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The 'Carrot Test': An approach to characterize individual differences in oral processing behaviour and eating rate

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ABSTRACT

Background: Eating rate is a modifiable risk factor for obesity and efficient methods to objectively characterise an individual's oral processing behaviours could help better identify people at risk of increased energy consumption. Many previous approaches to characterise oral processing and eating rate have relied on specialised equipment or wearable devices that are time consuming, expensive or require expertise to administer. The current trial used video-coding of the consumption of a standardised test food (the 'carrot test') to measure oral processing.

Objective: We sought (i) to test whether self-reported eating rate (SRER) is predictive of food oral processing derived from coded eating behaviours captured in the laboratory with a standardised test food, and (ii) to test whether differences in SRER are predictive of oral processing behaviours, eating rate and intake of a test meal.

Methods: Two hundred and fifty-three volunteers (86 male and 167 female, mean age 39.5 ± 13.6 years, mean BMI 22.2 ± 3.4 kg/m^2) provided their SRER and anthropometric measurements of height, weight and dual-energy X-ray absorptiometry (DEXA) percentage fat mass. Participants were also video recorded eating a fixed 50 g portion of carrot and an *ad libitum* lunch meal of fried rice. Average eating rate (g/min), bite size (g) and number of chews per bite for the carrot and lunch were derived through behavioural coding of the videos. Energy intake (kcal) was recorded at lunch and a later afternoon snack.

Results: Faster SRER significantly predicted faster eating rate, larger bite size and more chews per bite observed during intake of the carrot ($\beta = -0.26$–0.21, $p \leq 0.001$) and the lunch ($\beta = -0.26$–0.35, $p \leq 0.014$). SRER did not significantly predict intake at lunch or during the afternoon snack ($\beta = 0.05$–0.07, $p \geq 0.265$). Participants' oral processing of the carrot significantly predicted oral processing of the lunch ($\beta = -0.25$–0.40, $p \leq 0.047$) and faster eating rate of the carrot significantly predicted increased lunch intake ($\beta = 0.119$, $p = 0.045$). None of the oral processing behaviours predicted afternoon snack intake ($\beta = -0.01$–0.05, $p \geq 0.496$). None of these associations were moderated by BMI or body composition.

Conclusion: We confirm that SRER is a valid measure of group level differences in individual oral processing behaviours, but did not predict an individual's energy intake at a lunch-time meal. With this approach, it is possible to characterise differences in eating rate by coding eating behaviours for a standardized test food (in this case, a fixed portion of raw carrot). This approach could be used to provide an objective measure of a person's habitual oral processing behaviour, and was shown to be a significant predictor of eating rate and energy intake for a later test meal.

Abbreviations: SRER, Self-Reported Eating Rate; BMI, Body Mass Index.

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1. Introduction

Faster eating is associated with increased energy intake within a meal (Robinson et al., 2014) and has been identified as a risk factor for overweight and obesity in adults and children (Ohkuma et al., 2015). Several strategies have been proposed to modify eating rate in order to reduce energy intake, including training people to eat slower with electronic feedback devices (Scisco et al., 2011; Hermsen et al., 2016), modifying the texture of food (McCrickerd et al., 2017) and instructing people to slow down their eating speeds (Melanson et al., 2023; Shah et al., 2014). As a modifiable behaviour, there is value in quantifying and understanding these individual differences in oral processing and eating rate, as they relate to habitual energy intakes.

Methods to capture individual differences in eating rate can be grouped into questionnaire self-reported measures and laboratory measures, which include information captured by universal eating monitors (Kissileff et al., 1980), bite trackers (Scisco et al., 2011; Hermans et al., 2017) and video recordings (McCrickerd and Forde, 2017). Self-reported eating rate (SRER) is a convenient and rapid way to categorize people according to their perceived eating speed, which is often measured by asking, "How fast is your rate of eating?" with 'very slow' to 'very fast' as responses on either a four-or five-point scale (Otsuka et al., 2006). Research has shown that faster SRER is related to oral processing behaviours measured in the laboratory, such as faster eating rate, decreased number of chews per bite, and shorter total duration of chewing (Ekuni et al., 2012; Hamada et al., 2017). However, the majority (≥84.7 %) of participants in these studies rated themselves as moderate to very fast eaters (Otsuka et al., 2008; Leong et al., 2011; van den Boer et al., 2017), which is possibly a reflection of SRER being best suited to only identify faster eaters, or restricted by an individual's assessment of their own rate of eating in comparison to others (van den Boer et al., 2017). This suggests that SRER could be limited in its sensitivity to capture the full range of eating speeds and may even be biased by the eating speeds of an individual's typical eating companions (van den Boer et al., 2017).

By contrast, laboratory-based observational measures of eating behaviours can provide a more detailed view of individual differences in eating speed (Forde et al., 2013). In its simplest form, eating rate can be estimated by accurately recording the total duration of an eating occasion and combining this with a measure of total food consumed (gram weight or kilocalories) to get an average measure of food or energy intake per minute (Andrade et al., 2008; Bellisle and Le Magnen, 1981). More detailed measures of the microstructural patterns of eating have been achieved through the use of a Universal Eating Monitor (UEM). A UEM typically consists of a concealed balance that covertly measures and records the weight of food that is removed from a plate in real-time (e.g., every second) (Kissileff and Guss, 2001). Plotting the pattern in which the weight of food is removed from the plate over time can provide information used to plot a cumulative intake curve that tracks the acceleration or deceleration of eating speed, as well as changes in bite size and bite frequency.

UEM measures of eating rate have been shown to have good test–retest reliability (Hubel et al., 2006), but are limited by difficulties in tracking consumption of multi-component meals (Dovey et al., 2009) and high measurement errors (Kissileff et al., 1980), though measurement errors associated with UEM have decreased considerably since its initial application (Robinson et al., 2015). An alternative method is to video-record and code the eating behaviours (each bite, chew and swallow) of people eating food items and meals of a known quantity and composition (Forde et al., 2013; Gisel et al., 1984). This method is non-invasive and requires no specialised equipment, and has the advantage that it captures total oral exposure time, which represents the total time food spends in the mouth from first bite to last swallow. This is distinct from meal duration, which includes inter-bite intervals. Eating rate as measured via behavioural coding of videos is defined as the rate of meal intake (g/min) or energy intake (kcal/min) that does not include pauses. When total oral exposure time is combined with the coded eating behaviours (i.e. bites, chews, swallows) and the amount of food consumed (g or kcal), this approach can be used to derive a series of summary measures of oral processing behaviours that are specific to the meal and the individual (Forde et al., 2013). A longer total oral exposure time has been shown to promote increased fullness per kcal consumed, and associated with a greater release of neuro-endocrine signals related to satiety (Miquel-Kergoat et al., 2015). This behavioural coding approach has been used to compare the oral processing behaviours exhibited when consuming liquids, semi-solids and solid foods of different textures (Forde et al., 2017; Viskaal-van Dongen et al., 2011). Similarly, researchers have used this approach to identify faster eating adults and children and shown that faster eating is associated with a larger average bite sizes, less chews less per bite, shorter oral exposure times and greater energy intake, compared to slower eating rates (McCrickerd and Forde, 2017; Fogel et al., 2017; Fogel et al., 2017). Importantly, individual differences in these oral processing behaviours have been shown to be consistent across meals and are predictive of energy intake at different eating occasions (McCrickerd and Forde, 2017).

Although behavioural coding of oral processing provides a rich characterisation of modifiable oral processing behaviours associated with faster eating rates, it is time-consuming and requires consistency in coding schemes, clear high-quality videos and a significant amount of validation across coders (Forde, 2018; Lausberg & Sloetjes, 2009). It is unclear how well behavioural coding relates to the much more convenient and rapid measure of SRER often favoured in the literature. To date, only four studies have attempted to validate different methods of measuring eating rate against each other. Petty and colleagues showed that faster SRER predicted faster eating measured in the laboratory using a UEM, but did not predict eating rates derived from participant's self-recorded meal duration outside of the laboratory (Petty et al., 2013). A potential reason for this could be inaccurate self-reporting of intake, or the variability of meals consumed which differed in food type and texture. Similarly, other researchers compared SRER against laboratory-measured eating rate derived from researcher-recorded meal duration and total intake (Forde et al., 2013; Woodward et al., 2020). Although the average laboratory-measured eating rates were significantly faster in the fast SRER groups than average or slow SRER groups, there were still large variations within each group, with half of the individuals' measured eating rates deviating from their SRER groups. In a school canteen environment, Fagerberg and colleagues evaluated researcher-recorded meal duration and total intake from portable food scales against SRER of high school students (Fagerberg et al., 2021). While on a group level, students who self-reported eating faster had significantly faster objective eating rate of 13.7 g/min on average than those who self-reported eating slower, SRER had poor sensitivity at an individual level. This lends support to the idea that the sensitivity of SRER could be limited (van den Boer and Mars, 2015).

In oral biology, masticatory efficiency describes the time it takes for a bite of food to be swallowed and is related to the degree and rate of food degradation generated through oral processing (de Abreu et al., 2014). Evidence that oral processing of a standardised test food can predict eating behaviours at subsequent meals could provide a more time- and cost-effective but an equally descriptive measure of individual differences in oral processing and eating rate, compared to those currently used. Typically, test materials such as silicon cubes (i.e., Optosil) (Edlund and Lamm, 1980; Fontijn-Tekamp et al., 2004), or a standardised test food, such as beef, apple, peanut or carrot are consumed to characterise aspects of masticatory function (Kapur et al., 1964; Yurkstas and Manly, 1950) and these measures have been linked to bite size, eating rate (Fulks et al., 2017; Park and Shin, 2015; van der Bilt et al., 2006), and obesity (Tada and Miura, 2018). The current trial adopted a similar approach by measuring participants eating behaviours during the consumption of a standardised test food. The 'carrot test' was developed whereby an individual's oral processing behaviours were coded while consuming a small quantity of a standardised test food (2 x

15 g identical raw carrot sticks). This provided a more efficient characterisation of habitual oral processing behaviours and eating speed than behavioural coding of an entire meal. Therefore, individual differences in oral processing and eating rate were characterised using a standardised test food and were compared to the oral processing behaviours and energy intake for a later test meal.

To date no study has evaluated the link between an individual's SRER, behavioural coding of their eating rate and oral processing behaviours and subsequent food intake. Similarly, it remains unclear whether there is a relationship between an individual's eating rate for a standardised test food and their SRER, and whether these differences track with later food intake. The current study sought to consider the relationship between SRER and oral processing derived from coding eating behaviours captured in the laboratory. The study further compared the predictive validity of behavioural coding consumption of a standardised test food to characterise an individual's eating rate and oral processing behaviours (the carrot test), and whether this predicted the eating rate and intake of a subsequent lunchtime meal.

2. Methods

2.1. Participants

Participants were 264 (92 male and 172 female) volunteers who took part in a cross-sectional study aimed at characterising the body composition of a representative sample of adults in Singapore, conducted in the Clinical Nutrition Research Centre (CNRC) between June 2015 and January 2017. Body composition, oral processing behaviours and *ad libitum* energy intake were measured as part of the study. Recruitment criteria specified healthy participants aged 21 years or older, without any allergies or aversions to the study foods, not diagnosed with any major diseases or pregnant, and not taking any medications that would affect appetite or energy metabolism. The research activities were approved by the National Health Group Domain Specific Review Board (Reference number: 2013/00783) and all participants provided written consent to the use of their data for current and future-related research.

2.2. General procedure

The general procedure of the study is summarised in Fig. 1. All participants were screened for their eligibility prior to the session. Participants arrived at the centre between 8 and 8.30am on the test day having fasted overnight for at least 10 h and avoided vigorous physical activity. Measures of height, weight and basal metabolic rate were taken in a fasted state, followed by a series of other measures that are described elsewhere (Bi et al., 2017). A standardised breakfast was served approximately an hour after arrival, comprising two slices of bread (Gardenia, 57 g, 263 kcal/100 g) with kaya spread (NTUC Fair Price, 32 g, 300 kcal/100 g) and orange juice (Marigold, 250 ml, 46 kcal/100 ml). The total energy content for breakfast was 360.9 kcal and participants were required to finish the full breakfast as a means of standardizing appetite before the intake and oral processing measures later in the day. In between breakfast and assessment of eating behaviours of standardised test food and lunch, further anthropometric and sensory measurements were taken, including skin-fold measurements and olfactory and taste tests, which are not reported in the current paper. Immediately prior to lunch, participants were allocated approximately five minutes to consume two raw carrot sticks while their eating behaviours were video-recorded. In the same test room, participants were then given an initial 15 min to consume their lunch until they were comfortably full and could request further time if this was not sufficient. The time scale was based on initial pilot tests of the meal paradigm and previous research (Forde et al., 2013).Participants were free to request more of the test meal and time extensions of 5-additional minutes. For lunch, they provided pre- and post-meal appetite ratings and continued to rate their appetite every 15 min for the next 75 min. During this time, participants completed a series of questionnaires electronically, including their SRER. Dual Energy X-ray Absorptiometry (DEXA) scan was performed on each participant to assess their body composition. Finally, participants were provided an afternoon snack at the end of the test session approximately two hours after the lunchtime meal, where intake was again recorded.

3. Measures

3.1. Body composition

Participants' height (cm) and weight (kg) were measured with an electronic weighing and measuring station (Seca 763 digital scale, Birmingham, UK). BMI (kg/m^2) was calculated as weight divided by height squared. The percentage fat mass of participants used in this analysis were obtained from DEXA (QDR 4500A, fan-beam densitometer, Hologic, Waltham, MA, USA). Participants were instructed to remove all metal items on them and change into an authorised gown before the scan. A licensed radiographer supervised the DEXA scan and made all calculations through the manufacturer's software (version 8.21).

3.2. The 'carrot test' – oral processing of a standardised test food

Carrot was chosen as the standardised test food as it posed a moderate masticatory challenge, has a consistent texture, is easy to source and is broadly accepted, and has low energy density and was thus predicted to have minimal impact on subsequent appetite. Carrots were peeled and cut into similar dimensions as much as possible, keeping to 15 g per stick. Outer harder parts were mostly discarded to ensure the cuboid shape for each stick. Before the test, participants were asked to rate their liking of peeled raw carrot on a 100-point visual analog scale (VAS) from "Not at all liked" (0) to "Extremely liked" (100) and the majority (88 %) reported neutral to positive liking of raw carrot.

Participants were seated in individual booths with laptops and given two identical 15 g rectangular sticks of peeled raw carrot. They were instructed to consume the carrots as they normally would and refrain from using their mobile phones. Participants should avoid wearing clothes that may preclude the video-recording of swallows during and impinge on the behavioural coding. Consumption was video-recorded with a webcam (Logitech HD c310) mounted on to the laptop (HP Stream 11.6-inch). Participants were instructed to look directly at camera mounted on each laptop, but were unable to see themselves being recorded, and were instead presented with an instruction screen.

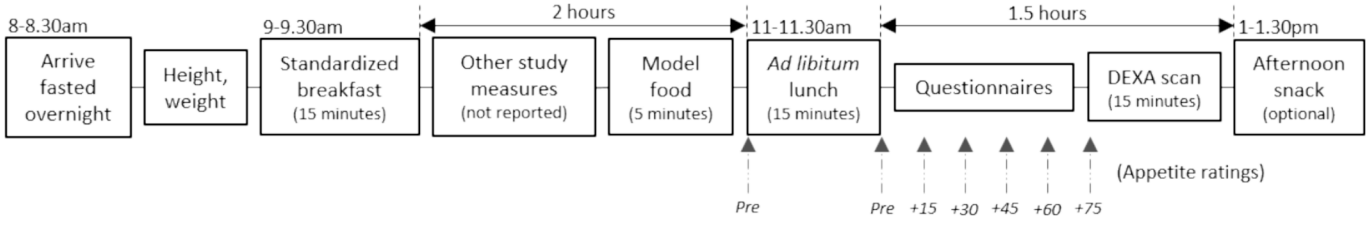

Fig. 1. General study procedure for test session. Notes: DEXA – Dual-Energy X-ray Absorptiometry.

Post-hoc video recording was completed using the behavioural annotation software ELAN [version 4.9.1, Max Planck Institute for Psycholinguistics, The Netherlands: 45] by trained coders who followed a standardised coding scheme, described elsewhere (Forde et al., 2017). The frequency of every bite, chew and swallow taken starting from the first bite to the final swallow were recorded. The total oral exposure time (s) and inter-bite interval (s) were calculated and combined with the weight of the test meal consumed to further derive a series of oral processing behaviours: average eating rate (g/min), bite size (g/bite) and number of chews per bite. Eating rate (g/min) was based on total amount of the meal consumed divided by the total oral exposure time, not the total meal duration. A second trained coder validated 10 % of the coded videos to reach a minimum of 80 % agreement among coders for the data to be accepted for analysis (McCrickerd and Forde, 2017). Intra-class correlation coefficient using two-way mixed, consistency, single-measures indicated excellent consistency between the coders across all oral processing behaviours, ICC = 0.943 – 0.991 (95 % CI, 0.908–0.994).

3.3. Rated appetite

Prior to lunch, participants were asked to rate their hunger, desire to eat, prospective consumption and fullness on 100-point VAS (McCrickerd et al., 2017). These questions were mostly asked as "How < measure > do you feel right now?" and "How much food could you eat right now?". Anchors used were "Not at all < measure>" and "Extremely < measure>". A composite score per participant was derived by averaging their rating of hunger, desire to eat, prospective consumption and a negation of fullness (100 − rating), which were shown to have good consistency (Cronbach's Alpha = 0.82) (McCrickerd and Forde, 2017).

3.4. Lunch intake and oral processing

The *ad libitum* lunch consisted of 1000 g olive vegetarian fried rice (1.89 kcal/g: JR Foods, Singapore) and a glass of water (250 ml). Before lunch, participants were asked to rate their liking of olive vegetarian fried rice on a 100-point VAS and the majority (91 %) reported neutral to positive liking of fried rice. The rice was prepared according to manufacturer instructions and served warm at 60 °C. Participants were seated in individual booths and asked to eat in their normal way and consume the meal until they were comfortably full, and were free to serve themselves from an *ad libitum* serving portion onto a separate plate. The weight of the serving bowl and plate were recorded away from the view of the participants before and after the meal to derive energy intake from lunch. Weight was measured using a Sartorius balance accurate to 0.001 g. Participants were again video-recorded consuming their lunch and their oral processing behaviours were coded and derived using the same behavioural coding methodology and validation process as described for the standardised test food.

3.5. Questionnaires and Self-Reported eating rate (SRER)

Participants completed a series of questionnaires electronically, which measured different aspects of their eating styles and food preferences. This included Three Factor Eating Questionnaire (TFEQ) (Fedoroff et al., 1997) and SRER. The SRER question was based on a previously published approach and asked on a five-point scale as "How fast is your rate of eating?", with 'very slow' to 'very fast' as responses (Sasaki et al., 2003).

3.6. Afternoon snack

At the end of the test session, participants were provided with afternoon snacks for which consumption was not compulsory. Snacks included cheese sandwich biscuit (Julie's, 56 g, 536 kcal/100 g), lemon puff biscuit (Khong Guan, 44 g, 527 kcal/100 g) and orange juice (Marigold, 250 ml, 46 kcal/100 ml). The total energy content was 647 kcal. Leftover snacks and drinks were covertly weighed to derive intake and participants were not video-recorded during snack consumption such that oral processing was not measured.

3.7. Data analysis

Power analysis was not specifically calculated to determine variations in the eating rates of the population surveyed in the current study, but the sample size is consistent with or larger than other studies that similarly attempted to validate different methods of measuring eating rate (Petty et al., 2013; Woodward et al., 2020; Fagerberg et al., 2021; van den Boer and Mars, 2015). The data were screened for outliers and checked for normality using Shapiro-Wilk test, skewness and kurtosis. A total of 11 outliers were identified within the eating behaviour measures as having three times the interquartile range above the upper quartile and skewed the data. The data from these 11 people were removed from all analyses (n = 1 from carrot bite size, n = 4 from carrot chew per bite, n = 3 from lunch eating rate, n = 1 from lunch bite size, n = 1 from lunch chew per bite and n = 1 from lunch intake). No other outliers were identified across any of the measures. This resulted in data from a total of 253 participants included in the analyses. Participant characteristics are presented as means, standard deviations (SD) and range.

The first research question was to assess the link between SRER and oral processing derived from coding eating behaviours captured in the laboratory. To do this, separate multiple regression analyses were used to assess the relationship between participant SRER and eating rate (g/min), bite size (g) and number of chews per bite recorded for the standardised test food (carrot), and the lunchtime meal (olive fried rice). Additional regression analyses were used to assess the relationship between SRER and energy intake (kcal) at lunch and during the afternoon snack. To compare the classification of eating rate based on SRER against objective measurements, SRER was re-grouped by combining 'very slow' and 'slow' and 'very fast' and fast' to classify participants as slow, average or fast eaters. Agglomerative hierarchical clustering with proximity based on similarities using Pearson correlation coefficient and agglomeration based on weighted pair-group average was conducted to categorise participants based on their measured eating rate, bite size and number of chews per bite. This was conducted separately for carrot and lunchtime meal. Chi-square test of independence and Pearson's Phi coefficient were used to evaluate the strength and significance of associations between the three categorisations.

The second research question was to test the ability of oral processing behaviours captured for a standardised test food to predict oral processing and energy intake in another eating occasion. Separate multiple regression analyses were carried out to test the relationship between eating rate (g/min), bite size (g) and number of chews per bite recorded for carrot and the same oral processing behaviours recorded at lunch. Further regression analyses were conducted to assess the relationship between oral processing behaviours of carrot and energy intake (kcal) at lunch and during the afternoon snack.

All regressions were presented as unadjusted and adjusted analyses. The adjusted analyses controlled for variables identified as potential covariates of oral processing and energy intake: sex, age, BMI, percentage fat mass, TFEQ-restraint score and pre-meal appetite score (McCrickerd and Forde, 2017). Pre-lunch appetite was found to be significantly correlated with intake ($r(253) = 0.32$, $p < 0.001$) and adjusted for in the analysis. Additional adjusted analysis was conducted to include the interaction terms to test whether the relationship between the predictor and outcome variables was likely to be moderated by any of the covariates identified. All regression were also split by sex to assess for potential differences, although conclusions were not drawn as male had half the sample size (n = 86) of female (n = 167). All analyses were conducted in IBM SPSS Statistics version 23 and a result was considered significant when $p < 0.05$.

4. Results

4.1. Participants

Participant characteristics are presented in Table 1. Participants had a mean age of 39.5 years (SD = 13.6, ranging 21 to 69 years), mean BMI of 22.2 kg/m^2 (SD = 3.43, ranging 16.3 to 37.8 kg/m^2) and mean fat mass of 31.5 % (SD = 7.43, ranging 13.2 to 51.1 %). Their mean lunch duration was 8.4 min (SD = 3.4, ranging 1.6 to 18.9 min). The sex difference in age were not significant ($p > 0.655$). Males had significantly higher BMI than females but lower percentage fat mass ($p < 0.001$). Males also rated their appetite significantly higher and self-reported a faster eating rate ($p < 0.005$). There were no significant sex differences in lunch duration and dietary restraint.

4.2. Relationship between Self-Reported eating Rate, measured oral processing behaviours and intake

The associations between SRER and the oral processing behaviours associated with eating the carrot sticks are presented in Table 2. SRER significantly predicted carrot eating rate of males ($\beta = 0.347$, $t = 3.20$, $p = 0.002$, $R^2_{Adjusted} = .231$) but not of females ($\beta = 0.140$, $t = 1.82$, $p = 0.071$, $R^2_{Adjusted} = 0.083$). SRER significantly predicted chews per bite but not bite size. Participants who self-reported a faster eating rate consumed the lunchtime meal at a faster rate. SRER was related to a larger average bite size and fewer chews per bite of food at lunch for females ($\beta \geq 0.180$, $t \geq 2.27$, $p \leq 0.024$, $R^2_{Adjusted} \geq 0.033$) but for not males ($\beta \geq 0.085$, $t \geq 0.72$, $p \geq 0.119$, $R^2_{Adjusted} \geq 0.013$). There was no significant relationship between SRER and energy intake at lunch and during the afternoon snack. Importantly, all relationships remained after adjustment of the covariates and were not significantly moderated by any covariates ($\beta = -0.025$ to 0.113, $p \geq 0.070$).

The associations between categorisation based on SRER, on oral processing of the carrot and on oral processing of the lunchtime meal are summarised in Table 3. Categorising participants with SRER is strongly related to categorising participants by their oral processing of the standardised test food, and very strongly related to categorising participants by their oral processing at lunch (X^2 (4, $N = 253$) = 14.1 – 29.6, $p \leq 0.007$; $\varphi = 0.236 – 0.342$).

4.3. Relationship between oral processing of the standard Food, oral processing behaviours at lunch and energy intake

The relationship between oral processing of the standardised test food (carrot) and oral processing and energy intake at lunch, and energy intake at the afternoon snack are summarised in Table 4. Eating the carrot portion at a faster rate predicted a faster eating rate and less chewing per bite of food at lunch. Eating rate of the carrot significantly predicted bite size of the lunchtime meal for females ($\beta = 0.217$, $t = 2.72$, $p = 0.007$, $R^2_{Adjusted} = 0.046$) where faster eating predicted larger bite sizes, but not for males ($\beta = 0.005$, $t = 0.04$, $p = 0.966$, $R^2_{Adjusted} = 0.087$). Taking a larger bite of the carrot predicted a larger bite size and faster eating rate during the lunchtime meal. It also predicted a higher number of chews per bite taken by males only ($\beta = 0.318$, $t = 2.89$, $p = 0.005$, $R^2_{Adjusted} = 0.080$ vs. ($\beta = 0.096$, $t = 1.24$, $p = 0.218$, $R^2_{Adjusted} = 0.047$). Taking a higher number of chews per bite of the carrot significantly predicted more chews per bite and a slower eating rate at lunch. It predicted larger bite size taken by males only ($\beta = 0.278$, $t = 2.76$, $p = 0.007$, $R^2_{Adjusted} = 0.168$ vs. $\beta = 0.001$, $t = 0.01$, $p = 0.994$, $R^2_{Adjusted} = 0.002$).

Eating rate (g/min) of the standardised test food was the only parameter to significantly predict energy intake at lunch meal and only for females ($\beta = 0.216$, $t = 2.82$, $p = 0.005$, $R^2_{Adjusted} = 0.119$ vs. $\beta = -0.002$, $t = -0.02$, $p = 0.984$, $R^2_{Adjusted} = 0.027$), with a faster eating rate of the carrot significantly predicting a higher energy intake during the lunchtime meal. Bite size and number of chews per bite of the carrot did not predict lunch intake, and all of the oral processing behaviours of the standardised test food failed to significantly predict energy intake at the afternoon snack.

Adjusting the analysis for relevant covariates had little impact on any of the relationships tested. Moreover, none of the interactions were significant ($\beta = -0.076$ to 0.082, $p \geq 0.160$), indicating that these relationships were not moderated by any of the covariates tested, including participants' BMI and body composition.

Table 1
Mean and (Range of) Participant Characteristics.

Participant Characteristics	Total (N = 253)	Male (n = 86)	Female (n = 167)
Age (years)	39.5 ± 13.6 *(21.3–68.6)*	40.0 ± 13.6 *(21.7–68.0)*	39.2 ± 13.7 *(21.3–68.6)*
BMI (kg/m^2)	22.2 ± 3.4 *(16.3–37.8)*	23.2 ± 2.9^b *(16.3–29.0)*	21.7 ± 3.6 ^{a} *(16.4 ± 37.8)*
Fat Mass (%)	31.5 ± 7.4 *(13.2–51.1)*	25.1 ± 5.5 ^{a} *(13.2–36.3)*	34.9 ± 6.0^b *(21.9 ± 51.1)*
Pre-meal Appetite (1–100 score)	53.3 ± 18.3 *(5.0–94.0)*	57.9 ± 17.0^b *(17.3–90.3)*	50.8 ± 18.5 ^{a} *(5.0–94.0)*
SRER (1–5 score)	3.2 ± 0.7 *(1–5)*	3.4 ± 0.8^b *(2–5)*	3.1 ± 0.7 ^{a} *(1–5)*
TFEQ-Restraint (0–21 score)	10.3 ± 5.3 *(0–21)*	9.5 ± 5.3 *(1–21)*	10.7 ± 5.2 *(0–20)*
Lunch Duration (minutes)	8.4 ± 3.4 *(1.6–18.9)*	8.8 ± 3.4 *(2.5–18.9)*	8.2 ± 3.3 *(1.6–17.4)*

Notes: SRER = Self-Reported Eating Rate. TFEQ-Restraint = Three-Factor Eating Questionnaire Restraint Component. Means denoted by a different letter indicate significant differences between male and female ($p < 0.005$).

5. Discussion

We investigated the relationship between self-reported and observed measures of eating rate by comparing SRER to an objective measure of oral processing using a standard test food ('the carrot test'). These relationships were further associated to the oral processing exhibited during an *ad libitum* test meal, to investigate how well self-report and test food measures predicted oral processing behaviour and energy intake. SRER significantly predicted eating rate and number of chews per bite of both the carrot and lunch-time meal. Females' SRER predicted all oral processing at their lunchtime meal. Classification of slow, average and fast eaters based on SRER was strongly associated with eating rate based on objective measurements of carrot and of the lunchtime meal separately. A faster average eating rate and larger bite size of the carrot predicted the same behaviour for the lunch-time meal. More chews per bite of the carrot predicted more chews per bite and slower eating rate at lunch. Whereas SRER did not correlate with carrot eating rate of females and energy intake, faster carrot eating rate of females was a significant predictor of all lunch oral processing and greater energy intake at lunch. None of the oral processing behaviours predicted later snack intake.

Data on the predictive validity of SRER measures are limited, and previous studies have demonstrated agreement between higher SRER and faster eating rates for test foods, and a laboratory test meal (van den Boer et al., 2017), with weaker relationships observed for measures of free-living eating behaviours (Petty et al., 2013). The current results align with this, where differences in SRER significantly predicted eating rate measured using the carrot test. However, contrary to previous findings (McCrickerd and Forde, 2017; Forde et al., 2013), SRER did not predict higher energy intake at a later meal in the current study. Our results indicate that SRER may be less sensitive that objectively measured eating behaviour with a test food, because individuals can only be classed in an eating-rate category, rather than have an individual value. As such this may be useful to stratify participants at group level, but less predictive of an individual's eating rate or acute energy intake, as reported previously (Petty et al., 2013; Woodward et al., 2020;

Table 2
Results of multilinear regression models of self-reported eating rate with carrot oral processing behaviours, lunch oral processing behaviours and intake separately as dependent variables.

	Carrot Eating Rate (g/min)			**Carrot Bite Size (grams)**			**Carrot Chews/Bite (no.)**		
	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*
Unadjusted SRER	1.384	0.306 0[.187,.424]	0<.001	0.146	0.082 [-0.042,.206]	0.193	−6.005	−0.245 [-0.366,-0.125]	0<.001
Adjusted SRER	0.950	0.210 0[.087,0.33]	0.001	−0.035	−0.020 [-0.143,.104]	0.751	−6.436	−0.263 [-0.389,-0.136]	0<.001
	Adjusted R^2 = 0.151			Adjusted R^2 = 0.140			Adjusted R^2 = 0.099		
	Lunch Eating Rate (g/min)			**Lunch Bite Size (grams)**			**Lunch Chews/Bite (no.)**		
	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*
Unadjusted SRER	6.788	0.450 0[.339,.561]	0<.001	0.543	0.181 0[.058,.303]	0.004	−4.105	−0.312 [-0.430,-0.193]	0<.001
Adjusted SRER	5.227	0.347 0[.236,.457]	0<.001	0.463	0.154 0[.031,.227]	0.014	−3.476	−0.264 [-0.390,-0.137]	0<.001
	Adjusted R^2 = 0.312			Adjusted R^2 = 0.147			Adjusted R^2 = 0.097		
	Lunch Intake (kcal)			**Afternoon Intake (kcal)**					
	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*			
Unadjusted SRER	39.089	0.146 0[.023,.269]	0.020	9.223	0.042 [-0.082,.166]	0.507			
Adjusted SRER	17.766	0.066 [-0.051,.183]	0.265	10.783	0.049 [-0.079,.177]	0.450			
	Adjusted R^2 = 0.229			Adjusted R^2 = 0.079					

Notes: SRER = Self-Reported Eating Rate. Adjusted = adjusted for sex, age, body mass index (BMI), percentage fat mass, Three Factor Eating Questionnaire-restraint score and pre-meal appetite composite score. B = Unstandardized beta; ß = Standardized beta. 95 % CI refers to the confidence interval of which the range of values has 95 % probability to include the true value. Adjusted R^2 refers to the percentage of variance accounted for by the predictors adjusted for sex, age, BMI, appetite and dietary restraint. g/min = grams per minute. No. = number of chews per bite. Kcal = kilocalories.

Table 3
Results of test of independence and strength of association between categorisation of eating rate based on SRER and objective oral processing measures.

Categorisation based on	**SRER**	**Carrot Oral Processing Measures**	**Lunch Oral Processing Measures**
Slow eaters, n=	36	49	51
Average eaters, n=	131	97	113
Fast eaters, n=	86	107	89
Comparison of SRER against carrot/lunch	$\boldsymbol{X^2}$ (4, N = 253)	14.1, p = 0.007	29.6, p < 0.001
	$\boldsymbol{\varphi}$	0.236	0.342
Comparison of carrot against lunch		X^2 (4, N = 253) = 19.8, p = 0.001; Pearson's φ = 0.280	

Notes: SRER = Self-Reported Eating Rate. Oral processing measures: measured eating rate (g/min), bite size (g) and chews per bite (no.) $\boldsymbol{X^2}$ = Chi-Square Statistic. φ = Pearson's Phi Coefficient.

Fagerberg et al., 2021). A *meta*-analysis showed a consistent positive relationship between SRER and BMI across 22 studies, but with wide-variation in the strength of associations (Ohkuma et al., 2015). In a population based survey those reporting higher SRER consumed an excess 105 kcal/day, had a 5 kg increased body weight, 1.3 kg/m^2 higher BMI and 3.1 cm larger waist-circumference on average (Teo et al., 2020). Higher SRER was also shown to be a significant predictor of higher blood pressure, circulating triglycerides and cholesterol, suggesting SRER could provide a robust behavioural marker for increased energy intake body weight, adiposity and several cardio-metabolic health indicators (Teo et al., 2020). A retrospective analysis of SRER ratings has shown it is predictive of longitudinal changes in body weight, with one study over 8-years showing weight gain of an average of 1.9 kg among those reporting high SRER, compared to 0.8 kg among those reporting lower SRER (Tanihara et al., 2011). Findings from the current work show that self-reported eating rate remains a valid measure that reflects differences in measured eating rates, but failed to predict an individual's eating behaviours and intake within a test-meal.

Oral processing behaviours observed during carrot consumption significantly predicted the same oral processing behaviours, and overall energy intake, during the lunch meal. The consistency of eating behaviours has previously been reported and described as a stable 'trait' that predicts energy intake and tracks against prospective changes in body composition (Stunkard et al., 2004; Berkowitz et al., 2010; Teo et al., 2019). Individual differences in eating rate have been observed from infancy (Stunkard et al., 2004), and are known to track against growth rates throughout childhood (Berkowitz et al., 2010). Research has shown that oral processing and eating rate are consistent across meals (McCrickerd and Forde, 2017; Martin et al., 2005) and laboratory studies have shown favourable test–retest reliability, demonstrating the stability of eating behaviour within an individual and across sessions meals (Kissileff and Guss, 2001; Martin et al., 2005). Whereas oral processing behaviour varies considerably between people and across foods, these behaviours have been shown to be consistent within individuals for the same food (Engelen et al., 2005). The current study highlights the stability and consistency of eating rate when using a standardised test food to characterise an individual's behaviour, and that these behaviours are predictive of oral processing and energy intake

Table 4
Results of multilinear regression models of carrot oral processing behaviours with lunch oral processing behaviours and intake separately as dependent variables.

	Lunch Eating Rate (g/min)			Lunch Bite Size (grams)			Lunch Chews/Bite (no.)		
	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*
Unadjusted	1.440	0.432	0<.001	0.102	0.154	0.014	−0.843	−0.290	0<.001
Carrot ER		0[.320,.544]			0[.031,.277]			[-0.409,-0.171]	
Carrot Bite Size	1.777	0.210	0.001	0.640	0.379	< 0.001	0.678	0.092	0.147
		0[.088,.331]			0[.264,.494]			[-0.032,.215]	
Carrot Chew/Bite	−0.126	−0.204	0.001	0.021	0.174	0.006	0.212	0.394	0<.001
		[-0.326,-0.083]			0[.051,.296]			0[.280,.508]	
Adjusted	1.151	0.346	0<.001	0.088	0.132	0.038	−0.728	−0.250	<0.001
Carrot ER		0[.235,.456]			0[.008,.256]			[-0.377,-0.123]	
	Adjusted R^2 = 0.311			Adjusted R^2 = 0.142			Adjusted R^2 = 0.091		
Carrot Bite Size	0.499	0.059	0.337	0.525	0.311	0<.001	1.243	0.168	0.013
		[-0.062,.180]			0[.190,.431]			0[.036,.299]	
	Adjusted R^2 = 0.207			Adjusted R^2 = 0.209			Adjusted R^2 = 0.059		
Carrot Chew/Bite	−0.149	−0.243	0<.001	0.015	0.121	0.047	0.216	0.402	0<.001
		[-0.353,-0.132]			0[.002,.239]			0[.286,.517]	
	Adjusted R^2 = 0.261			Adjusted R^2 = 0.140			Adjusted R^2 = 0.190		

	Lunch Intake (kcal)			Afternoon Intake (kcal)		
	B	β [95 % CI]	*p*	B	β [95 % CI]	*p*
Unadjusted	11.690	0.198	0.002	0.471	0.010	0.878
Carrot ER		0[.076,.320]			[-0.115,.134]	
Carrot Bite Size	33.510	0.223	0<.001	10.765	0.087	0.167
		0[.102,.344]			[-0.037,.211]	
Carrot Chew/Bite	−0.317	−0.029	0.646	0.313	0.035	0.580
		[-0.153,.095]			[-0.089,.159]	
Adjusted	7.037	0.119	0.045	0.461	0.009	0.884
Carrot ER		0[.002,.236]			[-0.119,.138]	
	Adjusted R^2 = 0.237			Adjusted R^2 = 0.077		
Carrot Bite Size	9.296	0.062	0.308	5.574	0.045	0.496
		[-0.057,.181]			[-0.085,.175]	
	Adjusted R^2 = 0.228			Adjusted R^2 = 0.079		
Carrot Chew/Bite	−0.967	−0.089	0.122	−0.064	−0.007	0.909
		[-0.201,.024]			[-0.130,.116]	
	Adjusted R^2 = 0.232			Adjusted R^2 = 0.077		

Notes: ER = Eating Rate. Adjusted = adjusted for sex, age, body mass index (BMI), percentage fat mass, Three Factor Eating Questionnaire-restraint score and pre-meal appetite composite score. B = Unstandardized beta; ß = Standardized beta. 95 % CI refers to the confidence interval of which the range of values has 95 % probability to include the true value. Adjusted R^2 refers to the percentage of variance accounted for by the predictors adjusted for sex, age, BMI appetite and dietary restraint.

at later meal occasions.

Behavioural coding of meals is an effective approach for characterising the eating behaviours associated with greater energy intakes, but have the disadvantage of being time consuming and can be affected by the texture properties of the test meal. A significant advantage of the current 'carrot test' is that it standardises the texture challenge when evaluating oral processing behaviours, and requires no specialised equipment to implement, and much less time to objectively code behaviours. Many previous approaches to characterise oral processing and eating rate have relied on specialised equipment such as the mandometer or the universal eating pattern monitor (Kissileff et al., 1980; Kissileff and Guss, 2001; Hubel et al., 2006), or the use of wearable devices such as the bite counter (Scisco et al., 2011; Hermsen et al., 2016). Numerous methods and test foods have been used to evaluate oral processing and eating rate of individuals, but none of them is considered as the gold standard. The advantage of the 'carrot test' is its low cost, easy to source and prepare in a standardised way, consistency in texture while posing a sufficient mastication challenge to measure oral processing, its widely accepted taste and low energy density, and in the small quantity served is unlikely to significantly influence fullness. The 'carrot test' is easy to replicate, is predictive of later behaviours and has low respondent burden. Previous researchers have proposed chewing a fixed quantity of carrot as a standardised test food to measure normative masticatory function among participants with Down Syndrome or denture wearers (Woda et al., 2010) and to identify individuals presenting with hampered mastication. In the future, it may be possible to align these procedures to gather information on oral processing, eating rate and masticatory function using the same test food. Previous proposed tests of normative masticatory function utilised carrot cylinders (3–4 g), whereas our 'carrot test' utilised two rectangular lengths of carrot (15 g each). Recent research has demonstrated that carrot shape can impact the observed oral processing behaviours where julienned carrot is consumed more rapidly than carrot spirals (Van Eck et al., 2019) and whole carrot was consumed at a faster rate than carrot pieces (Liem and Russell, 2019). Future application of our standardised 'carrot test' (2 x 15g rectangular sticks) could be used to measure differences in individual oral processing behaviours and eating rates, and should therefore use a standardised weight and shape of the test-food to ensure consistency of test results.

The current work highlights that using a standardised test food to characterise eating rate provides detailed information on oral processing behaviours such as bite size and chews per bite, and is a significant predictor of later energy intake within a meal context. Importantly, these oral processing behaviours can be altered through texture modifications, which in turn influences intake (McCrickerd et al., 2017; Ferriday et al., 2016). Eating rate has been identified as a modifiable risk factor for obesity, with faster eating associated with higher energy intake, adiposity and BMI (Robinson et al., 2014; Ohkuma et al., 2015; Fogel et al., 2017; Fogel et al., 2017). The finding that oral processing behaviours observed using a carrot were a significant predictor of later meal oral processing and intake, suggests this simple approach could be applied to study individuals' oral processing behaviours. Faster eating

rate of the standardised test food significantly predicted larger bite size and fewer chews per bite, which have previously been described as an "obesogenic eating style" among children where these eating behaviours were linked to greater energy consumption and higher BMI (Fogel et al., 2017). By extension, classifying faster eating rates using a standardised test food such as a carrot could be useful in identifying individuals who may exhibit this "obesogenic eating style", and benefit from interventions targeted at reducing their eating speed (James et al., 2018). Using a standardised test food, along with newly developed automatic video-coding of meal consumption (Konstantinidis et al., 2020), could efficiently help identify and understand individual factors that influence eating rates, such as basal metabolic rate (Henry et al., 2018). Notably, findings are limited to the test population studied in the current trial, and further research is needed to extrapolate the relationship between 'carrot test' eating rate and meal energy intake in other populations. Although the results of the 'carrot test' provide an indicator of an individual's habitual eating rate, they may also be influenced by differences in participant need state and other drivers of food intake. The 'carrot test' provides an important indicator of relative differences between groups of individuals in terms of their eating rate, but should not be considered as an absolute or immutable value.

The simplicity of the 'carrot test' to categorize eating rate may also be its limitation. Biphasic foods and foods of a composite nature such as a burger with meat patty, onion and cheese may result in more complicated oral processing behaviours and variations in how individuals adjust their eating behaviour would not be captured by the 'carrot test' (Päßler et al., 2012). The addition of condiments can also directly impact eating rate and oral processing behaviours (Van Eck et al., 2019). Both the standardised test food, carrot, as well as *ad libitum* lunch, fried rice, were all homogenous, and future research should test whether behaviours used when consuming the carrot are also predictive of eating behaviours and intake for other, more complex meals. Nonetheless, in the current study, oral processing behaviour and eating rate were consistent within an individual, suggesting that the use of a standardized test food could provide a novel approach to classify individuals as faster or slower eaters.

6. Conclusion

The current trial showed that self-reported eating rate is reflected in the eating rate of a test food, but did not predict meal eating rate or intake. The oral processing behaviours exhibited during consumption of a standardized test food were a significant predictor of the same behaviours during a realistic lunch-time meal, and were significantly associated with eating rate and energy consumed at that meal. We demonstrate that using a standardized test food to characterise an individual's eating rate predicted their eating rate at a subsequent test-meal, independent of their weight status. This approach can be applied to measure individual differences in oral processing and eating rate and may be a useful tool when characterising or screening participants or when studying food properties that influence energy intake. Future research should expand this focus and use the standardised 'carrot test' to characterise participants and determine the consistency of eating rate as a trait that predicts energy intake across different meals, contexts and for more complex foods.

CRediT authorship contribution statement

Claudia S. Tang: Writing – review & editing, Writing – original draft, Formal analysis. **Keri McCrickerd:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Ciaran G. Forde:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Author disclosures

CGF is a member of the Scientific Advisory Board for Kerry Health and Nutrition Institute, and CGF and KMC has received reimbursements for speaking at meetings sponsored by companies that produce food and nutritional products. The authors report no conflicts of interest.

Author contributions

CGF and KMC conceptualized and designed the study and completed data collection. CT, KMC and CGF contributed to data analysis, interpretation and manuscript preparation. All authors approved the final manuscript for submission.

Ethical statement

The research activities were approved by the National Health Group Domain Specific Review Board (Reference number: 2013/00783) and all participants provided written consent to the use of their data for current and future-related research.

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Further reading

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