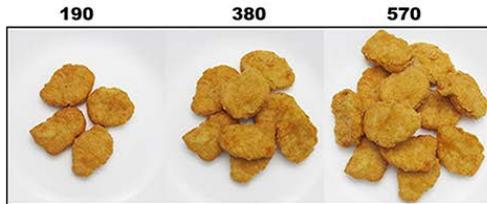


Please press the space bar to continue.

Portion Size

Check these images out. They show how the same food can have so many more calories depending on how much of the food there is.

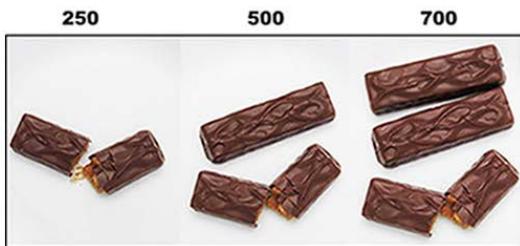
Chicken Nuggets



Junior Mints



Snickers



Please press the space bar to continue.

the BOTTOM LINE

Be sure to pay attention to the food's portion size, when you estimate how many calories are in each food.



Please press the space bar to continue.

**What foods do you tend to eat in large portions?
Press ENTER when you have finished your response.**

How the Food is Prepared

Sometimes, we **UNDERESTIMATE** the caloric content of food, because we focus more on the **HEALTHY** aspects of food, rather than the **UNHEALTHY** parts.

Let's think about fried chicken (a high fat, low sugar food). An otherwise healthy chicken breast quickly becomes unhealthy when it is covered in breading and fried.



Please press the space bar to continue.



Another example is chocolate-covered cherries. Though cherries are typically considered nutritious, their health benefits decrease when covered in chocolate (a high-fat, high-sugar topping).

Candied nuts are another example. Nuts, which are full of nutrients, become less beneficial when they are “candied” or coated in added sugar.



Please press the space bar to continue.

the BOTTOM LINE

Pay attention to what kinds of dressings or toppings (like butter) are on the food, when you estimate how many calories are in it. These dressings or toppings may be full of added fat or added sugar, which changes the caloric content of the food.



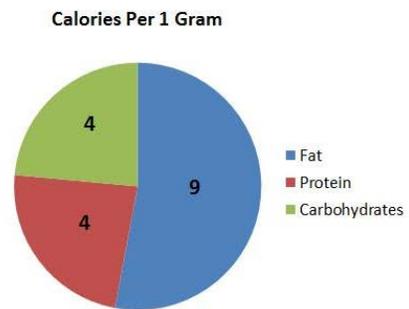
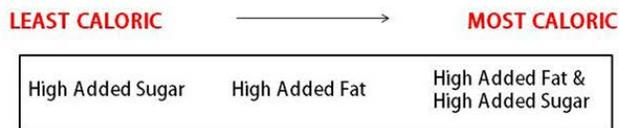
Please press the space bar to continue.

**What other foods do you make more caloric by how you prepare them?
Press ENTER when you have finished your response.**

We've thought about three main points: 1) what a calorie is, 2) how different nutrients contribute different numbers of calories to food, and 3) other characteristics to keep in mind when estimating how many calories are in food (portion size and how the food is prepared).



You may find it helpful to return to the main points when estimating caloric content.



- 1) Think about whether each food contains added fat, added sugar, or both. Keep in mind: the added fat or added sugar may be in how the food is prepared.
- 2) Focus on the food's portion size.

Please press the space bar to continue.

HOW TO ESTIMATE CALORIES IN UNHEALTHY FOOD:

- 1) Categorize the food. Is it high in fat, sugar, or both?
- 2) Consider its portion size.
- 3) Consider how the food is prepared.

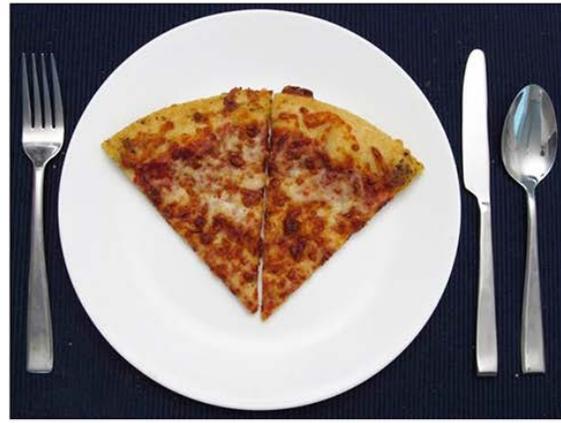
Based on your answers to those questions, and the information you've learned today, you should be able to make an educated guess!



Please press the space bar to continue.

Now let's PRACTICE. You will see pairs of foods.
Choose which food contains more calories.

Which food contains more calories?



1 slice of cheese
pizza

2 slices of cheese
pizza

Correct! 2 slices of cheese pizza contain more calories than 1 slice, because of portion size.

Which food contains more calories?



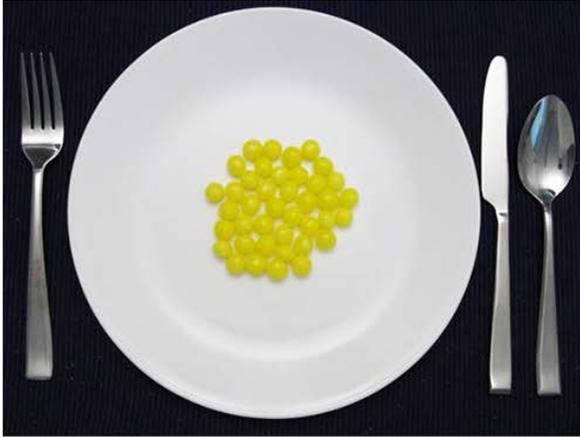
Sugar Cookie



Cheez-Its

Correct! Sugar Cookie contain more calories than Cheez-Its, because it is high in ADDED SUGAR and ADDED FAT.

Which food contains more calories?



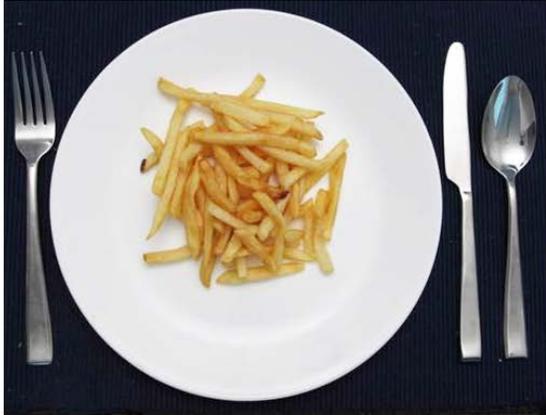
Lemon Heads



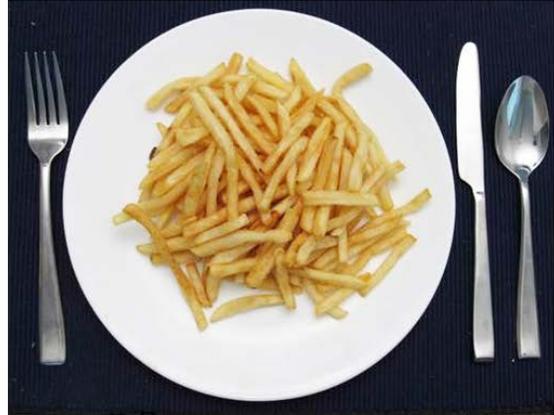
French Fries

Correct! French Fries contain more calories than Lemon Heads, because French Fries are high in ADDED FAT.

Which food contains more calories?



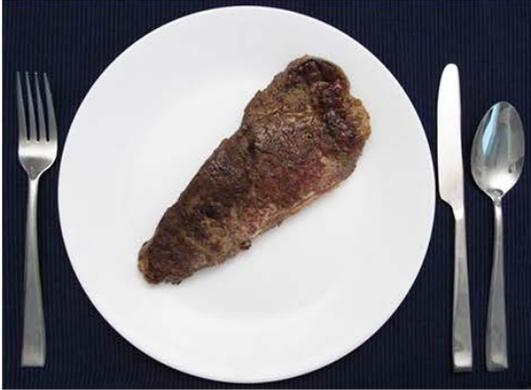
1 medium serving
of French Fries



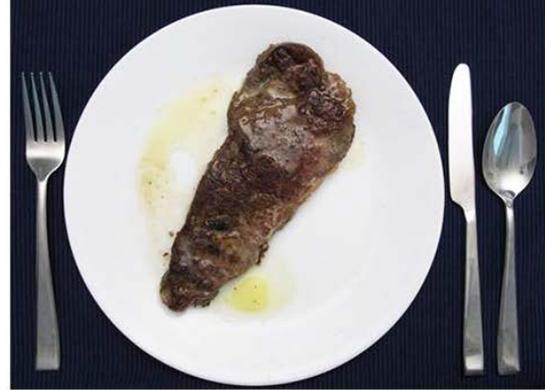
1 large serving of
French Fries

Correct! 1 large serving of French Fries contains more calories because of portion size.

Which food contains more calories?



Steak without
butter



Steak with butter

Correct! Steak with butter contains more calories
because of how the food is prepared.

Which food contains more calories?



**Salad without
dressing**



**Salad with
dressing**

**Correct! Salad with dressing contains more calories
because of how the food is prepared.**

**Good job! It's time to get started.
Please estimate the number of calories each food contains.**



Please press the space bar to continue.

When selecting and eating food, how well do you think you can estimate food's caloric content?

0	1	2	3	4	5	6	7	8	9	10
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Never

Always

You will be making caloric ratings of foods.

Press the space bar to begin making caloric ratings of foods.

Appendix C. Parametric Correlations between Parameters across First Three Tasks

Table C1. Parametric Correlations between Parameters across First Three Tasks

	Training Intercept	Trainin_LinSens	Training QuadSens	Proximal Intercept	Proximal LinSens	Proximal QuadSens	Distal Intercept	Distal LinSens
Training Intercept	1.000							
Training LinSens	0.903**	1.000						
Training QuadSens	-0.337**	0.099	1.000					
Proximal Intercept	0.723**	0.657**	-0.235**	1.000				
Proximal LinSens	0.679**	0.672**	-0.099	0.941**	1.000			
Proximal QuadSens	-0.535**	-0.363**	0.445**	-0.703**	-0.421**	1.000		
Distal Intercept	-0.161	-0.079	0.199*	-0.196**	-0.114	.286**	1.000	
Distal LinSens	-0.148	-0.074	0.182*	-0.205**	-0.132	.272**	0.964**	1.000
Distal QuadSens	0.034	0.014	-0.048	-0.043	-0.073	-0.037	-0.087	0.182**