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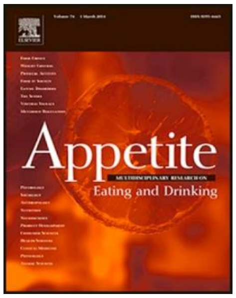

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EFFECTS OF SUCROSE DETECTION THRESHOLD AND WEIGHT STATUS ON INTAKE OF FRUIT AND VEGETABLES IN CHILDREN.

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Highlights

- We measured sucrose detection threshold (SDT) and BMI centile of children
- Their effects on 24 hour intake of fruit and vegetables were analysed
- Children with moderate SDT consumed the most non-astringent fruit
- Children with high SDT consumed the most cruciferous vegetables
- Weight had no effect on intake of fruit and vegetables

Abstract

Past research on the relationship between taste sensitivity and fruit and vegetable (FV) intake in children has focused on sensitivity to bitter taste. The effects of sensitivity to sweet taste on intake of FV have never been investigated. Furthermore, the effects of children's weight on intake of FV are inconclusive. This study measured the effects of Sucrose Detection Threshold (SDT) and weight status on intake of FV in children. The participants of this study were 99 children between 5-9 years old. Parents reported their own and their children's 24 hour intake of FV and completed a measure of children's sensory sensitivity. Children completed the triangle test with suprathreshold concentrations of sucrose ranging between 0.2%- 1.6%, in 0.2% increments. Two MANCOVAs showed that, controlling for parental intake and children's sensory sensitivity, there was a main effect of SDT on intake of fruit ($p<0.05$), which was exclusive to non-astringent fruit ($p<0.05$), and cruciferous vegetables ($p<0.01$). Weight status had no effect on intake of FV. Mechanisms behind the effects of SDT are discussed in the context of past research on bitter taste sensitivity.

Keywords

Children, fruit, vegetables, weight, sucrose detection threshold

Abbreviations

FV- fruit and vegetables; SDT- Sucrose Detection Threshold; SSP- Short Sensory Profile

Effects of sucrose detection threshold and weight status on intake of fruit and vegetables in children.

1. Introduction

Research consistently shows that consumption of fruit and vegetables (FV) among children and adults is too low (for a review see Krolner, Rasmussen, Brug, Klepp, Wind & Due, 2011), yet a diet rich in FV has been linked to reduced prevalence of cancer (Maynard, Gunnell, Emmett, Frankel & Davey Smith, 2003). One of the main determinants of dietary choices is the flavour of food (Prescott, Bell, Gillmore, Yoshida et al., 1997). It is therefore not surprising that FV are the most commonly rejected group of products by children (Cooke, Carnell & Wardle, 2006), as they are naturally low in palatable fats and in the case of vegetables also low in sweet carbohydrates with some degree of bitterness which makes them a relatively unattractive food option. This additionally prevents flavour learning thus increasing predisposition for future rejection.

Past research has shown that both environmental and physiological factors affect consumption of FV in children. Important environmental contributors include exposure to tastes in infancy (Birch, Gunder, Grimm-Thomas & Laing, 1998), parental FV consumption (Gibson, Wardle & Watts, 1998), socio-economic status of parents and home availability (Rasmussen, Krølner, Klepp, Lytle, Brug, Bere & Due, 2006). There are also some physiological contributors that have been linked to consumption of FV (for a full review on intrinsic and extrinsic influences of FV consumption, see Blissett & Fogel, 2013). An important individual difference affecting FV consumption is children's sensory processing. Children who are particularly sensitive to sensory stimuli such as odour, colour, or texture are more likely to reject FV that are characterised by intense or unusual flavour, scent, colour or lumpy texture, due to the differences in acceptance thresholds for external stimulation (Dunn, 1997). Coulthard and Blissett (2009) showed that parental reports of children's sensory sensitivity are related to children's consumption of FV. In their study, children who were the most sensitive to taste and smell were also less likely to consume adequate portions of FV. Possibly, those most sensitive children are more likely to detect changes in flavour of foods and reject the product if it departs from an internally stored prototype of what particular product should taste like. Smith, Roux, Naidoo and Venter (2005) showed that children who have atypical sensitivity in the tactile domain known as 'Tactile Defensiveness', had a lower preference for vegetables compared to non tactile defensive peers, they ate fewer vegetables and rejected vegetables based on their texture. Typicality of colour and departure from the known and accepted colour of FV was also shown to affect preference and acceptance of vegetables (Poelman & Delahunty, 2011), showing the impact of visual/auditory sensitivity on acceptance of FV. Atypical sensitivity in visual/auditory, taste/smell and tactile domains should therefore be taken into account when analysing the potential effects of flavour specific sensitivity on intake of FV.

Past research on sensitivity to taste and intake of FV has been mainly focused on sensitivity to bitter taste, which is measured as the ability to detect a bitter tasting compound 6-n-propylthiouracil (PROP) or its predecessors propylthiouracil (PTU) and phenylthiocarbamide (PTC). Past studies showed that bitter taste sensitivity can predict intake of bitter tasting FV in children (e.g. Bell & Tepper, 2006; Keller, Steinmann, Nurse & Tepper, 2002), as FV contain different degrees of bitter alkaloids that affect the degree to which humans perceive them as bitter (Drewnowski & Carneros, 2000). At the same time there are individual differences in the perceived intensity of bitterness of FV due to the polymorphic nature of genes responsible for bitter taste recognition (Duffy, Hayes & Barthoshuk, 2010). People sensitive to the bitter alkaloids should be more likely to reject bitter FV, as the detected bitterness would negatively affect palatability of those products (Duffy, Hayes, Davidson, Kidd, Kidd & Bartoshuk, 2010). The Brassicaceae family of vegetables (cruciferous vegetables) is the group that contains the highest degree of bitter alkaloids, so sensitivity to bitter compounds should have the highest impact on acceptance of this specific family within the vegetable group. However, data showing the link between bitter taste sensitivity and FV consumption is inconclusive, since several studies failed to show that FV intake differs by bitter taste sensitivity status, both within the general FV group (Feeney, O’Brien, Scannell, Markey & Gibney, 2014) and specifically in the cruciferous vegetables family (Baranowski, Baranowski, Watson, Jago et al., 2011). Within the fruit range, fruit with astringent properties would be most likely to be affected by bitter taste sensitivity. Fruit rich in phenolic compounds, which contribute to bitterness and astringency, would be more likely to be rejected given the universal predisposition to dislike bitter or sour flavours (Birch, 1999), and even more so by people sensitive to bitter flavours.

An alternative explanation for individual differences in FV intake that has not been thoroughly researched is that the degree of FV sweetness is likely to affect how palatable they are and in this way affect acceptance. Individual differences in sensitivity to sweet flavour may help explain variation in FV intake, especially since bitter taste sensitivity cannot be used to explain intake of non-bitter FV (those that lack the bitter alkaloids). Sensitivity to sweet taste requires particular research attention due to the suggested polymorphic connection between transduction mechanisms of bitter and sweet compounds (e.g. Fushan, Simons, Slack & Drayna, 2010; Looy & Weingarten, 1992). Gustducin is thought to be involved in transmitting of both bitter and sweet compounds, which suggests that a similar mechanism may be involved in their detection, which leads to a question of the role of sweet taste sensitivity in the acceptance of FV (Fushan et al., 2010). Past studies focused on both detection (lowest concentration of tastant detected) and recognition thresholds (lowest concentration of tastant recognised as particular flavour e.g. sweet). Low detection/recognition thresholds are indicative of high sensitivity to the flavour. There is evidence for a link between phenotypic sensitivity to sweet and to the bitter taste. Hong, Chung, Kim and Chung et al. (2004) demonstrated that participants who were blind to the taste of the bitter chemical PTC (hence showed low bitter taste sensitivity) had a significantly higher sucrose detection threshold (SDT) and sucrose recognition thresholds, which both were indicative of low sensitivity to the sweet compounds, thus showing a positive link between the two types of sensitivity. Chang, Chung, Kim, Chung et al. (2006) showed further support for the link between bitter and sweet taste sensitivity using PROP as the bitter tastant and demonstrated that PROP non-tasters (indicative of low sensitivity to bitter taste) had a higher SDT (indicative of low sensitivity to sweet taste) compared to PROP tasters. Given the link between the sweet and bitter taste sensitivity we propose that sensitivity to sweet taste might affect intake of FV, which would be particularly evident in children, who in the past have been shown to have higher liking for sweet products than adults (Mennella, 2008). Since children also show high rejection rates of FV, the role of individual differences in SDT in intake rates of FV should be analysed.

Children's intake of FV has also been analysed in the context of child's weight status, however the information is rather limited and findings inconclusive (Field, Gillman, Rosner, Rockett & Colditz, 2003; for review see Dietary Guidelines for Americans DGAC, 2010). Miller, Moore and Kral (2011) showed that in a group of 5-6 year old children, overweight/obese children consumed fewer portions of FV than their healthy weight peers. Similarly, Lorson, Mergal-Quinonez and Taylor (2009) demonstrated that in a sample of 3040 children between 2-11 years old, the overweight children consumed less fruit than the healthy weight or at risk of overweight children, but no differences in vegetable intake were found. Contrary, to those findings Field et al. (2003) did not find an association between FV intake and change in BMI in a sample of 14,918 children between 9-14 years old. It is important to point out that those studies differed in employed objectives and methodologieswhich provides an explanation for why the findings are inconsistent. More specifically, past research showed that intake of FV in children differs by age, ethnicity, gender and household income (Lorson et al., 2009), which makes comparison of the results of the studies on the effects of weight status on intake of FV difficult. Different measures of FV intake may yield different results, particularly comparing parental reports and data collected empirically (e.g. skin carotenoid status) or observational results in naturalistic settings. Also differences in applied definitions of portion sizes, inclusion of different FV into the count (e.g. potatoes, fruit juice, vegetable juice or pulses) all may contribute to inconsistent reports of intake of FV among healthy weight and overweight children.

Interestingly, recent findings suggest that the relationship between SDT, weight status and food intake may warrant investigation. For example, it has been demonstrated that SDT can be affected by leptin levels in healthy weight but not overweight adults (Yoshida, Niki, Jyotaki, Sanematsu et al., 2013). Consequently, SDT might affect dietary choices differently in healthy weight individuals compared to overweight/obese individuals. A study by Ettinger, Duizer and Caldwell (2012) also showed that overweight adult women might have higher detection threshold for sucrose compared to normal weight women, but this finding requires further research. For this reason it would be interesting to look at SDT levels and their possible effects on FV intake in the context of children's weight status, as the analysed effects of SDT on FV intake may differ in healthy weight and overweight/obese individuals.

Studies so far have not investigated whether individual detection thresholds for sweet compounds are related to FV intake in children and whether this relationship varies by weight status. In addition there is limited evidence for differences in FV intake in healthy weight and overweight/obese children. It is possible that individuals who have a high detection threshold for sweet compounds (indicative of low sensitivity) perceive the flavour of FV differently to those with lower SDT (higher sensitivity), which might be reflected in their FV intake. Hypothetically, their subjective perception of FV flavour pleasantness may differ from children with low SDT who possibly could easily detect sweetness in FV, especially in the non-bitter or non-astringent family. Past studies which examined the relationship between FV intake and weight in children are inconclusive and there are no data on the relationship between weight and FV intake in the context of individual SDT. The aim of this study was to test whether children's individual SDT are linked to intake of fruit and vegetables, and more specifically fruit with astringent properties and cruciferous vegetables. To make it possible to compare with the previous studies, cruciferous vegetables were analysed separately, as past studies on bitter taste sensitivity were often focused on this particular family of vegetables (e.g. Baranowski et al., 2011; Glanville & Kaplan, 1965; Drewnowski & Carneros, 2000). Fruit with astringent properties were also analysed separately as they differ in sensory properties from non-astringent fruit. Further, we aimed to investigate whether weight status is related to intake of FV, and whether possible effects of SDT on intake of FV differ in healthy weight and overweight/obese children, while controlling for sensitivity in taste/smell, visual/auditory and tactile domain, as well as parental consumption of FV.

2. Method

2.1 Participants

Initially 108 parents and their children were recruited to the study, however because of the absence from school, lack of consent form, underlying medical conditions (e.g. diabetes) or uncompleted documents, only 99 children (50 boys and 49 girls) completed the study. Children were recruited from 4 primary schools from affluent areas of Birmingham, UK (top 5% of the most affluent areas in the UK, as measured by the Index of Multiple Deprivation Rank IMDR, 2010). The mean age of the sample was M=7.21 (SD=1.3) years old. The majority of the children were White British (n=90), and the remaining 9 children were of Asian (n=5) or Mixed origin (n=4). The paper measures collected in this study were completed by mothers (n=88), fathers (n=9) or the grandparent (n=2). Parental mean age was 38.16 (SD= 9.24) years old. Children whose parents reported their illnesses affecting nose or throat within the 4 weeks prior to data collection were tested at least 3 weeks after the reported illness date (n=3). Participants who were ill on the day of testing were excluded from the study (n=1). The children were tested in the school setting.

2.2 Materials and Measures

2.2.1 Sucrose Detection Threshold

Sucrose solutions were prepared at the University of Birmingham food laboratory from standard sugar and distilled water, by diluting an appropriate amount of sugar in distilled water and mixing until the sugar was completely dissolved. The concentration of sugar in the solution was then confirmed with the use of a refractometer (Mettler Quick-Brix 60 Meter) on two occasions. The solutions were served at room temperature (22°C) in white non-opaque paper cups (10 ml per serving). The following sucrose concentrations were used to establish the children's SDT: 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2%, 1.4% and 1.6%. Those concentrations were chosen after an initial pilot study that showed that these concentrations could differentiate between children with various SDT.

2.2.2. Sensory sensitivity

To assess general sensory sensitivity of a child, parents were asked to complete the Short Sensory Profile questionnaire (SSP; Dunn, 1999). This contains 38 items that evaluate sensitivity in 7 domains, but for the purpose of this study only 3 domains previously related to dietary preferences (Coulthard & Blissett, 2011; Smith et al., 2005) were assessed: Tactile (e.g. *Reacts emotionally or aggressively to touch*), Taste/Smell (e.g. *Will only eat certain tastes*), Visual/Auditory (e.g. *Holds hands over ears to protect ears from sound*) sensitivity. The responses range from always to never on a 5 point Likert scale. This measure has been previously used in studies examining children's eating behaviours (e.g. Farrow & Coulthard, 2012; Smith, Roux, Naidoo & Venter, 2005).

2.2.3 Fruit and vegetables

FV consumption over the past 24 hours was reported by the parents who completed a measure designed specifically for this study. Parents were given an extensive list of FV available in the local supermarkets (the list included 63 fruit and 59 vegetables). They were asked to mark which products they and their children consumed over the past 24 hours, as well as provide information about the portion size (what constituted a portion was clearly stated next to each product). FV were then split into sub-groups. Fruit count included all fruit without fruit juice. Fruit was further split into astringent fruit group and non-astringent fruit group. Astringent fruit contained fruit with astringent and irritant properties due to high content of tannins (berries, sharon fruit, pomegranate), naringin and hesperidin (lemons and limes) and ascorbic acid (kiwis and pineapple). Vegetable count included all vegetables listed, except for potatoes which were not included in the analyses. Vegetables were further split into cruciferous vegetables and non-cruciferous vegetables.

2.3 Procedure

Schools which agreed to participate in the study distributed the full information and questionnaire packs among the pupils. Parents who consented to participate returned the completed questionnaires back to school (the return rate was 24%) and their child was tested within 7 days. Children were asked not to eat or drink anything other than water for 1 hour prior to the study. All children were tested in the morning hours before lunch.

The method for establishing the SDT was adapted after Zhang, Zhang, Wang, Zhan et al. (2008). The child was asked to sip and spit three liquids during each round. Each round consisted of two presentations of water and a solution. In each round, one of the liquids was the sucrose solution (S) and two of the liquids were distilled water (W). The order of the presentation of liquids in each round was randomized and was recorded (WWS, WSW, SWW). The solutions were presented in increasing concentrations. The cups had random numbers written on them, to aid children's memory when recalling the different tasting solution. The participant was asked to rinse their mouth with each one out of the three liquids and spit it out to the bowl. The participant was asked to indicate which one of the three liquids was different from the other two. If the participant could not make the distinction they were requested to guess, since there was a possibility that they were not consciously aware that they could taste the difference. Then the participant was asked to rinse their mouth with water and spit it out twice. The inter-trial interval was approximately 60 seconds. The procedure was repeated for all of the remaining concentrations. The test was stopped when the child identified the correct solution on three consecutive trials. Individual SDT was established as the middle solution correctly identified by the child, or as the highest possible when the child correctly identified only the last solution presented. The middle correctly identified solution was used as a SDT measure to control for the first correctly identified solution occurring by chance. The middle solution identified during the three rounds was therefore thought to be a more reliable indicator of SDT. The participant was weighed in light clothing without the shoes using standard kitchen scales (accurate to 0.1 kg) and height was measured using the stadiometer (Seca Leicester Portable height measure) at the end of the experiment.

3. Results

3.1 Sucrose detection threshold

The median SDT in the sample was 1.0% (SD=0.37). SDTs were not normally distributed (KS; $p<0.05$). Past studies on bitter taste sensitivity using PROP tastant have divided the participants into three classes: non-tasters, tasters and super-tasters, despite PROP sensitivity being a continuous variable (Anliker & Barthoshuk, 1991; Baranowski et al. 2012; Bell & Tepper, 2006; Catanzaro, Chesbro & Velkey, 2013; Duffy et al., 2010). For comparative reasons, participants in this study also were divided into three classes based on suprathreshold sucrose detection levels. Children were classified as having low (0.4 and 0.6%; n=35), moderate (0.8-1.2%; n=36) and high SDT (1.4 and 1.6%; n=28). There was no relationship between SDT and children's age (Spearman's rho; r=-0.16, p>0.05) and there were no gender differences in SDT (Mann Whitney U; U= 1169.50; p>0.05). Children with the different level of SDT did not differ in weight (ANOVA; F(2,96)= 0.93, p>0.05).

3.2 Fruit and Vegetable consumption

Data on FV intake was collected from both weekend (27.5%) and week days (72.5%). There were no differences in the number of portions of fruit or vegetables consumed between the children whose mother reported weekend and weekday intake (Mann-Whitney U; U=846.5, p>0.05 for fruit; U=804.0, p>0.05 for vegetables). The range of reported portions of FV consumed by children over the 24 hour period was between 0-28 portions. This unusually high range was an indication of possible parental over-reporting, so outliers who scored more than 3 SD from the median have been excluded from the analyses (n=3). Baranowski et al., (2012) dealt with over-reporters by excluding participants who scored more than 1.4SD from the mean, however due to the smaller sample of this study the exclusion criteria were less restrictive. After removing the outliers from the upper range, the range of reported intake of FV was 0-17 portions. Data for fruit and/or vegetable consumption of children and parents did not meet assumptions of normality (KS; p<0.05). Mean values and SE of children's and parents' reported intake of FV over the 24 hour period after exclusion of over-reporters and relationship between parental and child's intake (Spearman's rho) are presented in Table 1.

3.3 Weight

Weight data of two children were not available for analyses because children did not consent to being weighed. Based on their height and weight, children's BMI z-scores were calculated using British 1990 Child Growth Reference Chart (UK90; M=0.17, SE=0.12) and were shown to be normally distributed (KS; p>0.05). BMI z-scores were later converted to the corresponding BMI centiles (M= 52.09, SE= 3.04) to allow a split into two categories, healthy weight (n=77) and overweight/obese (n= 19). The groups were split based on the BMI centile cut offs as recommended by National Obesity Observatory (NOO, 2011) at 85th centile indicating overweight and above 95th centile indicating obese. For the purpose of these analyses overweight (n=16) and obese (n=3) children were classified as one group, which will be referred to as Overweight. There were no underweight children in this sample.

3.4 Short Sensory Profile

Data from SSP were used to assess sensitivity of children across the three domains. Sensory sensitivity in various domains was correlated with SDT, BMI centile and FV intake. Sensitivity to taste and visual/auditory stimuli was correlated with several subdivisions of FV intake. There were no relationships with SDT or BMI centile. Data are summarised in Table 2.

3.5 SDT, Weight and FV

Two two-factor Multivariate Analyses of Covariance were conducted to test for the effects of SDT and Weight status on the reported intake of FV, while controlling for sensory sensitivity in taste/smell and visual/auditory domains, as well as for parental consumption of FV. One analysis focussed on overall fruit and vegetable intake and the second analysis examined subdivisions of FV consumption (astringent/non astringent fruit, cruciferous/non-cruciferous vegetables). MANCOVAs were used despite non-normal distribution of data as other assumptions were not violated. Box's M test indicated that there was no violation of the assumption of homogeneity of the variance-covariance matrices (p>0.05) and assumptions of multicollinearity have not been violated, hence it was deemed appropriate to use MANCOVA to test the hypotheses.

The first MANCOVA was conducted with two dependent variables; fruit and vegetable intake, controlling for parental intake and taste sensitivity. The results are summarised in Table 3. Using Pillai's trace, the effect of SDT on the dependent variables missed the level of significance, V=0.11, F(4,158)=2.31 p=0.06. Separate univariate ANOVAs on the outcome variables revealed significant effects of SDT on intake of fruit but not vegetables.

Bonferroni post-hoc analysis showed that children with moderate SDT consumed significantly more fruit (M= 4.60) than children with low SDT (M=2.77; p=0.042). The difference in fruit intake between children with moderate and high SDT was not significant (M=3.17, p=0.135). Also, there was no difference in fruit intake between children with low and high SDT (p=1.000; see Fig 1).

Using Pillai's trace there was not a significant effect of weight status on the dependent variables, V=0.01, F(2,78)=0.38, P=0.679. Separate ANOVAs showed that there were no effects of weight status on intake of fruit or vegetables. The interaction of SDT with weight status also did not influence FV intake at multivariate level (Pillai's trace; V=0.07, F(4,158)=1.48, p=0.212). Separate ANOVAs showed that interaction of SDT with weight status had no effect on intake of fruit or vegetables.

The second MANCOVA analysis included 4 dependent variables of subgroups of FV: astringent fruit, non-astringent fruit, cruciferous vegetables and non-cruciferous vegetables. Parental FV intake and taste and AV sensitivity were controlled for. The results are summarised in Table 4.

Using Pillai's trace, there was a significant effect of SDT on the dependent variables, V=0.22, F(8, 152)=2.33, p=0.022. Separate univariate ANOVAs on the outcome variables revealed significant effects of SDT on intake of cruciferous vegetables and non-astringent fruit. There were no effects of SDT on non-cruciferous vegetables and astringent fruit intake.

Bonferroni post-hoc analysis showed that children with high SDT (M=0.98) consumed significantly more cruciferous vegetables than children with low SDT (M=0.13; p=0.006). The difference in cruciferous vegetables intake between children with moderate (M=0.36) and high SDT missed significance (p=0.07). Also, there was no difference in cruciferous vegetables intake between children with low and moderate SDT (p=1.00; see Fig 2).

Bonferroni post-hoc analysis further showed that children with moderate SDT consumed the most non-astringent fruit (M=3.81), compared to children with low

(M=2.38) and high SDT (M=2.60). However, the differences were not significant. The difference between children with moderate and low SDT missed significance at p=0.07 level (see Fig 3).

Using Pillai's trace, there was not a significant effect of weight status on the dependent variables, V=0.03, F(4,75)=0.64, p=0.637. Separate ANOVAs showed that there were no effects of weight status on any of the dependent variables.

The interaction of weight status and SDT also did not influence the dependent variables at the multivariate level, V=0.10, F(8, 152)=0.97, p=0.460. Separate ANOVAs did not show effects of the interaction on the dependent variables. However, the interaction of weight status and SDT on the intake of non-astringent fruit missed significance at p=0.058 level.

4. Discussion

The aim of this study was to test if individual SDT and weight status affect FV intake in children. We also wanted to explore possible interactions between SDT and weight status on FV intake, whilst controlling for parental FV intake and children's sensory sensitivity. The results showed that when controlling for taste/smell and visual/auditory sensitivity and parental FV intake, individual SDT had an effect on the intake of non-astringent fruit and cruciferous vegetables. General intake of vegetables, non-cruciferous vegetables or astringent fruit was not affected by SDT. Weight status had no effect on the number of portions of fruit or vegetables consumed. Weight status and SDT did not interact to affect FV intake.

4.1 Fruit

There was a main effect of SDT on the intake of fruit. Surprisingly, children with moderate SDT consumed the most fruit and significantly more than the children with low SDT, while the difference between children with moderate and children with high SDT just missed significance. Children with moderate SDT were reported to consume almost twice as many portions of fruit as children with low SDT. Further analysis revealed that the difference in intake of fruit is exclusive to non-astringent fruit. This finding is unexpected and mechanism behind it is unclear.

As evident from the results, children who could easily detect sweet compounds were reported to consume the smallest number of fruit, and specifically, non-astringent fruit, and had a similar mean intake level to children with high SDT. There are reasons to believe that two different mechanisms are responsible for fruit acceptance in children with low and high SDT as the theoretical framework currently does not offer an explanation for why children at the two opposite ends of SDT spectrum would show similar patterns of non-astringent fruit intake. Bartoshuk (2000) in a review paper showed that 11 out of 16 studies reported an association between detection of sweet and bitter compounds, and she concluded that the results of the 5 remaining studies could be explained by methodological shortcomings in the use of psychophysical measures. Given the common transduction mechanisms of sweet and bitter tasting compounds (Zhang et al., 2003) it was expected that children with low SDT would be the most sensitive to fruit with astringent properties. Consequently, the possible increased sensitivity to bitter compounds among children with low SDT would have an inhibitory effect on acceptance and further intake of fruit, and in particular astringent fruit. Past studies demonstrated that individuals sensitive to bitter tasting PROP could distinguish between different degree of bitterness and astringency in products rich or poor in the astringent tannins. Further, PROP sensitive participants had a lower acceptance level for foods with various degrees of bitter tasting polyphenols in foods (Dinehart, Hayes, Bartoshuk, Lanier & Duffy, 2006). Laaksonen, Ahola and Sandell (2013) further demonstrated that individuals with the bitter tasting genotype disliked juices from astringent tasting fruit significantly more than the individuals without the bitter tasting genotype. Surprisingly, in the present study there were no differences in the astringent fruit intake among children with different levels of SDT. On the contrary, SDT showed effects on intake of non-astringent fruit. Perhaps, the astringent properties of fruit were equally aversive to all children, irrespective of their SDT. This would explain why the average intake of the astringent fruit in the sample was almost 3 times smaller than the intake of non-astringent fruit. Interestingly, the effects of SDT were evident in the non-astringent fruit group. This might be attributable to the larger variance of the level of sweetness in the non-astringent fruit group, or alternatively by the level of sweetness which is not overshadowed by the unpleasant astringent properties. SDT might affect intake of fruit only when universally aversive properties such as astringency are absent.

An alternative interpretation is that children with high SDT might be affected by a different inhibitory mechanism. We might speculate that children with high SDT might require a higher level of sweetness than that found in fruit in order to find fruit palatable and satisfying, and consequently may show a lower intake rate. Looy and Weingarten (1992) in their study on PROP sensitivity and hedonic responses to sweet tastants showed that PROP nontasters were almost always sweet likers and PROP tasters tended to be sweet dislikers. Perhaps children with high SDT, who based on past research would tend to be PROP nontasters, would require higher concentration of sweetness to find fruit palatable and even fruit within the non-astringent group would not offer the optimal level of sweetness that would be palatable to children with high SDT. However, the relationship between detection thresholds for tastants and their perceived intensity is not completely understood. Keast and Roper (2007) showed that subjects who could detect the bitter tasting PROP at lower concentrations showed higher perceived intensity of PROP at higher concentrations. Those results were not repeated for other bitter tastants though. It suggests that the relationship between tastant detection threshold and perceived intensity is not a linear function. A similar mechanism might be present in detection threshold for sucrose and consequently higher SDT might show an inverse relationship with perceived intensity of sweetness, which might be further related to experiences of intensity of sweetness in fruit. This hypothesis would explain why children with high SDT showed lower intake of fruit compared to children with moderate SDT (although the difference just missed significance). Since the effect was present only for non-astringent fruit we might speculate that perceived intensity of sweetness has an effect on intake only in absence of aversive stimulus such as astringency.

Alternatively, environmental effects of diet on SDT might explain the lower intake of fruit in children with high SDT. Possibly, high SDT is a result of a diet rich in sweet carbohydrates. Increased exposure to highly sweetened product might increase detection threshold for sweet compounds. Lacey, Stanley, Crutchfield and Crisp (1977) showed that SDT is affected by calorific intake and carbohydrate-deprived diet. In their study on patients with Anorexia Nervosa they demonstrated that anorexic patients and healthy controls did not differ in SDT but both anorexic patients and controls had lower SDT and demonstrated higher sensitivity to sweet flavours if they were on low calorie diet. Children with Moderate SDT, who based on past studies might be likely to able to detect bitterness but not find it intensely aversive, might not be affected by either of those mechanisms, and would perhaps show an increased intake of fruit due to the lack of inhibitory mechanisms aiding fruit rejection. Moderate SDT might be optimal for fruit acceptance, unless food has aversive astringent or irritant properties, in which case they would be less likely to be accepted irrespective of SDT. We might also speculate that SDT might affect acceptance of fruit not only in terms of quantity, but also in terms of the fruit type. Possibly, SDT might affect preference or liking of sweet carbohydrate rich fruit or fruit juice, but this would not be evident from an examination of the number of portions consumed and would require further analysis of the different types of fruit consumed, and perhaps a different experimental design, which was not the goal of this study. As no studies to date have looked at the relationship between children's SDT and fruit intake, unfortunately the results cannot be discussed in the context of past findings.

4.2 Vegetables and cruciferous vegetables

When vegetables were considered as the total of the reported portions consumed, intake did not vary by weight or SDT, and the two factors did not interact to affect intake. When only a subgroup of cruciferous vegetables was analysed there was an effect of SDT on intake, which provides support for the previously discussed common transduction mechanisms for sweet and bitter compounds. In the present study children with high SDT consumed more cruciferous vegetables than children with low SDT. This finding suggests that children with low SDT, who are likely to be bitter tasters, might reject the bitter tasting cruciferous vegetables, as the bitterness would make them unpalatable. Past studies on the relationship between cruciferous vegetables intake and bitter taste sensitivity in children are inconclusive (Baranowski et al., 2012; Bell & Tepper, 2006; Keller et al., 2002). The relationship between intake of vegetables and SDT has never been analysed, so again those findings cannot be analysed in the context of past research on SDT. However, Dineheart, Hayes, Bartoshuk, Lanier and Duffy (2006) in their study on the adult population demonstrated that vegetable bitterness and sweetness were independent predictors of preference and intake of the sampled products. In addition, they showed that those who tasted PROP as more bitter tasted the vegetables as most bitter and least sweet, showing an inverse relationship between the two perceived flavour intensities that would separately contribute to intake. In accordance with Dineheart et al. (2006) children with Low SDT might perceive cruciferous vegetables as more bitter, but at the same time they might also perceive them as least sweet, which would affect the acceptance and intake in two independent but additive ways.

The results of this study show that intake of cruciferous vegetables in children is affected by SDT. Further studies are needed to assess whether bitter taste sensitivity and SDT are independent predictors of cruciferous vegetables intake, or whether they are inter-dependent. SDT did not affect intake of vegetables in general, however this is not surprising given that children might compensate for low intake of cruciferous vegetables by an increased intake of the accepted and liked vegetables such as non-bitter carrots (Bell & Tepper, 2006; Lakkakula, Geaghan, Znovec, Pierce & Tuuri, 2010; Peracchio, Henebery, Sharafi, Hayes & Duffy, 2012). Bell and Tepper (2006) demonstrated that non-bitter vegetable intake (such as carrots) was independent of bitter taste sensitivity in pre-school children, but significant differences were found for the bitter tasting vegetables (e.g. olives and broccoli). The results of the present study show a similar pattern with regards to SDT, as intake of non-bitter vegetables was not affected by SDT, but significant differences were found for the cruciferous family.

4.3 Limitations

The main limitation of this study was the reliance on parental report of child FV intake and the resulting apparent tendency for parents to over-report their children's FV intake. The number of portions reported departed from the national data, which might be due to the measure used. Parents might have misjudged the number of portions consumed or despite instruction, were not aware that partial portions e.g. ¼, 1/3, could be reported. A novel measure of FV intake in the form of a food frequency questionnaire was developed as it allowed us to get detailed information about the different forms of consumed products (raw and processed FV were listed separately). Also, listing of the FV was supposed to act as a memory aid. The portions were listed next to each item which was supposed to help the parents report the actual intake, however it likely resulted in over-reporting. The reports of FV intake might therefore reflect the variety of FV consumed rather than the actual portions. The most extreme cases of over-reporters were excluded from the analyses as has been done in previous studies. It should be pointed out that past studies have showed that parents can accurately report FV intake of their children. Linneman, Hessler, Nanney, Steger-May et al. (2004) demonstrated that parents misjudged intake of fruit juice and raisins from cereal, but provided an accurate account of all other FV consumed. It is also possible that data were reported accurately and the sample had an unusually high level of health consciousness (there was low variability in the sample, who was predominantly white British from the affluent areas of Birmingham). Possibly, only extremely health conscious parents agreed to participate in the study, which was advertised as a study on 'Fruit & Veg', hence there might be an issue of self-selection bias. Furthermore, data on intake of other foods could have been collected to place FV intake in the context of other foods and to estimate the proportion of FV intake in the entire diet. Future projects will aim at establishing the effects of SDT on intake of foods from all groups. Another limitation might be the methodology of collecting SDT data. Ideally repeating of the SDT procedure for confirmation of the initial result would increase reliability, however due to the length of the whole test this was not practically possible when working with this age group.

4.4 Conclusions

This was the first study to look at the relationships between SDT, weight status and FV intake in children. The results showed that weight status was not related to intake of FV. SDT affected intake of fruit and cruciferous vegetables. Further analyses showed that effects of SDT on fruit intake were exclusive to non-astringent fruit. Children with moderate SDT consumed more non-astringent fruit than children with low or high SDT, but the differences missed significance in the post hoc analyses. The exact mechanism behind this is unclear, but it is possible that SDT affects intake of fruit only in the absence of aversive stimulus such as astringency. Children with high SDT consumed more cruciferous vegetables than children with low SDT, in a similar pattern that bitter taste sensitivity showed in some of the past studies. Future studies should focus on the effects of SDT on intake of FV and general intake of foods.

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Fig. 1. Differences in the number of portions of fruit consumed over the past 24 hours between children with different SDT, controlling for sensitivity in taste/smell visual/auditory domain and parental consumption of FV in the past 24 hours.

* $p < 0.05$

Fig. 2. Differences in the number of portions of cruciferous vegetables consumed over the past 24 hours between children with different SDT, controlling for sensitivity in taste/smell visual/auditory domain and parental consumption of FV in the past 24 hours. **$p < 0.01$

Fig.3. Differences in the number of portions of non-astringent fruit consumed over the past 24 hours between children with different SDT, controlling for sensitivity in taste/smell visual/auditory domain and parental consumption of FV in the past 24 hours.

Table 1. Mean number of portions and SE (in brackets) of fruit and vegetables reported over the 24 hour period for parent and the child, and relationship between intake in the mother-child dyads.

	Child	**Parent**	**Correlation (r)**
Fruit	2.48 (0.23)	3.25 (0.28)	0.21[a]
Astringent	1.0 (0.11)	0.96 (0.12)	0.46***
Non-astringent	2.78 (0.23)	2.64 (0.17)	0.16
Vegetables	3.34 (0.28)	4.71 (0.40)	0.54***
Cruciferous	0.53 (0.09)	0.66 (0.10)	0.65***
Non-cruciferous	2.80 (0.24)	4.05 (0.35)	0.46***
Fruit and Vegetables (total)	5.83 (0.39)	7.97 (0.54)	0.41***

<0.01; *<0.001; a=0.051

Table 2. Relationships between sensory sensitivity in various domains and SDT, BMI centile and FV intake of children.

	Sensory sensitivity		
	Taste	**Tactile**	**Visual/auditory**
Fruit	0.20	0.05	0.07
Astringent fruit	0.05	-0.02	0.05
Non-astringent fruit	0.20[a]	-0.01	0.05
Vegetables	.31**	0.01	0.17
Cruciferous vegetables	0.12	-0.18	-0.04
Non-bitter vegetables	0.31**	0.04	0.21*

FV total	.34***	0.02	0.19
SDT	0.16	0.09	0.01
BMI centile	0.10	0.09	0.10

* p< 0.05; ** p< 0.01; *** p< 0.001; a=0.054

Table.3. Multivariate analysis of covariance looking at the effects of weight status and SDT on the number of portions of fruit and vegetables consumed by children over the last 24 hours, as reported by the parent. Covariates include child's score on sensitivity in taste/smell domain as measured by SSP, and parental consumption of fruit and vegetables over the last 24 hours.

Variables	Source of variation	Df	F-value	Significance
Fruit	Weight	1	0.01	0.956
	SDT	2	3.52	0.034*
	Weight x SDT	2	2.57	0.083
Vegetables	Weight	1	0.75	0.390
	SDT	2	1.03	0.360
	Weight x SDT	2	0.25	0.780

Table 4. Multivariate analysis of covariance looking at the effects of weight status and SDT on the number of portions of subgroups of fruit and vegetables consumed by children over the last 24 hours, as reported by the parent. Covariates include child's score on sensitivity in taste/smell and visual/auditory domain as measured by SSP, and parental consumption of fruit and vegetables over the last 24 hours.

Variables	**Source of variation**	**df**	**F-value**	**Significance**
Astringent f.	Weight	1	0.80	0.373
	SDT	2	0.63	0.533
	Weight x SDT	2	0.13	0.88
Non-astringent f.	Weight	1	0.24	0.624
	SDT	2	3.12	0.05*
	Weight x SDT	2	2.95	0.058
Cruciferous v.	Weight	1	0.01	0.974
	SDT	2	5.57	0.005**
	Weight x SDT	2	0.971	0.38
Non-cruciferous v.	Weight	1	1.30	0.26
	SDT	2	0.12	0.88
	Weight x SDT	2	0.04	0.96