Original Article

PROP taster status, food preferences and consumption of high-calorie snacks and sweet beverages among 6-year-old ethnically diverse children

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Abstract

A healthy diet is important for optimal growth and development in children. Food preferences are a main determinant of children's intake. The aim of this study was to examine the associations of 6-n-propylthiouracil (PROP) taster status (taste sensitivity to PROP) with children's food preferences and consumption of high-calorie snacks and sweet beverages among ethnically diverse children. We analysed data from 5585 6-year-old children enrolled in the Generation R Study, a birth cohort study in Rotterdam, the Netherlands. PROP taster status was evaluated using a suprathreshold screening solution. Food preferences of the children were assessed by a two-stage protocol using photographs of eight food items (candy, chocolate, mayonnaise, whipped cream, soup, potato chips, carrot and bread), yielding both hedonic ratings (1–3) and rank order scores (1–8). Univariate and multivariable linear and logistic regression analyses were performed, using tasters as the reference group. Non-tasters had a slightly higher preference for carrots (β : -0.07 ; 95% CI: -0.13 , -0.02 and β : -0.15 ; 95% CI: -0.27 , -0.02 for hedonic ratings and rank order scores, respectively) and bread (hedonic ratings; β : -0.06 ; 95% CI: -0.11 , -0.01) compared with tasters. No differences were found in children's preference for sweet, fat or salty food items. Furthermore, there were no associations of PROP taster status with the consumption of high-calorie snacks ≥ 2 times/day (aOR: 1.06; 95% CI: 0.91, 1.24) or sweet beverages ≥ 3 glasses/day (aOR: 1.06; 95% CI: 0.92, 1.23). Other factors relating to the family food environment may be more important for young children's food preferences and consumption of high-calorie snacks and sweet beverages than their innate taste sensitivity.

Keywords: PROP, 6-n-propylthiouracil, food preference, snack, sweet beverages, birth cohort study.

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Introduction

A healthy diet is crucial for optimal growth and development in children. However, a large proportion of children does not meet dietary guidelines (Munoz *et al.* 1997; Brady *et al.* 2000; Huybrechts *et al.* 2008). In general, children have a tendency towards a high intake of low nutrient, energy dense foods (i.e. snacks and sweetened beverages) and a low intake of nutritious foods (i.e. fruit and vegetables) (Munoz *et al.* 1997; Brady *et al.* 2000; Huybrechts *et al.* 2008). Consumption of sweetened beverages and snacks has been associated

with adverse health outcomes, including dental caries and childhood overweight and obesity (Ludwig *et al.* 2001; Marshall *et al.* 2003; Johansson *et al.* 2010). In order to reduce children's consumption of these unhealthy food items, insight into the factors underlying dietary behaviours is crucial.

Studies among children and adolescents have shown that preference for soft drinks is among the strongest predictors of actual soft drink consumption (Grimm *et al.* 2004; Bere *et al.* 2008). In turn, children's food preferences are influenced by dietary experience (i.e. exposure to foods), availability and accessibility of foods,

role modelling by peers and adults, parental feeding practices (e.g. restricting children's intake or using food as reward) and taste perception (Birch & Fisher 1998; Birch 1999). One such taste perception associated with children's food preferences is the sensitivity to taste the bitter compound 6-n-propylthiouracil (PROP) (Keller *et al.* 2002). PROP is chemically related to the bitter substance glucosinolate found in cruciferous vegetables (e.g. broccoli and kale), and taste sensitivity to this compound is genetically determined (Tepper 1998). Research has also shown that PROP tasters are more sensitive to sweet taste and the texture of fats compared with PROP non-tasters (Tepper 2008; Tepper *et al.* 2009), implying that PROP taster status might serve as a measure of general taste ability (Tepper *et al.* 2009). It has been hypothesized that PROP tasters dislike foods that have these sensory qualities of bitter, sweet and fattiness, which may influence their subsequent dietary behaviours (Tepper 2008; Tepper *et al.* 2009).

However, studies on the associations between PROP taster status and the preference for and intake of sweet and fatty food items have reported conflicting findings (Keller *et al.* 2002; Keller & Tepper 2004). For example, Keller *et al.* did not find taster group differences in the preference for milk/semisweet chocolates, yet their results indicated that non-taster girls had a higher preference for full fat milk (Keller *et al.* 2002). In the same study, Keller *et al.* reported a higher intake of discretionary fats among non-taster girls, but no taster group differences in children's intake of sweet and fatty snacks (Keller *et al.* 2002). In contrast, a follow-up study by Keller and Tepper found that taster and non-taster children consumed about the same proportion of daily energy from discretionary fats and that taster children consumed a greater proportion of daily energy from dietary sugars, mainly from sweet snacks (Keller & Tepper 2004).

These previous studies have been conducted in small samples, mostly consisting of Caucasian children with a high socioeconomic background, which may limit generalizability to other, more heterogeneous, populations. The present study aimed to address the inconsistencies in the literature by examining the associations of PROP taster status with children's food preferences and children's consumption of high-calorie snacks and sweet beverages in a large population-based sample of ethnically diverse 6-year-old children.

Materials and methods

Study design

This cross-sectional study was embedded in the Generation R Study, a population-based prospective cohort study from fetal life onwards. The Generation R Study was designed to identify early environmental and genetic determinants of growth, development and health and has been described previously in detail (Jaddoe *et al.* 2012). The study was conducted in accordance with the guidelines proposed in the World Medical Association Declaration of Helsinki and has been approved by the Medical Ethical Committee at Erasmus MC, University Medical Center Rotterdam. Written informed consent was obtained from parents of all participating children.

Study population

Invitations to participate in the study were made to all pregnant women who had an expected delivery date between April 2002 and January 2006 and who lived in the study area (Rotterdam, the Netherlands) at time of delivery. In total, 8305 children from the original 9749 known live born children of the Generation R cohort participate in the school aged period (5 years onwards). At the age of 6 years, participating children

Key messages

- Non-taster children reported a higher preference for carrots and bread compared with tasters. No differences were found for the preference for food items with sweet taste characteristics (candy and chocolate), fat taste characteristics (mayonnaise and whipped cream), or salty taste characteristics (soup and potato chips).
- Non-taster children and taster children did not differ in parent-reported intake of high-calorie snacks or sweet beverages.
- Other factors relating to the family food environment (e.g. dietary experience, parenting practices, modeling, availability, and accessibility of foods) may be more important for young children's food preferences and consumption of high-calorie snacks and sweet beverages than their innate taste sensitivity.

and their mothers were invited to a well-equipped and dedicated research centre in the Erasmus Medical Center—Sophia's Children's Hospital. In total, 6690 children visited the research centre where the PROP test and food preferences test were conducted (Jaddoe *et al.* 2012). We first excluded participants with missing information on PROP taster status ($n = 645$), followed by participants with missing information on both food preferences and dietary behaviours ($n = 61$). To avoid clustering of data, we furthermore excluded second ($n = 391$) and third children ($n = 8$) of the same mother, leaving a study population of 5585 participants. Of these, 5354 participants had information on food preferences, and 4667 participants had information on dietary behaviours (Fig. 1).

PROP taster status

PROP taster status was determined using a method developed by Keller *et al.* (2002). Children were classified as 'tasters' or 'non-tasters' by giving them 5 mL of 0.56 mmol/L solution of PROP (6-propyl-2-thiouracil, pharmacy of Erasmus Medical Center, Rotterdam) after which they were asked the question: 'Do you taste anything?' (Keller *et al.* 2002). Children who reported 'no' or 'like water' were classified as non-tasters. Children who reported 'no' or 'water' but showed classic rejection signs such as grimacing or frowning were classified as tasters (Keller *et al.* 2002). Those who reported a taste for the solution were further questioned as to what the solution tasted like. Children with responses like 'bad',

Fig. 1. Flow chart of the study population.

'bitter', 'sour', 'yucky' and 'spicy' were classified as tasters. Children who reported that the solution tasted 'good' or 'yummy' were classified as non-tasters. Children who gave discordant answers such as 'good' and 'bitter' were classified as tasters ($n = 125$).

Food preferences

Food preferences of the children were assessed by a two-stage protocol using photographs of eight food items with sweet taste characteristics (candy, chocolate), fat taste characteristics (mayonnaise, whipped cream), salty taste characteristics (soup, potato chips) or neutral taste characteristics (carrot, bread), a method that has shown to produce reliable results in 5-year-old children (Birch & Sullivan 1991; Guthrie *et al.* 2000). First, children were asked to allocate the food items to three categories, representing liking (smiling face), indifference (neutral face) or disliking (frowning face). At the second stage, children were asked to indicate which food item they liked best, starting with the food items that were allocated to the smiling face (most favourite category). After the child indicated its most favourite food item, this item was removed and the process was repeated until all food items within this category had been given a rank order. This process was then repeated for food items allocated to the neutral and least favourite category. The two-stage protocol yields two types of scores, including hedonic ratings (1–3) and rank order scores (1–8). For both scales, lower scores indicate a higher preference.

Consumption of high-calorie snacks and sweet beverages

Consumption of high-calorie snacks and consumption of sweet beverages (weekdays and weekend days separately) were assessed in a parent-reported questionnaire when the child was 6 years old. For snack consumption the following question was used: 'How often does your child eat a high-calorie snack each day on average (something that is eaten in between the three main meals, for example sweets, potato chips, chocolate bars, ice cream)?'. Answer categories for this question included: 'never', 'once per day', '2–3 times per day', '4–6 times per day' and '7 or more per day'. Consumption

of sweet beverages was assessed using the question: 'How often does your child have sweet drinks?' Sweet beverages were defined as those beverages containing a lot of (added) sugar, including soft drinks, fruit juices, lemonade and sweetened milk products (e.g. chocolate milk). Answer categories ranged from 'less than one glass per day' to '7 or more glasses per day' (eight categories in total). Week and weekend day variables were combined to estimate the average daily consumption using the following formula: $(5 \times \text{weekday consumption} + 2 \times \text{weekend day consumption}) / 7$. For snack consumption, midpoints of the categories were used (e.g. 2.5 times for 2–3 times) to estimate weekday and weekend day consumption. Because of a skewed distribution, average daily consumption of high-calorie snacks and sweet beverages per day were subsequently dichotomized into '≥2 times per day' (vs. '<2 times per day') and '≥3 glasses per day' (vs. '<3 glasses per day'), respectively. Cut-points for these variables were based on the distribution of the data and previous research on dietary behaviours in young children (Veldhuis *et al.* 2012).

Potential confounders

The following variables were considered potential confounders in the associations between PROP taster status and children's food preferences and dietary behaviours on the basis of existing literature (Birch & Fisher 1998; Birch 1999; Grimm *et al.* 2004; Dubois *et al.* 2007): child's sex, child's age, child's ethnicity, family socioeconomic position (maternal educational level, net household income) and parental feeding practices. The highest educational level attained by the mother was assessed by questionnaire when the child was 6 years old and categorized into four levels of education in line with the Dutch Standard Classification of Education: low (no education, primary school or three years or less general secondary school), mid-low (more than three years general secondary school), mid-high (higher vocational training) and high (university or PhD degree) (Statistics Netherlands 2004). Net income of the household was assessed by questionnaire when the child was 6 years old and categorized into two groups: <€1600/month (i.e. below modal income (Netherlands Bureau for Economic Policy Analysis n.d.)), and ≥€1600/month. In accordance

with Statistics Netherlands, ethnicity of the child was defined according to country of birth of the child's parents (Statistics Netherlands 2010). Children with both parents born in the Netherlands were considered native Dutch, children with at least one parent born in Europe (Turkey excluded), North-America, Oceania, Indonesia and Japan were assigned an other-Western ethnicity, and children with at least one parent born in another country were assigned a non-Western ethnicity (Statistics Netherlands 2010). Three subscales of the validated Child Feeding Questionnaire (CFQ) were used to assess parental feeding practices, including monitoring (3 items), restriction (8 items) and pressure to eat (4 items) (Birch *et al.* 2001).

Statistical analyses

Bivariate associations between PROP taster status and potential confounders were studied using Chi-square tests for categorical variables and ANOVA and Kruskal–Wallis tests for normally and non-normally distributed continuous variables, respectively. The agreement between the two food preference measures (i.e. hedonic ratings and rank order scores) was assessed by Spearman correlation coefficients.

Series of linear regression analyses were performed to assess the associations between PROP taster status and children's food preferences, using tasters as the reference group. Unadjusted associations were assessed in crude models, using PROP taster status as single independent variable. Basic models were adjusted for potential confounders, i.e. those variables associated with PROP taster status. Given the large sample size, fully adjusted models were built to increase precision of the effect estimates. Effect estimates of interest included unstandardized betas, representing the (adjusted) difference in mean score between non-tasters and tasters, and estimated marginal means, representing the (adjusted) means for tasters and non-tasters. Analyses were performed for each food item separately, and for hedonic ratings and rank order scores separately. Standardized mean differences (Cohen's *d*) were calculated to assess the effect size of observed associations (Cohen 1988; Wilson). Associations between PROP tasters status

and children's consumption of high-calorie snacks and sweet beverages were assessed by performing similar series of logistic regression analyses, using tasters as the reference group. Sensitivity analyses using the original continuous variables were also performed.

Previous research has suggested that the influence of PROP taster status may vary according to child's sex and ethnicity, family socioeconomic position or parental feeding practices (Keller & Tepper 2004; Lumeng *et al.* 2008; Tepper *et al.* 2009; Bouthoorn *et al.* 2013). In order to evaluate possible effect modification by any of these variables, interaction terms were added to models containing the main effects only (e.g. PROP taster status, child's sex and PROP taster status $\times$ child's sex). When significant, stratified analyses were performed. To reduce bias associated with missing data, multiple imputation of the potential confounders was performed (Greenland & Finkle 1995). Five imputed datasets were generated, thus taking into account the uncertainty of the imputed values. Imputations were based on the relationships between all the variables included in this study. All analyses were conducted with Statistical Package for Social Sciences (SPSS) version 20.0 for Windows (SPSS Inc., 2011, Chicago, IL, USA). This study used a significance level (α) of 0.05.

Nonresponse analyses

Children excluded from the analyses based on missing data ($n = 706$) were compared with children with complete data ($n = 5984$). No differences were found for child's sex ($\chi^2 = 2.06$, $df = 1$, $P = 0.15$), ethnicity ($\chi^2 = 2.29$, $df = 2$, $P = 0.32$), maternal educational level ($\chi^2 = 0.59$, $df = 3$, $P = 0.90$) or household income ($\chi^2 = 0.00$, $df = 1$, $P = 0.99$). Children excluded from the analyses were younger compared with those included in the analyses (6.13 years vs. 6.18 years) ($F = 5.89$, $df = 1$, $P = 0.02$).

Results

Characteristics of the study population

In the total study population of 5585 children, 78% were tasters and 22% were non-tasters (Table 1). There were

Table 1. Characteristics of the total study population and according to PROP taster status ($n = 5585$)

		Missing (n,%)	Total ($n = 5585$) (n,%)	Tasters ($n = 4338$) (n,%)	Non-Tasters ($n = 1247$) (n,%)	<i>P</i> -value*
Sociodemographic characteristics						
Sex	Girl	0	2814 (50.4)	2227 (51.3)	587 (47.1)	<0.01
	Boy		2771 (49.6)	2111 (48.7)	660 (52.9)	
Age	Years (mean, SD)	0	6.2 (0.5)	6.2 (0.5)	6.2 (0.5)	0.22
Ethnicity	Dutch	140 (2.5)	3052 (56.1)	2361 (55.8)	691 (57.0)	0.36
	Other-Western		496 (9.1)	378 (8.9)	118 (9.7)	
	Non-Western		1897 (34.8)	1494 (35.3)	403 (33.3)	
Maternal educational level	High	815 (14.6)	1293 (27.1)	999 (27.0)	294 (27.7)	0.54
	Mid-high		1298 (27.2)	1021 (27.5)	277 (26.1)	
	Mid-low		1543 (32.4)	1206 (32.5)	337 (31.8)	
	Low		636 (13.3)	483 (13.0)	153 (14.4)	
Household income	≥1600 euro/month	1080 (19.3)	3705 (82.8)	2881 (82.3)	824 (82.2)	0.93
	<1600 euro/month		800 (17.8)	621 (17.7)	179 (17.8)	
CFQ [†] monitoring	1–5 (median, 90% range)	2120 (38.0)	5.0 (3.0–5.0)	5.0 (3.0–5.0)	5.0 (2.7–5.0)	0.14
CFQ [†] restriction	1–5 (mean, SD)	2126 (38.1)	3.0 (0.8)	3.0 (0.8)	3.0 (0.8)	0.45
CFQ [†] pressure to eat	1–5 (mean, SD)	2112 (37.8)	3.1 (1.0)	3.1 (1.0)	3.1 (1.0)	0.58
Food preferences (rank order scores)						
Candy	1–8 (median, 90% range)	231 (4.1)	2.0 (1.0–7.0)	2.0 (1.0–7.0)	2.0 (1.0–7.0)	0.17
Chocolate	1–8 (median, 90% range)	231 (4.1)	2.0 (1.0–7.0)	2.0 (1.0–7.0)	2.0 (1.0–7.0)	0.69
Mayonnaise	1–8 (median, 90% range)	231 (4.1)	6.0 (3.0–8.0)	6.0 (3.0–8.0)	6.0 (3.0–8.0)	0.21
Whipped cream	1–8 (median, 90% range)	231 (4.1)	4.0 (1.0–8.0)	4.0 (1.0–8.0)	4.0 (1.0–8.0)	0.75
Soup	1–8 (median, 90% range)	231 (4.1)	6.0 (1.0–8.0)	6.0 (1.0–8.0)	6.0 (1.0–8.0)	0.29
Potato chips	1–8 (median, 90% range)	231 (4.1)	3.0 (1.0–7.0)	3.0 (1.0–7.0)	3.0 (1.0–7.0)	0.36
Carrot	1–8 (median, 90% range)	231 (4.1)	7.0 (2.0–8.0)	7.0 (2.0–8.0)	7.0 (2.0–8.0)	0.11
Bread	1–8 (median, 90% range)	231 (4.1)	6.0 (2.0–8.0)	6.0 (2.0–8.0)	6.0 (2.0–8.0)	0.32
Consumption behaviours						
High-calorie snacks	<2 times/day	918 (16.4)	3386 (72.6)	2641 (72.8)	745 (71.6)	0.42
	≥2 times/day		1281 (27.4)	985 (27.2)	296 (28.4)	
Sweet beverages	<3 glasses/day	918 (16.4)	2981 (63.9)	2330 (64.3)	651 (62.5)	0.31
	≥3 glasses/day		1686 (36.1)	1296 (35.7)	390 (37.5)	

Table is based on non-imputed dataset. *Differences between tasters and non-tasters were evaluated using ANOVA and Kruskal–Wallis tests for continuous variables, and Chi-square tests for categorical variables. †CFQ, Child Feeding Questionnaire.

significantly more boys in the non-taster group compared with the taster group ($P < 0.01$). Family socioeconomic position, parental feeding practices, child's ethnicity and child's age did not vary according to PROP taster status. Comparable results were observed after multiple imputation of the data (data not shown).

PROP taster status and children's food preferences

Spearman correlation coefficients assessing the agreement between both food preference measures ranged from modest to strong ($r = 0.42$ – 0.72 , all $P < 0.001$). The associations between PROP taster status and children's food preferences are shown in Table 2 and Fig. 2a,b. Analyses on the hedonic ratings showed that

non-tasters liked carrots (β : -0.07 ; 95% CI: -0.13 , -0.02) and bread (β : -0.06 ; 95% CI: -0.11 , -0.01) more compared with tasters. Analyses on the rank order scores showed that non-tasters preferred carrots significantly more than tasters (β : -0.15 ; 95% CI: -0.27 , -0.02). Standardized mean differences of these associations were very small (all Cohen's $d = -0.08$). No differences in hedonic ratings or rank order scores were found for the remaining food items. There was significant interaction between PROP taster status and income on the preference for candy, using hedonic ratings only ($P < 0.05$). Stratified analyses showed different effects of PROP taster status, depending on household income (Table 3). However, neither effect estimate was statistically significant at $P < 0.05$.

Table 2. Associations between PROP taster status and children's food preferences ($n = 5354$)

Food items	Hedonic ratings		
	Crude model	Basic model*	Full model†
	β (95% CI)	β (95% CI)	β (95% CI)
Candy	-0.00 (-0.03,0.03)	-0.00 (-0.03,0.02)	-0.00 (-0.03,0.03)
Chocolate	0.01 (-0.02,0.05)	0.01 (-0.02,0.04)	0.01 (-0.02,0.05)
Mayonnaise	-0.03 (-0.08,0.03)	-0.03 (-0.08,0.03)	-0.02 (-0.08,0.03)
Whipped cream	-0.03 (-0.07,0.02)	-0.03 (-0.08,0.01)	-0.03 (-0.07,0.02)
Soup	-0.00 (-0.06,0.05)	-0.00 (-0.06,0.05)	-0.01 (-0.06,0.05)
Potato chips	-0.01 (-0.03,0.02)	-0.01 (-0.03,0.02)	-0.01 (-0.03,0.02)
Carrot	-0.07 (-0.12, -0.01)	-0.07 (-0.13, -0.02)	-0.07 (-0.13, -0.02)
Bread	-0.06 (-0.11, -0.01)	-0.06 (-0.11, -0.01)	-0.06 (-0.11, -0.01)
Food items	Rank order scores		
	Crude model	Basic model*	Full model†
	β (95% CI)	β (95% CI)	β (95% CI)
Candy	0.08 (-0.04,0.20)	0.08 (-0.04,0.20)	0.10 (-0.02,0.21)
Chocolate	0.05 (-0.07,0.18)	0.06 (-0.07,0.18)	0.07 (-0.06,0.19)
Mayonnaise	-0.08 (-0.19,0.03)	-0.07 (-0.18,0.04)	-0.07 (-0.18,0.04)
Whipped cream	0.01 (-0.12,0.14)	0.00 (-0.12,0.13)	0.00 (-0.12,0.13)
Soup	0.07 (-0.07,0.20)	0.07 (-0.07,0.20)	0.06 (-0.08,0.19)
Potato chips	0.06 (-0.05,0.17)	0.07 (-0.04,0.18)	0.06 (-0.05,0.17)
Carrot	-0.13 (-0.25,0.00)	-0.14 (-0.26, -0.01)	-0.15 (-0.27, -0.02)
Bread	-0.07 (-0.18,0.04)	-0.07 (-0.18,0.04)	-0.07 (-0.18,0.04)

Table is based on imputed dataset. CI, confidence interval. Betas are derived from (multiple) linear regression analyses and represent the difference in mean score between non-tasters and tasters (reference group). A lower score indicates a higher preference for this food item. Bold print indicates statistical significance at $P < 0.05$. *Adjusted for child's sex. †Adjusted for child's sex, child's age, child's ethnicity, maternal educational level, household income and parental feeding practices (monitoring, restriction and pressure to eat).

PROP taster status and children's consumption of high-calorie snacks and sweet beverages

Compared with tasters, non-tasters had similar odds of consuming high-calorie snacks ≥ 2 times/day (aOR: 1.06; 95% CI: 0.91,1.24) and sweet beverages ≥ 3 glasses/day (aOR: 1.06; 95% CI: 0.92,1.23) (Table 4). Sensitivity analyses using continuously measured consumption of high-calorie snacks (times/day) and sweet beverages (glasses/day) showed highly similar results (Table 4). No interaction effects were observed.

Discussion

The current study aimed to assess the associations of PROP taster status with children's food preferences and consumption of high-calorie snacks and sweet beverages. Non-tasters reported a higher preference for

carrots and bread compared with tasters, but did not differ in the consumption of high-calorie snacks or sweet beverages.

No associations were found between PROP taster status and children's preferences for any of the sweet, fat or salty food items. These findings support earlier research in children that failed to find PROP taster differences in the preference for sweet and/or fat food items such as milk and semisweet chocolates (Keller *et al.* 2002), lemonade (Anliker *et al.* 1991; Turnbull & Matisoo-Smith 2002), beef hotdogs (Keller *et al.* 2002) and whole milk (Turnbull & Matisoo-Smith 2002). Non-tasters did show a higher preference for carrots and bread compared with tasters. Contrary to broccoli and other cruciferous vegetables, carrots do not contain glucosinolate compounds and therefore do not have the bitter taste. It may be that children generalized the concept of carrots to all vegetables; the observed PROP

Fig. 2. (A) Estimates marginal means (95% CI) represent the mean hedonic scores (range 1–3), adjusted for child's sex, child's age, child's ethnicity, maternal educational level, household income and parental feeding practices (monitoring, restriction and pressure to eat). A lower score indicates a higher preference for this food item. Only p values < 0.05 are shown. (B) Estimates marginal means (95% CI) represent the mean rank order scores (range 1–8), adjusted for child's sex, child's age, child's ethnicity, maternal educational level, household income and parental feeding practices (monitoring, restriction and pressure to eat). A lower score indicates a higher preference for this food item. Only p values < 0.05 are shown.

taster differences may then reflect children's preference for vegetables in general, including more bitter tasting vegetables. Similarly, children may have associated bread with its toppings such as sandwich spreads, cured meats or cheeses, all of which contain sweet and fat taste properties. This explanation would be in line with previous research showing non-taster children to have a higher preference for (high-fat) American cheese (Keller *et al.* 2002) and Cheddar cheese (Anliker *et al.* 1991) than taster children. Furthermore, a previous

study among US university students showed that while PROP tasters liked all breads equally, tasters had a preference for refined bread over whole wheat bread, potentially because of more bitterness in whole wheat bread (Bakke & Vickers 2007). Therefore, an increased bitterness perception in taster children may explain why non-taster children had a higher preference for bread compared with taster children.

Alternatively, spurious associations may have occurred as a result of multiple testing. The

Table 3. Associations between PROP taster status and hedonic ratings for candy, stratified by household income ($n = 5354$)

Income	Crude model	Basic model*	Full model†
	β (95% CI)	β (95% CI)	β (95% CI)
<1600 euro/month	0.07 (−0.01,0.15)	0.07 (−0.01,0.15)	0.07 (−0.01,0.15)
≥1600 euro/month	−0.02 (−0.05,0.01)	−0.02 (−0.05,0.01)	−0.02 (−0.05,0.01)

Table is based on imputed dataset. CI, confidence interval. Betas are derived from (multiple) linear regression analyses and represent the difference in mean score between non-tasters and tasters (reference group). A lower score indicates a higher liking.*Adjusted for child's sex.†Adjusted for child's sex, child's age, child's ethnicity, maternal educational level, household income and parental feeding practices (monitoring, restriction and pressure to eat).

Table 4. Associations between PROP taster status and children's consumption of high-calorie snacks and sweet beverages ($n = 4667$)

	High-calorie snacks (≥ 2 times/day)	Sweet beverages (≥ 3 glasses/day)	High-calorie snacks (times/day)	Sweet beverages (glasses/day)
	OR (95% CI)	OR (95% CI)	β (95% CI)	β (95% CI)
Crude model	1.07 (0.91,1.24)	1.08 (0.93,1.24)	0.05 (−0.01,0.12)	0.04 (−0.05,0.14)
Basic model*	1.07 (0.91,1.24)	1.06 (0.92,1.23)	0.05 (−0.01,0.12)	0.04 (−0.06,0.13)
Full model†	1.06 (0.91,1.24)	1.06 (0.92,1.23)	0.05 (−0.02,0.12)	0.04 (−0.06,0.13)

Table is based on imputed dataset. CI, confidence interval. Odds ratios are derived from (multiple) logistic regression analyses and represent the ratio in odds between non-tasters and tasters (reference group). Betas are derived from (multiple) linear regression analyses and represent the difference in mean score between non-tasters and tasters (reference group).*Adjusted for child's sex.†Adjusted for child's sex, child's age, child's ethnicity, maternal educational level, household income and parental feeding practices (monitoring, restriction, pressure to eat).

commonly used Bonferroni correction would imply that observed P -values smaller than α/k are considered statistically significant (Bland & Altman 1995; Bender & Lange 2001). Under the premise that eight independent comparisons were made (eight food items), none of the associations remained significant. Furthermore, the effect sizes of observed observations, as calculated by the standardized mean difference, were almost negligible. Taken together, these results suggest that there are more important predictors of children's food preferences, e.g. dietary experience, parental feeding practices and modelling by parents and peers (Birch & Fisher 1998; Birch 1999), than innate taste sensitivity. Additional large studies are needed to replicate the current findings.

With respect to the consumption of high-calorie snacks, our results are in line with earlier studies that found no association between PROP taster status and children's intake of sweet and fatty snacks (Keller *et al.* 2002; Lumeng *et al.* 2008). Similarly, a study among 18 to 30 year old women did not find an effect of PROP taster status on the reported consumption of chocolates

(Ly & Drewnowski 2001). In contrast, one study did find differences in the percentage of daily energy from sugars according to PROP taster status (Keller & Tepper 2004). In this study, taster children reportedly consumed a higher percentage of daily energy sugars, mainly from sweet and fatty snacks, compared with non-taster children (Keller & Tepper 2004). To our knowledge, PROP taster differences in the consumption of sweet beverages have not been studied before. However, prior studies found no associations between PROP taste sensitivity and the preference for lemonade (Anliker *et al.* 1991; Turnbull & Matisoo-Smith 2002). The findings of this study confirm the premise that the associations of PROP taste sensitivity with preference for and intake of sweet and fatty foods remain ambiguous and warrant further research (Keller *et al.* 2002).

Study strengths and limitations

The main strength of this study is the size and diversity of the study population, which allowed us to assess multiple interaction effects and to correct for

potential confounders. Several limitations should be considered when interpreting the results. First, 10% of all children visiting the research centre were excluded from the analyses because of missing information on PROP or both outcome variables. However, given that non-response analyses showed participants and non-participants to be highly similar, we do not think that selection bias affected our results to a great extent. Second, social desirability bias in the assessment of consumption of high-calorie snacks and sweet beverages may have occurred because of the use of parent-reported questionnaires. Previous studies have shown selective energy under-reporting for overweight parents and parents with a low educational level (LioRET *et al.* 2011; Livingstone *et al.* 2004). Because parental educational level was not associated with PROP taster status, we assume that it is unlikely that differential underreporting has affected our results. Similarly, children's reporting of their food preferences may have been influenced by the presence of the main caregiver in the room. However, in order to have biased our results, the desire to give 'correct' answers should be different between tasters and non-tasters, which seems unlikely. Third, although we were able to include a wide range of potential confounders, we did not have information on children's exposure to the eight food items used in the food preference test and were therefore unable to estimate the potential effects of familiarity on children's food preferences (Anzman-Frasca *et al.* 2012; Mallan *et al.* 2015). Fourth, sensitivity to PROP was assessed by a forced choice method developed for young children that categorizes children as tasters or non-tasters (Keller *et al.* 2002). Although this method has shown good test-retest reliability and has been widely used in research on food preferences and consumption behaviours among young children (Keller *et al.* 2002; Keller & Tepper 2004; Bell & Tepper 2006; Lumeng *et al.* 2008; Keller *et al.* 2010), this classification does not take into account the more continuous character of PROP tasting (non-tasters to super-tasters) (Tepper 2008) and as a consequence may have resulted in a lack of power to detect associations. Similarly, it may be that the use of a three-point hedonic scale resulted in less ability to detect

small differences between taster groups. Although this method has been validated in previous research (Birch & Sullivan 1991; Guthrie *et al.* 2000), more recent studies have shown that 4- to 5-year-old children can reliably use a five-point hedonic scale (Keller *et al.* 2002; Bell & Tepper 2006). Fifth, results presented in this study were based on a multiple imputed dataset (Greenland & Finkle 1995). In order to reduce bias and improve precision, multiple imputation is increasingly used when dealing with missing data. Multiple imputation is considered valid when missing data can be explained by observed data (i.e. missing at random condition) (Greenland & Finkle 1995; Sterne *et al.* 2009; Spratt *et al.* 2010). We increased the chances of data being missing at random by including a wide range of potentially important predictor variables in the imputation model, including outcome variables (Sterne *et al.* 2009). Imputed values in the different imputed datasets showed little variability, supporting the validity of our imputation model. Results from analyses using complete cases were similar to the results presented here, although the association of PROP taster status with children's preference for carrot did not reach statistical significance in complete case analyses (data not shown). Finally, while the food preference test included a range of sweet, fat and salty taste food items, it did not include sweet beverages specifically.

Conclusion

In summary, this study showed no associations of PROP taster status with children's preferences for sweet, fat or salty food items and consumption of high-calorie snacks or sweet beverages. Other factors relating to the family food environment, including dietary experience, parenting practices, modelling and availability and accessibility of foods, may be more important for young children's food preferences and consumption of high-calorie snacks and sweet beverages than their innate taste sensitivity. Further research is needed to replicate the current findings in various age groups and varied samples to increase our understanding of the development of food preferences and dietary behaviours in childhood.

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Conflicts of interest

The authors declare that they have no conflict of interests.

Contributions

AIW was responsible for the statistical analyses, the interpretation of the data and the revisions of the manuscript. She also wrote the first draft of the manuscript. HR and WJ are responsible for the original research idea and supervised AIW with data-analysis, interpretation of the data and writing and revising of the manuscript. SHB, JCK, PWJ and OHF contributed to the interpretation of the data, and critically revised the

manuscript. VWVJ, AH and HR designed the study, were responsible for the infrastructure in which the study was conducted, contributed to the original data collection and critically revised the manuscript for important intellectual content. All authors read and approved of the final version of the manuscript.

References

- Anliker J.A., Bartoshuk L., Ferris A.M. & Hooks L.D. (1991) Children's food preferences and genetic sensitivity to the bitter taste of 6-n-propylthiouracil (prop). *American Journal of Clinical Nutrition* **54**, 316–320.
- Anzman-Frasca S., Savage J.S., Marini M.E., Fisher J.O. & Birch L.L. (2012) Repeated exposure and associative conditioning promote preschool children's liking of vegetables. *Appetite* **58**, 543–553.
- Bakke A. & Vickers Z. (2007) Consumer liking of refined and whole wheat breads. *Journal of Food Science* **72**, S473–480.
- Bell K.I. & Tepper B.J. (2006) Short-term vegetable intake by young children classified by 6-n-propylthiouracil bitter-taste phenotype. *American Journal of Clinical Nutrition* **84**, 245–251.
- Bender R. & Lange S. (2001) Adjusting for multiple testing—when and how? *Journal of Clinical Epidemiology* **54**, 343–349.
- Bere E., Glomnes E.S., Te Velde S.J. & Klepp K.I. (2008) Determinants of adolescents' soft drink consumption. *Public Health Nutrition* **11**, 49–56.
- Birch L.L. (1999) Development of food preferences. *Annual Review of Nutrition* **19**, 41–62.
- Birch L.L. & Fisher J.O. (1998) Development of eating behaviors among children and adolescents. *Pediatrics* **101**, 539–549.
- Birch L.L., Fisher J.O., Grimm-Thomas K., Markey C.N., Sawyer R. & Johnson S.L. (2001) Confirmatory factor analysis of the child feeding questionnaire: a measure of parental attitudes, beliefs and practices about child feeding and obesity proneness. *Appetite* **36**, 201–210.
- Birch L.L. & Sullivan S.A. (1991) Measuring children's food preferences. *Journal of School Health* **61**, 212–214.
- Bland J.M. & Altman D.G. (1995) Multiple significance tests: the bonferroni method. *British Medical Journal* **310**, 170.
- Bouthoorn S.H., Van Lenthe F.J., Kiefte-De Jong J.C., Taal H.R., Wijtzes A.I., Hofman A. *et al.* (2013) Genetic taste blindness to bitter and body composition in childhood: a mendelian randomization design. *International Journal of Obesity* **38**, 1005.
- Brady L.M., Lindquist C.H., Herd S.L. & Goran M.I. (2000) Comparison of children's dietary intake patterns with us dietary guidelines. *British Journal of Nutrition* **84**, 361–367.
- Cohen J. (1988) *Statistical Power Analysis for the Behavioral Sciences*, 2nd edn. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

- Dubois L., Farmer A., Girard M. & Peterson K. (2007) Regular sugar-sweetened beverage consumption between meals increases risk of overweight among preschool-aged children. *Journal of the American Dietetic Association* **107**, 924–934 discussion 934–925.
- Greenland S. & Finkle W.D. (1995) A critical look at methods for handling missing covariates in epidemiologic regression analyses. *American Journal of Epidemiology* **142**, 1255–1264.
- Grimm G.C., Harnack L. & Story M. (2004) Factors associated with soft drink consumption in school-aged children. *Journal of the American Dietetic Association* **104**, 1244–1249.
- Guthrie C.A., Rapoport L. & Wardle J. (2000) Young children's food preferences: a comparison of three modalities of food stimuli. *Appetite* **35**, 73–77.
- Huybrechts I., Matthys C., Vereecken C., Maes L., Temme E.H., Van Oyen H. *et al.* (2008) Food intakes by preschool children in Flanders compared with dietary guidelines. *International Journal of Environmental Research and Public Health* **5**, 243–257.
- Jaddoe V.W., Van Duyn C.M., Franco O.H., Van Der Heijden A.J., Van Iizendoorn M.H., De Jongste J.C. *et al.* (2012) The generation r study: design and cohort update 2012. *European Journal of Epidemiology* **27**, 739–756.
- Johansson I., Holgerson P.L., Kressin N.R., Nunn M.E. & Tanner A.C. (2010) Snacking habits and caries in young children. *Caries Research* **44**, 421–430.
- Keller K.L., Reid A., Macdougall M.C., Cassano H., Song J.L., Deng L. *et al.* (2010) Sex differences in the effects of inherited bitter thiourea sensitivity on body weight in 4–6-year-old children. *Obesity* **18**, 1194–1200.
- Keller K.L., Steinmann L., Nurse R.J. & Tepper B.J. (2002) Genetic taste sensitivity to 6-n-propylthiouracil influences food preference and reported intake in preschool children. *Appetite* **38**, 3–12.
- Keller K.L. & Tepper B.J. (2004) Inherited taste sensitivity to 6-n-propylthiouracil in diet and body weight in children. *Obesity Research* **12**, 904–912.
- Lioret S., Touvier M., Balin M., Huybrechts I., Dubuisson C., Dufour A. *et al.* (2011) Characteristics of energy under-reporting in children and adolescents. *British Journal of Nutrition* **105**, 1671–1680.
- Livingstone M.B., Robson P.J. & Wallace J.M. (2004) Issues in dietary intake assessment of children and adolescents. *British Journal of Nutrition* **92** (Suppl 2), S213–222.
- Ludwig D.S., Peterson K.E. & Gortmaker S.L. (2001) Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective, observational analysis. *Lancet* **357**, 505–508.
- Lumeng J.C., Cardinal T.M., Sitto J.R. & Kannan S. (2008) Ability to taste 6-n-propylthiouracil and BMI in low-income preschool-aged children. *Obesity (Silver Spring)* **16**, 1522–1528.
- Ly A. & Drewnowski A. (2001) Prop (6-n-propylthiouracil) tasting and sensory responses to caffeine, sucrose, neohesperidin dihydrochalcone and chocolate. *Chemical Senses* **26**, 41–47.
- Mallan K.M., Fildes A., Magarey A.M. & Daniels L.A. (2015) The relationship between number of fruits, vegetables, and noncore foods tried at age 14 months and food preferences, dietary intake patterns, fussy eating behavior, and weight status at age 3.7 years. *Journal of the Academy of Nutrition and Dietetics*. doi: 10.1016/j.jand.2015.06.006.
- Marshall T.A., Levy S.M., Broffitt B., Warren J.J., Eichenberger-Gilmore J.M., Burns T.L. *et al.* (2003) Dental caries and beverage consumption in young children. *Pediatrics* **112**, e184–191.
- Munoz K.A., Krebs-Smith S.M., Ballard-Barbash R. & Cleveland L.E. (1997) Food intakes of us children and adolescents compared with recommendations. *Pediatrics* **100**, 323–329.
- Netherlands Bureau for Economic Policy Analysis. Available: <http://www.cpb.nl> [Accessed 01-02 2013].
- Spratt M., Carpenter J., Sterne J.A., Carlin J.B., Heron J., Henderson J. *et al.* (2010) Strategies for multiple imputation in longitudinal studies. *American Journal of Epidemiology* **172**, 478–487.
- Statistics Netherlands (2004) *Standaard Onderwijsindeling 2003*. Voorburg/Heerlen.
- Statistics Netherlands (2010) *Jaarrapport Integratie 2010*. Den Haag/Heerlen.
- Sterne J.A., White I.R., Carlin J.B., Spratt M., Royston P., Kenward M.G. *et al.* (2009) Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. *British Medical Journal* **338**, b2393.
- Tepper B.J. (1998) 6-n-propylthiouracil: a genetic marker for taste, with implications for food preference and dietary habits. *American Journal of Human Genetics* **63**, 1271–1276.
- Tepper B.J. (2008) Nutritional implications of genetic taste variation: the role of prop sensitivity and other taste phenotypes. *Annual Review of Nutrition* **28**, 367–388.
- Tepper B.J., White E.A., Koelliker Y., Lanzara C., D'adamo P. & Gasparini P. (2009) Genetic variation in taste sensitivity to 6-n-propylthiouracil and its relationship to taste perception and food selection. *Annals of the New York Academy of Sciences* **1170**, 126–139.
- Turnbull B. & Matisoo-Smith E. (2002) Taste sensitivity to 6-n-propylthiouracil predicts acceptance of bitter-tasting spinach in 3–6-y-old children. *American Journal of Clinical Nutrition* **76**, 1101–1105.
- Veldhuis L., Vogel I., Renders C.M., Van Rossem L., Oenema A., Hiraasing R.A. *et al.* (2012) Behavioral risk factors for overweight in early childhood; the 'be active, eat right' study. *International Journal of Behavioral Nutrition and Physical Activity* **9**, 74.
- Wilson D. B. *Practical meta-analysis effect size calculator* [Online]. The Campbell Collaboration. Available: http://www.campbellcollaboration.org/resources/effect_size_input.php [Accessed 21-08 2015].