

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

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Author post-print (accepted) deposited in CURVE October 2016

**Original citation & hyperlink:**

Fogel, A. and Blissett, J. (2014) Effects of sucrose detection threshold and weight status on intake of fruit and vegetables in children. *Appetite*, volume 83 : 309-316

<http://dx.doi.org/10.1016/j.appet.2014.09.003>

DOI 10.1016/j.appet.2014.09.003

ISSN 0195-6663

ESSN 1095-8304

Publisher: Elsevier

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# Accepted Manuscript

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

Author: Anna Fogel, Jackie Blissett

PII: S0195-6663(14)00444-9

DOI: <http://dx.doi.org/doi: 10.1016/j.appet.2014.09.003>

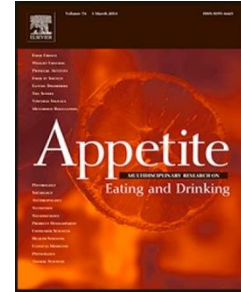
Reference: APPET 2273

To appear in: *Appetite*

Received date: 27-2-2014

Revised date: 29-8-2014

Accepted date: 4-9-2014



Please cite this article as: Anna Fogel, Jackie Blissett, Effects of sucrose detection threshold and weight status on intake of fruit and vegetables in children., *Appetite* (2014), <http://dx.doi.org/doi: 10.1016/j.appet.2014.09.003>.

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

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16  
17  
18 This work was supported by a grant from Internationale Stiftung für  
19 Ernährungsforschung und Ernährungsaufklärung (International Foundation for  
20 the Promotion of Nutrition Research and Nutrition Education).

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**Highlights**

25

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

31

32

**Abstract**

33 Past research on the relationship between taste sensitivity and fruit and  
34 vegetable (FV) intake in children has focused on sensitivity to bitter taste. The  
35 effects of sensitivity to sweet taste on intake of FV have never been investigated.  
36 Furthermore, the effects of children's weight on intake of FV are inconclusive.  
37 This study measured the effects of Sucrose Detection Threshold (SDT) and weight  
38 status on intake of FV in children. The participants of this study were 99 children  
39 between 5-9 years old. Parents reported their own and their children's 24 hour  
40 intake of FV and completed a measure of children's sensory sensitivity. Children  
41 completed the triangle test with suprathreshold concentrations of sucrose  
42 ranging between 0.2%- 1.6%, in 0.2% increments. Two MANCOVAs showed that,  
43 controlling for parental intake and children's sensory sensitivity, there was a  
44 main effect of SDT on intake of fruit ( $p < 0.05$ ), which was exclusive to non-  
45 astringent fruit ( $p < 0.05$ ), and cruciferous vegetables ( $p < 0.01$ ). Weight status had

46 no effect on intake of FV. Mechanisms behind the effects of SDT are discussed in  
47 the context of past research on bitter taste sensitivity.

48 **Keywords**

49 Children, fruit, vegetables, weight, sucrose detection threshold

50 **Abbreviations**

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

53  
54 Effects of sucrose detection threshold and weight status on intake of fruit and  
55 vegetables in children.

56 **1. Introduction**

57 Research consistently shows that consumption of fruit and vegetables  
58 (FV) among children and adults is too low (for a review see Krolner, Rasmussen,  
59 Brug, Klepp, Wind & Due, 2011), yet a diet rich in FV has been linked to reduced  
60 prevalence of cancer (Maynard, Gunnell, Emmett, Frankel & Davey Smith, 2003).  
61 One of the main determinants of dietary choices is the flavour of food (Prescott,  
62 Bell, Gillmore, Yoshida et al., 1997). It is therefore not surprising that FV are the  
63 most commonly rejected group of products by children (Cooke, Carnell & Wardle,  
64 2006), as they are naturally low in palatable fats and in the case of vegetables also  
65 low in sweet carbohydrates with some degree of bitterness which makes them a  
66 relatively unattractive food option. This additionally prevents flavour learning  
67 thus increasing predisposition for future rejection.

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

93 of visual/auditory sensitivity on acceptance of FV. Atypical sensitivity in  
94 visual/auditory, taste/smell and tactile domains should therefore be taken into  
95 account when analysing the potential effects of flavour specific sensitivity on  
96 intake of FV.

97           Past research on sensitivity to taste and intake of FV has been mainly  
98 focused on sensitivity to bitter taste, which is measured as the ability to detect a  
99 bitter tasting compound 6-n-propylthiouracil (PROP) or its predecessors  
100 propylthiouracil (PTU) and phenylthiocarbamide (PTC). Past studies showed that  
101 bitter taste sensitivity can predict intake of bitter tasting FV in children (e.g. Bell  
102 & Tepper, 2006; Keller, Steinmann, Nurse & Tepper, 2002), as FV contain  
103 different degrees of bitter alkaloids that affect the degree to which humans  
104 perceive them as bitter (Drewnowski & Carneros, 2000). At the same time there  
105 are individual differences in the perceived intensity of bitterness of FV due to the  
106 polymorphic nature of genes responsible for bitter taste recognition (Duffy,  
107 Hayes & Barthoshuk, 2010). People sensitive to the bitter alkaloids should be  
108 more likely to reject bitter FV, as the detected bitterness would negatively affect  
109 palatability of those products (Duffy, Hayes, Davidson, Kidd, Kidd & Bartoshuk,  
110 2010). The Brassicaceae family of vegetables (cruciferous vegetables) is the  
111 group that contains the highest degree of bitter alkaloids, so sensitivity to bitter  
112 compounds should have the highest impact on acceptance of this specific family  
113 within the vegetable group. However, data showing the link between bitter taste  
114 sensitivity and FV consumption is inconclusive, since several studies failed to  
115 show that FV intake differs by bitter taste sensitivity status, both within the  
116 general FV group (Feeney, O'Brien, Scannell, Markey & Gibney, 2014) and  
117 specifically in the cruciferous vegetables family (Baranowski, Baranowski,

118 Watson, Jago et al., 2011). Within the fruit range, fruit with astringent properties  
119 would be most likely to be affected by bitter taste sensitivity. Fruit rich in  
120 phenolic compounds, which contribute to bitterness and astringency, would be  
121 more likely to be rejected given the universal predisposition to dislike bitter or  
122 sour flavours (Birch, 1999), and even more so by people sensitive to bitter  
123 flavours.

124 An alternative explanation for individual differences in FV intake that  
125 has not been thoroughly researched is that the degree of FV sweetness is likely to  
126 affect how palatable they are and in this way affect acceptance. Individual  
127 differences in sensitivity to sweet flavour may help explain variation in FV intake,  
128 especially since bitter taste sensitivity cannot be used to explain intake of non-  
129 bitter FV (those that lack the bitter alkaloids). Sensitivity to sweet taste requires  
130 particular research attention due to the suggested polymorphic connection  
131 between transduction mechanisms of bitter and sweet compounds (e.g. Fushan,  
132 Simons, Slack & Drayna, 2010; Looy & Weingarten, 1992). Gustducin is thought to  
133 be involved in transmitting of both bitter and sweet compounds, which suggests  
134 that a similar mechanism may be involved in their detection, which leads to a  
135 question of the role of sweet taste sensitivity in the acceptance of FV (Fushan et  
136 al., 2010). Past studies focused on both detection (lowest concentration of tastant  
137 detected) and recognition thresholds (lowest concentration of tastant recognised  
138 as particular flavour e.g. sweet). Low detection/recognition thresholds are  
139 indicative of high sensitivity to the flavour. There is evidence for a link between  
140 phenotypic sensitivity to sweet and to the bitter taste. Hong, Chung, Kim and  
141 Chung et al. (2004) demonstrated that participants who were blind to the taste of  
142 the bitter chemical PTC (hence showed low bitter taste sensitivity) had a



143 significantly higher sucrose detection threshold (SDT) and sucrose recognition  
144 thresholds, which both were indicative of low sensitivity to the sweet  
145 compounds, thus showing a positive link between the two types of sensitivity.  
146 Chang, Chung, Kim, Chung et al. (2006) showed further support for the link  
147 between bitter and sweet taste sensitivity using PROP as the bitter tastant and  
148 demonstrated that PROP non-tasters (indicative of low sensitivity to bitter taste)  
149 had a higher SDT (indicative of low sensitivity to sweet taste) compared to PROP  
150 tasters. Given the link between the sweet and bitter taste sensitivity we propose  
151 that sensitivity to sweet taste might affect intake of FV, which would be  
152 particularly evident in children, who in the past have been shown to have higher  
153 liking for sweet products than adults (Mennella, 2008). Since children also show  
154 high rejection rates of FV, the role of individual differences in SDT in intake rates  
155 of FV should be analysed.

156 Children's intake of FV has also been analysed in the context of child's  
157 weight status, however the information is rather limited and findings  
158 inconclusive (Field, Gillman, Rosner, Rockett & Colditz, 2003; for review see  
159 Dietary Guidelines for Americans DGAC, 2010). Miller, Moore and Kral (2011)  
160 showed that in a group of 5-6 year old children, overweight/obese children  
161 consumed fewer portions of FV than their healthy weight peers. Similarly, Lorson,  
162 Mergal-Quinonez and Taylor (2009) demonstrated that in a sample of 3040  
163 children between 2-11 years old, the overweight children consumed less fruit  
164 than the healthy weight or at risk of overweight children, but no differences in  
165 vegetable intake were found. Contrary, to those findings Field et al. (2003) did  
166 not find an association between FV intake and change in BMI in a sample of  
167 14,918 children between 9-14 years old. It is important to point out that those

168 studies differed in employed objectives and methodologies which provides an  
169 explanation for why the findings are inconsistent. More specifically, past research  
170 showed that intake of FV in children differs by age, ethnicity, gender and  
171 household income (Lorson et al., 2009 ), which makes comparison of the results  
172 of the studies on the effects of weight status on intake of FV difficult. Different  
173 measures of FV intake may yield different results, particularly comparing  
174 parental reports and data collected empirically (e.g. skin carotenoid status) or  
175 observational results in naturalistic settings. Also differences in applied  
176 definitions of portion sizes, inclusion of different FV into the count (e.g. potatoes,  
177 fruit juice, vegetable juice or pulses) all may contribute to inconsistent reports of  
178 intake of FV among healthy weight and overweight children.

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

191 Studies so far have not investigated whether individual detection  
192 thresholds for sweet compounds are related to FV intake in children and whether

193 this relationship varies by weight status. In addition there is limited evidence for  
194 differences in FV intake in healthy weight and overweight/obese children. It is  
195 possible that individuals who have a high detection threshold for sweet  
196 compounds (indicative of low sensitivity) perceive the flavour of FV differently to  
197 those with lower SDT (higher sensitivity), which might be reflected in their FV  
198 intake. Hypothetically, their subjective perception of FV flavour pleasantness may  
199 differ from children with low SDT who possibly could easily detect sweetness in  
200 FV, especially in the non-bitter or non-astringent family. Past studies which  
201 examined the relationship between FV intake and weight in children are  
202 inconclusive and there are no data on the relationship between weight and FV  
203 intake in the context of individual SDT. The aim of this study was to test whether  
204 children's individual SDT are linked to intake of fruit and vegetables, and more  
205 specifically fruit with astringent properties and cruciferous vegetables. To make  
206 it possible to compare with the previous studies, cruciferous vegetables were  
207 analysed separately, as past studies on bitter taste sensitivity were often focused  
208 on this particular family of vegetables (e.g. Baranowski et al., 2011; Glanville &  
209 Kaplan, 1965; Drewnowski & Carneros, 2000). Fruit with astringent properties  
210 were also analysed separately as they differ in sensory properties from non-  
211 astringent fruit. Further, we aimed to investigate whether weight status is related  
212 to intake of FV, and whether possible effects of SDT on intake of FV differ in  
213 healthy weight and overweight/obese children, while controlling for sensitivity  
214 in taste/smell, visual/auditory and tactile domain, as well as parental  
215 consumption of FV.

## 216 **2. Method**

### 217 ***2.1 Participants***

218 Initially 108 parents and their children were recruited to the study,  
219 however because of the absence from school, lack of consent form, underlying  
220 medical conditions (e.g. diabetes) or uncompleted documents, only 99 children  
221 (50 boys and 49 girls) completed the study. Children were recruited from 4  
222 primary schools from affluent areas of Birmingham, UK (top 5% of the most  
223 affluent areas in the UK, as measured by the Index of Multiple Deprivation Rank  
224 IMDR, 2010). The mean age of the sample was  $M=7.21$  ( $SD=1.3$ ) years old. The  
225 majority of the children were White British ( $n=90$ ), and the remaining 9 children  
226 were of Asian ( $n=5$ ) or Mixed origin ( $n=4$ ). The paper measures collected in this  
227 study were completed by mothers ( $n=88$ ), fathers ( $n=9$ ) or the grandparent  
228 ( $n=2$ ). Parental mean age was  $38.16$  ( $SD= 9.24$ ) years old. Children whose parents  
229 reported their illnesses affecting nose or throat within the 4 weeks prior to data  
230 collection were tested at least 3 weeks after the reported illness date ( $n=3$ ).  
231 Participants who were ill on the day of testing were excluded from the study  
232 ( $n=1$ ). The children were tested in the school setting.

## 233 ***2.2 Materials and Measures***

### 234 ***2.2.1 Sucrose Detection Threshold***

235 Sucrose solutions were prepared at the University of Birmingham  
236 food laboratory from standard sugar and distilled water, by diluting an  
237 appropriate amount of sugar in distilled water and mixing until the sugar was  
238 completely dissolved. The concentration of sugar in the solution was then  
239 confirmed with the use of a refractometer (Mettler Quick-Brix 60 Meter) on two  
240 occasions. The solutions were served at room temperature ( $22^{\circ}\text{C}$ ) in white non-  
241 opaque paper cups (10 ml per serving). The following sucrose concentrations

242 were used to establish the children's SDT: 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1.0%,  
243 1.2%, 1.4% and 1.6%. Those concentrations were chosen after an initial pilot  
244 study that showed that these concentrations could differentiate between children  
245 with various SDT.

### 246 **2.2.2. Sensory sensitivity**

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

### 257 **2.2.3 Fruit and vegetables**

258 FV consumption over the past 24 hours was reported by the parents  
259 who completed a measure designed specifically for this study. Parents were given  
260 an extensive list of FV available in the local supermarkets (the list included 63  
261 fruit and 59 vegetables). They were asked to mark which products they and their  
262 children consumed over the past 24 hours, as well as provide information about  
263 the portion size (what constituted a portion was clearly stated next to each  
264 product). FV were then split into sub-groups. Fruit count included all fruit

265 without fruit juice. Fruit was further split into astringent fruit group and non-  
266 astringent fruit group. Astringent fruit contained fruit with astringent and irritant  
267 properties due to high content of tannins (berries, sharon fruit, pomegranate),  
268 naringin and hesperidin (lemons and limes) and ascorbic acid (kiwis and  
269 pineapple). Vegetable count included all vegetables listed, except for potatoes  
270 which were not included in the analyses. Vegetables were further split into  
271 cruciferous vegetables and non-cruciferous vegetables.

### 272 ***2.3 Procedure***

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

279 The method for establishing the SDT was adapted after Zhang, Zhang,  
280 Wang, Zhan et al. (2008). The child was asked to sip and spit three liquids during  
281 each round. Each round consisted of two presentations of water and a solution. In  
282 each round, one of the liquids was the sucrose solution (S) and two of the liquids  
283 were distilled water (W). The order of the presentation of liquids in each round  
284 was randomized and was recorded (WWS, WSW, SWW). The solutions were  
285 presented in increasing concentrations. The cups had random numbers written  
286 on them, to aid children's memory when recalling the different tasting solution.  
287 The participant was asked to rinse their mouth with each one out of the three  
288 liquids and spit it out to the bowl. The participant was asked to indicate which

289 one of the three liquids was different from the other two. If the participant could  
290 not make the distinction they were requested to guess, since there was a  
291 possibility that they were not consciously aware that they could taste the  
292 difference. Then the participant was asked to rinse their mouth with water and  
293 spit it out twice. The inter-trial interval was approximately 60 seconds. The  
294 procedure was repeated for all of the remaining concentrations. The test was  
295 stopped when the child identified the correct solution on three consecutive trials.  
296 Individual SDT was established as the middle solution correctly identified by the  
297 child, or as the highest possible when the child correctly identified only the last  
298 solution presented. The middle correctly identified solution was used as a SDT  
299 measure to control for the first correctly identified solution occurring by chance.  
300 The middle solution identified during the three rounds was therefore thought to  
301 be a more reliable indicator of SDT. The participant was weighed in light clothing  
302 without the shoes using standard kitchen scales (accurate to 0.1 kg) and height  
303 was measured using the stadiometer (Seca Leicester Portable height measure) at  
304 the end of the experiment.

### 305 **3. Results**

#### 306 ***3.1 Sucrose detection threshold***

307 The median SDT in the sample was 1.0% (SD=0.37). SDTs were not  
308 normally distributed (KS;  $p < 0.05$ ). Past studies on bitter taste sensitivity using  
309 PROP tastant have divided the participants into three classes: non-tasters, tasters  
310 and super-tasters, despite PROP sensitivity being a continuous variable (Anliker  
311 & Barthoshuk, 1991; Baranowski et al. 2012; Bell & Tepper, 2006; Catanzaro,  
312 Chesbro & Velkey, 2013; Duffy et al., 2010). For comparative reasons,

313 participants in this study also were divided into three classes based on  
314 suprathreshold sucrose detection levels. Children were classified as having low  
315 (0.4 and 0.6%; n=35), moderate (0.8-1.2%; n=36) and high SDT (1.4 and 1.6%;  
316 n=28). There was no relationship between SDT and children's age (Spearman's  
317 rho;  $r=-0.16$ ,  $p>0.05$ ) and there were no gender differences in SDT (Mann  
318 Whitney U;  $U=1169.50$ ;  $p>0.05$ ). Children with the different level of SDT did not  
319 differ in weight (ANOVA;  $F(2,96)=0.93$ ,  $p>0.05$ ).

### 320 ***3.2 Fruit and Vegetable consumption***

321 Data on FV intake was collected from both weekend (27.5%) and week days  
322 (72.5%). There were no differences in the number of portions of fruit or  
323 vegetables consumed between the children whose mother reported weekend and  
324 weekday intake (Mann-Whitney U;  $U=846.5$ ,  $p>0.05$  for fruit;  $U=804.0$ ,  $p>0.05$  for  
325 vegetables). The range of reported portions of FV consumed by children over the  
326 24 hour period was between 0-28 portions. This unusually high range was an  
327 indication of possible parental over-reporting, so outliers who scored more than  
328 3 SD from the median have been excluded from the analyses (n=3). Baranowski et  
329 al., (2012) dealt with over-reporters by excluding participants who scored more  
330 than 1.4SD from the mean, however due to the smaller sample of this study the  
331 exclusion criteria were less restrictive. After removing the outliers from the  
332 upper range, the range of reported intake of FV was 0-17 portions. Data for fruit  
333 and/or vegetable consumption of children and parents did not meet assumptions  
334 of normality (KS;  $p<0.05$ ). Mean values and SE of children's and parents' reported  
335 intake of FV over the 24 hour period after exclusion of over-reporters and



336 relationship between parental and child's intake (Spearman's rho) are presented  
337 in Table 1.

338

### 339 ***3.3 Weight***

340 Weight data of two children were not available for analyses because children did  
341 not consent to being weighed. Based on their height and weight, children's BMI z-  
342 scores were calculated using British 1990 Child Growth Reference Chart (UK90;  
343  $M=0.17$ ,  $SE=0.12$ ) and were shown to be normally distributed (KS;  $p>0.05$ ). BMI  
344 z-scores were later converted to the corresponding BMI centiles ( $M= 52.09$ ,  $SE=$   
345  $3.04$ ) to allow a split into two categories, healthy weight ( $n=77$ ) and  
346 overweight/obese ( $n= 19$ ). The groups were split based on the BMI centile cut  
347 offs as recommended by National Obesity Observatory (NOO, 2011) at 85<sup>th</sup>  
348 centile indicating overweight and above 95<sup>th</sup> centile indicating obese. For the  
349 purpose of these analyses overweight ( $n=16$ ) and obese ( $n=3$ ) children were  
350 classified as one group, which will be referred to as Overweight. There were no  
351 underweight children in this sample.

### 352 ***3.4 Short Sensory Profile***

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

### 358 ***3.5 SDT, Weight and FV***

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

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

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

381 Using Pillai's trace there was not a significant effect of weight status on the  
382 dependent variables,  $V=0.01$ ,  $F(2,78)=0.38$ ,  $P=0.679$ . Separate ANOVAs showed

383 that there were no effects of weight status on intake of fruit or vegetables. The  
384 interaction of SDT with weight status also did not influence FV intake at  
385 multivariate level (Pillai's trace;  $V=0.07$ ,  $F(4,158)=1.48$ ,  $p=0.212$ ). Separate  
386 ANOVAs showed that interaction of SDT with weight status had no effect on  
387 intake of fruit or vegetables.

388

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

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

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

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

406 (M=2.38) and high SDT (M=2.60). However, the differences were not significant.

407 The difference between children with moderate and low SDT missed significance

408 at  $p=0.07$  level (see Fig 3).

409 Using Pillai's trace, there was not a significant effect of weight status on the

410 dependent variables,  $V=0.03$ ,  $F(4,75)=0.64$ ,  $p=0.637$ . Separate ANOVAs showed

411 that there were no effects of weight status on any of the dependent variables.

412 The interaction of weight status and SDT also did not influence the dependent

413 variables at the multivariate level,  $V=0.10$ ,  $F(8, 152)=0.97$ ,  $p=0.460$ . Separate

414 ANOVAs did not show effects of the interaction on the dependent variables.

415 However, the interaction of weight status and SDT on the intake of non-astringent

416 fruit missed significance at  $p=0.058$  level.

417

#### 418 **4. Discussion**

419 The aim of this study was to test if individual SDT and weight status

420 affect FV intake in children. We also wanted to explore possible interactions

421 between SDT and weight status on FV intake, whilst controlling for parental FV

422 intake and children's sensory sensitivity. The results showed that when

423 controlling for taste/smell and visual/auditory sensitivity and parental FV intake,

424 individual SDT had an effect on the intake of non-astringent fruit and cruciferous

425 vegetables. General intake of vegetables, non-cruciferous vegetables or astringent

426 fruit was not affected by SDT. Weight status had no effect on the number of

427 portions of fruit or vegetables consumed. Weight status and SDT did not interact

428 to affect FV intake.

429 **4.1 Fruit**

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

438 As evident from the results, children who could easily detect sweet  
439 compounds were reported to consume the smallest number of fruit, and  
440 specifically, non-astringent fruit, and had a similar mean intake level to children  
441 with high SDT. There are reasons to believe that two different mechanisms are  
442 responsible for fruit acceptance in children with low and high SDT as the  
443 theoretical framework currently does not offer an explanation for why children at  
444 the two opposite ends of SDT spectrum would show similar patterns of non-  
445 astringent fruit intake. Bartoshuk (2000) in a review paper showed that 11 out of  
446 16 studies reported an association between detection of sweet and bitter  
447 compounds, and she concluded that the results of the 5 remaining studies could  
448 be explained by methodological shortcomings in the use of psychophysical  
449 measures. Given the common transduction mechanisms of sweet and bitter  
450 tasting compounds (Zhang et al., 2003) it was expected that children with low  
451 SDT would be the most sensitive to fruit with astringent properties.  
452 Consequently, the possible increased sensitivity to bitter compounds among

453 children with low SDT would have an inhibitory effect on acceptance and further  
454 intake of fruit, and in particular astringent fruit. Past studies demonstrated that  
455 individuals sensitive to bitter tasting PROP could distinguish between different  
456 degree of bitterness and astringency in products rich or poor in the astringent  
457 tannins. Further, PROP sensitive participants had a lower acceptance level for  
458 foods with various degrees of bitter tasting polyphenols in foods (Dinehart,  
459 Hayes, Bartoshuk, Lanier & Duffy, 2006). Laaksonen, Ahola and Sandell (2013)  
460 further demonstrated that individuals with the bitter tasting genotype disliked  
461 juices from astringent tasting fruit significantly more than the individuals without  
462 the bitter tasting genotype. Surprisingly, in the present study there were no  
463 differences in the astringent fruit intake among children with different levels of  
464 SDT. On the contrary, SDT showed effects on intake of non-astringent fruit.  
465 Perhaps, the astringent properties of fruit were equally aversive to all children,  
466 irrespective of their SDT. This would explain why the average intake of the  
467 astringent fruit in the sample was almost 3 times smaller than the intake of non-  
468 astringent fruit. Interestingly, the effects of SDT were evident in the non-  
469 astringent fruit group. This might be attributable to the larger variance of the  
470 level of sweetness in the non-astringent fruit group, or alternatively by the level  
471 of sweetness which is not overshadowed by the unpleasant astringent properties.  
472 SDT might affect intake of fruit only when universally aversive properties such as  
473 astringency are absent.

474           An alternative interpretation is that children with high SDT might be  
475 affected by a different inhibitory mechanism. We might speculate that children  
476 with high SDT might require a higher level of sweetness than that found in fruit in  
477 order to find fruit palatable and satisfying, and consequently may show a lower

478 intake rate. Looy and Weingarten (1992) in their study on PROP sensitivity and  
479 hedonic responses to sweet tastants showed that PROP nontasters were almost  
480 always sweet likers and PROP tasters tended to be sweet dislikers. Perhaps  
481 children with high SDT, who based on past research would tend to be PROP  
482 nontasters, would require higher concentration of sweetness to find fruit  
483 palatable and even fruit within the non-astringent group would not offer the  
484 optimal level of sweetness that would be palatable to children with high SDT.  
485 However, the relationship between detection thresholds for tastants and their  
486 perceived intensity is not completely understood. Keast and Roper (2007)  
487 showed that subjects who could detect the bitter tasting PROP at lower  
488 concentrations showed higher perceived intensity of PROP at higher  
489 concentrations. Those results were not repeated for other bitter tastants though.  
490 It suggests that the relationship between tastant detection threshold and  
491 perceived intensity is not a linear function. A similar mechanism might be present  
492 in detection threshold for sucrose and consequently higher SDT might show an  
493 inverse relationship with perceived intensity of sweetness, which might be  
494 further related to experiences of intensity of sweetness in fruit. This hypothesis  
495 would explain why children with high SDT showed lower intake of fruit  
496 compared to children with moderate SDT (although the difference just missed  
497 significance). Since the effect was present only for non-astringent fruit we might  
498 speculate that perceived intensity of sweetness has an effect on intake only in  
499 absence of aversive stimulus such as astringency.

500           Alternatively, environmental effects of diet on SDT might explain the  
501 lower intake of fruit in children with high SDT. Possibly, high SDT is a result of a  
502 diet rich in sweet carbohydrates. Increased exposure to highly sweetened

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

#### 524 ***4.2 Vegetables and cruciferous vegetables***

525 When vegetables were considered as the total of the reported portions  
526 consumed, intake did not vary by weight or SDT, and the two factors did not



527 interact to affect intake. When only a subgroup of cruciferous vegetables was  
528 analysed there was an effect of SDT on intake, which provides support for the  
529 previously discussed common transduction mechanisms for sweet and bitter  
530 compounds. In the present study children with high SDT consumed more  
531 cruciferous vegetables than children with low SDT. This finding suggests that  
532 children with low SDT, who are likely to be bitter tasters, might reject the bitter  
533 tasting cruciferous vegetables, as the bitterness would make them unpalatable.  
534 Past studies on the relationship between cruciferous vegetables intake and bitter  
535 taste sensitivity in children are inconclusive (Baranowski et al., 2012; Bell &  
536 Tepper, 2006; Keller et al., 2002). The relationship between intake of vegetables  
537 and SDT has never been analysed, so again those findings cannot be analysed in  
538 the context of past research on SDT. However, Dineheart, Hayes, Bartoshuk,  
539 Lanier and Duffy (2006) in their study on the adult population demonstrated that  
540 vegetable bitterness and sweetness were independent predictors of preference  
541 and intake of the sampled products. In addition, they showed that those who  
542 tasted PROP as more bitter tasted the vegetables as most bitter and least sweet,  
543 showing an inverse relationship between the two perceived flavour intensities  
544 that would separately contribute to intake. In accordance with Dineheart et al.  
545 (2006) children with Low SDT might perceive cruciferous vegetables as more  
546 bitter, but at the same time they might also perceive them as least sweet, which  
547 would affect the acceptance and intake in two independent but additive ways.

548 The results of this study show that intake of cruciferous vegetables in children is  
549 affected by SDT. Further studies are needed to assess whether bitter taste  
550 sensitivity and SDT are independent predictors of cruciferous vegetables intake,  
551 or whether they are inter-dependent. SDT did not affect intake of vegetables in

552 general, however this is not surprising given that children might compensate for  
553 low intake of cruciferous vegetables by an increased intake of the accepted and  
554 liked vegetables such as non-bitter carrots (Bell & Tepper, 2006; Lakkakula,  
555 Geaghan, Znovec, Pierce & Tuuri, 2010; Peracchio, Henebery, Sharafi, Hayes &  
556 Duffy, 2012). Bell and Tepper (2006) demonstrated that non-bitter vegetable  
557 intake (such as carrots) was independent of bitter taste sensitivity in pre-school  
558 children, but significant differences were found for the bitter tasting vegetables  
559 (e.g. olives and broccoli). The results of the present study show a similar pattern  
560 with regards to SDT, as intake of non-bitter vegetables was not affected by SDT,  
561 but significant differences were found for the cruciferous family.

#### 562 **4.3 Limitations**

563 The main limitation of this study was the reliance on parental report of child FV  
564 intake and the resulting apparent tendency for parents to over-report their  
565 children's FV intake. The number of portions reported departed from the national  
566 data, which might be due to the measure used. Parents might have misjudged the  
567 number of portions consumed or despite instruction, were not aware that partial  
568 portions e.g.  $\frac{1}{4}$ ,  $\frac{1}{3}$ , could be reported. A novel measure of FV intake in the form  
569 of a food frequency questionnaire was developed as it allowed us to get detailed  
570 information about the different forms of consumed products (raw and processed  
571 FV were listed separately). Also, listing of the FV was supposed to act as a  
572 memory aid. The portions were listed next to each item which was supposed to  
573 help the parents report the actual intake, however it likely resulted in over-  
574 reporting. The reports of FV intake might therefore reflect the variety of FV  
575 consumed rather than the actual portions. The most extreme cases of over-

576 reporters were excluded from the analyses as has been done in previous studies.  
577 It should be pointed out that past studies have showed that parents can  
578 accurately report FV intake of their children. Linneman, Hessler, Nanney, Steger-  
579 May et al. (2004) demonstrated that parents misjudged intake of fruit juice and  
580 raisins from cereal, but provided an accurate account of all other FV consumed. It  
581 is also possible that data were reported accurately and the sample had an  
582 unusually high level of health consciousness (there was low variability in the  
583 sample, who was predominantly white British from the affluent areas of  
584 Birmingham). Possibly, only extremely health conscious parents agreed to  
585 participate in the study, which was advertised as a study on 'Fruit & Veg', hence  
586 there might be an issue of self-selection bias. Furthermore, data on intake of  
587 other foods could have been collected to place FV intake in the context of other  
588 foods and to estimate the proportion of FV intake in the entire diet. Future  
589 projects will aim at establishing the effects of SDT on intake of foods from all  
590 groups. Another limitation might be the methodology of collecting SDT data.  
591 Ideally repeating of the SDT procedure for confirmation of the initial result would  
592 increase reliability, however due to the length of the whole test this was not  
593 practically possible when working with this age group.

#### 594 **4.4 Conclusions**

595 This was the first study to look at the relationships between SDT, weight status  
596 and FV intake in children. The results showed that weight status was not related  
597 to intake of FV. SDT affected intake of fruit and cruciferous vegetables. Further  
598 analyses showed that effects of SDT on fruit intake were exclusive to non-  
599 astringent fruit. Children with moderate SDT consumed more non-astringent

600 fruit than children with low or high SDT, but the differences missed significance  
601 in the post hoc analyses. The exact mechanism behind this is unclear, but it is  
602 possible that SDT affects intake of fruit only in the absence of aversive stimulus  
603 such as astringency. Children with high SDT consumed more cruciferous  
604 vegetables than children with low SDT, in a similar pattern that bitter taste  
605 sensitivity showed in some of the past studies. Future studies should focus on the  
606 effects of SDT on intake of FV and general intake of foods.

### 607 **Acknowledgments**

608 This work was supported by a grant from Internationale Stiftung für  
609 Ernährungsforschung und Ernährungsaufklärung (International Foundation for  
610 the Promotion of Nutrition Research and Nutrition Education). We thank the  
611 schools for accommodating data collection and volunteers who participated in  
612 the study.

613

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746 Fig. 1. Differences in the number of portions of fruit consumed over the past 24  
747 hours between children with different SDT, controlling for sensitivity in  
748 taste/smell visual/auditory domain and parental consumption of FV in the past  
749 24 hours.

750 \*  $p < 0.05$

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

755

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

760

761

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

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

765 \*\*<0.01; \*\*\*<0.001; a=0.051

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

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

<b>FV total</b>	.34***	0.02	0.19
<b>SDT</b>	0.16	0.09	0.01
<b>BMI centile</b>	0.10	0.09	0.10

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

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

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

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

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

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Accepted Manuscript