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Effects of Bite Count Feedback from a Wearable Device and Goal-Setting on Consumption in Young Adults

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Abstract

Background—New technologies are emerging that may be able to help individuals engage in healthier eating behaviors. One paradigm to test the efficacy of a technology is to determine its effect relative to environmental cues that are known to cause individuals to overeat.

Objective—The purpose of this work was to independently investigate two questions: 1) How does the presence of a technology that provides bite count feedback alter eating behavior?; and 2) How does the presence of a technology that provides bite count feedback *paired with a goal* alter eating behavior?

Design—Two studies investigated these research questions. The first study tested the effects of a large and small plate crossed with the presence or absence of a device that provided bite count feedback on intake. The second study tested the effects of a bite count goal with bite count feedback again crossed with plate size on intake. Both studies used a 2×2 between subjects design.

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Protocol access: Access to the protocol can be accessed by contacting Phillip W. Jasper at pwjaspe@clemson.edu.

JAND – Conflict of Interest statement/disclosure

STATEMENT OF POTENTIAL CONFLICT OF INTEREST

Authors ERM and AWH have formed a company, “Bite Technologies,” to market and sell a bite counting device. Clemson University owns a US patent for intellectual property known as “The Weight Watch”, USA, Patent No. 8310368, filed January 2009, granted November 13, 2012. Bite Technologies has licensed the method from Clemson University and has been funded by South Carolina Launch, a state organization that incubates startup companies associated with university intellectual property, and has received funding from the National Institutes of Health to validate the device. ERM and AWH receive royalty payments from bite counting device sales.

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Participants/setting—In the first study, 94 subjects (62 female, Age 19.0±1.6 years, BMI 23.04±3.6) consumed lunch in a laboratory. The second study examined 99 subjects (56 female, Age 18.5±1.5 years, BMI 22.73±2.70) under the same conditions.

Intervention—In both studies subjects consumed a single-course meal, using either a small or large plate. In the first study participants either wore or did not wear an automated bite counting device. In the second study all participants wore the bite counting device and were given either a low bite count goal (12 bites) or a high bite count goal (22 bites).

Statistical Analyses—Effect of PLATE SIZE, FEEDBACK, and GOAL on consumption (grams) and number of bites taken were assessed using 2×2 ANOVAs. As adjunct measures, the effects of serving size, bite size (grams per bite), post-meal satiety and satiety change were also assessed.

Results—In the first study there was a main effect of PLATE SIZE on grams consumed and number of bites taken such that eating from a large plate led to greater consumption (p=.001) and a greater number of bites (p=.001). There was also a main effect of FEEDBACK on consumption and number of bites taken such that those who received feedback consumed less (p=.011) and took fewer bites (p<.001). In the second study there was a main effect of PLATE SIZE on consumption such that those eating from a large plate consumed more (p=.003) but did not take more bites. Further analysis revealed a main effect of GOAL on number of bites taken such that those who received the low goal took fewer bites (p<.001) but did not consume less.

Conclusion—Providing feedback on the number of bites taken from a wearable intake monitor can reduce overall intake during a single meal. Regarding the first research question, providing feedback significantly reduced intake in both plate size groups and reduced the overall number of bites taken. Regarding the second research question, participants were successful in eating to their goals. However, individuals in the low goal condition appeared to compensate for the restricted goal by taking larger bites leading to comparable levels of consumption between the low and high goal groups. Hence, the interaction of technology with goals should be considered when introducing a health intervention.

Keywords or descriptive phrases

Consumption; feedback; behavior change; wearable monitoring; plate size

INTRODUCTION

Overweight and obesity have reached epidemic levels in the United States[1]. One of the driving forces behind this trend may be a “mindless margin” in which humans can overeat and not notice[2]. Wansink and colleagues have shown that various environmental cues (e.g. portion size, serving dish size, plate size, social interaction) can lead to an increase in eating within the mindless margin For example, people will eat more from a larger popcorn container than from a smaller popcorn container without realizing it, even if the popcorn in the larger container is stale[3]. Students still served themselves 55% more from a larger bowl without believing the size of the bowl played into their own serving sizes demonstrating that the effect persisted in spite of the warning[4]. Further studies have shown that individuals using larger plates, even nutritionists and dietitians – individuals who were expected to show

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increased sensitivity to such an effect – consistently serve and consume greater amounts compared to using a smaller plate[5]. The experiments in this paper were motivated by the idea that an objective intake monitoring technology might be able to help an individual avoid this mindless margin.

Technologies such as the Hapifork, Mandometer, and Bite Counter provide objective real-time measurements during eating. The HapiFork (Hapilabs, Hong Kong, CN) is an eating tool that measures duration of eating, eating rate, and the number of bites an individual takes[6]. It is based upon an electric circuit that is closed when the fork is inserted into the mouth. The Mandometer (Mandometer, Brighton, Victoria, AU) is a portable scale connected to a computer that generates a real-time graph of weight representing food removal from a plate[7]. It can help individuals control their eating rate by providing feedback relative to a goal rate, represented by a line on the computer monitor.

The Bite Counter (Bite Technologies, Pendleton, SC, US) is worn like a watch and tracks wrist motion to detect a pattern indicative of a hand-to-mouth gesture (i.e. a bite). It counts the detections and thus provides feedback on the number of bites taken. One proposed mechanism behind why bite count feedback would reduce overeating is that it provides a more precise measure of behavior beyond that of basic visual input i.e. simply viewing the plate as one eats. Research has shown that the more complete and precise the monitoring and feedback is the greater ability one has to reach a goal[8,9]. In this case, the goal is to eat less, thus by providing an accurate measure of how much is eaten, individuals should be able to successfully eat less than they otherwise would.

The Bite Counter has been shown to count bites with 94% accuracy under controlled conditions and 86% in uncontrolled conditions[10]. A recent study of 273 free-eating people in a cafeteria found it correctly detected 82% of bites across a wide range of foods, utensils, and participants. Furthermore, bite count has been shown to correlate with calories. One study found an average per-meal correlation of 0.53 between bites and calories for 83 people using the Bite Counter for two weeks[11]. Automatically measured bite count was compared against a computerized food diary program with a resulting correlation of bites to kilocalories (kcal) in the range of 0.4 to 0.8 for 76% of those participants. Results from these studies provides support for the Bite Counter’s ability to provide individuals with real-time portion feedback.

The overall purpose of this work was to separately investigate two research questions. The first research question was designed to explore how the presence of the Bite Counter with feedback presented in isolation alters eating behavior compared to not wearing it. The second research question was designed to explore how bite count feedback coupled with either a low or high goal alter eating behavior. Research has shown that self-monitoring alone is useful in helping individuals achieve success[12]. However, self-monitoring when paired with a goal has been shown to be more effective[13].

The design, methods, results and discussion for both research questions, which were investigated in two separate studies, are presented conjointly followed by a conclusion tying together the findings regarding both research question.

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STUDY DESIGN AND HYPOTHESES

Research question 1: How does the presence of a technology that provides bite count feedback alter eating behavior?

The first research question was investigated using a 2 (plate size) × 2 (device feedback) design. The first independent variable was PLATE SIZE with two levels: “small plate” and “large plate”. The second independent variable was FEEDBACK with two levels: “no feedback” and “feedback”. Specifically, in the FEEDBACK condition participants wore the Bite Counter and saw their bite count or they did not. Participants were not given a reference or instruction regarding bite count or its usage they were simply told that it was a device that would count their bites. The two main dependent variables were *grams consumed* and *bites taken*.

PLATE SIZE was manipulated as an environmental cue known to affect eating intake, i.e. eating from a larger plate leads to increased intake. It was therefore hypothesized that there would be a main effect of PLATE SIZE such that those eating from a larger plate would consume more and take more bites. The rationale for using the PLATE SIZE manipulation was to see if feedback from a Bite Counter intervention would reduce or eliminate this known environment cue/plate size effect on intake. It was therefore further hypothesized that there would be a main effect of FEEDBACK such that those who received feedback on the number of bites taken would consume less and take fewer bites. Finally, it was hypothesized that there would be an interaction between PLATE SIZE and FEEDBACK such that presence of the feedback would reduce the effect of plate size. This hypothesis is based on the notion that an external cue regarding how much one has eaten may be more impactful than the perceptual cue offered by the plate in this case. This is similar to studies that examined the effect of leaving food scraps, candy wrappers, and bottle caps visible to individuals as a cue to how much they have consumed, which consequently leads to a reduction in consumption.

Research question 2: How does the presence of a technology that provides bite count feedback *paired with a goal* alter eating behavior?

Based on the results from the first study, we sought to determine what effect providing bite count feedback along with a bite count goal would have on eating behavior. Specifically, would the implementation of a bite count goal reduce the effect of plate size?

In order to test the effects of feedback and the bite count goals, the authors provided participants with bite count feedback and gave them either a low goal or a high goal. Of particular interest was whether or not participants in the low goal condition would eat to their given goal without changing other behavioral outcomes such bite size. It was reasoned that if participants would eat to the low goal without changing other behaviors then bite count feedback along with a goal representing slightly less intake than normal would be a useful tool in getting people to stop eating earlier than they normally would without feeling less satisfied while eliminating the effect of plate size.

The study used a 2 (plate size) × 2 (goal) design. As with the first study, PLATE SIZE had two levels: “small plate” and “large plate”. The second independent variable was GOAL

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with two levels: a 12 bite “low goal” and a 22 bite “high goal”. Again, the two main dependent variables were *grams consumed* and *bites taken*.

It was hypothesized that there would be a main effect of PLATE SIZE such that those eating from a larger plate would consume more and take more bites. It was further hypothesized that there would be a main effect of GOAL such that those who received the low bite count goal would consume less and take fewer bites. Finally, it was hypothesized that there would be an interaction such that the presence of the GOAL would eliminate the effect of PLATE SIZE.

METHODS

Participants/setting

Participants were recruited for the studies from the Clemson University undergraduate population using an online recruitment tool. All participants were healthy. Exclusion criteria included history of an eating disorder and food allergies to macaroni and cheese. Participants were asked to abstain from food for at least three hours prior to the study. The data were collected in the Applied Psychophysiology Laboratory in Brackett Hall at Clemson University. This study received approval from the Institutional Review Board at Clemson University, prior to data collection. Informed consent was obtained from all participants at the beginning of the study, and the rights of all participants have been protected. Sample size was determined by using the Power and Sample Size program[14] using an alpha= .05 and power= .8 and an effect size =.4. This effect size was chosen due to the reported moderate effect of plate size as reported in studies such as those by Wansink[15]. A sample size of 12 per condition was calculated.

However, due to the unknown effect of the wearable intake monitor the researchers oversampled to increase the chances of avoiding a type II error.

Materials

Food item—Stouffer’s® Party Size Macaroni & Cheese (Nestle S. A., Vevey, Vaud, CH; dimensions = 33.02cm × 26.67cm × 3.81cm) was chosen as a meal because it is easy to prepare in the laboratory, is acceptable for lunch, and is amorphous and thus can be eaten in different sized bites without changing energy density. Participants did not state finding the meal item unusual as a lunch served by itself. Nutrition Facts per serving: serving size 225g, kcal 330, total fat 17g, cholesterol 25mg, sodium 920mg, total carb 31g, protein 14g. Serving temperature (120 degrees F).

Plates—Two differently sized plates were used. For the large plate condition a white plate with a diameter of 26.4cm was used. For the small plate condition a white plate with a diameter of 17cm was used. Participants did not report finding the size of the plate unusual.

Height and weight measurement—Height, weight, and BMI were obtained using the Tanita WB-3000 (Tanita, Tokyo, JP) scale with built-in stadiometer and BMI calculator.

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Bite Counter—The Bite Counter (Bite Technologies, www.icountbites.com) is worn on the wrist and uses a gyroscope to track wrist motion. It detects a pattern of motion distinctive of hand-to-mouth gestures used to ingest foods and beverages. The device has to be turned on at the start of eating and off at the end of eating. During eating it displays bite count for the current eating activity in real-time.

Instrumented eating station—Participants ate at a four-person table customized for the purpose of monitoring bite count and food weight. The table included four scales hidden in recesses cut out at each place setting for weighing the food pre and post meal. All of the measuring equipment was connected to two laptops.

Questionnaires

Satiety Labeled Intensity Magnitude (SLIM) scale: The SLIM scale allows for a quantitative index of hunger and fullness on a 0 to 100 scale with higher numbers indicating greater levels of fullness. The SLIM scale is a sensitive, reliable, and easy-to-use scale for measuring perceived satiety[16]. Thirty-seven subjects rated the semantic meaning of 47 phrases describing different levels of hunger / fullness using magnitude estimation. The scale was developed by evaluating eleven phrases based on response consistency, symmetry, bipolarity, and inclusion of end-point anchors. These phrases were placed along a vertical line scale at positions corresponding to their geometric mean magnitude estimates to create a labeled magnitude scale of satiety.

Relationship questionnaire: This questionnaire indexed any potential relationships the participants might have had with one another and to help characterize the composition of the social structure of the group. If any of the participants had a relationship with one or more of the other participants, they recorded the following: duration of relationship, source of relationship, and strength/quality of relationship. This information was collected to account for the known social effects on eating e.g. social facilitation and impression management[17]. This information was also collected as a reference when conducting outlier analysis. If a case was found to be an extreme outlier, we referenced the relationship questionnaire to see if a long standing relationship was held amongst the participants in that session.

Procedure

Participants entered the laboratory in groups of up to four people and completed an informed consent form as well as a demographic questionnaire. Height and weight were measured and used to derive BMI. Next, each participant completed the first of three SLIM scales and filled out the relationship questionnaire. Upon completion of the measurements and questionnaires, the participants were moved to the eating station. At this time the macaroni and cheese was removed from the oven and placed at the center of the pre-set table. Prior to each data collection session the group of participants was randomly assigned to one of the four conditions via the use of a random number generator. All participants in a single session ate from the same sized plate and all either did or did not use a Bite Counter. Participants ate in groups to simulate a somewhat natural eating environment for college students i.e., eating with others in the cafeteria.

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Participants were asked to listen to all instructions carefully before serving themselves and eating. As part of the experimental manipulation, during the *feedback* conditions, the instruction included the purpose of the Bite Counter and how to wear and operate it. Those participants in the *no feedback* condition did not wear the Bite Counter. All participants were told, "You are allowed to eat freely". Next, participants completed the second SLIM scale, which was introduced to determine if the presence of food or relocation to the eating station had an effect on satiety. Participants were then instructed to put on the Bite Counter in the *feedback* condition, and they were allowed to serve themselves from the macaroni and cheese tray. The participants were provided a serving utensil and were allowed to serve themselves ad libitum. Stable weights of the served portions were recorded using the recessed scales for the purposes of obtaining *serving size* and *grams consumed*. Participants were then asked to turn on the Bite Counter in the *feedback* condition. In all conditions, participants were then allowed to commence eating.

Participants were further instructed to eat as naturally as possible, including engaging in conversation with the other participants. This instruction was used to help mitigate the effects of the artificial setting. If participants indicated that they were finished, plate waste weight was recorded. Participants were instructed to wait until the rest of the participants were done eating. In the *feedback* condition, they were also asked to turn off and remove the Bite Counter. After the eating session participants completed the third SLIM scale.

The same setting, materials, and procedures were used in the second study. PLATE SIZE was manipulated as in the first study and it was crossed with GOAL (low or high bite count). Immediately prior to serving themselves participants in the low goal condition were told "Please eat 12 bites", while participants in the high goal condition were told "Please eat 22 bites". Once the bite goals were given, participants were allowed to serve themselves and commence eating in the same manner as described in the first research question. The high bite count goal was based on a previous study that found an average bite number of 22[11]. The low bite count goal was obtained from the lowest average bite count between the conditions in the first study described here which was 12 bites.

Statistical approach

Analyses of variance (ANOVA) were employed to investigate the effect of PLATE SIZE and FEEDBACK on the dependent variables. Analysis was performed with IBM SPSS version 20 (SPSS Inc., Chicago, IL, USA). The significance level was set to 0.05 for all tests.

The dependent variable of *grams consumed* was measured by subtracting plate waste, or the amount of food in grams left over on the plate after the participant indicated they were finished eating, from the amount of food in grams that the participants served themselves. The dependent variable of *bites taken* was measured and recorded using the Bite Counter. Additional dependent variables of interest were *serving size, bite size*, and *post-meal satiety. Serving size* was calculated by subtracting the weight of the fixed plastic plate and disposable paper plate from the total combined weight of the plastic plate, paper plate, and macaroni as reported by the recessed scales. Note that serving size is different than grams consumed because grams consumed considered plate waste and calculated actual amount consumed. *Bite size* was calculated by dividing *grams consumed* by the number of *bites*

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taken. Post-meal satiety was obtained from the third (post-meal) SLIM scale. Note: the Bite Counter was turned on after the participants served themselves the first course. For the purposes of this study, data from participants who consumed only one course were analyzed. Participants who consumed more than one course were excluded from all analyses. The rationale for this was because only a small subset of participants (less than 10%) requested a second serving, and given such a small number, we could not independently examine the effect of a second course in a statistically sound manner. Therefore, we excluded these participants from analysis as they potentially were different than the main body of participants as evidenced by their second course behavior.

RESULTS

No outliers were detected in the dataset for the first study. Outliers were predefined as individuals who consumed an unusually high or low amount. Specifically these outliers were considered those individuals who consumed 3 times more than the interquartile range. Ninety-four participants (62 female, Age 19.0±1.6 years, BMI 23.04 ± 3.6) completed the first study and only consumed a single course and were included in the analyses (Table 1).

Using the same outlier criteria in the second study, no outliers were detected in the dataset. Ninety-nine participants (56 female, Age 18.5±1.5 years, BMI 22.73 ± 2.70) completed the second study at only consumed a single course (Table 2).

Grams Consumed and Number of Bites Taken

Research question 1—Means and standard deviations of *grams consumed* and *bites taken* by condition can be found in Table 3. The analysis of *grams consumed* revealed a main effect of PLATE SIZE ($F(1, 90)=11.375$, $p=.001$) such that those eating from a larger plate consumed more than those eating from a smaller plate, on average 39.7 grams more. Further analysis revealed a main effect of FEEDBACK ($F(1, 90)=6.809$, $p=.011$) such that those who received bite count feedback consumed less than those who did not receive bite count feedback, on average 35.7 grams less. No interaction of PLATE SIZE and FEEDBACK on *grams consumed* was reported.

Furthermore, it was shown that there was an effect of PLATE SIZE on *bites taken* ($F(1, 90)=11.644$, $p=.001$) such that those eating from a larger plate took more bites than those eating from a smaller plate, on average 4.5 bites more. Additionally, it was shown that there was an effect of FEEDBACK ($F(1, 90)=15.051$, $p<.001$) such that those who received bite count feedback took fewer bites than those who did not receive feedback, on average 5.0 ± 5.3 bites fewer. No interaction of PLATE SIZE and FEEDBACK on *bites taken* was reported.

Research question 2—Means and standard deviations of *grams consumed* and *bites* taken can be found in Table 4. Analysis of *grams consumed* indicated a main effect of PLATE SIZE ($F(1, 95)=9.029$, $p=.003$) such that those eating from a larger plate consumed more than those eating from a smaller plate, on average 36.2 grams more. Further analysis revealed no main effect of GOAL indicating that there was no difference in intake between those who received the low bite count goal and those who received the high bite count goal.

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No interaction of PLATE SIZE and GOAL on *grams consumed* was found indicating that neither the low goal nor high goal altered how much people ate.

Analysis of *bites taken* indicated a main effect of GOAL ($F(1, 95)=27.691$, $p<.001$) such that those who received the low bite count goal took fewer bites than those who received the high bite count goal, on average 5 bites fewer. No effect of PLATE SIZE or an interaction between PLATE SIZE and GOAL on *bites taken* was found.

Bite Size, Serving Size, Post-Meal Satiety, and Satiety Change

Research question 1—Further analyses were conducted on *bite size, serving size, post-meal satiety* and *satiety change*. No effect of PLATE SIZE or FEEDBACK were found on *bite size*. Analyses revealed a main effect of PLATE SIZE on *serving size* ($p<.001$), *post-meal satiety* ($p=.031$), and *satiety change* ($p=.025$) such that those who ate from a larger plate served themselves more, reported greater satiety after the meal, and reported greater satiety change from pre-meal levels. Furthermore, analysis revealed a main effect of FEEDBACK on *satiety change* ($p=.004$) such that those who received feedback reported less *satiety change* than those who did not receive feedback. Finally, no interaction ($p=.489$) was found indicating that average satiety change for those who received feedback was lesser than those who did not receive feedback regardless of plate size. No effect of FEEDBACK on *serving size* or *post-meal satiety* was found. Finally, no interaction between PLATE SIZE and FEEDBACK was reported for *bite size, serving size*, or *post-meal satiety*.

Research question 2—Analyses revealed a main effect of PLATE SIZE on *serving size* ($p=.032$) such that those eating from a larger plate served themselves more than those eating from a smaller plate, on average 34.9 grams more. No effect of PLATE SIZE on *bite size*, *post-meal satiety* or *satiety change* was found. Analyses further revealed a main effect of GOAL on *bite size* ($p=.003$), *serving size* ($p=.023$), *post-meal satiety* ($p<.001$) and *satiety change* ($p<.001$) such that those who received the low goal served themselves more, took larger bites, reported lower levels of satiety after the meal (i.e. lesser fullness) and reported less satiety change from pre-meal levels. Finally, an interaction between PLATE SIZE and GOAL was found on *satiety change* ($p=.014$) such that those who ate from the small plate reported significant changes in *satiety change* between goal levels compared to those who ate from the large plate who did not report significant differences between goal levels. No interaction of PLATE SIZE and GOAL on *bite size, serving size*, or *post-meal satiety* was found.

DISCUSSION

Research question 1: How does the presence of a technology that provides bite count feedback alter eating behavior?

The hypotheses stated that participants would consume more and take more bites when eating from a large plate than participants who ate from a small plate. The findings support this hypothesis. It was further hypothesized that participants who received bite count feedback would consume less and take fewer bites. Likewise, the findings support this hypothesis.

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It has been shown in some previous work that grams consumed and bite count do correlate[11]. The concept behind this research is that a reduction in bite count should result in a reduction in grams consumed. Furthermore, research has shown that when provided with an external cue regarding how much has been consumed (e.g. allowing bottle caps or candy wrappers to accumulate, not bussing tables at a restaurant) individuals will consume less than they otherwise would[16]. It is along this line that by providing bite count as an external cue regarding how much has been consumed, individuals will consume less than they otherwise would.

The plate size cue was considered as a suitable manipulation to test the effect of continuous bite count feedback on eating behavior. It was found that the presence of the feedback did reduce overall consumption however it did not eliminate the plate size effect as people receiving feedback still consumed more when eating from a larger plate than those eating from a smaller plate. It was found that individuals decreased the number of bites they took when receiving feedback, without changing their bite size. This finding shows that people will change their behavior, in this case how many bites they take, without engaging in compensatory behavior such as increasing bite size. Taken together, these results suggest that it may be possible to help people to stop eating earlier than they otherwise would, without feeling any less full immediately following the meal. In other words, it may be possible that by providing bite count feedback, people may stop eating when they are in the low end of the mindless margin.

The results of this research question show that the presence of bite count feedback reduced intake but did not eliminate the effect of plate size. It may be that in order to eliminate this effect, individuals need to be provided with a bite count goal. It is suggested that individuals will eat to a goal regardless of the size of their plates, without changing other impactful behaviors, thus eliminating the effect.

Research question 2: How does the presence of a technology that provides bite count feedback *paired with a goal* alter eating behavior?

Similar to the first research question, it was hypothesized that participants would consume more and take more bites when eating from a larger plate than participants who ate from a smaller plate. The findings of the second research question support the hypothesis. It was further hypothesized that participants who received the low bite count goal would consume less and take fewer bites. The findings did not support this hypothesis. Even though participants in the low bite count goal condition took significantly fewer bites, they did not consume less than those in the high bite count goal. The current study issued participants a goal of eating a certain number of bites. Our results indicate that people were successful in eating to their bite goals. This finding is consistent with current literature that shows if you give people a goal relating to their eating behavior that they will be successful in achieving their goal[18]. However, as highlighted in the current study, efforts to meet target goal behaviors may have unintended consequences on secondary behaviors if these behaviors are also not considered as part of the goal. For example, in the current study, some participants were given a low bite goal but were not instructed to decrease consumption. Although participants were successful in eating to their bite goal, a change in other behaviors was

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observed (i.e., changing bite size) leading to no change in consumption compared to those given a high bite goal.

It was found that those in the low goal condition significantly increased their bite size over those in the high goal condition, taking on average 3.5 more grams per bite. It is possible that individuals believed 12 bites to be an inappropriately low number of bites to take during a lunch-time meal. The finding from this research question of increased serving sizes in the low goal condition lends support to the notion that individuals may have changed their behavior in anticipation of only being able to take 12 bites, prior to serving, in this case making sure they had enough food supply to maximize each allowed bite. Once eating commenced, it is plausible that participants took much larger bites in an effort to feel satisfied in the presence of a restricting goal from the experimenter.

If a bite-by-bite analysis revealed that participants took larger bites starting with the first bite, then there would be support for the above hypothesis. Alternatively, if the analysis revealed that participants only increased their bite size as they approached the bite goal then there would be support for the hypothesis that participants became conscious of the fact that 12 bites is less than they would typically take while eating. However, a microanalysis of the bite by bite eating behavior is beyond the scope of the current work as bite to bite grams consumed data were not monitored.

CONCLUSION

The purposes of the two studies described above were to determine if the availability of continuous feedback on the number of bites taken would: (a) have an effect on overall intake; and (b) have an effect on the eating behavior of individuals affected by the cue of plate size. Furthermore, the purpose was to determine if feedback would (c) have an effect on overall intake when paired with an eating goal, and (d) have an effect on the eating behavior of individuals affected by the cue of plate size when paired with an eating goal.

It was found that the presence of bite count feedback led to a reduction in overall consumption. This finding is consistent with current literature that shows feedback on consumption leads people to consume less[19]. It was found however that this type of feedback does not eliminate the effect of environmental cues such as plate size. Individuals may eat less when they receive bite count feedback, but feedback alone may not be sufficient in terms of helping them to take an “appropriate” or “normal” number of bites, particularly in the presence of large plates. One possible explanation for this is that individuals may not know what exactly constitutes an “appropriate” or “normal” number of bites; even if bite count feedback is present, they don’t know when to stop eating thus environmental cues are still influential. The notion that individuals do not know what an “appropriate” or “normal” number of bites are, is in line with current literature that has shown that humans have a poor ability to control intake and to estimate calories[20]. To test this hypothesis and in an attempt to mitigate the plate size effect, we further investigated the effect of a bite count goal.

As described above, the findings were partially unexpected. Of particular note is that individuals who received the low bite count goal did not consume any less than those who

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received the high bite count goal. Although participants who were given the low goal were successful in eating to and stopping at their bite count goal, a concurrent increase in bite size resulted in comparable consumption regardless of goal assignment. It is possible that this compensatory behavior is intentional, a reaction to a perceived limitation such that participants believed 12 bites to be to restricting of a goal. In other words, in an effort to reach satiety while not surpassing the given goal, participants felt as though they needed to take larger bites perhaps than they typically would.

The question then becomes not “will individuals use bite count feedback to eat to a given goal”, but “how can individuals or practitioners set appropriate goals, such that individuals working towards the goal do not feel compelled to compensate by changing other behaviors?” The answer to that question is not immediately clear. One possible approach is a bite count goal titration method such that a goal is based on an individual’s average bite count, and formulated by subtracting only a small number of bites at a time (e.g. two or three). This method could be implanted multiple times until a change in bite size is observed.

Limitations

Generalizability of this research is limited due to a homogenous sample: Participants were all college undergraduates, most of whom fell within healthy BMI ranges. Furthermore, the authors did not block on BMI to determine if that measure would affect the outcome. Additionally, this research question could have implemented more measures to ensure for greater comparability between the groups. Although the groups were balanced by gender composition, other impactful factors such as restrained eaters were not considered. In future experiments, a more diverse sample should be examined and other characteristics controlled for and balanced such as those above.

Another limitation is that the exact cause of the change in *bite size* among those in the low bite goal condition is unknown. Such hypotheses as those proposed in the discussion of the second research question and accompanying analyses were outside the scope of the current study however future studies could implement such approaches, as well as the inclusion of additional controls, manipulation checks, and subjective inquiries in an attempt to isolate the cause of the effects observed.

Future research should also consider implementing a manipulation in all groups. The authors acknowledge that all groups should receive some form of manipulation as it may be unclear if the specific feedback itself in the first research question was the catalyst for the change in behavior or if the fact that one group had a manipulation and the other did not was the cause of the behavior change.

Additional future research should examine the micro-structural pattern of intake i.e. eating rate. The influence of the Bite Counter on behavioral outcomes such as inter-bite-interval (time between bites) and cumulative food intake curves is of great interest as it has been shown that these behaviors influence intake[21].

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Finally, it may be beneficial to obtain participant baselines prior to subjecting them to a goal condition as reported in research question 2. As seen in the results, individuals were successful at eating to their given bite goals. However they changed other behaviors leading to no difference in intake between conditions. A consideration of baseline behaviors prior to goal creation and implementation may be useful in achieving a reduction in intake.

Application

Although the results from these studies highlight the broader reaching impacts of bite count goals without providing a fool-proof method of controlling impactful behaviors , the utility of bite count feedback as a mechanism to help people monitor intake has been shown to be valuable as its mere presence leads people to eat less than they typically would.

Wearable technologies, particularly wrist-worn devices such as the “Apple iWatch”, “Pebble”, and “Fitbit” are becoming increasingly popular[22]. These are some examples of the devices discussed above that aim at augmenting human performance and health outcomes[23]. The results of the current study show that it is important for scientists to study how interventions which employ these devices may affect primary (the behavior intended to be changed) and secondary behaviors (behaviors not intended to be changed). In the case of the Bite Counter, it is clear that feedback from the device alone can reduce intake and bite count in a single eating session. However, when the feedback is coupled with a goal, if the bite count goal is somehow considered unreasonable by the individual targeted, they may compensate by altering other behaviors, i.e. increasing bite size. Therefore, specific device feedback and intervention goals should be simultaneously considered in future research.

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Table 1

Sample size and demographics by condition for the feedback only study.

	No feedback		Feedback	
	Large plate	**Small plate**	**Large plate**	**Small plate**
Sample size	20	25	22	27
Gender (females)	14	15	16	17
Age (mean±SD)	18.9±1.2	19.1±2.2	18.8±1.2	19.2±1.5
BMI (mean±SD)	22.6±2.9	23.2±4.3	22.8±2.9	23.4±4.4
Ethnicity (Caucasian)	15	18	15	23

Feedback refers to the presence of visible real-time bite count provided by the Bite Counter

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Table 2

Sample size and demographics by condition for the feedback + goal study.

	Low goal		High goal	
	Large plate	**Small plate**	**Large plate**	**Small plate**
Sample size	28	32	22	17
Gender (females)	16	17	11	12
Age (mean±SD)	18.3±.98	18.6±1.2	18.4±2.4	18.8±1.3
BMI (mean±SD)	22.7±2.9	22.8±3.2	22.1±1.8	23.3±2.2
Ethnicity (Caucasian)	27	26	20	14

Goal is defined by a target bite count. The low and high goals are 12 and 22 bites respectively

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Table 3

Descriptive statistics of *grams consumed* and *bites taken* of 94 participants who completed the study to determine the effect of plate size and feedback on intake. On *grams consumed*, plate size (p=.001) and feedback (p=.011) had significant effects. On *bites taken*, plate size (p=.001) and feedback (p<.001) had significant effects.

		No feedback		Feedback	
		Large plate	**Small plate**	**Large plate**	**Small plate**
Variable	Grams consumed (mean±SD)	166.95 ± 63.31	144.06 ± 34.03	151.64 ± 57.24	107.53 ± 27.31
	Bites taken (mean±SD)	20.5 ± 6.8	18.5 ± 6.2	17.9 ± 5.2	12.0 ± 3.8

Feedback refers to the presence of visible real-time bite count provided by the Bite Counter

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Table 4

Descriptive statistics of *grams consumed* and *bites taken* of 99 participants who completed the study to determine the effect of plate size and bite count goal on intake. On *grams consumed*, plate size (p=.003) had a significant effect. On *bites taken*, bite count goal (p<.001) had a significant effect.

		Low goal		High goal	
		Large plate	**Small plate**	**Large plate**	**Small plate**
Variable	Grams consumed (mean±SD)	172.59 ± 59.49	132.51 ± 49.71	174.56 ± 58.40	146.26 ± 52.20
	Bites taken (mean±SD)	12.2 ± 1.6	11.7 ± 3.2	17.5 ± 4.8	16.2 ± 5.8

Goal is defined by a target bite count. The low and high goals are 12 and 22 bites respectively.

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