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Oral processing behaviours that promote children's energy intake are associated with parent-reported appetitive traits: Results from the GUSTO cohort

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Abstract

Oral processing behaviours associated with faster eating rates have been consistently linked to increased energy intakes, but little is known about their links to children's appetitive traits. This

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Declarations

Ethics approval and consent to participate

Informed written consent was obtained from participants, and the study was approved by the National Healthcare Group Domain Specific Review Board and SingHealth Centralized Institutional Review Board.

Competing interests

K. M. G., Y. S. L., Y.-S. C. and CGF have received reimbursement for speaking at conferences sponsored by companies selling nutritional products. They are part of an academic consortium that has received research funding from Abbott Nutrition, Nestec and Danone. Lisa Fries is an employee of Nestec SA, working at the Nestlé Research Center. The other authors have no financial or personal conflict of interests.

Authors' contributions

This study was conceived and designed by CGF, AF, MFFC and LRF. Analyses were performed and interpreted by AF, KMC and CGF. ATG, JYT and MJC collected the data. AF, KMC and CGF prepared the draft manuscript with input from LRF, QPL and MFFC. YSC, KHT, FY, LPS, MJM, BFPB, YSL and KMG were responsible for conception and recruitment for the GUSTO cohort. All authors reviewed and approved the final draft.

study used the Child Eating Behaviour Questionnaire (CEBQ) to explore cross-sectional and prospective associations between parent-reported appetitive traits and observed oral processing behaviours. Participants were 195 children from the Growing Up in Singapore Towards healthy Outcomes cohort, who participated in a video-recorded *ad libitum* lunch at 4.5 (Time 1) and 6 years (Time 2). Their mothers completed the CEBQ around the same time points. Children's bites, chews and swallows were coded, and used to calculate their eating rate, bite size, chews per bite, chew rate, oral exposure time and oral exposure per bite. At Time 1, children with higher scores in slowness in eating had lower eating and chew rates. At Time 2, higher scores for food enjoyment and lower for satiety responsiveness, slowness in eating, and food fussiness were linked with higher eating rates and greater energy intakes ($r > 0.16$, $p < 0.05$). Post-hoc analyses revealed that these associations were moderated by BMI and only present among children with higher BMI. Faster eating rates mediated the associations between greater food enjoyment, lower slowness in eating, lower food fussiness and higher intakes of energy. Children with higher slowness in eating scores had lower increases in eating rates over time, and children with higher BMI who had greater food enjoyment and food responsiveness scores had greater increases in eating rates over time. The findings suggest that oral processing behaviours linked with increased obesity risk may be underpinned by appetitive traits and may be one of the behavioural pathways through which these appetitive traits influence energy intakes.

Keywords

Eating behaviours; oral processing; appetitive traits; CEBQ; eating rates

1.0 Introduction

An early predisposition to accumulate excess fat has been linked with genetic and epigenetic factors, as well as features of the early food environment (Rhee et al., 2012, Chong et al., 2014, Gluckman and Hanson, 2008, McAllister et al., 2009, Lin et al., 2017). It has been previously proposed that a pathway between genetic factors and future obesity risk is mediated by appetitive traits and eating behaviours that promote greater energy intakes, in what has been referred to as the 'behavioural susceptibility theory of obesity' (Llewellyn and Wardle, 2015). Variability in appetitive traits may help to explain why it is not the case that every child brought up in an obesogenic food environment will become obese. Instead, appetitive traits that promote overeating may increase a child's vulnerability to weight gain in an environment characterised by large portions and high availability of palatable, energy dense foods.

Behavioural studies in paediatric populations generally support the idea that children with healthy weight differ from children with overweight in certain appetitive traits. For example, it has been demonstrated that children with overweight tend to have poorer satiety responsiveness, are more responsive to external food cues, such as portion size or food availability, and show higher motivation to work for food compared to children with healthy weight (Temple et al., 2007, Jansen et al., 2003, Savage et al., 2012). Psychometric measures have been developed to capture different aspects of these appetitive traits in children, of which the Children's Eating Behaviour Questionnaire (CEBQ: Wardle et al., 2001) is

considered to be the most comprehensive and widely used. This questionnaire measures eight dimensions of appetitive traits that describe food approach and food avoidance behaviours. Food approach behaviours captured in the CEBQ include food responsiveness, enjoyment of food, desire to drink and emotional over-eating, while food avoidance behaviours are comprised of slowness in eating, emotional under-eating, food fussiness and satiety responsiveness. Previous studies have demonstrated positive associations between food approach subscales of the CEBQ and children's BMI, while food avoidance behaviours have typically been associated with lower weight (Sleddens et al., 2008, Webber et al., 2009, Viana et al., 2008). However, it is important to identify specific behaviours through which these appetitive traits are expressed.

Oral processing behaviours are hypothesised to be one of the behavioural markers of appetitive traits (Wardle and Carnell, 2009). Eating rate has been shown to be heritable (Llewellyn et al., 2008), consistent within an individual (Hubel et al., 2006, McCrickerd and Forde, 2017) and stable over time (Berkowitz et al., 2010). Studies in adult and child populations show that faster eating rates promote energy intake during an *ad libitum* meal and are linked with a higher risk of unhealthy weight gain and obesity (Llewellyn et al., 2008, Tanihara et al., 2011, Sasaki et al., 2003, Otsuka et al., 2006, Maruyama et al., 2008, Ohkuma et al., 2015, Robinson et al., 2014, Drabman et al., 1977, Drabman et al., 1979, Chei et al., 2005, Ochiai et al., 2012, Ochiai et al., 2016). We recently demonstrated that 4.5 year old children who ate a meal at faster rates consumed on average 75% more energy than children who ate at slower rates, and had higher BMI and whole-body and abdominal adiposity (Fogel et al., 2017a). Using an observational approach to objectively characterise a child's eating behaviours within a meal, we have identified an "obesogenic eating style" characterised by eating faster and taking larger bites that spend less time in mouth and are processed using fewer chews. Importantly, these oral processing behaviours consistently predicted higher energy intakes, particularly when combined with longer total meal duration (Fogel et al., 2017b). While overweight children were significantly more likely to eat faster, there were a number of healthy weight children who were also eating at faster rates (Fogel et al., 2017a), suggesting that perhaps this behaviour may only be problematic when it co-occurs with other appetitive traits that support increased energy intake and/or occurs in the presence of an obesogenic food environment.

Little is known about how oral processing behaviours relate to other appetitive traits. In the original studies that led to the development of the CEBQ, items from the slowness in eating subscale loaded together with the satiety responsivity subscale, indicating that these two behaviours may co-occur and be highly correlated and characterised by the same parent-reported behaviours (Wardle et al., 2001). One study that focused on selected subscales from the CEBQ has shown that slower measured eating rates were associated with higher satiety responsiveness, as well as lower food responsiveness and lower enjoyment of food in a sample of 4-5 year old children (Carnell and Wardle, 2007), highlighting that specific appetitive traits may underlie faster eating rates. Whether these appetitive traits map onto different parameters of children's oral processing such as bite size, chew rate or oral exposure per bite remains unclear. As one of the subscales of the CEBQ directly assesses child's slowness in eating, it is important to understand what parameters of oral processing, such as eating rate, eating duration or both, are captured in that parent-reported scale. More

broadly, understanding how appetitive traits are linked with specific oral processing parameters will help design intervention strategies targeting specific oral processing behaviours (such as large bite size) that can be observed by parents, in an effort to reduce faster eating rates, which are a risk factor for overeating and unhealthy weight gain.

The aim of the current study was to investigate whether parent-reported appetitive traits are linked with children's oral processing behaviours at 4.5 and 6 years old. We further sought to explore whether appetitive traits reported by parents in the CEBQ could predict children's prospective oral processing behaviours. We hypothesised that faster eating rates and the associated oral processing parameters would be positively associated with food approach behaviours (i.e. enjoyment of food, desire to drink, emotional over-eating) and negatively associated with food avoidance behaviours (i.e. food fussiness, satiety responsiveness and emotional under-eating). We further hypothesised that the slowness in eating subscale would be negatively associated with eating rates and positively associated with meal duration.

2.0 Methods

2.1 Sample

The participants in this study were child and mother pairs from the Growing Up in Singapore Towards healthy Outcomes (GUSTO) cohort (N=1247), who attended an *ad libitum* lunch at 4.5 and 6 years of age. Eligibility criteria and the GUSTO study profile are described elsewhere (Soh et al., 2014). Selection criteria for participation in the lunch task are described in the participant flowchart (Supplementary material A). At 4.5 years (± 2 months; Time 1), 484 children and their mothers attended a buffet lunch and a total of 386 children had their oral processing behaviours successfully video-coded. When the same children were 6 years old (± 2 months; Time 2), 227 attended a follow-up *ad libitum* lunch which they consumed on their own, and a total of 195 children had their oral processing behaviours successfully video-coded. Videos were excluded if children were outside the camera view, video had poor quality, children shared food with their mother (Time 1 only) or if children consumed lunch for less than 3 minutes as reliable oral processing parameters during that lunch could not be calculated. As a result, 98 videos were excluded at Time 1 and 32 videos at Time 2. Mothers completed the CEBQ within 6 months (Time 1) or one month (Time 2) of participating in the lunch. Full data comprising of oral processing measures and completed CEBQs from 195 children were available at both time points. There were 99 boys and 96 girls considered in the analyses, who were of Chinese (n= 105), Malay (n= 51) or Indian (n= 38) ethnicity, and one child of unreported ethnicity.

2.2 *Ad libitum* lunchtime meal

At both time points, lunch took place in the same test room, which was equipped with child appropriate furniture and utensils, and high resolution cameras placed in three corners of the room. Children were fasted for a minimum of 3 hours before the meal.

At Time 1 children consumed lunch with only their mother present in the room. Prior to the meal mothers were requested to not interfere with children's food choice and to interact with children in the usual manner. Participants were told they could eat as much or as little as

they wished, and were given up to 30 minutes to consume the meal. Children were served an *ad libitum* buffet lunch consisting of 9 foods and 3 drinks, previously identified as liked and accepted in food frequency questionnaires collected from the same cohort at an earlier time point. The foods and drinks served were: white bread (Gardenia; 2.63 kcal/g; 6 slices), Honey Stars cereal (Nestle; 3.8 kcal/g; 80g), pancakes (Aunty Jemima; 3 kcal/g; 70g), chocolate cake (Sara Lee; 4.3 kcal/g; 80g), cheese (Cowhead; 2.95 kcal/g; 66g), chicken cocktail sausage (Fairprice; 2.95 kcal/g; 192g), chicken nuggets (CP; 2.29 kcal/g; 216g), apple slices (0.44 kcal/g; 204g), canned corn (Hosen; 0.81 kcal/g; 160g), apple juice (Marigold; 0.5 kcal/ml; 6 boxes), full cream milk (Marigold; 0.65 kcal/ml; 6 boxes) and water. Additional portions of each item were available should any single item have been fully consumed during the meal.

At Time 2, children consumed lunch on their own without their mother present. They were asked to select their own portion and were told that they could eat as much or as little as they wished within a similar time frame. Children were served an *ad libitum* meal of vegetarian fried rice (1.86 kcal/g), which was the most common and accepted main meal item in this population as identified in the same food frequency questionnaire. Children were free to self-serve their own portions of rice from a large (800 g) serving dish. Additional servings were made available if the child required more. To measure food intake, at both time points, foods were weighed before and after consumption to measure the energy consumed during lunch.

2.3 Oral processing behaviours

Oral processing behaviours were video-coded using behavioural annotation software (ELAN 4.9.1, Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands). A coding scheme was adapted after previously published approaches (Forde et al., 2013). Three ‘point’ events were coded as total frequencies: bites, chews and swallows. A bite was defined as an act which resulted in a piece of food being cut off, not spat out, and subsequently chewed and swallowed. A chew was defined as movement of jaws after a bite and resulted in swallowing. A swallow was defined as the cessation of chewing followed by a movement in the oesophagus area. These coded behaviours were used to derive a series of oral processing parameters defined in Table 1. All oral processing parameters were averaged across the meal. The total oral exposure time was analysed separately from total meal duration, to differentiate the time children spent actively consuming food from their total meal time. A ratio of total oral exposure time to total meal duration was derived to capture the ratio of ‘active / total meal time’, with lower values indicating that children who had a longer meal during did so by taking longer breaks and actively consumed food for a relatively shorter period of time.

Behavioural video coding at both time points was completed by a single trained video-coder and later validated by a second trained video-coder. Two-way mixed effects intra-class correlation coefficients showed excellent absolute agreement between coders at Time 1 (ICC>0.954) and Time 2 (ICC>0.995).

2.4 Children's Eating Behaviour Questionnaire

The Children's Eating Behaviours Questionnaire [CEBQ; Wardle et al., 2001] is a parent-reported questionnaire that consists of 35 items and measures 8 dimensions of children's appetitive traits: food responsiveness (e.g. *Even if my child is full up s/he finds room to eat his/her favourite food*), emotional overeating (e.g. *My child eats more when worried*), emotional undereating (e.g. *My child eats less when angry*), enjoyment of food (e.g. *My child loves food*), slowness in eating (e.g. *My child eats slowly*), food fussiness (e.g. *My child refuses new foods at first*), satiety responsiveness (*My child gets full up easily*) and desire to drink (e.g. *My child is always asking for a drink*). CEBQ responses are scored from 1-5 for each subscale, with higher scores indicating higher level of behaviour in any given domain. This questionnaire has been used extensively in studies focused on children's eating behaviours and showed good consistency and test-retest reliability among various socioeconomic samples (Carnell and Wardle, 2007, Frankel et al., 2014). A confirmatory factor analysis supported construct validity of the CEBQ (Cronbach's alpha estimates between 0.70-0.85) and convergent validity with BMI in 5-6 year old Singaporean children from the GUSTO Cohort (unpublished data).

3.0 Statistical analysis

Items within the subscales of the CEBQ have been averaged to control for the missing data from individual questions, in line with previously published approaches (Carnell and Wardle, 2007). Mean scores for the subscales of the CEBQ and oral processing behaviours at Time 1 and Time 2 are presented in supplementary material B. Scores for individual CEBQ subscales did not show normal distribution at either time point, so they were log transformed, which improved normality. Correlation analyses (Pearson's r) were used to explore the associations between the CEBQ and children's oral processing behaviours and energy intake. Additional post-hoc mediation analyses were used to test whether any significant associations between the CEBQ subscales and energy intake were mediated by children's eating rates.

Regression analysis was conducted to assess independent covariates of eating rate from child sex, BMI at 4.5 years, ethnicity, gestational age, birth weight, mother's pre-pregnancy weight and mother's age. This identified child sex and BMI as potential confounders. Subsequently, regression analyses were conducted to investigate the associations between the CEBQ subscales and oral processing behaviours at both time points, with sex and BMI accounted for in the models. Post-hoc models examining potential interactions with sex and BMI were explored. Post-hoc models were limited to examining those associations that changed after addition of covariates, and to those that showed significant associations between oral processing characteristics and CEBQ subscales, to limit multiple comparisons.

To analyse the associations between the CEBQ scores at Time 1 and prospective eating behaviours at Time 2, change in oral processing behaviours from Time 1 to Time 2 was calculated (Time 2 – Time 1). Regression models predicting the change in oral processing behaviours, adjusted for sex, BMI and the baseline oral processing characteristics were conducted. Subsequent post-hoc models testing interactions between sex/BMI and the CEBQ variables on changes in eating rates over time were examined. Two-tailed tests were

used in all analyses and $p < 0.05$ was considered statistically significant. All statistical analyses were performed in SPSS version 23.0 (IBM).

4.0 Results

4.1 Unadjusted cross-sectional associations between CEBQ and oral processing behaviours

Cross-sectional unadjusted associations between children's scores on the CEBQ subscales and oral processing behaviours measured at Time 1 and Time 2 are presented in Table 2. At Time 1, children who had higher scores for slowness in eating ate food at slower rates, and had a lower rate of chewing, compared to children rated lower in slowness in eating. There was a non-significant trend for children with higher food fussiness scores to eat at slower rates. The association between higher scores for slowness in eating and lower measured eating rates was also observed at Time 2. Children with higher slowness in eating scores also had longer oral exposure time per bite of food, lower chewing rates and longer total and active meal duration. At Time 2, there were additional appetitive traits that showed links with oral processing behaviours, such that children who had higher scores for food enjoyment and lower scores for food fussiness and satiety responsiveness had higher eating rates and consumed more energy during the meal. Post-hoc mediation analyses showed that at Time 2, the relationships between enjoyment of food (indirect effect: $B = 178.84$, CI95% [82.76, 311.23]; $p < 0.01$), slowness in eating (indirect effect: $B = -193.69$, CI95% [-319.95, -79.63]; $p < 0.0001$), food fussiness (indirect effect: $B = -148.99$, CI95% [-285.44, -52.07]; $p < 0.001$) and intake of energy were mediated by child's eating rates. Children with higher enjoyment of food, lower food fussiness and lower slowness in eating scores consumed more energy through eating at faster rates.

4.2 Adjusted cross-sectional associations between CEBQ and oral processing behaviours

Some of these associations changed after adjusting the analyses for sex and BMI. At Time 1, the association between slowness in eating and eating rate was no longer statistically significant ($\beta = -0.13$, $p = 0.16$) and the trend between higher food fussiness scores and lower eating rates showed statistical significance after adjusting for sex and BMI ($\beta = -0.20$, $p = 0.03$). At Time 2, the associations between slowness in eating and oral processing behaviours remained virtually identical after adjusting for sex and BMI. However, enjoyment of food ($\beta = 0.04$, $p = 0.69$), food fussiness ($\beta = -0.06$, $p = 0.50$) and satiety responsiveness ($\beta = 0.08$, $p = 0.39$) no longer predicted children's eating rates after the adjustments.

To unpick the effects that child's sex and BMI have on the relationship between the CEBQ subscales and oral processing behaviours, post-hoc interactions between BMI/sex and CEBQ scores were conducted. At Time 1, post-hoc tests showed no significant interactions between BMI and the slowness in eating score ($B = -0.81$, CI95% [-4.50, 2.88], $p = 0.66$) or food fussiness ($B = -1.09$, CI95% [-4.41, 2.23], $p = 0.52$) on eating rates. However, at Time 2 the relationships between eating rates and satiety responsiveness ($B = -6.66$, CI95% [-12.19, -1.14], $p = 0.01$) and enjoyment of food ($B = 9.11$, CI95% [2.52, 15.70], $p < 0.001$) that had

disappeared in the adjusted models were significantly moderated by BMI, and were present only among children with higher BMI ($p < 0.02$) and not in children with mid-range or lower BMI ($p > 0.3$). A similar pattern was seen in the relationship between eating rate and food fussiness, where conditional effects of BMI on food fussiness showed that lower food fussiness was linked with faster eating rates only among children with higher BMI ($p = 0.047$) and not lower ($p = 0.45$) or mid-range BMI ($p = 0.11$). However, the interaction term was not significant ($B = 1.89$, CI95% [-6.10, 2.32], $p = 0.38$). BMI also moderated the association between food enjoyment and energy intake, such that children with higher BMI consumed more energy if they were reported to enjoy food more ($B = 227.52$, CI95% [104.43, 350.62], $p < 0.001$). There was no interaction between food fussiness and BMI on energy intake ($B = -46.0$ CI95% [-125.52, 33.51], $p = 0.26$). There were no two-way interactions between the CEBQ subscales and sex, nor three-way interactions with BMI on child's eating rates at either time point.

4.3 Prospective associations between CEBQ and oral processing behaviours

Regression analyses predicting change in oral processing behaviours from Time 1 to Time 2 from CEBQ scores are reported in Table 3. Slowness in eating was the only subscale that predicted change in oral processing behaviours from Time 1 to Time 2. Children with higher scores in slowness in eating had a smaller increase in eating rates and oral exposure per bite of food between Time 1 and Time 2. Higher scores in slowness in eating at Time 1 also predicted larger increases in meal duration and in oral exposure of food, as well as a larger increase in the duration of pauses during the meal, indicative of a lower proportion of active to total mealtime.

Post-hoc analyses assessing the possible interactions between reported appetitive traits with child sex/BMI showed that there was an interaction between BMI and food responsiveness ($B = 4.94$, CI95% [0.52, 9.35], $p = 0.03$) and enjoyment of food ($B = 7.99$, CI95% [2.24, 13.75], $p < 0.001$) on change in eating rates over time. Children with higher BMI who were reported to enjoy food more ($p < 0.001$) and to be more food responsive ($p = 0.01$) had significantly larger increase in eating rates over time, compared to children with similar CEBQ scores but lower BMI ($p > 0.3$).

Discussion

The aim of this study was to investigate whether parent-reported appetitive traits are associated with, and predictive of, children's oral processing behaviours and energy intake. The results show that parent-reported appetitive traits are linked with children's measured oral processing behaviours, predict changes in oral processing behaviours over time, and to some extent may be moderated by BMI.

Children with higher scores for food enjoyment, and lower scores for food fussiness, slowness in eating and satiety responsiveness tended to eat at faster rates, and these links were stronger among children with higher BMI. Food approach behaviours from the CEBQ have been linked with higher BMI and food avoidance behaviours with lower BMI in other populations (Carnell and Wardle, 2007, Sanchez et al., 2016, Johnson and Birch, 1994, Santos et al., 2011). However, little is known about the behavioural pathways through which

appetite is linked with weight. Here, we demonstrated that appetitive traits previously linked with obesity were associated with higher intakes of energy, and this relationship was mediated by faster eating rates. Oral processing behaviours may be one of the behavioural markers of these appetitive traits and a potential behavioural pathway through which appetite influences weight gain trajectories (Carnell and Wardle, 2007, Sanchez et al., 2016, Johnson and Birch, 1994).

The links between oral processing characteristics and appetitive traits were primarily observed among children with higher BMI. Previous research from our laboratory shows that children who ate faster had higher BMI, but not all children with higher BMI ate fast, and not every fast eater had obesity (Fogel et al., 2017a). The results from the current study suggest that faster eating may contribute to positive energy balance and obesity when it co-occurs with other traits linked to obesity, such as greater food enjoyment, lower satiety responsiveness and food fussiness (Carnell and Wardle, 2007, Sanchez et al., 2016, Johnson and Birch, 1994). However, the CEBQ relies on parental perception of child's behaviours, so the co-occurrence of these traits may be biased by parent's or child's characteristics, such as weight status (Warschburger and Kröller, 2009, Jansen et al., 2014). The results of the current study suggest that the CEBQ may be an efficient tool to identify children who may develop a faster eating style and be at risk for overeating. This highlights an opportunity for potential intervention strategies to reduce energy intakes among children with appetitive traits that make them vulnerable to overeating, by slowing down eating rates. Past research identified external monitors of eating rates as one potential strategy to reduce eating speed and support weight reduction (Hamilton-Shield et al., 2014, Salazar Vázquez et al., 2015, Ford et al., 2010). Alternatively, the speed of eating could also be reduced via introducing food textures that extend mastication and lower energy intakes, while maintaining food liking (Forde et al., 2013, Viskaal-van Dongen et al., 2011, McCrickerd et al., 2017). The efficacy of this as a strategy for managing energy intake and body weight over time has yet to be tested in adults and children, though findings from experimental studies suggest this could be an option in the future (McCrickerd et al., 2017, Bolhuis et al., 2014).

One of the appetitive traits measured in the CEBQ is slowness in eating, with higher scores indicative of greater slowness in eating, and lower scores indicative of more typical eating speed. This subscale consists of 4 items, and 3 of them are focused on eating speed and meal duration. At Time 2, children who had slower eating rates *and* longer meal durations had higher slowness in eating scores, confirming that the slowness in eating subscale accurately reflects both of these parameters. Interestingly, this subscale also reflected more detailed oral processing parameters such as oral exposure per bite, chew rate and total oral exposure time. Slowness in eating subscale can be used to identify children who eat at slow rates and have long meals. Of note, the opposite i.e. higher eating rates *and* shorter meal duration do not necessarily describe children who are faster eaters. Faster eating is the most problematic when it co-occurs with longer meal duration (Fogel et al., 2017b), so lower scores on the slowness in eating subscale are not a good predictor of, and do not indicate faster eating style *per se*. As such, this subscale may be more appropriate to identify slower rather than faster eaters, and differentiate them from children with more typical eating speed.

Analysis of the prospective associations between the CEBQ scores and changes in eating rate revealed that children who at Time 1 were perceived by the parents to be slower eaters, showed smaller increases in eating rates and larger increases in meal duration and within-meal pauses over time. This suggests that specific appetitive traits and oral processing patterns continue to be established and consolidated during this period. Children who were perceived by their parents to be more food responsive and enjoy food more had larger increases in eating rates over time, but only when they had higher BMI at baseline. Together, this suggests that the appetitive traits may influence the development of eating behaviours and shape weight gain trajectories earlier in life, and are established by 6 years of age. However, the direction of the relationship between eating behaviours, appetitive traits, and weight gain cannot be established from the current cross-sectional data set and future research is required to establish how they are related over time.

Some age related differences were observed in the associations between oral processing behaviours and CEBQ at Time 1 and 2. At the earlier time point, slowness in eating was the only significant correlate of observed oral processing behaviours. When these associations were tested at age 6 years, the links between additional appetitive traits and observed oral processing behaviours were stronger, and these relationships were moderated by children's BMI. This could be due to the differences in the meals served at the two time points, as using a single-food meal at Time 2 could have resulted in a more sensitive measure of individual differences in oral processing behaviours. The alternative explanation is that the behaviours captured by the CEBQ may be better reflected in the oral processing behaviours observed in older children. Although the CEBQ has been validated in populations as young as 3 years (Wardle et al., 2001), recent research within the GUSTO cohort assessed the stability of the CEBQ subscales between 3-6 years, and identified that these are more stable among older children (Quah et al., under review).

A strength of the current study was the large representative multi-ethnic sample of children with observed oral processing behaviours and analogue measures of appetitive traits at two time points. This enabled an exploration of the convergence between parent-reported appetitive traits against objectively measured oral processing behaviours. However in our approach energy intake was measured at the end of the meal, so any potential changes in energy intake and oral processing behaviours that spontaneously occurred during the meal could not be recorded throughout the meal. Another potential limitation was the 6 month gap between the meal at Time 1 and parental completion of the CEBQ at Time 1. Although not ideal, recent findings from the same cohort suggest that CEBQ shows acceptable stability between these two time points (Quah et al., under review). Finally, findings from the current study are based on multiple associations and parental reports of child's appetitive traits, where only the eating behaviours observed within the meal were objectively measured. Future studies should aim to go further than the current parental self-report measures to investigate these associations using objective behavioural measures that reflect the CEBQ appetitive traits, and capture variation in behaviours linked with greater energy intakes.

Conclusions

The current study showed that children's appetitive traits reported in the CEBQ were associated with the oral processing behaviours they exhibit when consuming a meal. These associations were stronger among children with higher BMI. Oral processing behaviours, such as eating rate, may be the behavioural markers of appetitive traits and a mediator between appetite and energy intakes, particularly among children with higher weight. Future studies should further investigate these associations at earlier time points and trace their co-development with measured appetitive traits over time. These results suggest that interventions strategies aimed at reducing eating rates could be effective in reducing energy intakes and promoting healthy weight gain in childhood, particularly among children with higher BMI, who exhibit eating behaviours that make them vulnerable to overeating.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

FR	Food responsiveness
EOE	Emotional over-eating
EF	Enjoyment of food
DD	Desire to drink

SR	satiety responsiveness
SE	Slowness in eating
SUE	Emotional Undereating
FF	Food fussiness
OE	Oral exposure
A/T	Active/Total

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Table 1

Description of oral processing behaviours derived from the recorded videos.

Eating behaviour	Definition
Eating Rate (g/min)	Total amount of food consumed divided by total time spent eating.
Bite Size (g/bite)	Total amount consumed divided by the total number of bites.
Chews per bite	Total number of chews divided by total number of bites.
Chew rate (Chew/sec)	Number of chews per bite divided by children's oral exposure time per bite.
Meal duration (min)	Time between the first bite and the last swallow.
Oral exposure time (min)	Time between every bite and every swallow cumulated over the course of the meal.
Oral Exposure per bite (sec/bite)	Total oral exposure time of food in mouth across the meal, divided by the total number of bites.
Active/Total mealtime	Ratio of oral exposure time to total meal duration.

Table 2

Relationships between CEBQ scores and oral processing behaviours observed at both time points.

	CEBQ Subscales							
	FR	EOE	EF	DD	SR	SE	EUE	FF
Time 1								
Eating Rate (g/min)	.03	-0.05	0.07	-0.06	-0.06	-0.14 [*]	0.02	-0.12 ^a
OE per bite (s)	0.06	0.08	0.09	-0.03	0.02	0.10	0.03	-0.05
Bite Size (g/bite)	0.07	-0.03	0.12 ^a	-0.10	-0.08	-0.02	-0.01	-0.11
Chews per bite	0.01	0.04	0.04	-0.03	-0.05	0.01	-0.08	-0.08
Chew rate	-0.03	0.02	-0.02	0.01	-0.16 [*]	-0.19 ^{**}	-0.15 [*]	-0.09
A/T mealtime	-0.07	-0.06	-0.01	-0.15 [*]	-0.06	-0.03	-0.13 ^a	-0.01
Meal duration	-0.02	0.01	-0.05	-0.03	0.01	0.09	0.14 [*]	0.01
Oral exposure (min)	-0.04	-0.01	-0.05	-0.10	-0.04	0.06	0.04	0.01
Energy (kcal)	0.09	0.05	0.14	-0.11	-0.13	-0.14	0.05	-0.12
Time 2								
Eating Rate (g/min)	.10	0.01	0.22 ^{**}	0.04	-0.17 [*]	-0.30 ^{***}	-0.12 ^a	-0.21 ^{**}
OE per bite (s)	-0.08	-0.07	-0.24 ^{**}	-0.10	-0.07	0.23 ^{***}	0.01	0.04
Bite Size (g/bite)	-0.04	-0.02	0.02	-0.12	-0.13 ^a	-0.01	-0.05	-0.10
Chews per bite	-0.11	-0.06	-0.06	-0.14 ^a	-0.16 [*]	0.13 ^a	-0.05	-0.04
Chew rate	-0.10	-0.06	0.08	-0.03	0.03	-0.16 [*]	-0.13 ^a	-0.08
A/T mealtime	0.05	0.09	0.12 ^a	-0.05	-0.16 [*]	-0.10	-0.02	-0.13 ^a
Meal duration	-0.01	-0.03	-0.13 ^a	-0.07	0.05	0.21 ^{**}	0.08	0.03
Oral exposure (min)	0.01	-0.01	-0.07	-0.08	-0.01	0.20 [*]	0.07	-0.01
Energy (kcal)	0.09	0.03	0.18 [*]	-0.03	-0.13 ^a	-0.19 ^{**}	-0.10	-0.18 [*]

FR: Food responsiveness; **EOE:** Emotional over-eating; **EF:** Enjoyment of food; **DD:** Desire to drink; **SR:** satiety responsiveness; **SE:** Slowness in eating; **SUE:** Emotional Undereating; **FF:** Food fussiness

OE: Oral exposure; **A/T:** Active/Total; Values are Pearson's r , ^{*} $p < 0.05$; ^{**} $p < 0.01$; ^{***} $p < 0.001$, ^a $p < 0.1$

Table 3

Prospective associations between CEBQ subscales at Time 1 and change in children's oral processing behaviours between Time 1 and Time 2, after controlling for covariates¹

OP	CEBQ at Time 1							
	FR	EOE	EF	DD	SR	SE	EUE	FF
Eating Rate (g/min)	0.13	0.02	0.02	-0.07	0.08	-0.18 [*]	-0.05	-0.05
OE per bite (s)	0.13	-0.05	-0.02	-0.07	0.08	-0.18 [*]	-0.05	-0.05
Bite Size (g/bite)	0.01	0.12	-0.05	-0.09	-0.05	0.02	-0.03	-0.01
Chews per bite	-0.07	-0.05	-0.08	0.01	-0.06	0.06	0.04	-0.08
Chew rate	-0.02	0.03	-0.17	0.10	-0.02	-0.09	0.07	-0.09
A/T mealtime	0.08	-0.06	-0.03	0.06	0.06	-0.15 [*]	0.01	-0.12 ^a
Meal duration	-0.04	0.01	0.08	-0.05	-0.02	0.16 [*]	0.03	0.05
Oral exposure (min)	-0.01	-0.04	0.07	-0.03	-0.03	0.13 [*]	0.05	0.01
Energy (kcal)	0.05	0.03	0.09	-0.09	0.04	-0.05	-0.02	-0.01

¹ Adjusted for sex, BMI and oral processing parameter at Time 1.

FR: Food responsiveness; **EOE:** Emotional over-eating; **EF:** Enjoyment of food; **DD:** Desire to drink; **SR:** satiety responsiveness; **SE:** Slowness in eating; **SUE:** Emotional Undereating; **FF:** Food fussiness

OE: Oral exposure; **A/T: Active/Total;** **OP=** Oral processing

Values are standardised Betas, ^{*}*p*<0.05; ^a*p*<0.1