Association between tactile over-responsivity and vegetable consumption early in the introduction of solid foods and its variation with age

Journal:	*Maternal & Child Nutrition*
Manuscript ID:	MCN-03-15-OA-1458.R2
Manuscript Type:	Original Article
Keywords:	Complementary Feeding, Complementary Foods, Infant Feeding, Infant and Child Nutrition, Infant Feeding Decisions, Infant Feeding Behaviour

Abstract

The main aim of the current study was to test the hypothesis that early reactions to a vegetable in infants may be associated with sensory processing, in particular, tactile over-responsivity. A secondary aim was to see whether the relationship between sensory over-responsivity and vegetable consumption would be moderated by the age of the infant. A sample of 61 infants was recruited from children's centres and playgroups in South Birmingham, UK. Infant's acceptance of carrot was measured in grams during the first week of complementary feeding in one testing situation. Mothers filled in self-report measures of infant sensory processing, as well as their own fruit and vegetable consumption. Infant carrot consumption in the first week of solid food consumption was negatively associated with total sensory over responsivity across different sensory domains ($p<0.01$). Across the sensory domains only tactile over responsivity predicted carrot consumption, accounting for 10.7% of the variance in consumption scores. Across the sample as a whole, the relationship between carrot consumption and tactile over-responsivity varied according to the age of introduction to solid foods. In particular, those who were weaned later and had high tactile over-responsivity ate less carrot ($p<0.001$). Infants who were weaned early ate a similar amount of carrot, regardless of their tactile responsivity ($p>0.05$). This study constitutes some of the first evidence to suggest that sensory processing styles be associated with early vegetable acceptance, however more research is needed to evaluate the best strategies to use when feeding infants who are sensitive to tactile information.

KEYWORDS: VEGETABLE CONSUMPTION, INFANTS, SENSORY OVER-RESPONSIVITY, SENSORY PROCESSING, COMPLEMENTARY FEEDING

Introduction

There is well-documented evidence to suggest that most young infants in the early stages of complementary feeding have a tendency to be accepting of new flavours and textures (Gerrish & Mennella, 2001; Coulthard, Harris & Emmett, 2009; Maier et al., 2008; Schwartz et al., 2001; Mennella & Beauchamp, 1997; Forestell & Mennella, 2011). In particular, during the early complementary feeding period, infants will increase their liking of a new food after only one exposure (Sullivan & Birch, 1994), even if they express initial dislike or distaste (Maier et al. 2007b). The early readiness to accept foods decreases in the infant's second year of life, as children become more food neophobic (Pliner, 1994;Birch & Marlin, 1982) and getting them to taste foods becomes more challenging throughout early childhood (Blissett et al., 2012). It is recommended that caregivers provide a variety of complementary feeding foods in early feeding (Gerrish & Mennella, 2001;Birch & Marlin, 1982), which are rotated frequently (Maier et al., 2008) to provide constantly varied intake. In this way infants are desensitised to variations in taste and texture prior to the onset of food neophobia (Schwartz et al., 2011; Nicklaus, 2011).

Historically, in the field of research into taste perception, there has been little experimental research which has addressed whether there is a period of plasticity, or a sensitive period, where infants are more accepting of foods. Despite the lack of experimental evidence there is a consensus that there probably are sensitive periods for both taste (Cashdan, 1994; Harris, Thomas & Booth, 1990; Illingworth & Lister, 1964) and textures (Maier et al., 2008;Northstone et al., 2001), although the exact timing of these sensitive periods is hard to assess. A recent series of studies examining acceptance of the distinctive flavour of protein hydrolysed formula, suggest that there may be a sensitive period before the age of 4 months for optimal acceptance (Mennella, Griffin & Beauchamp, 2004; Mennella et al., 2011; Mennella & Castor, 2012). Feeding tastes of solid foods prior to 4 months is not suitable for physiological reasons of inadequate maturation (Prezyrembel, 2012), however the evidence that delaying introduction of complementary feeding to six months, as recommended by the World Health Organisation (WHO, 2001), has an impact on feeding behaviour is contradictory, and has not been adequately assessed (Fewtrell, 2011). There have been some studies which suggest that late introduction to solid food may be associated with consumption of a more narrow range of fruits and vegetables in later childhood (Coulthard, Harris &

Emmett, 2009; Blissett et al, 2012; Northstone et al., 2001), however these are retrospective studies which neither control for the ongoing fruit and vegetable environment nor consider the inherent appetite of the infant (Harris, 1988; Kramer et al., 2002). There is a growing body of evidence that there are individual differences in reactions to foods in infants. This is evident in the fact that nearly a third of children show initial facial expressions of distaste when trying new foods (Schwartz et al., 2012), and that infants who score low on the approach temperament dimension seem to react more negatively to new foods (Forestell & Mennella, 2012).There has been some recent evidence that the sensory experience of eating may differ between individuals (Coulthard& Blissett, 2009; Farrow & Coulthard, 2012; Dovey et al., 2012; Naish & Harris, 2013; Davis et al., 2013). Sensory processing refers to how individuals process information from the environment across a variety of sensory modalities. Eating is, undoubtedly, an intensely sensory experience; we see food, smell it, and touch it with our lips, mouth, and sometimes our fingers. For the individual who has a low threshold to sensory input, or is over responsive to sensory stimuli (Ben-Sasson et al., 2013), the act of eating must be an intense experience especially in relation to novel foods that have unfamiliar sensory characteristics. Dunn (2001) suggests, however, that despite initial responses to sensory information our threshold may alter as a consequence of familiarity with a stimulus, which is the main goal of exposure (Cooke, 2007).

There has been some recent research which shows that children, who have higher levels of sensory over responsivity, have differences in food acceptance. In particular, they eat fewer fruits and vegetables (Coulthard & Blissett, 2009), and are more selective (Bruce et al., 2013) and neophobic in their eating patterns (Farrow & Coulthard, 2012). This is especially true of sensory processing in the tactile domain in children (Coulthard & Blissett, 2009, Bruce et al., 2013). In behavioural studies it has also been found that food acceptance is reduced if children dislike playing with sticky, messy substances (Coulthard & Thakker, in press), dislike the feel of non-sticky substances (Nederkoorn, Jansen& Havermans, 2015) and if tactile alterations are made to foods (Werthmann et al., 2015). In addition it has been found that interventions which include multisensory exposure, which include looking at, smelling and touching foods, result in increased acceptance of fruits and vegetables (Dazeley & Housten-Price, 2015). This growing body of evidence suggest that individual processing in the tactile domain is associated with food acceptance, but there is insufficient evidence from these cross sectional studies as to whether this is due to a lack of tactile stimulation in the environment or due to the inherent processing of the child.

There has been no research, to date, that has examined whether sensory processing influences early responses to food, in particular infants during the early complementary feeding process. At this stage in the feeding process, infants have has a minimal exposure to foods, and therefore it is the optimum time to examine whether a general sensitivity to sensory information is associated with initial reactions to the feeding process. The fact that the majority of infants have an early readiness to accept new tastes, which gradually diminishes throughout the first year of life, suggests that for some infants sensory processing may become a more crucial factor in acceptance later in the complementary feeding period. In addition there is some evidence that infants weaned earlier are more accepting of tastes at 4 months (Harris et al., 1990) and of fruits and vegetables later in childhood (Coulthard et al., 2010). Therefore one of the main aims of the current research study was to examine whether there are variations in acceptance of solid foods in the early feeding period according to the introduction of solid foods, and that younger infants may be more accepting of foods in the early complementary feeding period. The main experimental hypothesis is that infants, who have sensory over responsivity (OR), will eat less of a food in the early complementary feeding period than those with low sensitivity to sensory information. The second hypothesis is that the age of introduction to solid foods will moderate the relationship between sensory processing and food acceptance, in that sensory over-responsivity will be associated with lower food acceptance if the infant is introduced to complementary foods later in the first year.

Materials and methods

Participants and design

Seventy-seven parent and infant dyads were recruited from children's centres, playgroups and postnatal groups around the South Birmingham area of the UK. This area has mixed ethnicity and social groups. Infants who were being weaned directed onto solid foods (baby-led weaning, n=2), had been given carrot (n=2), had started complementary feeding for a week or longer (n= 7) or had been bottle fed (n= 5) were excluded. Of those recruited, there were sixty-one infants in the final sample (32 boys and 29 girls). All infants were healthy and full term (38+ weeks), and had been breast fed from birth. Mothers had to be able to read and write in English, to complete the self-report forms. Although this criteria was set, all mothers approached had an acceptable standard of English language competency, and none were excluded on this basis. The range of introduction to complementary foods was 4-6, months, with the mean age of 5.18 (0.84) months. Ethical approval for the study was granted by University of Birmingham Research Ethics Committee.

The outcome variable was the amount of vegetables consumed in grams, of carrot during the testing session. The predictor variables were the sensory over responsivity variables, and age of introduction to solid foods.

Materials

Experimental food

Carrot was chosen as the experimental vegetable, as infants generally like its taste and responses would not be based in dislike of bitter taste that exists in some vegetables (Hetherington et al., 2015). The carrot puree was made in one cooking session by a food technician in the food laboratories at University of Birmingham. The purees were made from steaming then pureeing organic carrots that had been prepared by peeling and chopping. Some of the cooking juice was added during the blending process to make an extremely smooth puree similar in consistency to that found in a jar of commercial single taste food suitable from 4 months of age. The pureed carrots were placed in 250g portions into infant grade containers and frozen. No additives were added at any stage in the food preparation process. The food was defrosted, and then heated by the mothers to a room temperature that they felt would be suitable for their infant. Mothers were encouraged to test the heat of the food prior to testing by placing a dot on the back of their hand to ensure the food was not too hot or too cold.

Maternal FV consumption

FV consumption in mothers was measured using a scale which asked them to report how many portions of fruits (not fruit juices) then portions of vegetables (not potato) they ate in a typical 24 hour period ranging from 0 portions to more than 7 portions a day. It was made clear that typical meant an average day, which represented their usual diet. The size of a portion was clearly defined in the instructions, based on UK guidelines (NHS, 2013). This measure has been used in other studies (Coulthard& Blissett, 2009; Wardle et al., 2005), and has been validated against 4-day diaries (Bingham et al., 1994). If they ate less than one portion each day, then Mothers were asked to report how many portions of fruits (not fruit juices), and then vegetables (not potatoes) they consumed in a typical week. If they filled in the weekly score, then the scores were divided by 7 to give a daily consumption score. The scores for vegetable portions and fruit portions were summed to give a daily FV score.

Sensory over-responsivity

The Infant/Toddler Sensory Profile (Dunn & Daniels, 2002) has two versions dependent on the age of the infant; the present study used the first version, for infants aged 0-6 months. This was essential, as we wanted to test children's sensory processing before they had established solid food intake. This is a 36 item questionnaire which measures the infant's detection of, and reactions to, sensory stimulation across five domains; general, auditory, visual, tactile and vestibular. Within each subscale, questions are classified as to whether they relate to one of four quadrants of sensory processing; sensory sensitivity, sensation avoiding, sensation seeking and low registration. Previous research has combined the sensory sensitivity and sensation avoiding scores to produce a sensory over-responsivity score (SOR) (Ben-Sasson et al., 2013), which represents individuals with a low threshold to sensory stimulation. The number of SOR items across the five subscales was distributed as follows; General (3 items; e.g. 'My child has difficulty getting to sleep, and is easily awakened'), visual (3 items; e.g. 'My child gets fussy when exposed to bright lights'), auditory (2 items; e.g. 'My child startles easily at sound, compared to other children the same age'), tactile (5 items; e.g. 'My child becomes agitated when having hair washed') and vestibular (4 items; e.g. 'My child resists having head tipped back during bathing') domains. A total SOR score of the sum of the sixteen items was also used in analyses. The SOR has been found to be a reliable way of measuring sensory over responsivity (Ben-Sasson et al., 2013), and the reliability of the total SOR in the current study was good (α= 0.729). In the present study, reliability tests were also conducted on the SOR items from the five subscales (general, visual, auditory, tactile and vestibular). Two of the subscales, (auditory and visual) had very low reliability (0.44 – 0.32), and were excluded from the final analyses. The other three subscales (tactile, vestibular and general) had good internal reliability, with α>0.68, and were investigated as separate subscales.

Demographic variables

Mothers were asked to report their highest educational qualification, age and occupation. The infant's gender, date of birth and age of introduction to complementary feeding was measured.

Weight and length

During the experimental visit the weight and length of the infants was measured. The weight was recorded on a SECA 364 Infant & baby portable, professional-standard scales to the nearest 0.2 g. The infant's length was measured on a SECA 210 length measuring mat to the nearest 0.5cm. These scores were converted to z scores to control for the age and gender of the infant using Child Growth Foundation (2001)

Procedure

Women were contacted by phone one week before their proposed time of complementary feeding .On the first day of testing the infants had been eating foods other than milk for a period of 3-4 days, in order for them to be accustomed to the process of feeding (Harris, Thomas & Booth, 1990).

Women were contacted by telephone around their proposed time of complementary feeding, and were visited in their homes. If mothers had not yet weaned their infants, the research would agree to ring again at the new proposed age of complementary feeding. If they had already started complementary feeding, and this had occurred for longer than 5 days, they were excluded from the study. The timing of these visits was consistently 30 minutes before the infant's usual lunchtime. This was to ensure similar levels of hunger across the sample, without the infant being too hungry to accept solid foods as opposed to milk.

The instructions given to mothers about the food acceptance session were based on those used by Maier et al (2012), and are viewed as an example of good practice in this area. Mothers prepared the food to the usual temperature and used the normal utensils to feed the baby, and the infants were fed in their normal feeding position, usually a high chair. Mothers were asked to feed their infant in the usual way until he/she showed three clear refusals of the spoon. Both the researcher and the mother, to control for the influence of differences in maternal feeding practices, verified this refusal. A refusal sheet was given to mothers prior to the feeding session, which had the clear criteria for what would constitute a refusal. This included shutting the mouth, turning the head away, spitting the food out, batting the spoon with their hand and crying. Mothers were told they could touch the infant's lip with the spoon to initiate feeding, but were told not to vocalize, make noises or facial expressions during these feeding sessions, to ensure consistency. It was found that mother's naturally opened their mouths to initiate feeding, and this was permitted. The observers ensured that all mothers complied with these instructions. Mothers, who were accustomed to feeding their babies water in a bottle during mealtimes, were allowed to do so if they felt their babies required it.

Prior to feeding, the infant's bib, bowl and spoon were weighed, along with the food. The scale used was a SECA 852 digital food scale (accurate to 1g). The amount of test food provided for each infant was 200g, to ensure that the infant would not finish the full amount given and therefore to get a true reflection of intake. After feeding, the bib was used to wipe any access food from the baby's face and hands, and this was weighed, along with the spoon, bowl and any remaining, uneaten food.

Data analysis

A G Power a priori calculation was carried out, which stated that a minimum sample size of 54 was required for a large effect size of 0.8 (Cohen, 1992). Shapiro Wilk tests showed that some of the variables were normally distributed, in particular the over responsivity subscales of tactile OR, general OR, vestibular OR and total OR ($p>0.05$). The variables of age of introduction to solid foods, carrot consumption and maternal education, however were not normally distributed ($p<0.05$). Pearson's product moment correlations (or Spearman's rank for any correlation where at least one variable was not normally distributed) were carried out to see whether there were any relationships between demographic variables and sensory over-responsivity measures, and carrot consumption. A multiple linear regression was carried out and showed that carrot consumption was not associated with any of the demographic variables; therefore they were not entered as covariates in any of the regression analyses.

Moderated regression analyses (Aiken & West, 1991) were used to explore whether the relationships between infant's tactile over responsivity and carrot consumption were moderated by levels of introduction to complementary foods. Moderated regressions examine interactions between two variables, and whether the interaction accounts for variance in the dependent variable (carrot consumption). The independent variable (tactile over-responsivity) and the moderator (infant age) were centred prior to calculating the interaction effect and moderation was computed using a 2 step hierarchical regression controlling for the main effects of the independent variable and the moderator in step 1 (Baron & Kenny, 1986). Preliminary analyses were conducted and ensured that the assumptions of normality, linearity, multi collinearity and homoscedasticity had not been violated, and therefore regression analyses were deemed an appropriate methodology (Myers, 1990).

Results

Demographic factors, carrot consumption and tactile over-responsivity

Levels of carrot consumption, and tactile sensitivity were examined in relation to demographic factors, and it was found using tests of difference, that there were no differences in levels of tactile over responsivity or carrot consumption according to maternal age, maternal education, child sex, introduction to solids, child BMI and parental FV consumption levels (Table 1).

[TABLE 1 ABOUT HERE]

Associations between carrot consumption, sensory over responsivity and demographic variables

Carrot intake was associated with most of the sensory over-responsivity sub scales. Only general over-responsivity was associated with demographic variables (Table 2).

[TABLE 2 ABOUT HERE]

A stepwise regression analysis was used to examine whether the sensory processing variables could predict infant carrot consumption. The three sensory processing variables entered into the analysis were tactile processing, vestibular processing and general processing. Of the three variables entered as predictors, only tactile processing remained in the model, and predicted carrot consumption (β=-0.328, $p<0.05$). The model as a whole accounted for 10.7% of the variance in infant carrot consumption, $F(1,60) = 6.26$, $p< 0.05$.

Age of introduction to solids as a moderator of the relationship between tactile OR and carrot consumption

There was a significant interaction between levels of age of introduction and tactile over-responsivity in predicting carrot consumption in both adjusted ($F(5,44)=2.54$, $p<0.05$) and unadjusted ($F(3.52)=3.98$, $p<0.01$) regressions see table 3). The effects of the independent variable at different levels of the moderator were next evaluated using simple slope analysis (Aiken & West, 1991).

The interaction between children's levels of tactile over-responsivity and age of introduction was significant at predicting children's carrot consumption when the moderator (age of introduction) was at the mean (5.18 months; B=-0.42, t(56)=-1.93, $p<0.05$) and one standard deviation above the mean (6.02 months; B=-1.03, t(56)=-3.48, $p<0.001$), but not when the moderator was one standard deviation below the mean (4.36 months; B=0.18, t(56)=0.55, $p>0.05$). Figure I is a boxplot to illustrate levels of carrot consumption according to both age of the infant and tactile over responsivity. There was a strong relationship between tactile over-responsivity and carrot consumption, with infants with high tactile sensitivity consuming significantly less carrot. This relationship between children's sensory over-responsivity and carrot consumption is significant when children are introduced to complementary foods at moderate or later ages. However, for infants introduced to complementary foods earlier (one standard deviation below the mean), the relationship between tactile over-responsivity and carrot consumption was not significant. Contrary to our hypothesis, that tactile over-responsivity would reduce carrot consumption regardless of age of introduction, it suggests that infants introduced to foods later and have tactile over-responsivity are less likely to eat as much of a novel food at the beginning of complementary feeding.

[FIGURE 1 ABOUT HERE]

Discussion

This study aimed to examine whether sensory processing, in particular over-responsivity to sensory information, would be associated with early vegetable acceptance in infants. It was found that consumption of a vegetable (carrot) was strongly associated with tactile over-responsivity in our sample. In particular infants, who had higher responsivity to tactile information by generally showing aversion to such stimulation, consumed less carrot. In addition it was expected that the age of introduction to solid foods would moderate the relationship between sensory over-responsivity and early food acceptance, showing an indication of a sensitive period for acceptance. This was also supported by our results, in that children introduced to solids later who had higher levels of tactile over-responsivity, ate less carrot.

This research supports other cross sectional research that over-responsivity in the tactile domain may be associated with food neophobia and FV consumption in both normal (Coulthard & Blissett, 2009; Farrow & Coulthard, 2012; Naish & Harris, 2013; Dovey et al., 2012) and clinical samples (Bruce et al., 2013; Ben-Sasson et al., 2012). It has however, always been unclear in these studies, whether this association is environmentally determined by lack of exposure to taste and variety at recommended ages (Maier et al., 2008;Birch & Marlin, 1982; Schwartz et al., 2001; Nicklaus, 2011), or whether it is an inherent characteristic which determines children's responses to the sensory characteristics of food (Child Growth Foundation, 2002). As our research was carried out with children in the early complementary feeding period, within the first week of complementary feeding, it suggests that some children have a different physiological response to food, which affects their early complementary feeding behaviour, however more research would need to be carried out to examine whether it is consumption of carrot or consumption of foods in general, that is associated with sensory processing. The knowledge that some children adapt to complementary feeding more readily, is not a new preposition, and has been found in various experimental exposure studies as well as studies that have examined early feeding problems (Lindberg, Hagekull & Bohlin, 1991; Coulthard & Harris, 2003). This does not refute the immense importance of continued exposure through repeated presentations of foods that vary in taste and texture within the infant's feeding environment (Cooke, 2007).

One important consideration when performing natural studies in this area is that the decision to introduce complementary foods may be driven by the behaviour of the infant (Harris, 1988). Babies who are more food responsive or gaining weight more rapidly, consequently giving the appearance of a larger inherent appetite, may cause their parents to decide to introduce complementary foods earlier (Kramer et al. 2002; Wright et al, 2011). Increased food acceptance behaviour and the decision of when to feed complementary foods may both be underpinned by the biological appetite of the infant. This theory was not fully upheld by the findings of the current study, as neither the BMI of the infants nor the age of complementary feeding was associated with carrot consumption in the sample. However, for some infants in the sample this explanation may have credence. In order to fully compensate for the effect of the appetite of the infant it would be necessary to perform a randomised controlled trial, which would require randomisation of the age of introduction to solid foods.

The second hypothesis, based on the concept of sensitive periods, (Cashdan, 1994; Illingworth & Lister, 1964; Mennella et al., 2011) proposed that age of introduction to complementary feeding would moderate the relationship between over-responsivity and carrot consumption. This hypothesis was supported by the findings of the present study. In particular older children, with higher levels of tactile over responsiveness, ate significantly less carrot. It is important to note that there was no positive association between age and carrot consumption alone, so this study does not provide support for a general sensitive period for all infants prior to six months. Instead, these results lead us to a tentative suggestion that younger infants are physiologically ready to be more accepting of new flavours, regardless of their inherent characteristics, such as tactile processing. Research into sensitive periods and the development of neural systems, show that there are multiple sensitive periods for sensory processes, (Lewis & Maurer, 2005) and that these are integral to healthy neurological development (Reilly et al., 1995). In addition, there are multiple sensory periods within each particular sensory domain and researchers have found that there is often a reduced plasticity at the end of the sensitive period (Reilly et al., 1995). In relation to acceptance of variety, it is well accepted that following the period of acceptance in early infancy, the neophobic food response is seen in infants to varying degrees from the age of 12-18 months (Pliner, 1994; Birch & Marlin, 1982; Blissett et al., 2012).It is apparent, that although there is a wealth of experimental research into the sensitive periods for sensory processing in the visual domain, there is little research into sensitive periods in the gustatory domain. Research so far suggests that there may be separate sensitive periods for taste (Mennella, Griffin & Beauchamp, 2004; Mennella et al., 2011; Mennella & Castor, 2012) and texture (Coulthard et al., 2009). It may also be likely that there are different sensitive periods within these sub domains, such as acceptance of bitter flavours (Mennella et al., 2004) compared to less aversive flavours, and acceptance of textures that require different levels of oral motor skill acquisition (Rosenstein & Oster, 1988).

There are several limitations with the current study, which must be taken into account when evaluating the findings. Firstly, intake of only one food was recorded, whereas preferably a variety of foods should have been tested. As only one food was tested, it was decided that the generally liked vegetable of carrot would be a suitable experimental food. If a range of vegetables had been tested, it would have been possible to see whether tactile sensitivity was associated with reduced early acceptance across a variety of flavours. As we were measuring the amount eaten, which is a common indicator of preference in early complementary feeding

(Gerrish & Mennella, 2001; Maier et al., 2008), it would however, have been untenable to test the amount eaten of more than one food in a single testing occasion. Therefore, preferably, multiple testing occasions should have occurred, within the first week of complementary feeding, to record intake of a variety of vegetables. Alternatively facial expression analysis (Forestell & Mennella, 2007; Reilly et al., 1995), or even maternal ratings (Maier et al., 2008) could have been used to examine liking of carrot in the sample.

A further limitation was that early complementary feeding foods given in the first couple of days were not recorded, and consumption of other vegetables, in particular orange (sweet) vegetables, may have facilitated early carrot acceptance (Maier et al., 2008). Mothers also determined the timing of the introduction of complementary foods when they felt their infant was ready, and the researchers did not influence this. In natural experiments, there is always the possibility that a confounding variable may be responsible for the decision to give complementary foods at a certain time. For example parents, who perceive their infant to be a hungry baby, may introduce complementary foods earlier than anticipated. Alternatively, infants who do not seem interested in food may be started later than anticipated on complementary feeds.

An exclusively breast fed sample was used, rather than a mixed sample (Hetherington et al., 2015) or a formula fed sample (Mennella & Castor, 2012). This was not ideal, as infants could have been exposed to different levels of taste through the breast milk of their mothers, depending on the variety of foods consumed (Mennella & Beauchamp, 1991). Although the levels of fruit and vegetable consumption differed between mothers in the sample, this was not associated with levels of early carrot consumption. It has been found that maternal FV consumption influences FV feeding practices (Coulthard, Harris & Emmett, 2009) however, there is no evidence that maternal FV consumption influences very early reactions to solids, apart from studies where mothers have had to consume considerable levels of the specific food in question (Mennella & Beauchamp, 1991). To control for this, ideally an exclusively formula fed sample should have been recruited, however it would have been difficult to recruit formula fed infants who were not introduced to complementary foods until the age of 6 months.

The possibility that early sensory sensitivity may be associated with food acceptance, and might possibly influence the efficacy of exposure strategies is an area that warrants further research. One problem with this conclusion is the possibility that that some parents may delay introducing complementary foods to an infant who shows signs of a small appetite. Much more information would need to be gathered about parental rationales for introduction of complementary feeding to determine the causality of the relationship found in the older infants. In addition, the known association between food neophobia and sensory processing (Coulthard& Blissett, 2009; Farrow &Coulthard, 2012) needs to be further investigated, in particular to ascertain whether sensory sensitivity can predict food neophobic behaviour in the second year of life. It is unclear at this stage whether levels of tactile processing remain consistent throughout the lifespan, or whether environmental factors such as exposure can alter an individual's response to their environment. It would be interesting to examine the efficacy of exposure techniques according to the sensory processing style of the individual; in particular whether individuals who are over responsive to sensory information, need a greater number of exposures to induce acceptance. In addition, it would be crucial to examine whether maternal responses to infants who dislike the feel of many substances, may alter their parenting strategies as a consequence, and expose their infant to a more limited range of substances, across both food and non-food stimuli.

This is the first study to measure general sensory processing tendencies in infants, and examine them in relation to their early food acceptance. The findings suggest that the relationship between tactile over-responsivity and food acceptance seen in children and adults, is also seen in some infants in the early complementary feeding period, and may affect their first responses to foods. In addition, this research has found in this particular breast fed sample with one experimental food that infants introduced to complementary foods later may not respond as well to foods if they are also over responsive to tactile information. More research is needed to substantiate and replicate this claim, it suggests that infants who show early tactile over responsiveness should be introduced to complementary foods before 6 months. This study adds to a growing body of research that proposes that a single age of complementary feeding for all infants is perhaps too simplistic, and does not account for the heterogeneity of infant development.

Financial Support

This research was financed by a Feeding for Life Foundation grant; the funders had no role in the conception, design, analysis or writing of this grant.

Conflict of Interest

The Feeding for Life Foundation is owned by Danone who also own Cow & Gate. Cow & Gate produce ready prepared formula milks and complementary feeding foods.

References

Ben-Sasson, A., Soto, T., Martinez-Pedraza, F.& *Carter, A.S.*(2013). Early sensory over-responsivity in toddlers with autism spectrum disorders as a predictor of family impairment and parenting stress. *Journal of Child Psychology & Psychiatry, 54,* 846-853.

Bingham, S.A., Gill, C., Welch, A., Day, K., Cassidy, A. & Khaw,K. T. (1994).Comparison of dietary assessment methods in nutritional epidemiology: weighed records vs. 24-h recalls, food-frequency questionnaires and estimated-diet records. *British Journal of Nutrition*,72**,**619-643.

Birch, L.L.& Marlin, D.W. (1982). I don't like it- I never tried it- effects of exposure on 2-year-old children's food preferences. *Appetite, 3*, 353-360.

Blissett, J., Bennett, C., Donohoe,J., Rogers, S. & Higgs, S.(2012). Predicting successful introduction of novel fruit to children, *Journal of the Academy of Nutrition & Dietetics, 112,* 1959-1967.

Cashdan, E. (1994). A sensitive period for learning about food. *Human Nature,5,* 279-291.

Caton, S.J., Ahern, S.M., Remy, E., *Nicklaus, S., Blundell, P. & Hetherington, M.* (2013). Repetition counts: repeated exposure increases intake of a novel vegetable in UK pre-school children compared to flavour-flavour learning and flavour-nutrient learning. *British Journal of Nutrition, 109,* 2089-2097.

Child Growth Foundation (1990) *Cross sectional stature and weight reference curves for the UK.* London: Child Growth Foundation.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112, 1,* 155-159.

Cooke, L.J., Wardle, J., Gibson, E.L., Sapochnik, M., Sheiham, A. & Lawson, M. (2004). Demographic, familial and trait predictors of fruit and vegetable consumption by pre-school children. *Public Health Nutrition, 7***,** 295-302.

Cooke, L. (2007). The importance of exposure for healthy eating in childhood. A review. *Journal of Human Nutrition & Dietetics, 20,* 294-301

Coulthard, H.& Blissett, J. (2009). Fruit and vegetable consumption in children and their mothers; moderating effects of child sensory sensitivity. *Appetite, 52,* 410-415

Coulthard, H.& Harris, G. (2003). Early food refusal; the role of maternal mood. *Journal of Reproductive & Infant Psychology, 21,* 335-345.

Coulthard, H., Harris, G.& Emmett, P. (2009). Delayed introduction of lumpy foods during the complementary feeding period affects child’s food acceptance and feeding at seven years of age. *Maternal & Child Nutrition, 5,* 75-85.

Coulthard, H., Harris, G.& Emmett, P. (2010). Long-term consequences of early fruit and vegetable ~~weaning~~complementary feeding practices in the United Kingdom. *Public Health Nutrition, 13(12),* 2044-2051.

Coulthard, H. & Thakker, D. (in press). Enjoyment of tactile play is associated with food neophobia in preschool children. *Journal of the Academy of Nutrition & Dietetics.*

Davis, A.M., Bruce, A.S., Khasawneh, R., Schulz, T., Fox, C. & Dunn, W.(2013). Sensory processing issues in young children presenting to an outpatient feeding clinic. *Journal of Pediatric Gastroenterology & Nutrition,56,* 156-160.

Dazeley, P. & Housten-Price, C. (2015). Exposure to foods’ non taste sensory properties: a nursery intervention to increase children’s willingness to try fruit and vegetables. *Appetite, 84,* 1-6.

Dovey, T.M., Aldridge, V.K., Dignan,W., Staples, P.A., Gibson, E.L. & Halford, C.G.(2012). Developmental differences in sensory decision making involved in deciding to try a novel fruit. *British Journal of Health Psychology,72,* 258-272.

Dunn, W. (2001). The sensations of everyday life: Empirical, theoretical, and pragmatic considerations. *American Journal of Occupational Therapy, 55,* 608-620.
Dunn, W.& Daniels, D.B. (2002).Initial development of the infant/toddler sensory profile *Journal of Early Intervention, 25*,27-41.

Farrow, C.V.& Coulthard, H. (2012). Relationships between sensory sensitivity, anxiety and selective eating in children. *Appetite, 58,* 842-884.

Fewtrell, M.S. (2011). The evidence for public health recommendations on infant feeding. *Early HumanDevelopment, 87,*715-721

Forestell, C.A.& Mennella, J.A. (2007). Early determinants of fruit and vegetable acceptance. *Pediatrics, 120,* 1247-54.

Forestell, C.A.& Mennella, J.A. (2012). More than just a pretty face. The relationship between infant’s temperament, food acceptance, and mother’s perceptions of their enjoyment of food. *Appetite, 58,* 1136-1142.

Gerrish, C.J.& Mennella, J.A. (2001). Flavor variety enhances food acceptance in formula fed infants. *American Journal of ClinicalNutrition, 73,* 1080-85.

Harris, G.(1988). Determinants of the introduction of solid foods. Reproductive & Infant Psychology, 6(4), 241-249

Harris, G., Thomas, A.& Booth, D.A. (1990). Development of salt taste in infancy. *Developmental Psychology,26,* 534-538.

Hausner, H., Olsen, A.& Møller, P. (2012). Mere exposure and flavour-flavour learning increase 2-3 year old children’s acceptance of a novel vegetable. *Appetite,58,* 1152-1159.

Illingworth, R.S.& Lister, J. (1964). The critical or sensitive period, with special reference to feeding problems in infants and children. *Journal of Pediatrics, 65*, 839-848.

Kramer, M.S., Guo, T., Platt, R.W. et al. (2002). Breastfeeding and infant growth: biology or bias? *Pediatrics, 110,*343-47

Lange, C., Visalli,. M., Jacob, S., Chabanet, C., Schlich, P. & Nicklaus, S. (2013) Maternal feeding practices during the first year and their impact on infant's acceptance of complementary food. *Food Quality & Preference, 29,* 89-98.

Lewis, T.L.& Maurer, D. (2005). Multiple sensitive periods in human visual development: evidence from visually deprived children. *Developmental Psychobiology,26,* 163-183.

Lindberg L., Bohlin, G.& Hagekull, B. (1991). Early feeding problems in a normal population. *International Journal of Eating Disorders, 10,* 395-405.

NHS (2013). Portion sizes for children. http://www.nhs.uk/Livewell/5ADAY/Pages/Portionsizes.aspx (accessed October 2013)

Maier, A.S.Chabanet, C., Schaal. B., Leathwood, P.D.&Issanchou, S.N. (2008). Breast feeding and experience with variety early in ~~weaning~~complementary feeding increase infants' acceptance of new foods for up to two months. *Clinical Nutrition,27,* 849- 857.

Maier, A., Chabanet, C., Schaal, B.,Leathwood, P.D. &Issanchou, S.N. (2007a). Food-related sensory experience from birth through ~~weaning~~complementary feeding: Contrasted patterns in two nearby European regions. *Appetite, 49,* 429-440.

Maier, A., Chabanet, C., Schaal, B., Issanchou, S.N. &Leathwood, P.D. (2007b). Effects of repeated exposure on acceptance of initially disliked vegetables in 7-month infants. *Food Quality & Preference, 18,* 1023-1032.

Mennella, J.A.& Beauchamp, G.K. (1991). Maternal diet alters the sensory qualities of human milk and the nurslings behaviour. *Pediatrics88,* 737-744.

Mennella, J.A., Griffin, C.E.& Beauchamp, G.K. (2004). Flavor programming during infancy. *Pediatrics, 113,* 840-845.

Mennella, J.A., Lukasewycz, L.D., Castor, S.M.*et al.* (2011) The timing and duration of a sensitive period in human flavor learning: a randomized trial. *American. Journal of Clinical Nutrition,93,* 1019-1023.

Mennella, J.A.& Castor, S.M. (2012). Sensitive period in flavor learning: effects of duration of exposure to formula flavors on food likes during infancy. *Clinical Nutrition,31,* 1022-1025.

Myers, R.H. (1990). Classical and Modern Regression with Applications. Boston: PWS-Kent.

Naish, K.R.& Harris, G. (2013). Food Intake Is Influenced by Sensory Sensitivity. *Plos One,***7**, e43622.

Nederkoorn, C., Jansen, A. & Havermans, R.C. (2015). Feel your food. The influence of tactile sensitivity on picky eating in children. *Appetite, 84,* 7-10.

Nicklaus, S. (2011). Children's acceptance of new foods at ~~weaning~~complementary feeding. Role of practices of ~~weaning~~complementary feeding and of food sensory properties. *Appetite, 57,* 812-815.

Northstone, K., Emmett, P., Nethersole, F.&the ALSPAC study team (2001). The effect of age of introduction to lumpy foods eaten. *Journal of Human Nutrition & Dietetics, 14,* 43-54.

Pliner, P. (1994). Development of measure of food neophobia in children. *Appetite, 23,* 147-163.

Prezyrembel, H. (2012). Timing of introduction of complementary food: short and long term health consequences. *Annals of Nutrition & Metabolism,60,* 8-20.

Schwartz, C., Chabanet, C., Lange, C.,*et al*. (2011) The role of taste in food acceptance at the beginning of complementary feeding. *Physiology & Behavior*, *104,* 646-652.

Schwartz, C., Scholtens, P.A.M.J., Lalanne, A., *et al* (2011) Development of healthy eating habits early in life. Review of recent evidence and selected guidelines. *Appetite, 57*, 796-807.

Sullivan, S.A.& Birch, L.L. (1994). Infant dietary experience and acceptance of solid foods. *Pediatrics, 93*, 271-277.

Reilly, S. Skuse, D. Mathisen, B.& Wolke, D.(1995). The objective rating of oral-motor functions during feeding. *Dysphagia, 10,* 177-191.

Rosenstein, D.& Oster, H. (1988). Differential facial responses to 4 basic tastes in newborns. *Child Development, 59*, 1555-68.

Wardle, J., Carnell, S.& Cooke, L. (2005). Parental control over feeding and children's fruit and vegetable intake: how are they related? *Journal of theAmerican Dietetic Association,105,*227-232.

Werthmann, J. Jansen, A., Havermans, R., Nederkoorn, C., Kremers, S. & Roefs, A. (2015). Bits and pieces. Food texture influences food acceptance in young children. *Appetite, 84,* 181-187.

World Health Organisation (2001) *The optimal duration of exclusive breast feeding. Report of an expert consultation*. Geneva: WHO.

Wright, C.M., Cox, K.M. & Le C.A. (2011). How does infant behaviour relate to weight gain and adiposity? *Proceedings of the Nutrition Society,70(4),* 485-493.

Table 1: Carrot consumption and tactile sensitivity scores according to the demographic variables, FV consumption and infant BMI in the sample.

Demographic characteristics		**N**	**Tactile sensitivity Mean (SD)**	**Carrot consumption (g) Median (IQR)**
		61	20.33(2.91)	46.97(35.64) Range 2-136g
Sex				
Male		29	20.29(3.27)	38.00(49.75)
Female		32	20.38(2.45)	46.00(44.00)
Mean age ± standard deviation				
Mothers	32.42± 4.93 years			
Infants	5.18 ±0.84 months			
4 months		20	20.37(2.79)	34.00(35.50)
4.5-5.5 months		15	20.00(2.68)	42.00(60.00)
5.5 months- 6 months		26	20.48(3.23)	47.00(45.00)
Mean maternal education (years)± SD	15.86 ± 1.9 years			
up to A levels (aged 18)		10	20.39(3.00)	43.00(38.50)
Graduate		49	20.05(2.91)	36.00(58.00)
Mean maternal daily fruit and vegetable portions± standard deviation	3.62±1.86 portions			
Range daily fruit and vegetable portions	0.5- 12portions			
% achieving 5 portions of fruits and vegetables a day	23% (n= 14)			
<2 portions		13	20.38(2.83)	33.00(70.00)
2-<4 portions		22	20.41(2.66)	33.00(37.00)
4 portions or greater		20	20.20(3.38)	42.00(57.00
Infant BMI				
<-1 SD		17	20.33(2.84)	46.00(40.00)
-1-1 SD		33	20.43(2.63)	44.00(59.00)
>1SD		7	20.20(3.38)	36.00(18.00)

Table 2: Pearson's product-moment (Spearman's rank correlation where indiated) between demographic factors, infant BMI, maternal FV consumption, infant carrot intake and sensory over responsivity (OR) [a]

	Tactile OR	General OR	Vestibular OR	Total OR	Carrot intake (g)[b]
Mothers age (years)	0.150	-0.178	-0.038	0.035	-0.092
Maternal education (years)[b]	-0.191	**0.278***	-0.026	-0.162	0.046
Infants age (months)[b]	-0.004	0.070	-0.092	0.032	0.064
Maternal FV consumption (portions/day)	0.087	**-0.300***	-0.072	0.035	0.154
Infant BMI (Z scores)	-0.085	-0.008	-0.076	-0.136	-0.023
Carrot intake (g)[b]	**-0.244***	-0.147	**-0.233***	**-0.323****	**--------**

a. OR: over responsivity

b. Spearman rank correlations are reported all associations involving these variables

*p<0.05, **p<0.01

Table 3: moderated regression to examine whether tactile over responsivity and age of introduction to solids interact in their effect on carrot consumption (g)

Predictor	*B*	β	*SE*β	***Bootstrapped CI***
Adjusted[a]				
Step 1				
Introduction solids	3.41	0.08	1.83	*-7.18, 15.11*
Tactile over responsivity	-4.35	-0.34*	1.91	*-7.18, -0.20*
Step 2				
Interaction tactile SOR*age	-4.864	-0.32*	2.13	*-9.10, -0.26*
Unadjusted				
Step 1				
Introduction solids	2.51	0.06	5.62	*-9.28, 13.92*
Tactile over responsivity	-3.96	-0.32*	1.65	*-7.31, -0.26*
Step 2				
Interaction tactile SOR*age	-4.40	-0.29*	1.93	*-8.22, -0.30*

a Adjusted for maternal education (years), infant BMI (sds z scores), maternal FV consumption (portions/day) and infant gender(male/female)

**p*<0.05*

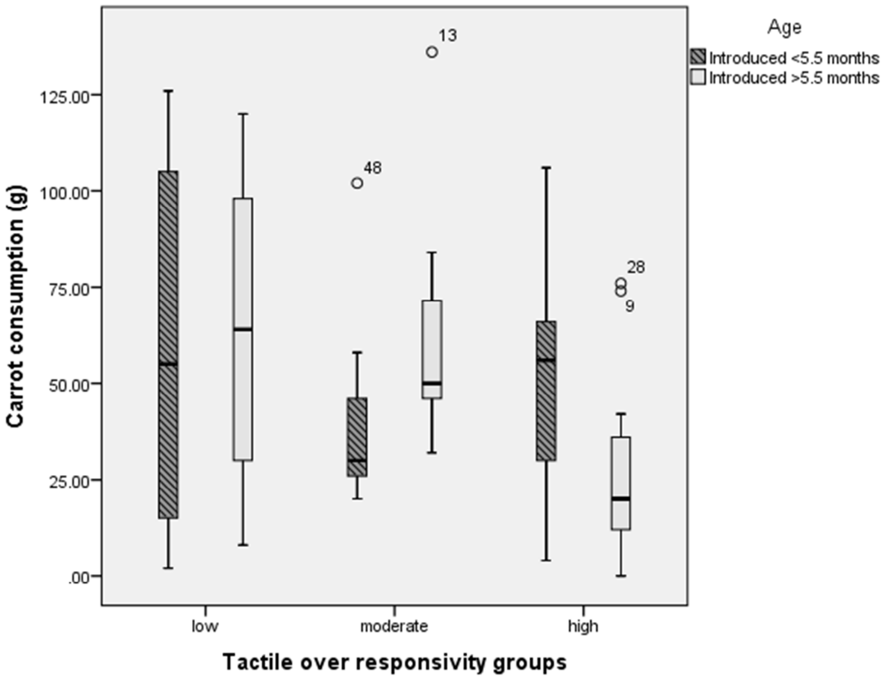

Figure 1: Boxplots to show differences in carrot consumption according to tactile over responsivity and age of complementary feeding