



# Orange juice intake and anthropometric changes in children and adolescents

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## Abstract

**Objective:** Evaluate associations between orange juice (OJ) consumption and anthropometric parameters.

**Design:** Prospective cohort study assessing the association between OJ intake and changes in BMI and height-for-age Z-score (HAZ) using mixed linear regression.

**Setting:** 2004–2008, USA.

**Participants:** Children from the Growing Up Today Study II (*n* 7301), aged 9–16 years at enrollment.

**Results:** OJ consumption was positively associated with 2-year change in HAZ in girls (mean (SE)): 0.03 (0.01) for non-consumers, 0.03 (0.02) for 1–3 glasses/month, 0.06 (0.01) for 1–6 glasses/week and 0.09 (0.02) for  $\geq 1$  glass/d after full adjustment ( $P_{\text{trend}} = 0.02$ ). However, OJ consumption was not associated with 2-year change in BMI percentile ( $\text{kg/m}^2$ , mean (SE)):  $-0.44$  (0.36) for non-consumers, 0.20 (0.41) for 1–3 glasses/month,  $-0.04$  (0.34) for 1–6 glasses/week and  $-0.77$  (0.62) for  $\geq 1$  glass/d in girls,  $P_{\text{trend}} = 0.81$ ;  $-0.94$  (0.53) for non-consumers,  $-1.68$  (0.52) for 1–3 glasses/month,  $-0.81$  (0.38) for 1–6 glasses per week and  $-1.12$  (0.61) for  $\geq 1$  glass/d in boys,  $P_{\text{trend}} = 0.49$ .

**Conclusion:** OJ consumption was favourably associated with height growth but unrelated to excess weight gain. OJ may be a useful alternative to whole fruit in the event that whole fruit intake is insufficient.

## Keywords

Orange juice  
Growing up today study  
Children  
BMI percentile  
Height-for-age Z-score

Fruit juices are popular beverages among children and adolescents in the USA. In particular, orange juice (OJ) is among the most frequently consumed type of juice<sup>(1)</sup> and is replete with nutrients and antioxidants. A six-fluid ounce serving of OJ provides over 100 % of the recommended dietary allowance for vitamin C and provides folate, K, thiamin, riboflavin, niacin and vitamin B<sub>6</sub><sup>(2)</sup>. Furthermore, Ca and vitamin D fortification of OJ is common, typically providing 15 % of the daily values per six-fluid ounce serving<sup>(3)</sup>. OJ is also rich in the flavanones hesperidin and naringin, which, along with vitamin C, have been implicated in the prevention of obesity<sup>(4,5)</sup>. Importantly, other types of juice commonly consumed by children such as apple and cranberry typically lack these flavanones and are less abundant in vitamin C<sup>(6)</sup>.

Despite the abundance of micronutrients in fruit juices, their sugar content has raised concerns regarding the potential contribution to excess weight gain in children. Several

epidemiologic studies have observed associations between juice consumption and obesity, particularly in pre-school-aged children<sup>(7–12)</sup>. However, others have found that child and adolescent juice consumers are not any more likely to be overweight or to gain excessive weight than non-consumers<sup>(13–30)</sup>. Notably, only a few studies evaluated fruit juice consumption in a longitudinal prospective cohort and none specifically evaluated OJ longitudinally. Still, the American Academy of Pediatrics recommends limiting juice intake to eight-fluid ounces per d for children aged 7–18 years due to the potential risk of obesity and dental caries from excess sugar consumption<sup>(31)</sup>. Similarly, the US Department of Agriculture's Dietary Guidelines for Americans 2015–2020 recommend consuming whole fruit instead of juice but acknowledge that juice can be an important contributor to overall fruit intake and thus recommend that no more than half of one's fruit intake is consumed in the

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form of juice<sup>(32)</sup>. As these guidelines are built upon the existing body of evidence, it is vital that all types of juice, including OJ, are adequately studied and represented. Given the unique nutrient composition of OJ as well as the paucity of longitudinal studies evaluating the association between fruit juice consumption and anthropometric measurements in school-aged children, we sought to determine the longitudinal associations between OJ consumption and anthropometric parameters in older children and adolescents.

## Methods

### *Study population*

The Growing Up Today Study (GUTS) is an ongoing prospective cohort study of the children of the Nurses' Health Study II participants with the objective of evaluating key factors in health and well-being. The second phase of the study, GUTS II, began in 2004, enrolling participants aged 9–16 years ( $n$  10 918). For inclusion in this longitudinal analysis, responses to the 2004 baseline questionnaire and the 2006 follow-up questionnaire were required. When available, 2008 questionnaire data were also examined for eligible children. Participants were excluded if their questionnaires had incomplete/invalid values for the intakes of orange juice (OJ), age, weight, height, screen time, extremely low BMI ( $<12$  kg/m<sup>2</sup>) or total daily caloric intake below 2092 kJ or above 20 920 kJ. Additionally, participants were excluded for implausible changes in energy intake between survey years ( $>8368$  kJ change). The final analytic cohort included 7301 children, for whom we analysed a total of 10 560 2-year intervals.

### *Assessment of orange juice intake*

The biennial survey included the Youth/Adolescent Questionnaire, which is a semi-quantitative FFQ, that was developed for and validated in older children<sup>(33,34)</sup>. Instructions on the FFQ asked participants to quantify their usual food and beverage intake over the preceding year. The question pertaining to the consumption of OJ was separate from questions pertaining to the consumption of other beverages or juices and included six categorical response options ranging from 'never/less than 1 glass per month' to 'more than 1 glass per d.' To succinctly and meaningfully present our findings, our data are presented with four consolidated OJ intake categories: 'never/less than 1 per month', '1–3 glasses per month', '1–6 glasses per week' and '≥ 1 glass per d.'. To examine trends across differing levels of OJ consumers, we also estimated weekly glasses of OJ as a continuous variable by converting the FFQ responses to quantitative values using the following procedures: for FFQ responses that included a range of intakes, OJ consumption was assumed to be equal to the midpoint of the range (e.g. '1–3 glasses per month' was counted as 2 glasses per month).

The option 'never/ $<1$  glass per month' was counted as 0 glasses consumed while '≥ 1 glass per d' was counted as 2 glasses per d.

### *Assessment of anthropometric data*

Participants self-reported height and weight on each survey, with specific measuring instructions and encouragement to seek assistance from their mothers who self-report their own weight for the Nurses' Health Study II<sup>(35)</sup>. Self-reported height and weight have previously been validated in this age group<sup>(36–38)</sup>. BMI, BMI percentile and height-for-age Z-score (HAZ), in addition to average 2-year change in these values, were calculated using the self-reported weight and height responses. BMI percentile corresponds to the US Centers for Disease Control and Prevention growth charts for children and teens aged 2 through 19 years<sup>(39)</sup>. Weight status was determined using the BMI percentile cut-offs defined by the US Centers for Disease Control and Prevention<sup>(40)</sup>.

### *Assessment of lifestyle and dietary data*

Total daily energy intake was estimated through the FFQ and total daily energy intake excluding OJ was calculated by subtracting the caloric contribution of OJ assuming that each glass of OJ consumed was six-fluid ounces and 355 kJ (85 kcal). This assumption was based off previously measured OJ intake in children<sup>(41)</sup> as well as reasonable judgement on the volume of OJ that a child is likely consume in a single serving. Moderate/vigorous physical activity was estimated as total metabolic equivalent hours per week, calculated by multiplying the number of hours spent each week engaged in all activities ≥ 4 metabolic equivalents by its metabolic equivalent and summing the values<sup>(42)</sup>. Screen time was calculated by summing the number of hours spent each week watching television, playing video games, watching videos/movies, and using the computer/internet. Average 2-year changes in dietary intakes, physical activity, and screen time were calculated from consecutive surveys.

### *Statistical analysis*

To examine the baseline characteristics of the eligible participants, we calculated mean values and SD and stratified by gender. Two year mean change in each characteristic was also calculated by averaging the differences in responses from consecutive surveys (2004–2006 and 2006–2008). To assess the relationship between OJ consumption and changes in anthropometric, dietary and lifestyle factors, OJ consumption at each interval's baseline (2004 for the 2004–2006 interval; 2006 for the 2006–2008 interval) was evaluated against the 2-year change in each variable using mixed linear regression. Since each participant could potentially have two interval observations (2004–2006 and 2006–2008), we analysed trends using each available observation of 2-year change instead of participants. Furthermore, the regression model was mixed because some participants



had repeated measures and therefore not all observations were independent. Similarly, to evaluate relationships between OJ consumption and change in BMI percentile and HAZ, we used mixed linear regression modelling to relate baseline OJ consumption to 2-year mean changes in BMI percentile and HAZ. For BMI percentile, covariates included baseline age, race and BMI percentile (model 1), and further included 2-year changes in total energy intake excluding OJ (model 2), physical activity and screen time (model 3). Screen time was only added as a covariate due to its potential interaction with BMI percentile. For HAZ, covariates included baseline age, race and HAZ (model 4) and further included 2-year changes in total energy intake excluding OJ (model 5) and physical activity (model 6). All baseline variables refer to the measurement at the beginning of each interval. *P*-values < 0.05 were considered statistically significant. All statistical analyses were conducted using SAS® software, version 9.4 (SAS Institute, Inc.).

## Results

### Baseline and 2-year changes in characteristics

Baseline and average 2-year changes in anthropometric, dietary and lifestyle characteristics of GUTS II participants are presented in Table 1. The majority of participants (>96%) identified as non-Hispanic white, and the mean

(SD) ages were 13.4 (1.8) years for boys and 13.5 (1.8) years for girls. The prevalence of overweight/obesity was 24.6% and 17.3% for boys and girls, respectively. Average OJ consumption was 2.6 (3.4) and 2.2 (3.0) glasses per week for boys and girls, respectively.

### Orange juice intake and corresponding changes in anthropometric, dietary and lifestyle characteristics

Mean 2-year changes in characteristics were stratified by categories of OJ intake. There was a slight decreasing trend in boys' height across OJ consumption categories, but the trend was not significant for HAZ (Table 2). Conversely, there was a significant increasing trend for 2-year changes in the intakes of OJ, total energy intake, total energy intake excluding OJ and physical activity in boys and girls ( $P_{\text{trends}} < 0.001$  for all). Additionally, there was an increasing trend for 2-year change in screen time in boys ( $P_{\text{trend}} = 0.04$ ). Two-year changes in weight, BMI and BMI percentile did not significantly differ by categories of OJ intake.

### Orange juice intake and corresponding changes in BMI percentile and height-for-age Z-score in adjusted models

In the multivariate linear regression model, 2-year change in BMI percentile was slightly negative in all OJ

**Table 1** Characteristics of the Growing Up Today Study II participants at baseline (2004) and 2-year mean changes (2004, 2006 and 2008)

Characteristic	Boys (n 3279)			Girls (n 4022)		
	Mean	SD	%	Mean	SD	%
Age, years	13.3	1.8		13.4	1.8	
Non-Hispanic white, %			96.3			96.4
Weight, kg	54.0	16.2		50.9	12.5	
2-year Δ Weight	11.4	7.4		6.1	6.0	
BMI	20.3	3.8		20.1	3.6	
2-year Δ BMI	1.4	2.2		1.2	2.2	
BMI percentile*	58.6	29.1		54.9	27.6	
2-year Δ BMI percentile	-1.1	17.8		-0.2	16.4	
Height, cm	158.8	14.3		155.5	10.5	
2-year Δ Height	10.4	7.5		4.70	6.0	
HAZ	0.1	1.2		-0.1	1.1	
2-year Δ HAZ	0.1	0.7		0.1	0.6	
Overweight/obese prevalence†, %			24.6			17.3
2-year Δ Overweight/obese prevalence	-2.3	34.7		-1.6	31.0	
OJ intake, glasses/week	2.6	3.4		2.2	3.0	
2-year Δ OJ intake	0.0	3.3		-0.2	2.8	
Total energy intake, kJ/d	9736	3016		8159	2657	
2-year Δ Total energy intake	-19.5	2946		-344	2473	
Total energy intake excluding OJ, kJ/d	9602	2975		8046	2619	
2-year Δ Total energy intake excl. OJ	-76.6	2904		-333	2443	
Screen time‡, hrs/week	23.9	16.2		19.4	14.4	
2-year Δ Screen time	0.4	17.4		-1.1	14.3	
Physical activity§, MET-h/week	92.1	66.5		69.4	51.3	
2-year Δ Physical activity	-1.3	62.3		-1.5	48.7	

HAZ, height-for-age Z-score; OJ, orange juice; MET, metabolic equivalent of task.

\*Corresponds to the BMI-for-age percentile based on the US Centers for Disease Control and Prevention growth charts for children and teens ages 2 through 19 years.

†Overweight/obese categorisation is based on the cut-offs defined by US Centers for Disease Control and Prevention (2016 update): BMI-for-age ≥ 85th percentile.

‡Including television, VCR/DVD videos, video games and computer/internet.

§Total metabolic equivalents per week calculated by summing time spent participating in various sports, games and intentional exercise of moderate/vigorous intensity (not including activities with METS < 4 such as walking).

**Table 2** Two-year mean changes in anthropometric, dietary and lifestyle factors by orange juice consumption categories\* among children in the Growing Up Today Study II (2004, 2006 and 2008)

Characteristic	Never or < 1 glass per month			1–3 glasses per month			1–6 glasses per week			≥ 1 glass per d			<i>P</i> <sub>trend</sub>
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	
<b>Boys</b>													
Observations	1014			1033			1935			762			
2-year Δ Weight, kg		11.7	7.4		11.5	7.6		11.3	7.4		11.1	6.9	0.14
2-year Δ BMI		1.5	2.1		1.4	2.3		1.4	2.3		1.5	1.9	0.79
2-year Δ BMI percentile†		−0.9	17.5		−1.8	17.7		−1.0	18.3		−0.7	16.9	0.48
2-year Δ Height, cm		10.6	7.4		10.9	7.6		10.2	7.5		10.0	7.4	0.02
2-year Δ HAZ		0.0	0.7		0.1	0.7		0.1	0.7		0.0	0.7	0.24
2-year Δ OJ intake, glasses/week		−0.8	1.7		−0.9	2.2		−0.3	3.1		3.0	4.8	<0.001
2-year Δ Total energy intake, kJ/d		−431	2866		−460	2941		−4.184	2870		724	2962	<0.001
2-year Δ Total energy intake excl. OJ, kJ/d		−395	2853		−398	2924		7.5	2883		569	2895	<0.001
2-year Δ Screen time‡, hrs/week		0.3	17.8		−0.3	18.0		0.3	17.3		1.5	16.3	0.04
2-year Δ Physical activity§, MET-hrs/week		−4.3	57.8		−3.4	60.7		−0.4	64.1		3.5	65.1	<0.01
<b>Girls</b>													
Observations	1775			1399			2039			603			
2-year Δ Weight, kg		6.1	6.4		6.1	6.1		6.0	5.7		6.0	5.3	0.63
2-year Δ BMI		1.2	2.2		1.3	2.5		1.2	1.8		1.0	2.6	0.09
2-year Δ BMI percentile†		−0.6	17.0		−0.2	16.0		0.3	16.1		−0.6	16.8	0.85
2-year Δ Height, cm		4.9	6.2		4.5	5.9		4.5	5.7		5.2	6.4	0.22
2-year Δ HAZ		0.1	0.6		0.0	0.6		0.1	0.6		0.1	0.7	0.14
2-year Δ OJ intake, glasses/week		−0.7	1.7		−0.9	2.1		−0.2	2.9		2.7	4.3	<0.001
2-year Δ Total energy intake, kJ/d		−615	2381		−527	2393		−146	2536		210	2561	<0.001
2-year Δ Total energy intake excl. OJ, kJ/d		−582	2372		477	2368		−137	2506		70.3	2519	<0.001
2-year Δ Screen time‡, hrs/week		−0.9	14.7		−0.6	15.0		−1.4	13.8		−1.2	13.1	0.45
2-year Δ Physical activity§, MET-hrs/week		−2.1	45.4		−3.6	49.3		−0.6	49.6		1.9	53.3	0.02

HAZ, height-for-age Z-score; OJ, orange juice; MET, metabolic equivalent of task.

*P*-value for trend calculated using mixed linear regression modelling.

\*Using OJ consumption reported at the end of the interval.

†Corresponds to the US Centers for Disease Control and Prevention BMI-for-age percentile growth charts for children and teens ages 2 through 19 years.

‡Including television, VCR/DVD videos, video games and computer/internet.

§Total metabolic equivalents per week calculated by summing time spent participating in various sports, games and intentional exercise of moderate/vigorous intensity (not including activities with METS &lt; 4 such as walking).

consumption categories except for 1–3 glasses per month for girls, although the trends across OJ consumption categories were not statistically significant (Table 3). Further adjusting for 2-year changes in total energy intake excluding OJ, physical activity and screen time did not significantly alter the results. Two year change in HAZ was positive for all OJ consumption categories. Girls in the lowest OJ consumption category had a 2-year HAZ change of 0.03, while girls in the highest category had a 2-year HAZ change of 0.09, and there was a significant increasing trend in HAZ by OJ consumption category ( $P_{\text{trend}} = 0.01$ ). This trend remained significant after further adjusting for 2-year changes in total energy intake excluding OJ and physical activity, although there was no difference in the magnitudes of HAZ change. In boys, there was no significant association between 2-year change in HAZ and OJ intake.

We performed the same analyses in a subset of participants who reported consuming the same amount/frequency of OJ between survey years to eliminate potential lag effects from the preceding year's OJ intake, which did not yield significantly different results (data not shown).

## Discussion

In this longitudinal study of US children and adolescents from GUTS II, we evaluated the associations between OJ consumption and anthropometric, dietary and lifestyle variables. OJ consumption was associated with a minor increase in HAZ in girls, with the magnitude of HAZ change being three times greater in the highest OJ category compared with the lowest OJ category. Two-year change in

**Table 3** Adjusted linear regression models of 2-year mean\* changes in BMI percentile and height-for-age Z-score by orange juice consumption categories† among children in the Growing Up Today Study II (2004, 2006 and 2008)

Characteristic	Never or < 1 glass per month			1–3 glasses per month			1–6 glasses per week			≥ 1 glass per day			<i>P</i> <sub>trend‡</sub>
	<i>n</i>	Mean	SE	<i>n</i>	Mean	SE	<i>n</i>	Mean	SE	<i>n</i>	Mean	SE	
<b>Boys</b>													
Observations	1014			1033			1935			762			
2-year Δ BMI percentile§													
Model 1		−0.96	0.53		−1.70	0.52		−0.80	0.38		−1.07	0.61	0.73
Model 2¶		−0.93	0.53		−1.68	0.52		−0.81	0.38		−1.11	0.61	0.80
Model 3**		−0.94	0.53		−1.68	0.52		−0.81	0.38		−1.12	0.61	0.81
2-year Δ HAZ													
Model 4††		0.04	0.02		0.07	0.02		0.05	0.01		0.03	0.02	0.41
Model 5‡‡		0.04	0.02		0.08	0.02		0.05	0.01		0.03	0.02	0.33
Model 6§§		0.04	0.02		0.08	0.02		0.05	0.01		0.03	0.02	0.30
<b>Girls</b>													
Observations	1775			1399			2039			603			
2-year Δ BMI percentile§													
Model 1		−0.43	0.36		0.20	0.41		−0.05	0.34		−0.77	0.62	0.49
Model 2¶		−0.44	0.36		0.19	0.41		−0.04	0.34		−0.76	0.62	0.50
Model 3**		−0.44	0.36		0.20	0.41		−0.04	0.34		−0.77	0.62	0.49
2-year Δ HAZ													
Model 4††		0.03	0.01		0.03	0.02		0.06	0.01		0.09	0.02	0.01
Model 5‡‡		0.03	0.01		0.03	0.02		0.06	0.01		0.09	0.02	0.02
Model 6§§		0.03	0.01		0.03	0.02		0.06	0.01		0.09	0.02	0.02

HAZ, height-for-age Z-score.

\*Adjusted mean.

†Using OJ consumption reported at the end of the interval.

‡*P*-value for trend calculated using mixed linear regression modelling.

§Corresponds to the US Centers for Disease Control and Prevention BMI-for-age percentile growth charts for children and teens ages 2 through 19 years.

||Model 1: adjusted for age, race and baseline BMI percentile.

¶Model 2: adjusted for age, race, baseline BMI percentile and 2-year change in total energy intake excluding OJ.

\*\*Model 3: adjusted for age, race, baseline BMI percentile and 2-year changes in total energy intake excluding OJ, physical activity and screen time.

††Model 4: adjusted for age, race and baseline HAZ.

‡‡Model 5: adjusted for age, race, baseline HAZ and 2-year change in total energy intake excluding OJ.

§§Model 6: adjusted for age, race, baseline HAZ and 2-year changes in total energy intake excluding OJ and physical activity.

BMI percentile was slightly negative for all categories of OJ consumption except for girls consuming 1–3 glasses per month, although there was no significant difference between the categories.

Compared with absolute BMI, which is routinely used to screen for obesity in adults<sup>(43)</sup>, BMI percentile accounts for fluctuations in expected growth due to age and gender<sup>(44)</sup>, and thus serves as a more meaningful indicator of adiposity in adolescents. Interestingly, 2-year mean BMI percentiles decreased for nearly each OJ intake group, including the low/non-consumer group. While this may simply be a result of natural growth of the participants in this cohort rather than weight loss, the degree of change is not clinically meaningful. The null association between OJ consumption and BMI percentile is consistent with findings from a recent cross-sectional study of GUTS I and II participants in which OJ intake was not associated with the odds of being overweight or obese at baseline<sup>(45)</sup>. This is also in agreement with cross-sectional analyses of children and adolescents in the National Health and Nutrition Examination Survey 2003–2006 in which OJ consumption was not associated with BMI or obesity<sup>(15,26)</sup>. Similarly, a 3-year longitudinal analysis of participants from the GUTS I cohort found no association between fruit juice

consumption – inclusive of OJ – and change in BMI Z-score<sup>(46)</sup>. However, Dennison *et al.* reported a higher prevalence of obesity among young children consuming fruit juice in excess of twelve-fluid ounces per d<sup>(8)</sup>, indicating that excess consumption is associated with adiposity.

In this study, greater OJ consumption was associated with greater increases in stature among girls, although the magnitude of change was relatively mild. Unfortunately, there is a paucity of longitudinal studies evaluating the relationship between OJ and height growth in preadolescents and adolescents to which can be compared, and the mechanisms underlying this observed relationship are unclear. However, the fortification of OJ with Ca and vitamin D may play an essential role in height growth. A key determinant of skeletal growth is nutrition<sup>(47,48)</sup>, of which Ca and vitamin D play significant roles<sup>(49)</sup>. OJ consumption is positively associated with serum concentrations and intakes of Ca and vitamin D, as well as femoral bone mineral density and content<sup>(50)</sup>, highlighting the importance of bone-related micronutrient intake as an integral component of skeletal growth. Fang *et al.* previously linked Ca intake to height velocity in male adolescents<sup>(51)</sup>, and others<sup>(52,53)</sup> have identified that deficiencies in micronutrients such as vitamins A and D, P,





Mg, Fe and Zn relate to stunted height growth. Intervention studies comparing height growth in response to fortified *v.* non-fortified OJ may best determine the importance of micronutrient fortification on height growth. Also, because OJ intake was associated with greater height attainment in girls but not in boys, there is a need to investigate gender-based differences and whether they are driven by biological, hormonal, behavioural or other factors that could not be fully evaluated in this study.

Our findings have important nutritional implications because OJ is a rich source of micronutrients such as K and vitamin C that have been highlighted as underconsumed nutrients or nutrients of public health concern by the US Department of Agriculture's Dietary Guidelines for Americans 2015–2020<sup>(32)</sup>. These nutrients are also essential for the health and growth of children who are the single largest group of juice consumers<sup>(54)</sup>. OJ is also a rich source of flavonoids and antioxidants: OJ consumers consume significantly greater amounts of  $\beta$ -cryptoxanthin, hesperidin, naringen, proanthocyanins and carotenoids compared with low OJ consumers<sup>(41)</sup>. Antioxidants are proposed to be vital mediators in bone metabolism by countering inflammation-mediated bone resorption<sup>(55–57)</sup>. However, the question of whether fruit juice causes poor health outcomes, such as weight gain, in children has been a subject of controversy. The key message to policy makers, clinicians and health educators is OJ can provide healthful nutrients without increasing the risk of overweight/obesity if consumed in moderate amounts. Even though those in the highest category of OJ consumption did not have greater increases in BMI percentile compared with those in the lower categories, it would be prudent to continue to recommend moderate consumption. The number of those who reported consuming  $\geq 1$  glass of OJ per d was relatively low, and this category was top-coded as two glasses per d since the FFQ did not allow one to specify consumption of greater than one glass per d. Therefore, those actually consuming greater than two glasses per d could not be distinguished from those consuming 1–2 glasses per d in this study, which limits the inferences we can make on high OJ consumers. Further research involving a more robust dietary assessment method is needed to fully evaluate the association between excess OJ intake and anthropometric changes.

A strength of this study is that we were able to evaluate the change in anthropometric measures over 2-year periods, which establishes a temporal relationship between OJ consumption and height and weight. Second, over 7000 participants were included, making this one of the largest longitudinal studies investigating fruit juice consumption and anthropometry in US children and adolescents, and to our knowledge the only longitudinal study specifically evaluating OJ. However, there are limitations. First, this analysis relied on self-reported dietary and anthropometric data and may therefore be subject to certain biases. However, self-reported dietary and

anthropometric data have been previously validated in this age group<sup>(33,34,36–38)</sup>. Second, the dietary data were derived from a semi-quantitative FFQ, which required us to make assumptions when estimating intakes using the categorical responses chosen by participants that may not reflect the true intakes. Third, our analysis focused purely on OJ with the understanding that diet is complex and composed of numerous components acting synergistically to impart biological effects. A single beverage is not consumed in a vacuum and there are likely other behavioural or dietary factors that confound results. However, we attempted to account for the important potential confounders such as physical activity, screen time and total energy intake excluding OJ, which is likely to be the single largest dietary factor in affecting BMI and height change. Finally, on the FFQ OJ was not explicitly defined as being 100 % derived from oranges, but there were opportunities to indicate the consumption of fruit-flavoured sugar-sweetened beverages, thus our analysis is likely to include only 100 % OJ.

## Conclusion

In conclusion, OJ consumption was associated with increased HAZ but not BMI percentile in this large cohort of US children and adolescents. To our best knowledge, this is the first longitudinal investigation of the association between OJ and growth/adiposity in this age group. Authorities providing dietary recommendations on fruit juice intake should continue to acknowledge that while excess fruit juice may have deleterious effects on health and body weight, reasonable consumption of OJ is unlikely to contribute to excess weight gain. Still, whole fruit should continue to be preferred over juice. Future longitudinal studies should continue to investigate more diverse populations to improve generalisability, investigate gender-based differences in anthropometric changes and further elucidate mechanisms underlying OJ's association with height growth.

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