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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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1 **Abstract**

2 Eating rate is a basic determinant of appetite regulation, as people who eat more slowly feel sated

3 earlier and eat less. Without assistance, eating rate is difficult to modify due to its automatic

4 nature. In the current study, participants used an augmented fork that aimed to decelerate their

5 rate of eating. A total of 114 participants were randomly assigned to the Feedback Condition

6 (FC), in which they received vibrotactile feedback from their fork when eating too fast (i.e.,

7 taking more than one bite per 10 seconds), or a Non-Feedback Condition (NFC). Participants in

8 the FC took fewer bites per minute than did those in the NFC. Participants in the FC also had a

9 higher success ratio, indicating that they had significantly more bites outside the designated time

10 interval of 10 seconds than did participants in the NFC. A slower eating rate, however, did not

11 lead to a significant reduction in the amount of food consumed or level of satiation. These

12 findings indicate that real-time vibrotactile feedback delivered through an augmented fork is

13 capable of reducing eating rate, but there is no evidence from this study that this reduction in

14 eating rate is translated into an increase in satiation or reduction in food consumption. Overall,

15 this study shows that real-time vibrotactile feedback may be a viable tool in interventions that

16 aim to reduce eating rate. The long-term effectiveness of this form of feedback on satiation and

17 food consumption, however, awaits further investigation.

18

19 Word count: 241

20

21 **Trial registration:** The research reported in this manuscript is registered in the Dutch Trial

22 Register with number NTR5237 ([www.trialregister.nl](http://www.trialregister.nl))

23

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

25

## Introduction

26 The worldwide prevalence of overweight and obesity are cause for concern (Finucane et al.,  
27 2011). A promising means to combat overweight may lie in reducing eating rate (Martin et al.,  
28 2007; Robinson et al., 2014). People who eat quickly tend to consume more than slower eaters  
29 (De Graaf & Kok, 2010; Robinson et al., 2014; Viskaal-Van Dongen, Kok, & De Graaf, 2011)  
30 and feel less sated after a meal (Rolls, 2007; Zijlstra, De Wijk, Mars, Stafleu, & De Graaf, 2009).  
31 Moreover, there is a cross-sectional association between eating rate and obesity; people who eat  
32 at a faster rate are more likely to be overweight or obese (Ohkuma et al., 2015; Otsuka et al.,  
33 2006; Tanihara et al., 2011)

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

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

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

68 This study therefore set out to assess the effect of real-time vibrotactile feedback on  
69 eating rate, satiation, and ad-libitum food intake. In the present study, we used an augmented fork  
70 that contains sensors and actuators that provides people with vibrotactile feedback when they are  
71 eating too fast. Specifically, the fork delivers real-time feedback at 10-second intervals between  
72 bites. If users take a bite too quickly (i.e., before the end of the 10-second interval), they feel a

73 gentle vibration in the handle of the fork. Although previous research indicates that the fork is  
74 perceived as a comfortable, accurate, and effective method to decelerate eating rate (Hermsen,  
75 Frost, Robinson, Higgs, Mars, & Hermans, 2016), it is still unclear whether vibrotactile feedback  
76 affects users' subsequent eating behavior. To examine this question, we conducted an experiment  
77 in which the real-time vibrotactile feedback of the fork was manipulated (i.e., vibrotactile  
78 feedback versus no feedback). First, we hypothesized that participants who received real-time  
79 vibrotactile feedback would decelerate their eating rate, conceptualized as eating fewer bites per  
80 minute and eating more bites outside the designated 10s time interval, compared to those who did  
81 not receive feedback. Second, we hypothesized that changes in eating rate would lead to  
82 increased satiation and decreased ad-libitum food consumption.

### 83 **Materials and Methods**

#### 84 *Experimental design and stimulus materials*

85 An experimental design with a single between-subjects factor (vibrotactile feedback versus no-  
86 vibrotactile feedback) was used. To provide participants with real-time feedback while eating, we  
87 used the 10sFork (SlowControl, Paris, France). This fork contains sensors to measure eating rate  
88 and actuators to deliver vibrotactile feedback when the user eats too quickly. In the Feedback  
89 Condition (FC), participants ate a lunch meal with the augmented fork. If participants took a bite  
90 too quickly (i.e., before the end of a pre-set 10 second time interval between bites), they felt a  
91 gentle vibration in the handle of the fork and saw a red indicator light. Pre-tests showed that this  
92 10s bite speed slows down fast eaters, without making it too difficult for them to finish their meal  
93 (Hermsen et al., 2016). In the No-Vibrotactile Feedback Condition (NFC), participants ate the  
94 same lunch meal with the same augmented fork, but did not receive any feedback regarding their  
95 eating rate. Participants were randomly assigned to either the FC or NFC condition. The size,  
96 weight and design of the augmented fork resembled a normal fork. The present study and its

97 primary and secondary outcome measures were pre-registered in the Dutch Trial Register  
98 (NTR5237).

### 99 *Participants*

100 To be able to detect a medium effect size, with a power of 0.80 and a significance level of 0.05,  
101 64 participants in each experimental condition were required. Therefore, we aimed to recruit 128  
102 participants. Due to practical constraints, the total sample that was recruited consisted of 123  
103 participants, of which 63% were female ( $n = 77$ ). Participants were mainly undergraduate or  
104 graduate students at Radboud University (63 %), or non-students, e.g. employees of the  
105 university or other institutions and companies (37%). Five participants were excluded before  
106 testing because of BMI scores ( $\text{BMI: kg/m}^2 = >35$ ) that did not comply with our inclusion  
107 criteria. Four participants were excluded after testing because their fork data showed severe  
108 inconsistencies (e.g., one participant appeared to have consumed 296 grams in only 30 seconds)<sup>1</sup>.  
109 Therefore, the final sample consisted of 114 participants (70 female, 44 male) (see **Figure 1** for  
110 the CONSORT Flow Diagram). The mean age of participants was 29.05 ( $SD = 13.16$ ).  
111 Participants' mean BMI was 23.51 ( $SD = 3.36$ ). In our sample, 75% of participants had a normal  
112 weight ( $18 \leq \text{BMI} \leq 25 \text{ kg/m}^2$ ) and 25% were overweight or obese ( $25 \leq \text{BMI} \leq 35$ ).

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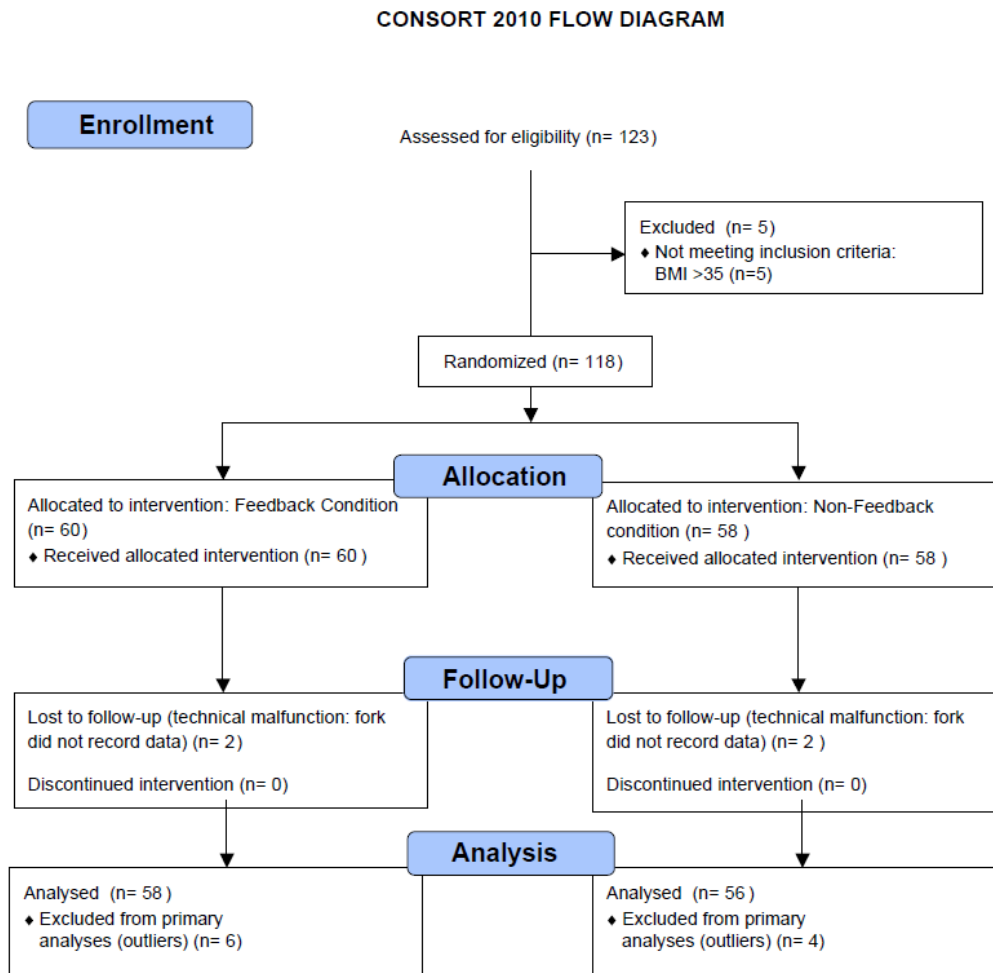
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<sup>1</sup> NB: Exclusion of these nine participants did not impact the significance and direction of the effects found in the present study.

119 **Figure 1**120 **Consort Flow Diagram of this study**

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128 *Procedures*

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

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

145 Participants were asked to read and provide written consent, after which the experimenter  
146 measured each participant's weight and height (Lohman, Roche, & Martorell, 1998). Participants  
147 then completed a series of questions to assess their self-perceived eating rate, perceived  
148 detrimental effect of their eating rate and any possible conditions that could influence their  
149 appetite or the consumption of the meal (e.g. colds, allergies). Then, in order to keep instructions  
150 constant over both conditions, all participants were told about the potential positive health effects  
151 of eating slowly and the potential of a smart fork to help them to achieve this goal. All

152 participants were told that their fork would monitor their eating rate, but only the participants in  
153 the FC were told about the possibility of receiving a gentle vibration in the handle of the fork  
154 when eating too fast. After some final instructions on how to switch the fork on or off,  
155 participants were then served a lunch meal, consisting of 800 grams of Pasta Bolognese (or  
156 vegetarian equivalent; see **Table 2** for the caloric and macronutrient content of both meals). The  
157 lunch was served in a large bowl, from which participants could self-serve their lunch. Thus,  
158 participants could select their own portion size. Furthermore, participants were told that they  
159 could eat as much or little as they wanted. The experimenter asked participants to directly switch  
160 the fork on/off when starting and finishing their meal, before leaving the room. Participants were  
161 not offered any drinks, neither were they allowed to drink their own beverages, during  
162 consumption of the meal.

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

172 *Measures*

173 *Descriptives*

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

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

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

#### 188 *Manipulation checks*

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

#### 196 *Dependent variables*

197 *Primary outcome measures.* In both conditions, the 10sFork was set up to automatically  
198 record each bite. Based on these data, *eating rate* (i.e., the total number of bites per minute) and  
199 *success ratio* (i.e., number of bites outside 10s time interval divided by total bites) were

200 calculated. To measure *ad-libitum food intake*, a digital scale (Kern 440; Kern & Sohn, Balingen,  
201 Germany) was used for measuring amounts served and consumed. At the end of each session, the  
202 amount of food consumed in grams was measured. Participants' total food intake was calculated  
203 by subtracting the amounts left on the plate and in the bowl from the initial amount of 800 grams  
204 that was served to them.

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

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

221 *Statistical analyses*

222 Before testing our hypotheses, we inspected all variables to look for any anomalies. Further, we  
223 inspected sampling distributions to test for normality of our data. To detect outliers, two methods

224 were used. First, outliers were identified by visual inspection of the data. In total, we identified  
225 seven participants with outliers: two participants showed very long meal durations (> 30  
226 minutes), two participants had a high number of bites (> 90 fork servings) and three participants  
227 had very long intervals between bites (> 60 seconds between bites). Second, participants who  
228 consistently provided extreme scores (in the most extreme 5%) were noted. This inspection  
229 revealed another three participants with extreme scores. Because we decided to exclude these 10  
230 participants from further data analysis, all secondary, primary and post-hoc analyses involved a  
231 total of 104 participants.<sup>2</sup> Subsequently, to check for baseline differences, we inspected how  
232 strongly potential confounders (i.e., sex, age, BMI, pre-experimental hunger, subjective eating  
233 rate, perceived detriments and motivation to change) differed between conditions. We used  
234 Cramér's V to determine whether any of the potential confounders differed with an effect size of  
235 moderate strength (cf. Gruijters, 2016).

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

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<sup>2</sup> NB: When participants with outliers were included in the analyses, no differences in significance and direction of effects were found.

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

## 248 Results

### 249 *Randomization checks*

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

253 **Table 1**

254 Variables measured, by condition

	Feedback Condition (FC) ( <i>n</i> = 58) <i>M</i> ± <i>SD</i>	No- Feedback Condition (NFC) ( <i>n</i> = 56) <i>M</i> ± <i>SD</i>
Sex	27 males, 31 females	17 males, 39 females
Age (in years)	29.97 ± 14.02	28.08 ± 12.26
BMI (kg / m <sup>2</sup> )	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

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

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

260 **Table 2**

261 Experimental foods used in the study

	Non-vegetarian meal	Vegetarian meal
Choice frequency ( <i>n</i> )	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

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

263 *Manipulation checks*

264 Participants in the FC condition did not differ from participants in the NFC in how aware they  
 265 were of their eating behavior during the experiment,  $t(1,102) = -1.31, p = .19$ . However,  
 266 participants differed significantly in their self-reported eating rate during the experiment;  
 267 participants in the FC reported that they ate more slowly than did participants in the NFC,  
 268  $t(1,102) = 5.55, p < .001$ . Furthermore, participants differed in how much they thought the fork  
 269 helped them to eat more slowly; participants in the FC had more confidence in the perceived  
 270 efficacy of the fork to change their eating rate than did those in the NFC,  $t(1,102) = -4.40 p <$   
 271  $.001$ ).

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275 *Main findings*276 *Primary outcomes*

277 With regard to participants' eating rate (i.e., total number of bites per minute), participants in the  
278 FC had fewer bites per minute than did those in the NFC,  $t(101.63) = 2.58, p = .011, d = 0.52,$   
279  $95\% \text{ CI} = [0.13, 0.91]$ . Participants in the NFC had 5.28 bites per minute ( $SD = 1.49$ ), whereas  
280 those in FC had 4.55 bites per minute ( $SD = 1.40$ ). In addition, participants in the FC had a higher  
281 success ratio than did those in the NFC,  $t(98.87) = -4.13, p < .001, d = -0.89, 95\% \text{ CI} = [-1.3, -$   
282  $0.49]$ . Participants in the FC consumed 66% of their bites outside the designated time interval,  
283 whereas those in the NFC consumed only 49% of their bites outside this interval. However, these  
284 differences did not translate into a difference in the total amount of food consumed,  $t(100.92) =$   
285  $-0.26, p = .797, d = -0.05, 95\% \text{ CI} = [-0.43, 0.34]$ ; participants in the FC consumed 435.77 grams  
286 of food ( $SD = 156.84$ ) and participants in the NFC consumed 428.21 grams ( $SD = 141.38$ ).

287 *Secondary outcomes*

288 A significant effect of condition on meal duration was found,  $t(101.93) = -2.44, p = .016, d = -$   
289  $0.47, 95\% \text{ CI} = [-0.86, -0.08]$ ; participants in the FC consumed their meal in 9 minutes and 44  
290 seconds, whereas those in the NFC consumed their meal in 8 minutes and 12 seconds. No  
291 differences between conditions were found in total fork servings,  $t(99.55) = -0.03, p = .975, d = -$   
292  $0.01, 95\% \text{ CI} = [-0.39, 0.38]$ , or the average time interval between fork servings,  $t(101.91) = -$   
293  $1.80, p = .074, d = -0.36, 95\% \text{ CI} = [-0.75, 0.03]$ . Finally, participants in the FC did not report  
294 being more satiated after their meal than did those in the NFC,  $t(96.4) = -0.24, p = .809, d = -$   
295  $0.05, 95\% \text{ CI} = [-0.34, 0.44]$ .

296 *Post-hoc analyses*

297 A significant effect of condition on grams of food consumed per minute was found,  $t(101.54) =$   
298  $2.1, p = .038, d = 0.43, 95\% \text{ CI} = [0.04, 0.82]$ ; participants in the FC consumed 48 grams per



299 minute ( $SD = 21.94$ ) whereas those in the NFC consumed 57.37 grams ( $SD = 23.46$ ). No  
300 differences were found in average bite size between conditions,  $t(101.27) = 0.54$ ,  $p = .59$ . In both  
301 conditions, participants consumed approximately 12 grams per bite.

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

### 305 Discussion

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

315 The finding that real-time vibrotactile feedback delivered through an augmented fork  
316 reduces eating rate is consistent with literature on eating rate interventions that have utilized other  
317 forms of technology to modify eating behavior (Ford et al., 2010; Ioakimidis, Zandian, Bergh,  
318 Södersten, 2009; Zandian et al., 2009). The vibrotactile feedback delivered by the fork may have  
319 disrupted the automatic tendency to eat fast and may have served as a trigger to make alterations  
320 to one's eating rate (Hermsen, Frost, Renes, & Kerkhof, 2016). Arguably, the feedback provided  
321 by the fork increases users' awareness of their eating rate. The real-time vibrotactile feedback  
322 enables users to compare their eating rate to their current goals (i.e., eating slower) and adapt

323 their eating rate when their behavior does not fit with their goals. Furthermore, it may also  
324 increase general self-awareness, which in turn increases one's abilities to inhibit undesired  
325 behaviors (Alberts, Martijn, & de Vries, 2011). Finally, it is known that among competing health-  
326 related behaviors, those supported by feedback are given priority over those without feedback  
327 (Northcraft, Schmidt, & Ashford, 2011). Thus, it is conceivable that receiving vibrotactile  
328 feedback when eating too fast has increased one's motivation to change one's eating behavior.  
329 The present findings demonstrate that real-time feedback delivered through digital technology  
330 may be an effective strategy to disrupt eating behavior; even a very simple, non-intrusive type of  
331 feedback in the form of a simple vibration can function as a trigger for behavior change and  
332 stimulate people to alter their eating rate.

333 Our results, however, failed to support the experimental hypothesis that a reduction in  
334 eating rate would lead to increased satiation and decreased ad-libitum food consumption.  
335 Although it has been shown that slower eating rate is associated with lower energy intake,  
336 regardless of the type of manipulation used to change the eating rate (e.g., type of instructions)  
337 (Robinson et al., 2014), the context of the present study might explain why changes in eating rate  
338 did not translate into changes in satiation or energy intake. Firstly, although we could derive  
339 specific within-meal behaviors from the data gathered by the fork that are known to influence  
340 energy intake and/or satiation, such as bite speed and bite size (Andrade et al., 2008; Zijlstra et  
341 al., 2009), the fork was not specifically developed to modify other within-meal behaviors than the  
342 number of bites per minute. The fact that the fork did to specifically modify behaviors that have  
343 been shown to lower energy intake, such as oral processing time and number of chews per unit of  
344 food (Bolhuis et al., 2013; Higgs & Jones, 2013; Weijzen, Smeets, & De Graaf, 2009), might  
345 explain the missing link between eating rate and reduced food intake in this study. Secondly,  
346 because it has been shown that there is a linear relationship between the size of experimental

347 manipulation to eating rate (i.e., how much eating rate has been reduced by) and energy intake  
348 (Robinson et al., 2014), a further explanation as to why the reduction in eating rate observed in  
349 the present study did not reduce food intake is because the effect of decrease to eating rate was  
350 not large enough in size to impact food consumption. Thirdly, it is possible that because  
351 participants were asked to self-serve their meal size, participants cleared their plate out of habit  
352 rather than adjusting their intake based on eating rate or feeling of fullness. Thus, it is possible  
353 that the initial effect of selected portion size may have overruled the effect of reducing eating rate  
354 (Brunstrom, 2011). Fourthly, it may be that specific characteristics of our test population have  
355 influenced our results. Our results demonstrated, for instance, that participants were not  
356 particularly motivated to change their eating rate in the near future. Feedback efficacy has been  
357 shown to be influenced by a high initial engagement with the target goal (i.e., reduction in eating  
358 rate) or strong motivation (i.e., to eat slower) (Bandura, 1997). Although participants were found  
359 to eat slower in a response to the vibrotactile feedback, subsequently they may have not been  
360 motivated to eat less. To further understand the link between real-time vibrotactile feedback,  
361 eating rate and food intake, future research might examine whether and how initial motivation to  
362 change one's eating rate or motivation to reduce food intake is affected by vibrotactile feedback.  
363 Finally, it has been argued that people may need to learn to associate the link between a slower  
364 eating rate, their satiety levels and energy intake (Brunstrom, 2011; Yeomans, Weinberg, &  
365 James, 2005). Although previous research has demonstrated the effects of a decelerated eating  
366 rate on food intake during a single meal (cf. Robinson et al., 2014), it is possible that receiving  
367 feedback would become effective across multiple meals. To test this assumption, future studies  
368 may provide users with consistent feedback over a few meals and measure satiation and food  
369 intake over time.

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

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

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405

406 Authors' contributions:

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

408 Conducted research: SH, RCJH

409 Analyzed the data: SH, RCJH

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

411 Primary responsibility for final content: SH, RCJH

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