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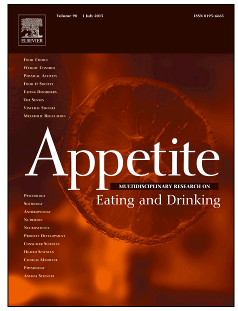

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The effect of real-time vibrotactile feedback delivered through an augmented fork on eating rate, satiation, and food intake

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Abstract

Eating rate is a basic determinant of appetite regulation, as people who eat more slowly feel sated earlier and eat less. Without assistance, eating rate is difficult to modify due to its automatic nature. In the current study, participants used an augmented fork that aimed to decelerate their rate of eating. A total of 114 participants were randomly assigned to the Feedback Condition (FC), in which they received vibrotactile feedback from their fork when eating too fast (i.e., taking more than one bite per 10 seconds), or a Non-Feedback Condition (NFC). Participants in the FC took fewer bites per minute than did those in the NFC. Participants in the FC also had a higher success ratio, indicating that they had significantly more bites outside the designated time interval of 10 seconds than did participants in the NFC. A slower eating rate, however, did not lead to a significant reduction in the amount of food consumed or level of satiation. These findings indicate that real-time vibrotactile feedback delivered through an augmented fork is capable of reducing eating rate, but there is no evidence from this study that this reduction in eating rate is translated into an increase in satiation or reduction in food consumption. Overall, this study shows that real-time vibrotactile feedback may be a viable tool in interventions that aim to reduce eating rate. The long-term effectiveness of this form of feedback on satiation and food consumption, however, awaits further investigation.

Word count: 241

Trial registration: The research reported in this manuscript is registered in the Dutch Trial Register with number NTR5237 (www.trialregister.nl)

Keywords: vibrotactile feedback; digital technology; eating rate; food intake; satiety.

Introduction

The worldwide prevalence of overweight and obesity are cause for concern (Finucane et al., 2011). A promising means to combat overweight may lie in reducing eating rate (Martin et al., 2007; Robinson et al., 2014). People who eat quickly tend to consume more than slower eaters (De Graaf & Kok, 2010; Robinson et al., 2014; Viskaal-Van Dongen, Kok, & De Graaf, 2011) and feel less sated after a meal (Rolls, 2007; Zijlstra, De Wijk, Mars, Stafleu, & De Graaf, 2009). Moreover, there is a cross-sectional association between eating rate and obesity; people who eat at a faster rate are more likely to be overweight or obese (Ohkuma et al., 2015; Otsuka et al., 2006; Tanihara et al., 2011)

Eating rate may influence satiation levels and energy intake through a number of mechanisms. When people eat slowly, this influences the secretion of satiety hormones such as insulin and glucacon-like peptide 1 (Cassady, Hollis, Fulford, Considine, & Mattes, 2009; Kokkinos et al., 2010). Slower eating also increases food oral exposure (Weijzen, Smeets, & De Graaf, 2009; Bolhuis, Lakemond, De Wijk, Luning, & De Graaf, 2011) and the number of chews per unit of food (Bolhuis, Lakemond, De Wijk, Luning, & De Graaf, 2013; 2014), which have both been shown to lower energy intake (Bolhuis et al., 2013; 2014; Weijzen et al., 2009). Finally, slower eating may decrease feelings of deprivation by enhancing and prolonging pleasurable aspects of eating (Brownell, 2000).

One barrier to changing eating rate is that it may be a highly automatic behavior, making eating rate difficult to change (Wilson, 2002). However, recent research suggests that real-time feedback can interrupt the execution of deeply engrained habitual behaviors and make them available for conscious scrutiny and behavior change (Hermsen, Frost, Renes, & Kerkhof, 2016). Furthermore, feedback is known to have motivational consequences, giving higher priority to the behavior that is the target of the feedback (Northcraft, Schmidt, & Ashford, 2011).

In the case of eating rate, visual and auditory mealtime feedback has been used to give eaters feedback on how much and at what rate to eat during a meal (Zandian, Ioakimidis, Bergh, Brodin, & Sodersten, 2009). This method has been found to be effective in reducing food intake and promoting weight loss, both in clinical as well as non-clinical contexts (Ford et al., 2010; Ioakimidis, Zandian, Bergh, Södersten, 2009; Zandian et al., 2009). A potential limitation of this type of feedback, however, could be that it can be too cumbersome or artificial to use in real-life eating contexts. Real-time vibrotactile feedback, the presentation of simple vibrations as a means of conveying alerts or information (Hoggan, Crossan, Brewster, & Kaaresoja, 2009; Qian, Kuber, & Sears, 2013) may present a viable alternative to visual and auditory mealtime feedback on eating rate. Vibrotactile feedback can provide straightforward real-time signals with little disruption to the visual and auditory channels (Hale & Stanney, 2004; Sigrist, Rauter, Riener, & Wolf, 2013). This form of feedback has been shown to improve motor skill acquisition (Van Erp, Saturday, & Jansen, 2006; Spelzeman, Jacobs, Hilgers, & Borchers, 2009), rehabilitation and posture control (Alahakone, Senanayake, & Arosha, 2009; 2010), and navigation and way finding (Heuten, Henze, Boll, & Pielot, 2008; Van Erp & Van Veen, 2004). Real-time feedback may also raise awareness about one’s speed of eating without interrupting conversations or other pleasurable aspects of a meal. By doing so, this method may be more easily applied to reduce people’s eating rate within real-world eating environments. However, little is known about the utility of real-time vibrotactile feedback to modify eating rate.

This study therefore set out to assess the effect of real-time vibrotactile feedback on eating rate, satiation, and ad-libitum food intake. In the present study, we used an augmented fork that contains sensors and actuators that provides people with vibrotactile feedback when they are eating too fast. Specifically, the fork delivers real-time feedback at 10-second intervals between bites. If users take a bite too quickly (i.e., before the end of the 10-second interval), they feel a gentle vibration in the handle of the fork. Although previous research indicates that the fork is perceived as a comfortable, accurate, and effective method to decelerate eating rate (Hermsen, Frost, Robinson, Higgs, Mars, & Hermans, 2016), it is still unclear whether vibrotactile feedback affects users' subsequent eating behavior. To examine this question, we conducted an experiment in which the real-time vibrotactile feedback of the fork was manipulated (i.e., vibrotactile feedback versus no feedback). First, we hypothesized that participants who received real-time vibrotactile feedback would decelerate their eating rate, conceptualized as eating fewer bites per minute and eating more bites outside the designated 10s time interval, compared to those who did not receive feedback. Second, we hypothesized that changes in eating rate would lead to increased satiation and decreased ad-libitum food consumption.

Materials and Methods

Experimental design and stimulus materials

An experimental design with a single between-subjects factor (vibrotactile feedback versus no-vibrotactile feedback) was used. To provide participants with real-time feedback while eating, we used the 10sFork (SlowControl, Paris, France). This fork contains sensors to measure eating rate and actuators to deliver vibrotactile feedback when the user eats too quickly. In the Feedback Condition (FC), participants ate a lunch meal with the augmented fork. If participants took a bite too quickly (i.e., before the end of a pre-set 10 second time interval between bites), they felt a gentle vibration in the handle of the fork and saw a red indicator light. Pre-tests showed that this 10s bite speed slows down fast eaters, without making it too difficult for them to finish their meal (Hermsen et al., 2016). In the No-Vibrotactile Feedback Condition (NFC), participants ate the same lunch meal with the same augmented fork, but did not receive any feedback regarding their eating rate. Participants were randomly assigned to either the FC or NFC condition. The size, weight and design of the augmented fork resembled a normal fork. The present study and its primary and secondary outcome measures were pre-registered in the Dutch Trial Register (NTR5237).

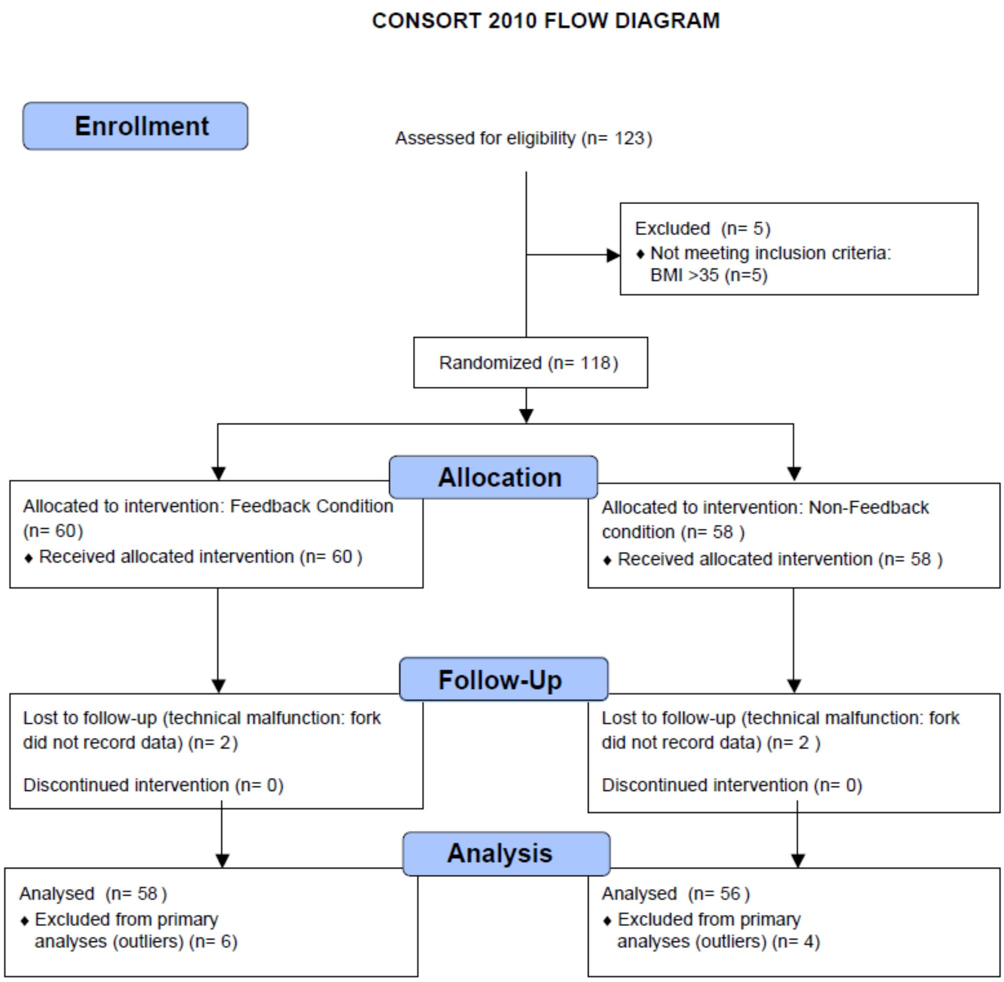
Participants

To be able to detect a medium effect size, with a power of 0.80 and a significance level of 0.05, 64 participants in each experimental condition were required. Therefore, we aimed to recruit 128 participants. Due to practical constraints, the total sample that was recruited consisted of 123 participants, of which 63% were female (n = 77). Participants were mainly undergraduate or graduate students at Radboud University (63 %), or non-students, e.g. employees of the university or other institutions and companies (37%). Five participants were excluded before testing because of BMI scores (BMI: kg/m^2 = >35) that did not comply with our inclusion criteria. Four participants were excluded after testing because their fork data showed severe inconsistencies (e.g., one participant appeared to have consumed 296 grams in only 30 seconds)[1]. Therefore, the final sample consisted of 114 participants (70 female, 44 male) (see **Figure 1** for the CONSORT Flow Diagram). The mean age of participants was 29.05 (SD = 13.16). Participants' mean BMI was 23.51 (SD = 3.36). In our sample, 75% of participants had a normal weight ($18 \geq BMI \leq 25$ kg/m^2) and 25% were overweight or obese ($25 \geq BMI \leq 35$).

[1] NB: Exclusion of these nine participants did not impact the significance and direction of the effects found in the present study.

Figure 1

Consort Flow Diagram of this study



Procedures

All participants were recruited through an internet sign-up program at the Behavioural Science Institute (BSI) of the Radboud University or via direct approach at campus. Specifically, we asked participants to register for our study if they considered themselves to be a fast eater and were motivated to learn to eat slower. The study was described as an investigation of the usability of a smart fork to help people to eat slower. Registration for our study was open to participants between 18 years and 80 years of age who had a BMI between 18 and 35. Participants were instructed to refrain from eating for three hours before participation in our study to control for individual variations in hunger. The study and all procedures involved received approval from the Ethics Committee of the Faculty of Social Sciences at Radboud University.

Data collection took place on weekdays between 11.30 AM and 2.30 PM in the period May – December 2015. To simulate a relatively naturalistic eating setting, the experiment took place in a laboratory furnished as a small restaurant (cf. a detailed description of this room in Hermans, Larsen, Herman, & Engels, 2012). All participants sat at single tables, separated by screens to avoid visual contact with the other participants in the room. A maximum of three people participated in one experimental session; if more than one participant took part in one single session; all participants were assigned to the same experimental condition.

Participants were asked to read and provide written consent, after which the experimenter measured each participant's weight and height (Lohman, Roche, & Martorell, 1998). Participants then completed a series of questions to assess their self-perceived eating rate, perceived detrimental effect of their eating rate and any possible conditions that could influence their appetite or the consumption of the meal (e.g. colds, allergies). Then, in order to keep instructions constant over both conditions, all participants were told about the potential positive health effects of eating slowly and the potential of a smart fork to help them to achieve this goal. All participants were told that their fork would monitor their eating rate, but only the participants in the FC were told about the possibility of receiving a gentle vibration in the handle of the fork when eating too fast. After some final instructions on how to switch the fork on or off, participants were then served a lunch meal, consisting of 800 grams of Pasta Bolognese (or vegetarian equivalent; see **Table 2** for the caloric and macronutrient content of both meals). The lunch was served in a large bowl, from which participants could self-serve their lunch. Thus, participants could select their own portion size. Furthermore, participants were told that they could eat as much or little as they wanted. The experimenter asked participants to directly switch the fork on/off when starting and finishing their meal, before leaving the room. Participants were not offered any drinks, neither were they allowed to drink their own beverages, during consumption of the meal.

After approximately ten minutes the experimenter checked whether participants had finished their meal. If this was the case, the experimenter collected the uneaten food. No time duration was set for participants to finish their meal. After consuming the meal, participants were asked to complete some post-meal questions about their satiation level, their perceived eating rate during the meal, the effect of the fork on their eating rate, and their overall impression of the study. After the participants had completed this questionnaire, they received a short debriefing about the purpose of the study. Participants received partial course credit or a gift voucher (€7.50) for their participation. After all data were collected, participants were fully debriefed about the study by e-mail.

Measures

Descriptives

BMI. Participants' weight and height were measured following standard procedures (38). Height was measured to the nearest 0.5 cm using a stadiometer (Seca 206; Seca GmbH &

Company, Hamburg, Germany) and weight was measured to the nearest 0.1 kg using a digital scale (Seca Bella 840; Seca GmbH & Company). Participants' BMI was calculated as weight in kilograms divided by height in meters squared. We determined whether participants were underweight, normal weight, overweight or obese using the International Classification of adult underweight, overweight and obesity according to BMI (WHO, 2010).

Participants' subjective eating rate, perceived detriments and motivation to change (self-report). Participants' rated how their eating rate compared with other people with one single item on a 5-point scale from 1 ('very slow') to 5 ('very fast') (before the meal). Furthermore, participants indicated how problematic their eating speed was on a 140 mm VAS scale anchored from 0 'not at all' to 140 'very problematic'. Finally, participants indicated their motivation to learn to eat slower on a 140 mm VAS scale anchored from 0 'not at all motivated' to 140 'very motivated'.

Manipulation checks

Awareness of eating rate. Participants' awareness of their eating rate during the experiment was assessed after the meal with two questions. First, participants were asked to indicate how aware they were of their own eating behavior on a 10-point scale from 1 ('not at all aware') to 10 ('very aware'). Second, they were asked to indicate whether they thought they had consumed their meal at a slower pace than usual. They could answer this question with 1 ('yes, I ate at a slower pace than normal'), 2 ('no, I ate a faster pace than normal'), or 3 ('no, I ate as fast or slow as I usually would do').

Dependent variables

Primary outcome measures. In both conditions, the 10sFork was set up to automatically record each bite. Based on these data, *eating rate* (i.e., the total number of bites per minute) and *success ratio* (i.e., number of bites outside 10s time interval divided by total bites) were calculated. To measure *ad-libitum food intake*, a digital scale (Kern 440; Kern & Sohn, Balingen, Germany) was used for measuring amounts served and consumed. At the end of each session, the amount of food consumed in grams was measured. Participants' total food intake was calculated by subtracting the amounts left on the plate and in the bowl from the initial amount of 800 grams that was served to them.

Secondary outcome measures. *Meal duration* was calculated as the time in minutes between the first and last bite. These data were recorded by the fork. If participants had not switched off their fork directly after having their last bite, we subtracted the time between last bite taken and the time after which the fork was switched off (n = 4). *The total number of fork servings* (i.e., number of fork servings during the meal) and *average time interval between fork servings (i.e., time in seconds per bite*; Hill & McCutcheon, 1984) were also recorded by the fork. *Satiation levels* were self-reported before and after the meal. Before the meal, participants rated their hunger level on a 140 mm VAS scale anchored from 0 'not at all' to 140 'very hungry' (cf. Hermans, Larsen, Lochbuehler, Nederkoorn, Herman, & Engels, 2013). After the meal, participants rated how satiated they were on the same 140 mm VAS scale anchored from 0 'not at all' to 140 'very satiated'.

Post-hoc analyses. In line with other studies on eating rate (e.g., Bolhuis & Keast, 2016), we also conceptualized *eating rate* as grams of food consumed per minute and average *bite size* (i.e. amount in grams consumed divided by total number of forks servings). These measures, however, were not included in the original analysis plan that was pre-registered in the Dutch Trial Register.

Statistical analyses

Before testing our hypotheses, we inspected all variables to look for any anomalies. Further, we inspected sampling distributions to test for normality of our data. To detect outliers, two methods were used. First, outliers were identified by visual inspection of the data. In total, we identified seven participants with outliers: two participants showed very long meal durations (> 30 minutes), two participants had a high number of bites (> 90 fork servings) and three participants had very long intervals between bites (> 60 seconds between bites). Second, participants who consistently provided extreme scores (in the most extreme 5%) were noted. This inspection revealed another three participants with extreme scores. Because we decided to exclude these 10 participants from further data analysis, all secondary, primary and post-hoc analyses involved a total of 104 participants.[2] Subsequently, to check for baseline differences, we inspected how strongly potential confounders (i.e., sex, age, BMI, pre-experimental hunger, subjective eating rate, perceived detriments and motivation to change) differed between conditions. We used Cramér's V to determine whether any of the potential confounders differed with an effect size of moderate strength (cf. Gruijters, 2016).

The independent variable was a manipulated, dichotomous variable. All dependent variables in the design were interval variables. Therefore, effect size measure Cohen's *d* is an adequate representation of the association between the independent variable (i.e., experimental condition) and independent variables (e.g., eating rate). Effect sizes and their confidence intervals were calculated. Effect sizes of 0.2, 0.5, and 0.8 are indicative of small, medium, and large effects, respectively (Cohen, 1992). All analyses in the present study were performed using the *t*-test for unequal variances (Ruxton, 2006). To provide additional information about the validity of our statistics, we also report the *p* values as a secondary measure of significance. In standard analysis, these *p* values are not corrected for multiple testing. Therefore, we also performed a final analysis in which these *p* values were corrected for multiple testing. Data were analyzed

[2] NB: When participants with outliers were included in the analyses, no differences in significance and direction of effects were found.

using SPSS for Macintosh version 22 and R: A Language and Environment for Statistical Computing.

Results

Randomization checks

The conditions did not differ in sex, age, BMI, hunger before meal, subjective eating rate, perceived detriments of eating rate, and motivation to change eating rate, indicating that our randomization procedure was successful (see **Table 1**).

Table 1

Variables measured, by condition

	Feedback Condition (FC) (*n* = 58) *M* ± *SD*	No- Feedback Condition (NFC) (*n* = 56) *M* ± *SD*
Sex	27 males, 31 females	17 males, 39 females
Age (in years)	29.97 ± 14.02	28.08 ± 12.26
BMI (kg / m^2)	24.02 ± 3.20	22.99 ± 3.46
Hunger before meal on VAS (140mm scale)	88.68 ± 26.45	96.65 ± 26.09
Subjective eating rate (5 point scale)	3.95 ± 0.51	3.86 ± 0.67
Perceived detriments of eating rate (140mm scale)	37.93 ± 32.75	39.05 ± 30.71
Motivation to change eating rate (140mm scale)	69.83 ± 33.92	67.05 ± 33.22

Because participants could choose between two types of meals (i.e. vegetarian or non-vegetarian pasta Bolognese), varying in caloric content, we also checked whether distribution of meals over conditions differed. No differences were found in meal choice between conditions, $\chi^2 = 1.03$, p =

.31. How often both meals were chosen and the caloric and macronutrient content of each meal is shown in **Table 2.**

Table 2

Experimental foods used in the study

	Non-vegetarian meal	Vegetarian meal
Choice frequency (*n*)	11 (7 NFC / 4 FC)	103 (49 NFC / 54 FC)
Energy per 100g (kcal)	202	277
Fat per 100g (g)	3	10
Protein per 100g (g)	7	15.5
Carbohydrates per 100g (g)	34.5	30
Fiber per 100g (g)	3.2	2
Salt per 100g (g)	1.5	2

Note: NFC = No-Feedback Condition; FC = Feedback Condition.

Manipulation checks

Participants in the FC condition did not differ from participants in the NFC in how aware they were of their eating behavior during the experiment, $t(1,102) = -1.31$, $p = .19$. However, participants differed significantly in their self-reported eating rate during the experiment; participants in the FC reported that they ate more slowly than did participants in the NFC, $t(1,102) = 5.55$, $p < .001$. Furthermore, participants differed in how much they thought the fork helped them to eat more slowly; participants in the FC had more confidence in the perceived efficacy of the fork to change their eating rate than did those in the NFC, $t(1,102) = -4.40$ $p < .001$).

Main findings

Primary outcomes

With regard to participants' eating rate (i.e., total number of bites per minute), participants in the FC had fewer bites per minute than did those in the NFC, $t(101.63) = 2.58$, $p = .011$, $d = 0.52$, 95% CI = [0.13, 0.91]. Participants in the NFC had 5.28 bites per minute ($SD = 1.49$), whereas those in FC had 4.55 bites per minute ($SD = 1.40$). In addition, participants in the FC had a higher success ratio than did those in the NFC, $t(98.87) = -4.13$, $p < .001$, $d = -0.89$, 95% CI = [-1.3, -0.49]. Participants in the FC consumed 66% of their bites outside the designated time interval, whereas those in the NFC consumed only 49% of their bites outside this interval. However, these differences did not translate into a difference in the total amount of food consumed, $t(100.92) = -0.26$, $p = .797$, $d = -0.05$, 95% CI = [-0.43, 0.34]; participants in the FC consumed 435.77 grams of food ($SD = 156.84$) and participants in the NFC consumed 428.21 grams ($SD = 141.38$).

Secondary outcomes

A significant effect of condition on meal duration was found, $t(101.93) = -2.44$, $p = .016$, $d = -0.47$, 95% CI = [-0.86, -0.08]; participants in the FC consumed their meal in 9 minutes and 44 seconds, whereas those in the NFC consumed their meal in 8 minutes and 12 seconds. No differences between conditions were found in total fork servings, $t(99.55) = -0.03$, $p = .975$, $d = -0.01$, 95% CI = [-0.39, 0.38], or the average time interval between fork servings, $t(101.91) = -1.80$, $p = .074$, $d = -0.36$, 95% CI = [-0.75, 0.03]. Finally, participants in the FC did not report being more satiated after their meal than did those in the NFC, $t(96.4) = -0.24$, $p = .809$, $d = -0.05$, 95% CI = [-0.34, 0.44].

Post-hoc analyses

A significant effect of condition on grams of food consumed per minute was found, $t(101.54) = 2.1$, $p = .038$, $d = 0.43$, 95% CI = [0.04, 0.82]; participants in the FC consumed 48 grams per minute (*SD* = 21.94) whereas those in the NFC consumed 57.37 grams (*SD* = 23.46). No differences were found in average bite size between conditions, $t(101.27) = 0.54$, $p = .59$. In both conditions, participants consumed approximately 12 grams per bite.

After correcting for multiple testing for all *p* values reported above, only the effects of condition on total number of bites per minute ($p = .017$) and success ratio ($p < .001$) remain significant.

Discussion

This study examined the effect of real-time vibrotactile feedback delivered through the use of an augmented fork on eating rate, satiation, and food intake. It was expected that the participants who ate with a fork that provided vibrotactile feedback on their eating rate would take fewer bites per minute and take more bites outside the designated 10s time interval than participants who did not receive feedback. It was further expected that that these changes in eating rate would lead to increased satiation and decreased ad-libitum food consumption. We found that participants who received feedback indeed had fewer bites per minute and consumed more bites outside the designated time interval of ten seconds. These changes, however, did not impact participants' satiation or food consumption.

The finding that real-time vibrotactile feedback delivered through an augmented fork reduces eating rate is consistent with literature on eating rate interventions that have utilized other forms of technology to modify eating behavior (Ford et al., 2010; Ioakimidis, Zandian, Bergh, Södersten, 2009; Zandian et al., 2009). The vibrotactile feedback delivered by the fork may have disrupted the automatic tendency to eat fast and may have served as a trigger to make alterations to one's eating rate (Hermsen, Frost, Renes, & Kerkhof, 2016). Arguably, the feedback provided by the fork increases users' awareness of their eating rate. The real-time vibrotactile feedback enables users to compare their eating rate to their current goals (i.e., eating slower) and adapt their eating rate when their behavior does not fit with their goals. Furthermore, it may also increase general self-awareness, which in turn increases one's abilities to inhibit undesired behaviors (Alberts, Martijn, & de Vries, 2011). Finally, it is known that among competing health-related behaviors, those supported by feedback are given priority over those without feedback (Northcraft, Schmidt, & Ashford, 2011). Thus, it is conceivable that receiving vibrotactile feedback when eating too fast has increased one's motivation to change one's eating behavior. The present findings demonstrate that real-time feedback delivered through digital technology may be an effective strategy to disrupt eating behavior; even a very simple, non-intrusive type of feedback in the form of a simple vibration can function as a trigger for behavior change and stimulate people to alter their eating rate.

Our results, however, failed to support the experimental hypothesis that a reduction in eating rate would lead to increased satiation and decreased ad-libitum food consumption. Although it has been shown that slower eating rate is associated with lower energy intake, regardless of the type of manipulation used to change the eating rate (e.g., type of instructions) (Robinson et al., 2014), the context of the present study might explain why changes in eating rate did not translate into changes in satiation or energy intake. Firstly, although we could derive specific within-meal behaviors from the data gathered by the fork that are known to influence energy intake and/or satiation, such as bite speed and bite size (Andrade et al., 2008; Zijlstra et al., 2009), the fork was not specifically developed to modify other within-meal behaviors than the number of bites per minute. The fact that the fork did to specifically modify behaviors that have been shown to lower energy intake, such as oral processing time and number of chews per unit of food (Bolhuis et al., 2013; Higgs & Jones, 2013; Weijzen, Smeets, & De Graaf, 2009), might explain the missing link between eating rate and reduced food intake in this study. Secondly, because it has been shown that there is a linear relationship between the size of experimental manipulation to eating rate (i.e., how much eating rate has been reduced by) and energy intake (Robinson et al., 2014), a further explanation as to why the reduction in eating rate observed in the present study did not reduce food intake is because the effect of decrease to eating rate was not large enough in size to impact food consumption. Thirdly, it is possible that because participants were asked to self-serve their meal size, participants cleared their plate out of habit rather than adjusting their intake based on eating rate or feeling of fullness. Thus, it is possible that the initial effect of selected portion size may have overruled the effect of reducing eating rate (Brunstrom, 2011). Fourthly, it may be that specific characteristics of our test population have influenced our results. Our results demonstrated, for instance, that participants were not particularly motivated to change their eating rate in the near future. Feedback efficacy has been shown to be influenced by a high initial engagement with the target goal (i.e., reduction in eating rate) or strong motivation (i.e., to eat slower) (Bandura, 1997). Although participants were found to eat slower in a response to the vibrotactile feedback, subsequently they may have not been motivated to eat less. To further understand the link between real-time vibrotactile feedback, eating rate and food intake, future research might examine whether and how initial motivation to change one’s eating rate or motivation to reduce food intake is affected by vibrotactile feedback. Finally, it has been argued that people may need to learn to associate the link between a slower eating rate, their satiety levels and energy intake (Brunstrom, 2011; Yeomans, Weinberg, & James, 2005). Although previous research has demonstrated the effects of a decelerated eating rate on food intake during a single meal (cf. Robinson et al., 2014), it is possible that receiving feedback would become effective across multiple meals. To test this assumption, future studies may provide users with consistent feedback over a few meals and measure satiation and food intake over time.

A few limitations of the current study warrant discussion. Although the augmented fork seems a promising instrument to modify eating rate, more research is clearly warranted. The present study examined the effect of real-time vibrotactile feedback in a single sitting in a laboratory setting; therefore the efficacy of the 10sFork in real-life settings is yet to be ascertained. Thus, replication studies in ecologically-valid settings are encouraged. It will be important for these studies to be adequately powered. Finally, because of the small variance in participants' BMI, the current study could not test potential differences among normal-weight and overweight individuals in the extent to which their eating rate is affected by the vibrotactile feedback. Such an analysis would be a useful elaboration of the current research, given that differences in eating rate have been found between normal and overweight individuals (e.g., Ohkuma et al., 2015).

Taken together, the present study indicates that real-time vibrotactile feedback delivered through an augmented fork can reduce eating rate. Vibrotactile feedback led participants to eat fewer bites per minute and more bites outside the designated time interval of ten seconds. This indicates that vibrotactile feedback may be a viable tool to reduce eating rate. The changes in eating rate, however, did not translate into changes in satiation or energy intake. Future studies should examine the utility of the fork in real world settings, whether sustained use of the fork may result in decreased energy intake, and the utility of the fork with different test populations.

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Authors' contributions:

Conceived and designed the experiment: SH, RCJH, ER, SH, MM, JF

Conducted research: SH, RCJH

Analyzed the data: SH, RCJH

Wrote the paper: SH, RCJH, ER, SH, MM, JF

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References

Alberts, H. J. E, M., Martijn, C. & De Vries, N. K., (2011). Fighting self-control failure: Overcoming ego depletion by increasing self-awareness. *Journal of Experimental Social Psychology*, *47*, 58-62.

Alahakone, A. U., Senanayake, S. M. N. A., & Arosha, M. N. (2009).Vibrotactile feedback systems: Current trends in rehabilitation, sports and information display. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 1148-1153.

Alahakone, A. U., Senanayake, S. M. N., Arosha, M. N. (2010). A real-time system with assistive feedback for postural control in rehabilitation. *IEEE/ASME Transactions on Mechanics, 15*, 226-233.

Andrade, A.M., Greene, G. W., & Melanson, K. J., (2008). Eating slowly led to decreases in energy intake within meals in healthy women. *Journal of the American Dietetic Association*, *108*, 1186-1191.

Bandura, (1997) Self-efficacy: The Exercise of Control. New York, NY: Freeman.

Bolhuis, D. P., Lakemond, C. M. M., De Wijk, R. A, Luning, P. A., & De Graaf, C. (2013). Consumption with large sip size increases food intake and leads to underestimation of the amount consumed. *PLoS ONE*, 8:e53288.

Bolhuis, D. P., Lakemond, C. M. M., De Wijk, R. A, Luning, P. A., & De Graaf, C. (2014). Both a higher number of sips and a longer oral transmit time reduce ad libitum intake. *Food Quality & Preference*, *32*, 234–240.

Bolhuis, D. P., & Keast, R. S. J. (2016). Assessment of eating rate and food intake in spoon versus fork users in a laboratory setting. *Food Quality and Preference*, *49,* 66-69.

Brownell, K. D. (2000). The LEARN program for weight management 2000. Dallas, TX. American Health Publishing Co.

Brunstrom J. M. (2011). The control of meal size in human subjects: a role for expected satiety, expected satiation and premeal planning. *Proceedings of the Nutrition Society*,*70*, 155-161.

Cassady, B. A., Hollis, J. H., Fulford, A. D., Considine, R. V., Mattes, R. D. (2009). Mastication of almonds: effects of lipid bioaccessibility, appetite and hormone response. *The American Journal of Clinical Nutrition*, *89*, 794–800.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*, 1-155.

De Graaf, C., & Kok, F. J. (2010). Slow food, fast food and the control of food intake. *Nature Reviews Endocrinology*, *6*, 290-93.

Finucane, M. M, Stevens, G. A., Cowan, M. J., Danaei, G., Lin, J. K., Paciorek, C. J, Singh, G. M., . . . Ezzati, M. (2011). National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9· 1 million participants. *The Lancet*, *377*, 557-67.

Ford, A. L., Bergh, C., Södersten P, Sabin, M. A., Hollinghurst, S., Hunt, L. P., & Shield, J. P. H. (2010). Treatment of childhood obesity by retraining eating behaviour: randomised controlled trial. *British Medical Journal*, 340:b5388.

Gruijters, S. L. K. (2016). Baseline comparisons and covariate fishing: Bad statistical habits we should have broken yesterday. *European Health Psychologist*, *18*, 205-209.

Hale, K. S. , & Stanney, K. M. (2004). Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations. *Computer Graphics and Applications*, *24*, 33-39.

Hermans, R. C. J., Larsen, J. K., Herman, C. P., & Engels, R. C. M. E. (2012). How much should I eat? Situational norms affect young women's food intake during meal time. *British Journal of Nutrition*, *107*, 588-594.

Hermans, R. C. J., Larsen, J. K., Lochbuehler, K., Nederkoorn, C., Herman, C. P., Engels, R. C. M. E. (2013). The power of social influence over food intake: examining the effects of attentional bias and impulsivity. *British Journal of Nutrition*, 109, 572-580.

Hermsen, S., Frost, J. H., Renes, R. J., & Kerkhof, P. (2016). Using feedback through digital technology to disrupt and change habitual behavior: A critical review of current literature. *Computers in Human Behavior*, *57*, 61-74.

Hermsen S., Frost, J. H, Robinson, E., Higgs, S., Mars, M., & Hermans, R. C. J. (2016). Evaluation of a smart fork to decelerate eating rate. *Journal of the Academy of Nutrition and Dietetics, 116*, 1066-1067.

Heuten, W., Henze, N., Boll, S., Pielot, M. (2008). Tactile wayfinder: a non-visual support system for wayfinding. *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges, ACM*, 172-181.

Hill, S. W., & McCutcheon, N. B. (1984). Contributions of obesity, gender, hunger, food preference, and body size to bite size, bite speed, and rate of eating. *Appetite*, *5*, 73-83.

Higgs, S., & Jones, A. (2013). Prolonged chewing at lunch decreases later snack intake. *Appetite, 62*, 91-95.

Hoggan E., Crossan, A., Brewster, S. A., Kaaresoja, T. (2009). Audio or tactile feedback: which modality when? *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM*, 2253–2256.

Kokkinos, A., Le Roux, C. W., Alexiadou, K., Tentolouris, N., Vincent, R. P., Kyriaki, D., & Katsilambros, N. (2010). Eating slowly increases the postprandial response of the anorexigenic gut hormones, peptide YY and glucagon-like peptide-1. *Journal of Clinical Endocrinology & Metabolism*, *95*, 333–337.

Lohman, T. G., Roche, A. F., & Martorell, R. (1998). Anthropometric Standardization Reference Manual. Champaign, IL: Human Kinetics.

Martin, C. K., Anton, S. D., Walden, H., Arnet, C., Greenway, F. L., & Williamson, D. A. (2007). Slower eating rate reduces the food intake of men, but not women: implications for behavioral weight control. *Behaviour Research and Therapy*, *45*, 2349-59.

Northcraft, G. B., Schmidt, A. M., & Ashford, S. J. (2011). Feedback and the rationing of time and effort among competing tasks. *Journal of Applied Psychology*, *96*, 1076-1086.

Ohkuma, T., Hirakawa, Y., Nakamura, U., Kiyohara, Y., Kitazono, T., & Ninomiya, T. (2015). Association between eating rate and obesity: a systematic review and meta-analysis. *International Journal of Obesity*, 39, 1589-96.

Otsuka, R., Tamakoshi, K., Yatsuya, H., Murata, C., Sekiya, A., Wada, K., & Toyoshima, H. (2006). Eating fast leads to obesity: Findings based on self-administered questionnaires among middle-aged Japanese men and women. *Journal of Epidemiology*, *16*, 117-24.

Qian, H., Kuber, R., & Sears, A. (2013). Tactile notifications for ambulatory users. *Proceedings of CHI'13 Extended Abstracts on Human Factors in Computing Systems, ACM*, 1569–1574.

Robinson, E., Almiron-Roig, E., Rutters, F., de Graaf, C., Forde, C. G., Tudur Smith, C., Nolan, S. J., & Jebb, S. A. (2014). A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *The American Journal of Clinical Nutrition, 100*, 123-51.

Rolls, E. T. (2007). Sensory processing in the brain related to the control of food intake. *Proceedings of the Nutrition Society*, *66*, 96-112.

Ruxton, G. D. (2006). The unequal variance t-test is an underused alternative to Student’s t-test and the Mann–Whitney U test. Behavioral Ecology, 17, 688-690.

Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review. *Psychological Bulletin Reviews, 20,* 21-53.

Spelzeman, D., Jacobs, M., Hilgers, A., & Borchers, J. (2009). Tactile motion instructions for physical activities. *Proceedings of the 27th International Conference on Human Factors in Computing Systems, ACM,* 2243–2252.

Tanihara S., Imatoh, T., Miyazaki, M., Babazono, A., Momose, Y., Baba, M., . . . Une, H. (2011). Retrospective longitudinal study on the relationship between 8-year weight change and current eating speed. *Appetite*, *59*, 179-83.

Van Erp, J. B. F., & Van Veen, H. (2004).Vibrotactile in-vehicle navigation system. Transportation Research Part F: *Psychology and Behaviour*, *7*, 247–256.

Van Erp, J. B. F., Saturday, I., Jansen, C. (2006). Application of tactile displays in sports: Where to, how and when to move. *Proceedings of the Eurohaptics International Conference,* 2006.

Viskaal-Van Dongen, M., Kok, F. J., & De Graaf, C. (2011). Eating rate of commonly consumed foods promotes food and energy intake. *Appetite*, *56*, 25-31.

Weijzen, P. L. G., Smeets, P. A. M., & De Graaf, C. (2009). Sip size of orangeade: effects on intake and sensory-specific satiation. *British Journal of Nutrition*, *102*, 1091–1097.

Wilson T. D. (2002). Strangers to ourselves: Discovering the adaptive unconscious. Cambridge, MA: Harvard University Press.

World Health Organization. Global Database on Obesity (2010). http://apps.who.int/bmi/index.jsp?introPage=intro_3.html (accessed 30 March 2016).

Yeomans, M.R., Weinberg, L., & James, S. (2005). Effects of palatability and learned satiety on energy density influences on breakfast intake in humans. *Physiology & Behavior*, *86,* 487-499.

Zandian, M., Ioakimidis, I., Bergh, C., Brodin, U., Sodersten, P. (2009). Decelerated and linear eaters: effect of eating rate on food intake and satiety. *Physiology & Behavior*, *96,* 270-275.

Zijlstra, N., De Wijk, R., Mars, M., Stafleu, A., De Graaf, C. (2009). Effect of bite size and oral processing time of a semisolid food on satiation. *The American Journal of Clinical Nutrition*, *90*, 269-75.