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Tracking food intake as bites: Effects on cognitive resources, eating enjoyment, and self-control

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While monitoring food intake is critical for controlling eating, traditional tools designed for this purpose can be impractical when one desires real-time feedback. Further, the act of monitoring can deplete valuable cognitive resources. In response to these concerns, technologies have been developed to aid those wanting to control their food intake. Of note, devices can now track eating in number of bites taken as opposed to more traditional units such as pieces or volume. Through two studies, the current research investigates the effects of tracking food portions at the bite level on cognitive resources, enjoyment of the eating experience, and objective and subjective self-control. Results indicate that using wearable technology to track bite portions, as compared to doing so mentally, (1) reduces cognitive resource depletion, (2) is equally as effective for allowing users to successfully achieve eating goals, and (3) does not reduce enjoyment of the eating experience. These results support the viability of tracking food intake at the bite level, which holds a number of potential implications for eating and weight management.

1. Introduction

Obesity has more than doubled worldwide since 1980 (World Health Organization, 2015). In the United States, approximately 35% of men and 40% of women are currently classified as obese (Flegal, Kruszon-Moran, Carroll, Fryar, & Ogden, 2016). Weight-related health and vanity concerns have led to a $60 billion market for weight-loss products in the United States alone (Marketdata Enterprises Inc. 2015). While numerous approaches for weight loss exist, clinical and behavioral research emphasizes the critical role of self-monitoring (Burke, Wang, & Sevick, 2011). Specifically, weight loss is associated with monitoring body weight, energy expenditure, and energy intake (e.g., Bravata et al., 2007; Buzzard et al., 1996). Body weight and energy expenditure are relatively easily assessed. However, the continuous, accurate, and externally valid long-term measurement of energy intake remains a challenge for free-living individuals (Allan, Johnston, & Campbell, 2010; Goris, Westerterp-Plantenga, & Westerterp, 2000).

Traditional tools designed to track energy intake, such as food diaries and food scales, can be cumbersome and impractical for real-time monitoring in normal daily living (Burke et al., 2008), and self-report measures using survey-type scales are subject to both validity and reliability limitations (Barclay, Rushton, & Forwell, 2015; Cade, Thompson, Burley, & Warm, 2002). Because the operationalization of constructs and the methods of measurement vary considerably across studies, inconsistencies in reported rates of excessive food consumption are not surprising. However, a number of technologies, including smartphone applications (Allen, Stephens, Dennison Himmelfarb, Stewart, & Hauck, 2013; Wharton, Johnston, Cunningham, & Sterner, 2014), wearable cameras (Doherty et al., 2013), and complex-but-portable systems (Norman et al., 2007; Sun et al., 2010), have recently been developed or adapted to enable users to self-monitor eating under conditions and at levels of precision not previously feasible. Importantly, technology-based interventions can be effective aids to weight loss, perhaps by equipping the user with a greater sense of control (Raaijmakers, Pouwels, Berghuis, & Nienhuijs, 2015).

The present research focuses on methods for tracking food intake at the bite level. In particular, we consider a wearable technology designed specifically for tracking the number of times food is placed in one's mouth (but not the number of times the food is chewed once it is in the mouth). Whereas food portions are typically defined by a number of pieces, such as three cookies, or volume, such as one cup of cereal (e.g., Marchiori, Papies, & Klein,

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2014), this counting device enables food portions to be defined by bites. The number of bites registered by the device is positively correlated with caloric intake, and, with calibration, the device leads to more accurate estimates of caloric intake than human methods (Salley, Hoover, Wilson, & Muth, 2016; Scisco, Muth, & Hoover, 2014). That is, the user must calibrate to his/her eating habits by gaining an understanding of the number of bites required to consume a desired number of calories for a given time period (e.g., a day) or eating episode (e.g., breakfast) based on the user's typical diet. This knowledge can then be used to set bite goals (e.g., 100 bites per day or 30 bites for breakfast). If necessary, the individual can adjust these goals based on actual or anticipated food intake (e.g., lowering the bite goal if high-calorie food has been or will be consumed). Thus, while the counter does not allow users to know the exact number of calories consumed, bites are positively correlated with caloric intake, and, if calibrated correctly, the device provides an accurate proxy.

Muth and colleagues (Dong, Hoover, Scisco, & Muth, 2012; Salley et al., 2016; Scisco et al., 2014; Wilson, Kinsella, & Muth, 2015) report the device to be highly accurate when measuring eating behavior in both controlled (laboratory) and uncontrolled (home, restaurant) meal settings. While accuracy is important, the device may have both positive and negative, and perhaps unintended, consequences that could ultimately impact its usefulness as a weight-loss tool. Thus, the present research addresses two primary research questions. First, does tracking food intake at the bite level influence enjoyment of the eating experience? If monitoring eating in this way reduces enjoyment of the food or of other aspects of the experience, people are less likely to use the technique. Second, if one tracks food intake at the bite level, can wearable monitoring devices conserve cognitive resources? As we subsequently discuss, an individual's cognitive resources are limited, and self-monitoring drains these limited resources. However, by delegating monitoring to the device, users may conserve cognitive resources for use in other ways, such as stopping eating at the appropriate time.

Two experimental studies examine these research questions. Study 1 addresses the first research question by assessing enjoyment of the eating experience. Study 2 addresses the second question by assessing cognitive resources. In the final sections, we discuss the results and implications of the findings, and we offer directions for future research.

2. Literature review

Although the causes of obesity are manifold, a lack of self-control while eating is often a contributing factor (Chapman, Benedict, Brooks, & Schiöth, 2012; Kaisari, Yannakoulia, & Panagiotakos, 2013). Baumeister (2002) proposes that self-control is a function of (1) goals or standards, (2) resources for engaging in self-control, and (3) behavior monitoring. While goals for energy intake during an eating episode are relatively easy to establish, the resources needed and means by which to engage in self-control and self-monitoring are more problematic (Baker & Kirschenbaum, 1993; Hofmann, Adriaanse, Vohs, & Baumeister, 2014; Wansink, Just, & Payne, 2009). Because resources and monitoring are inherently intertwined, self-monitoring can deplete cognitive resources (Baumeister, Bratslavsky, Muraven, & Tice, 1998).

Researchers studying food intake often desire to reduce the burden placed on study participants or other effects of food intake measurement on the natural physical and psychological processes of the participants (Andresen, 2000; Barclay et al., 2015; Tokudome et al., 2005). In such cases, devices that covertly monitor food consumption may prove useful. However, while covert devices reduce intrusion, their purpose is to observe normal eating behavior, not to encourage the user to change her or his behavior (Robinson, Kersbergen, Brunstrom, & Field, 2014; Thomas, Dourish, & Higgs, 2015). Conversely, when the goal is to alter real-time behavior, wearable monitoring technology designed to provide immediate feedback about food intake may encourage users to change their food consumption. Based on Baumeister's (2002) model, wearable monitoring technologies could improve self-control by making it easier for users to accurately monitor how much they have eaten without depleting the cognitive resources necessary for self-control.

A second factor that often derails people who are trying to control their weight is their delight in palatable foods (Stroebe, 2008). Stroebe, Van Koningsbruggen, Papies and Aarts (2013) propose that restrained eating behavior can be compromised by dieters' conflicting goals of weight loss and eating enjoyment. Indeed, food cravings consume cognitive resources (Kemps, Tiggemann, & Grigg, 2008). Dieters have trouble restricting their food intake because the presence of high-calorie, tasty food activates their anticipated eating pleasure and dampens their weight-loss objectives (Redden & Haws, 2013). Consequently, restricting high-calorie food intake is viewed by dieters as deprivation. Further, people who have lower levels of self-control pay less attention to their food intake when consuming unhealthy food. This results in a longer time interval before reaching satiation and eventual overeating (Redden & Haws, 2013). However, self-awareness increases self-control (Alberts, Martijn, & De Vries, 2011). Consider, for example, the finding that using a clicker counter to track each swallow of food allows those with low self-control to reach satiation for unhealthy foods at a rate similar to those with high self-control (Redden & Haws, 2013). Unfortunately, such means of focusing attention are often impractical outside of a controlled laboratory setting. However, wearable monitoring technologies may provide a compromise by allowing individuals to partake in tasty foods (within parameters) but also remain aware of their weight-loss goals and food intake.

There is abundant and consistent evidence that controlling food portions has a significant influence on reducing caloric intake (Hannum et al., 2004; Hollands et al., 2015; Rolls, 2003; Rolls, Morris, & Roe, 2002; Wansink, 1996; Young & Nestle, 2003). Nevertheless, individuals are notoriously inaccurate when it comes to estimating appropriate portions (Huizinga et al., 2009; Jonnalagadda et al., 1995; Wansink, Painter, & North, 2005) and often succumb to mindless eating (Wansink et al., 2009). To assist people in determining appropriate portions, many food manufacturers have implemented reduced-portion packaging (Jain, 2012; Peters, 2007). However, for dieters, small packages may provide conflicting cues (high-calorie, diet food), and can have the unintended result of overconsumption (Scott, Nowlis, Mandel, & Morales, 2008). Given this research background, the subsequent studies focus on the effects of various means of monitoring portion control at the bite level on (1) enjoyment of the eating experience (Study 1), (2) cognitive resources (Study 2), and (3) perceptions of the determinants of self-control (Studies 1 and 2).

3. Study 1

3.1. Participants, procedure and measures

Study 1 employed an experimental design to provide insight into the effects of various ways of monitoring eating on perceptions of the determinants of self-control, as specified by Baumeister (2002), and on enjoyment of the eating experience. For Study 1, IRB approval was obtained and all data were collected at the first two authors' university. In a controlled lab setting, participants ate bite-sized crackers (Cheez-Its) while watching a video to simulate the common act of eating while watching television. One hundred and sixteen undergraduate college students, profiled in Table 1, participated in Study 1 in exchange for $3 and extra course credit. Prior to beginning the study, participants were told what type of food they would be eating and could opt out. Those who chose to participate were randomly assigned to one of four conditions. Study sessions included between 1 and 10 participants, with assignment to the conditions done at the session level (i.e., everyone in a given session was in the same condition). Conditions were randomized throughout the day to avoid a time of day confound.

The four conditions were (1) wearable counter, (2) mental tracking, (3) controlled portion, and (4) eat-what-you-want (EWYW). In the wearable counter, mental tracking, and controlled portion conditions, participants were given the goal of eating 20 bite-sized crackers, and they were asked to eat one cracker at a time. Both the food used in the study and the 20-cracker goal were chosen after considerable pretesting of a number of food types, and details of the pretests are available from the authors upon request. In the wearable counter condition, participants used a Bite Counter™, shown in Fig. 1, to monitor the number of crackers eaten. This monitoring device, similar to a wrist watch, involves minimal participant effort and has been shown to accurately detect in real time the number of bites taken across a variety of eating conditions (Dong et al., 2012; Hoover, Muth, & Dong 2010). A bite is registered by the device when the participant places a cracker in his/her mouth, which was our operational definition of a bite. Thus, assuming participants followed instructions by eating one cracker at a time, the device served to track the number of crackers eaten. The number of bites taken was displayed on the device's screen, and participants could see this information at any time. Participants were given verbal instructions on how to use the device, which included a brief practice period. In the mental tracking condition, participants mentally counted the number of crackers they ate without the aid of a device. In the EWYW condition, participants were asked to eat one cracker at a time, as in the other conditions. However, they were told they could eat as many crackers as they desired, and they were not asked to track the number of crackers eaten. In the wearable counter, mental tracking, and EWYW conditions, the crackers were placed in a container of 60 total crackers, though participants did not know the number of crackers in the container and were not allowed to count the crackers prior to eating them. In the controlled portion condition, participants were given a container of exactly 20 crackers, and they were informed of the number of crackers in the container.

Notes: The Bite Counter™ is worn on the wrist like a watch, detects a wrist-rolling motion in order to observe that the wearer has taken a bite of food, and records a log of time-stamped bite count data in real-time. Further details can be found at www.icountbites.com.

Fig. 1. Bite Counter™.

While eating the crackers, participants watched a 7-min video, pretested to ensure that it was entertaining. They wore headphones and were separated by partitions to minimize distractions. In the mental tracking and wearable counter conditions, participants were instructed to stop eating upon reaching the stated goal. In the controlled portion condition, participants were instructed to eat all of the crackers. In the EWYW condition, participants were told that they could eat as many crackers as they desired. At the conclusion of the video, the containers were collected to determine the number of crackers each participant actually ate.

Participants then responded to two items pertaining to the video ("How enjoyable was the video? Not at all entertaining/Very entertaining," and "How much did you focus on the video? Very little/A lot") and three items pertaining to the crackers ("How enjoyable was the food? Not at all enjoyable/Very enjoyable," "How tasty was the food? Not at all tasty/Very tasty," and "How filling was the food? Not at all filling/Very filling"). Each item was assessed on a seven-point scale.

Next, participants responded to a series of seven-point Likert items based on Baumeister's (2002) determinants of self-control. Two items assessed participants' perceptions of the clarity of their eating goals ("Before I started eating, I knew precisely how much to eat," "Prior to eating, the amount that I should eat was

Table 1
Study 1 participant characteristics.

Characteristic	Overall sample[b] (n = 116)	Condition[a]			
		1 (n = 36)	2 (n = 28)	3 (n = 26)	4 (n = 26)
Gender	62% F	40% F	50% F	65% F	42% F
Currently on a diet	11%	13%	18%	8%	4%
Concern over weight[c,g]	2.94	2.93	3.00	3.04	2.81
	(1.42)	(1.44)	(1.39)	(1.54)	(1.36)
Need for cognition[d,g]	2.40	2.38	2.32	2.50	2.41
	(0.90)	(0.94)	(0.88)	(0.93)	(0.88)
Self-confidence[e,g]	4.14	4.15	4.07	4.31	4.04
	(0.95)	(1.05)	(0.94)	(0.79)	(0.96)
New technology adoption[f,g]	4.25	4.05	4.32	4.31	4.42
	(0.94)	(1.01)	(1.02)	(0.97)	(0.64)

Notes: Cells contain percentages (females and participants currently on a diet) or means (top number) and standard deviations (in parentheses). There were no significant differences in these characteristics across conditions.
[a] Condition 1 = wearable counter; Condition 2 = mental tracking; Condition 3 = controlled portion; Condition 4 = eat-what-you-want (EWYW).
[b] All participants were sophomore, junior, or senior level undergraduate students.
[c] Average of item "I am concerned about my weight".
[d] Average of three items such as "Thinking is not my idea of fun".
[e] Average of item "On the whole, I am satisfied with myself".
[f] Average of item "I like to use new technologies".
[g] Five-point scales anchored by "very uncharacteristic of me" and "very characteristic of me".

unmistakable"; $r = 0.80$). Two items assessed participants' perceptions of available resources for monitoring their eating ("While I was eating, my ability to monitor my eating was high," "I feel like I had the ability to focus on my eating while I was eating"; $r = 0.78$). Two items measured participants' perceptions of the extent to which they monitored their eating ("While eating, I kept track of how much I ate," "I checked the amount of food I ate while I ate"; $r = 0.63$). Two items measured participants' perceptions of the extent to which they exercised self-control ("I stopped eating when I should have," "I ate the appropriate amount"; $r = 0.60$). Responses to each of these pairs of items were averaged.

Finally, in hopes of ruling out individual differences as potential confounds for any differences in the primary dependent variables across conditions, participants responded to the items indicated in Table 1 that measured (1) gender, (2) whether the participant was currently on a diet, (3) concern about one's weight, (4) tendency to engage in and enjoy thinking (with three items from Cacioppo and Petty's (1982) need for cognition scale), (5) self-confidence, and (6) new technology adoption. The last four measures were assessed with five-point scales.

3.2. Statistical analysis

For the scaled response dependent variables and individual difference measures, we ran analysis of variance (ANOVA) to determine significant differences across conditions. For measures that did differ significantly across conditions, we ran Tukey range tests to determine which pairs of means were significantly different. The Tukey test corrects for the family-wise error rate due to multiple comparisons. For gender and being on a diet, we ran chi-square tests to determine if participant characteristics differed across conditions.

3.3. Results

ANOVA on the concern over weight, need for cognition, self-confidence, and new technology adoption measures shown in Table 1 indicated no significant differences across conditions (all p-values > 0.40). Chi-square tests indicated that the percentage of females/males (p-value = 0.21) and the percentage of participants currently on a diet (p-value = 0.37) did not significantly differ across conditions. Thus, these individual differences are not viable explanations for subsequent effects observed across conditions in the primary dependent variables.

Tables 2 and 3 contain the results of the ANOVA F-tests and subsequent Tukey tests, along with means and standard deviations for each dependent variable. As shown in Table 2, on average, participants ate significantly more crackers in the EWYW condition than in the conditions involving a goal. However, the average number of crackers eaten did not differ across the three conditions involving a 20-cracker goal. While perceptions of having a goal did not differ across the three goal conditions, perceptions of having a goal were significantly lower in the EWYW condition than in the goal conditions. Perceived resources for monitoring did not differ across the wearable counter and mental tracking conditions. However, monitoring resources perceptions were significantly lower in the controlled portion and EWYW conditions. Perceived monitoring was significantly higher in the wearable counter and mental tracking conditions than in the controlled portion and EWYW conditions. Perceived self-control was significantly higher in the controlled portion than in the EWYW condition, but did not differ for the other two conditions.

Regarding the experience, as shown in Table 3, enjoyment of the video did not differ across the eating goal conditions. However, participants in the EWYW condition enjoyed the video more than participants in the wearable counter condition. The controlled portion and EWYW conditions allowed participants to focus more on the video than did the mental tracking and wearable counter conditions, but focus on the video did not differ across the mental tracking and wearable counter conditions. Perceptions of the food (enjoyment, taste, filling) did not differ across any of the conditions.

3.4. Discussion

Participants in the EWYW condition ate significantly more crackers than participants in the other conditions. Thus, speaking to the realism of the imposed eating constraints, the eating control conditions (i.e., those with a 20-cracker goal) did restrict participants' natural eating behaviors. Demonstrating the accuracy of the counter, the number of crackers eaten did not differ across the wearable counter, mental tracking, and controlled portion conditions. Thus, although research shows that distractions such as socializing and watching television can negatively impact food intake monitoring (Wansink, 2004), this effect did not manifest in Study 1. Perceptions of having a goal, monitoring resources, actual monitoring, and self-control did not differ across the wearable counter and mental tracking conditions. However, participants had higher perceptions of monitoring resources and actual monitoring in the

Table 2
Study 1 results: number of crackers eaten and self-control constructs.

Condition	# of crackers eaten	Perceived goal[a,e]	Perceived monitoring resources[b,e]	Perceived monitoring[c,e]	Perceived self-control[d,e]
(1) Wearable counter	21.97	6.18	4.88	5.74	5.61
	(3.56)	(1.39)	(1.64)	(1.54)	(1.74)
(2) Mental tracking	20.39	6.80	4.39	5.54	5.39
	(3.38)	(0.39)	(1.43)	(1.18)	(1.62)
(3) Controlled portion	20.00	6.42	3.50	3.38	6.12
	(0.00)	(1.04)	(1.44)	(2.02)	(1.37)
(4) EWYW	32.81	2.90	3.08	2.87	4.81
	(13.39)	(1.46)	(1.22)	(1.38)	(1.38)
$F(3, 112)$	20.86	63.57	9.43	25.82	3.17
p-value	<0.01	<0.01	<0.01	<0.01	0.03
Tukey significant differences	(4) > (1), (2), (3)	(4) < (1), (2), (3)	(4) < (1), (2); (3) < (1)	(4) < (1), (2);(3) < (1), (2)	(3) > (4)

Notes: Cells in the four rows indicating the conditions contain means (top number) and standard deviations (in parentheses).
[a] Average of items "Before I started eating, I knew precisely how much to eat" and "Prior to eating, the amount that I should eat was unmistakable".
[b] Average of items "While I was eating, my ability to monitor my eating was high" and "I feel like I had the ability to focus on my eating while I was eating".
[c] Average of items "While eating, I kept track of how much I ate" and "I checked the amount of food I ate while I ate".
[d] Average of items "I stopped eating when I should have" and "I ate the appropriate amount".
[e] Seven-point scales anchored by "Strongly disagree" and "Strongly agree".

Table 3
Study 1 results: perceptions of the experience.

Condition	"How enjoyable was the video?"[a]	"How much did you focus on the video?"[b]	"How enjoyable was the food?"[c]	"How tasty was the food?"[d]	"How filling was the food?"[e]
(1) Wearable counter	5.28 (1.06)	4.83 (1.40)	5.75 (1.00)	5.78 (1.10)	3.61 (1.38)
(2) Mental tracking	5.50 (1.04)	4.79 (1.50)	5.86 (1.01)	5.75 (1.11)	3.29 (1.18)
(3) Controlled portion	5.50 (1.18)	5.77 (1.18)	5.77 (1.03)	5.81 (1.13)	3.88 (1.86)
(4) EWYW	6.08 (0.98)	6.15 (0.97)	5.88 (0.99)	6.04 (0.92)	4.15 (1.29)
F (3, 112)	2.95	7.92	0.13	0.41	1.82
p-value	0.04	<0.01	0.95	0.75	0.15
Tukey significant differences	(4) > (1)	(4) > (1), (2); (3) > (1), (2)			

Notes: Cells in the four rows indicating the conditions contain means (top number) and standard deviations (in parentheses).
[a] Severn-point scale anchored by "Not at all entertaining" and "Very entertaining".
[b] Seven-point scale anchored by "Very little" and "A lot".
[c] Seven-point scale anchored by "Not at all enjoyable" and "Very enjoyable".
[d] Seven-point scale anchored by "Not at all tasty" and "Very tasty".
[e] Seven-point scale anchored by "Not at all filling" and "Very filling".

wearable counter and mental tracking conditions compared to the controlled portion and EWYW conditions. Perceived self-control was higher for the controlled portion condition than for the EWYW condition, but did not differ across the other conditions.

While the wearable counter reduced enjoyment of the video relative to the EWYW condition, enjoyment of the video did not differ across the conditions in which participants controlled their eating. Further, enjoyment of the food did not differ across any of the conditions. In sum, the results of Study 1 suggest that, for people wanting to control their food intake, actively monitoring portions at the bite level is a viable strategy. Doing so allows participants to achieve the stated eating goal, does not detract from the eating experience, and has beneficial effects on perceived monitoring resources. Given that Baumeister (2002) argues that people need adequate resources for controlling their behavior, this last finding suggests further examination as to whether the Bite Counter™ goes beyond enhancing perceptions of conserving cognitive resources by objectively conserving these resources. Study 2 investigates this possibility.

4. Study 2

4.1. Participants, procedure and measures

As effectively used in previous research on self-regulation and resource depletion (e.g., Vohs, Baumeister, & Ciarocco, 2005), Study 2 employed a dual-task design to examine the effect of the monitoring device on users' cognitive resources. If an initial task depletes one's resources, the person's performance on a subsequent task will suffer. In Study 2, the initial task was regulating eating, and the subsequent task was solving a word scramble. We conducted an experiment by randomly assigning participants to one of two conditions. One hundred and five undergraduate college students, profiled in Table 4, participated in Study 2 in exchange for $5 and extra course credit. For Study 2, IRB approval was obtained, and all data were collected, at the first two authors' university. Study 2 participants had not participated in Study 1. Prior to beginning the study, participants were told what type of food they would be eating and could opt out. Forty-nine participants were assigned to the mental tracking condition, and 56 were assigned to the Bite Counter™ condition. In both conditions, participants were

Table 4
Study 2 participant characteristics.

Characteristic	Overall sample[a] (n = 105)	Condition	
		Wearable counter (n = 56)	Mental tracking (n = 49)
Gender	61% F	59% F	63% F
Currently on a diet	16%	14%	18%
Concern over weight[b,f]	3.49 (1.35)	3.52 (1.34)	3.45 (1.37)
Need for cognition[c,f]	2.32 (0.89)	2.40 (0.84)	2.24 (0.95)
Self-confidence[d,f]	4.10 (0.92)	4.12 (0.92)	4.08 (0.93)
New technology adoption[e,f]	4.20 (0.91)	4.21 (0.93)	4.18 (0.88)

Notes: Cells contain percentages (females and participants currently on a diet) or means (top number) and standard deviations (in parentheses). There were no significant differences in these characteristics across conditions.
[a] All participants were sophomore, junior, or senior level undergraduate students.
[b] Average of item "I am concerned about my weight".
[c] Average of three items such as "Thinking is not my idea of fun".
[d] Average of item "On the whole, I am satisfied with myself".
[e] Average of item "I like to use new technologies".
[f] Five-point scales anchored by "very uncharacteristic of me" and "very characteristic of me".

instructed to eat 35 bite-size cookies (Mini Chips Ahoy) by eating an entire cookie with each bite. As in Study 1, a bite was operationally defined as a participant placing a cookie in her/his mouth. Participants were given containers of 50 bite-sized cookies. Participants did not know the total number of cookies in the container, and they were not allowed to count the cookies prior to eating them. Participants were told to stop eating after consuming 35 cookies, and they turned in the remaining cookies so that the actual number of cookies eaten could be determined. In the mental tracking condition, participants mentally tracked the number of cookies they ate. In the wearable counter condition, participants used a Bite Counter™ to track the number of cookies eaten as in Study 1. Study sessions included between 1 and 10 participants, and assignment to the conditions was done at the session level (i.e., everyone in a given session was in the same condition). Conditions were randomized throughout the day to avoid a time-of-day confound. While eating the cookies, participants were separated by partitions to minimize distractions.

After the eating task, participants were presented with the word scramble task. Participants saw ten scrambled words, presented one at a time via computer and progressively more difficult. Performance on such tasks has been used previously as evidence of resource depletion in a dual-task design (Vohs & Heatherton, 2000; Vohs et al., 2005). Participants either attempted to solve the scrambled word or gave up and proceeded to the next word, and each participant's answers and the total time spent attempting to solve the scrambles were recorded. After the word scramble task, participants responded to a series of seven-point Likert items. Using the same measures as in Study 1, two items assessed participants' perceptions of the clarity of their eating goals ($r = 0.52$), two items assessed participants' perceptions of available resources for monitoring their eating ($r = 0.73$), two items measured participants' perceptions of the extent to which they monitored their eating ($r = 0.69$), and two items measured participants' perceptions of the extent to which they exercised self-control ($r = 0.89$). Responses to each of these pairs of items were averaged. One item assessed the perceived difficulty of the word scramble task ("Overall, how difficult did you find the word scramble task to be? Very easy/Very hard"). Finally, participants responded to the same demographic and individual difference measures as in Study 1.

4.2. Statistical analysis

For the scaled response dependent variables and individual difference measures, independent samples t-tests were used to test for differences across conditions. For gender and being on a diet, chi-square tests assessed if these participant characteristics differed across conditions.

4.3. Results

T-tests on the concern over weight, need for cognition, self-confidence, and new technology adoption measures shown in Table 4 indicated no significant differences across conditions (all p-values > 0.38). Chi-square tests indicated that the percentage of females/males (p-value = 0.62) and the percentage of participants currently on a diet (p-value = 0.52) did not significantly differ across conditions. Thus, these individual differences are not viable explanations for subsequent effects observed across conditions in the primary dependent variables.

Table 5 displays means and standard deviations for each dependent variable, along with results of t-tests comparing these measures across conditions. The average number of cookies eaten did not significantly differ across conditions, nor did it differ from the goal of 35 in either condition (mental: t (48) = −0.03, two-tailed $p = 0.97$; wearable counter: t (56) = 0.44, two-tailed $p = 0.66$). Thus, mental tracking and the wearable counter were equally effective at enabling participants to achieve the stated goal. Participants in the wearable counter condition perceived that they had more resources for monitoring their eating. No differences were found in perceptions of actual monitoring, having clear goals, or exercising self-control. This last result is also supported by the nonsignificant difference in objective self-control (i.e., the number of cookies eaten).

Testing for cognitive resource depletion, participants in the wearable counter condition correctly solved significantly more word scrambles than did participants in the mental tracking condition (t (103) = −2.42, two-tailed $p = 0.02$), and they spent significantly less time working to solve the scrambles (t (103) = 2.92, two-tailed $p < 0.01$). Supporting these results, participants in the wearable counter condition perceived that the word scramble task was (marginally) less difficult than did participants in the mental tracking condition ($t_{103} = 1.71$, two-tailed $p = 0.09$).

4.4. Discussion

As in Study 1, the Bite Counter™ was equally as effective as mental tracking for enabling participants to achieve the stated goal, further supporting the accuracy of this monitoring device (e.g., Dong et al., 2012). Central to the goal of Study 2, compared to mental tracking, the wearable counter enhanced participants' perceptions of their ability to monitor their eating and, importantly, conserved actual cognitive resources. Participants who used the counter were able to solve more word scrambles, and took less time doing so, than participants who tracked their eating mentally. These results suggest that individuals were able to delegate the psychological effort of monitoring their food intake to the counter.

Table 5
Study 2 results: number of cookies eaten, self-control constructs, and cognitive resource depletion.

Condition	# of cookies eaten	Perceived goal[a,e]	Perceived monitoring resources[b,e]	Perceived monitoring[c,e]	Perceived self-control[d,e]	# of correct word scrambles	Time spent solving scrambles (seconds)	Perceived difficulty of word scramble task
Wearable counter	35.21 (3.53)	6.51 (1.18)	6.47 (1.24)	6.53 (1.20)	6.06 (1.84)	9.55 (0.76)	77.19 (30.39)	3.52 (2.43)
Mental tracking	34.99 (3.01)	6.62 (0.88)	5.68 (1.27)	6.28 (0.95)	6.07 (1.29)	8.92 (1.79)	99.76 (47.86)	4.31 (2.28)
t (103)	-0.34	0.55	−3.22	−1.18	0.03	−2.42	2.92	1.71
p-value	0.73	0.58	<0.01	0.24	0.98	0.02	<0.01	0.09

Notes: Cells in the two rows indicating the conditions contain means (top number) and standard deviations (in parentheses).
[a] Average of items "Before I started eating, I knew precisely how much to eat" and "Prior to eating, the amount that I should eat was unmistakable".
[b] Average of items "While I was eating, my ability to monitor my eating was high" and "I feel like I had the ability to focus on my eating while I was eating".
[c] Average of items "While eating, I kept track of how much I ate" and "I checked the amount of food I ate while I ate".
[d] Average of items "I stopped eating when I should have" and "I ate the appropriate amount".
[e] Seven-point scales anchored by "Strongly disagree" and "Strongly agree".

Given the critical role that sufficient resources play in successful self-control (Baumeister, 2002), the counter may enhance self-control by conserving resources, thereby enabling users to stop eating at their eating goal.

5. General discussion

The present research reports two experimental studies conducted to investigate the effects of tracking food portions at the bite level with wearable technology (specifically, the Bite Counter™) and the implications for increasing an individual's self-control while eating. Previous research suggests that healthy satiation may be accomplished through attention to eating behavior, and that dieters often compromise their weight-loss goals in favor of anticipated food enjoyment. The results presented here suggest that tracking bite-level portions with a wearable counter does not reduce enjoyment of the overall eating experience. Specifically, the wearable counter did not detract from enjoyment of the food and did not interfere with the enjoyment of an accompanying activity (watching a video) when compared to other methods of portion measurement. Additionally, using the wearable counter was as effective as both mentally tracking bites and restricting portion size for helping participants regulate their eating, which suggests improved validity of measurement in both clinical and field study.

These results lend further empirical support to the strength model of self-control within an eating context (Baumeister, Vohs, & Tice, 2007; Muraven & Baumeister, 2000). Numerous studies have demonstrated that the act of exerting control weakens self-control by depleting resources necessary for monitoring and behavior change. Previous research has also suggested that self-control can be bolstered by preserving cognitive resources (e.g., Allan, Johnston, & Campbell, 2015), but these studies tend to focus on motivational incentives and framing as a means of doing so (Baumeister et al., 2007). In a social eating context, such as eating with a group of friends, resource depletion may be substantial because of the effort that goes into maintaining a conversation and managing others' impressions (Vohs et al., 2005). Consequently, in such contexts, the Bite Counter™ may be even more effective at helping one maintain self-control. More generally, the more distracted the individual is while eating, the greater the value of being able to rely on the counter to offload cognitive effort.

The studies presented here also offer further evidence of the benefits of using technology to boost self-control (Raaijmakers et al., 2015), suggesting that technology can serve as an accurate proxy for mentally tracking food intake with minimal disruption. Wharton et al. (2014) find that people are motivated to use technology to help them lose weight. While researchers have reported using technology such as smartphones and computer programs to help track food intake (Allen et al., 2013; Wharton et al., 2014), the current research is the first known study to report the effectiveness of defining portions as bites and the use of a wearable counter for enhancing eating self-control.

Finally, the current findings add to the growing discussion on appropriate portion sizes (Fisher, Goran, Rowe, & Hetherington, 2015; Spence et al., 2015). They suggest that defining portions as a given number of bites could help to circumvent inaccurate estimations of appropriate food portions (Huizinga et al., 2009; Jonnalagadda et al., 1995), and also minimize problematic contextual biases, such as plate and fork size (Jasper, 2014; Wansink, 2004; Wansink et al., 2005). For example, a person with the goal of eating 100 bites of food per day can easily monitor progress toward this goal without ambiguity or confusion. Further, when using wearable technology such as the Bite Counter™, individuals with low trait self-control can focus their attention on food consumption without compromising enjoyment, and thus avoid mindless eating that often occurs when faced with tasty food choices (Redden & Haws, 2013; Wansink et al., 2009).

5.1. Limitations and future research

Future research could address the generalizability of the current findings for different types of foods, eating contexts, and behaviors. Conceptualizing portions as bites seemingly ignores the actual food being eaten. As Wansink et al. (2009) suggest, what a person eats is just as important as how much a person eats. A bite of chocolate cake is inherently different from a bite of broccoli, and research suggests that food-related characteristics may contribute to portion size effects (English, Lasschuijt, & Keller, 2015; Spence et al., 2016). Although studies have suggested that, for weight loss, the type of food a person eats may be less important than generally limiting overeating (that is, everything in moderation; Sacks et al., 2009), it is possible that the ability to mentally track bites differs across food types. Specifically, amorphous foods (such as a bowl of cereal) could be more difficult to track mentally than unit foods (such as those used in the current studies), as variability in the quantity of food in each bite may attract attention and thereby reduce the cognitive resources available for monitoring. In such cases, the Bite Counter™ may be particularly useful at allowing the user to preserve cognitive resources, track food intake, and ultimately improve self-control. Importantly, the counter has proven to be accurate even for amorphous foods, and in the absence of calorie information, calorie estimations based on bite counts can be more accurate than human estimations (e.g., Salley et al., 2016; Scisco et al., 2014).

Using the Bite Counter™ could also help to remove biases in food consumption estimates due to visual cues of portion size, such as the amount of food on a plate (Wansink et al., 2005). Further, while the eating contexts considered in the current research are representative of snacking behavior, they do not represent all eating events. Thus, future research should examine longer eating episodes and other contexts such as eating with others, time of day, and one's mood (Turner, Luszczynska, Warner, & Schwarzer, 2010). While the present study investigates eating, wearable technology has been proposed as a means of controlling other behaviors, such as smoking (Sazonov, Lopez-Meyer, & Tiffany, 2013) and exercising (Fritz, , Huang, , Murphy, , & Zimmermann, 2014). Thus, future research should explore whether similar results are found in other self-regulatory contexts. Finally, the current research did not examine the physical characteristics of participants (e.g., height, weight). Thus, future research should examine relationships between such characteristics and the effectiveness of the counter. Despite these limitations and opportunities for future research, the current research indicates that tracking food intake at the bite level using devices such as the Bite Counter™ is a viable alternative to existing monitoring techniques and portion sizes. Not only does monitoring food intake in this way allow people to achieve their eating goals, it does so while preserving enjoyment of the eating experience and valuable cognitive resources.

Authors' note

This research was approved by Clemson University's IRB. All data were collected and analyzed at Clemson University by the first two authors. The Bite Counter™ device used in this research was developed by researchers at Clemson University. The authors have no financial or other conflicts of interest regarding the device or the developers of the device.

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