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# 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 ≥1 glass/d after full adjustment ($P_{trend}$ = 0·02). However, OJ consumption was not associated with 2-year change in BMI percentile (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 ≥1 glass/d in girls, $P_{trend}$ = 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 ≥1 glass/d in boys, $P_{trend}$ = 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

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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[1] 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 $B_6$[2]. Furthermore, Ca and vitamin D fortification of OJ is common, typically providing 15 % of the daily values per six-fluid ounce serving[3]. OJ is also rich in the flavanones hesperidin and naringen, which, along with vitamin C, have been implicated in the prevention of obesity[4,5]. 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[6].

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[7–12]. 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[13–30]. 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[31]. 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[32]. 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$^2$) 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[33,34]. 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[35]. Self-reported height and weight have previously been validated in this age group[36–38]. 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[39]. Weight status was determined using the BMI percentile cut-offs defined by the US Centers for Disease Control and Prevention[40].

### *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[41] 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[42]. 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



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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 ($P_{trends} < 0·001$ for all). Additionally, there was an increasing trend for 2-year change in screen time in boys ($P_{trend} = 0·04$). 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)

| | Boys (*n* 3279) | | | Girls (*n* 4022) | | |
|---|---|---|---|---|---|---|
| Characteristic | 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).

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**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)

| | Never or < 1 glass per month | | | 1–3 glasses per month | | | 1–6 glasses per week | | | ≥ 1 glass per d | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Characteristic | *n* | Mean | SD | *n* | Mean | SD | *n* | Mean | SD | *n* | Mean | SD | $P_{trend}$ |
| Boys | | | | | | | | | | | | | |
| 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 |
| Girls | | | | | | | | | | | | | |
| 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 < 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 ($P_{trend} = 0·01$). 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

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**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)

| | Never or < 1 glass per month | | | 1–3 glasses per month | | | 1–6 glasses per week | | | ≥ 1 glass per day | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Characteristic | *n* | Mean | SE | *n* | Mean | SE | *n* | Mean | SE | *n* | Mean | SE | $P_{trend}$‡ |
| Boys | | | | | | | | | | | | | |
| 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 |
| Girls | | | | | | | | | | | | | |
| 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[43], BMI percentile accounts for fluctuations in expected growth due to age and gender[44], 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[45]. 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[15,26]. 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[46]. However, Dennison *et al.* reported a higher prevalence of obesity among young children consuming fruit juice in excess of twelve-fluid ounces per d[8], 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[47,48], of which Ca and vitamin D play significant roles[49]. OJ consumption is positively associated with serum concentrations and intakes of Ca and vitamin D, as well as femoral bone mineral density and content[50], 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[51], and others[52,53] have identified that deficiencies in micronutrients such as vitamins A and D, P,

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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[32]. These nutrients are also essential for the health and growth of children who are the single largest group of juice consumers[54]. 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[41]. Antioxidants are proposed to be vital mediators in bone metabolism by countering inflammation-mediated bone resorption[55–57]. 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 ≥ 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[33,34,36–38]. 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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## References

1. Caswell H (2009) The role of fruit juice in the diet: an overview. *Nutr Bull* **34**, 273–288.
2. Miller NJ & Rice-Evans CA (1997) The relative contributions of ascorbic acid and phenolic antioxidants to the total antioxidant activity of orange and apple fruit juices and blackcurrant drink. *Food Chem* **60**, 331–337.
3. Rampersaud GC & Valim MF (2017) 100 % citrus juice: nutritional contribution, dietary benefits, and association with anthropometric measures. *Crit Rev Food Sci Nutr* **57**, 129–140.
4. Hossain MK, Dayem AA, Han J *et al.* (2016) Molecular mechanisms of the anti-obesity and anti-diabetic properties of flavonoids. *Int J Mol Sci* **4**, 569.
5. Garcia-Diaz DF, Lopez-Legarrea P, Quintero P *et al.* (2014) Vitamin C in the treatment and/or prevention of obesity. *J Nutr Sci Vitaminol* **60**, 367–379.
6. Bhagwat S & Haytowitz DB (2015) USDA Database for the Flavonoid Content of Selected Foods. Release 3.2. Nutrient Data Laboratory, Beltsville Human Nutrition Research Center, ARS, USDA. https://doi.org/10.15482/USDA.ADC/1324465 (accessed November 2019).
7. Auerbach BJ, Wolf FM, Hikida A *et al.* (2017) Fruit juice and change in BMI: a meta-analysis. *Pediatrics* **139**, e20162454.
8. Dennison BA, Rockwell HL & Baker SL (1997) Excess fruit juice consumption by preschool-aged children is associated with short stature and obesity. *Pediatrics* **99**, 15–22.
9. Faith MS, Dennison BA, Edmunds LS *et al.* (2006) Fruit juice intake predicts increased adiposity gain in children from low-income families: weight status-by-environment interaction. *Pediatrics* **118**, 2066–2075.
10. Tanasescu M, Ferris AM, Himmelgreen DA *et al.* (2000) Biobehavioral factors are associated with obesity in Puerto Rican children. *J Nutr* **130**, 1734–1742.
11. Sanigorski AM, Bell AC & Swinburn BA (2007) Association of key foods and beverages with obesity in Australian school children. *Public Health Nutr* **10**, 152–157.
12. Frantsve-hawley J, Bader JD, Welsh JA *et al.* (2017) A systematic review of the association between consumption of sugar-containing beverages and excess weight gain among children under age 12. *J Public Health Dent* **77**, S43–S66.
13. Crowe-White K, O'Neil CE, Parrott JS *et al.* (2016) Impact of 100 % fruit juice consumption on diet and weight status of children: an evidence-based review. *Crit Rev Food Sci Nutr* **56**, 871–884.
14. Danyliw AD, Vatanparast H, Nikpartow N *et al.* (2012) Beverage patterns among Canadian children and relationship to overweight and obesity. *Appl Physiol Nutr Metab* **37**, 900–906.
15. Wang Y, Lloyd B, Yang M *et al.* (2012) Impact of orange juice consumption on macronutrient and energy intakes and body composition in the US population. *Public Health Nutr* **15**, 2220–2227.
16. Dong D, Bilger M, van Dam RM *et al.* (2015) Consumption of specific foods and beverages and excess weight gain among children and adolescents. *Health Aff* **34**, 1940–1948.
17. Field AE, Gillman MW, Rosner B *et al.* (2003) Association between fruit and vegetable intake and change in body mass index among a large sample of children and adolescents in the United States. *Int J Obes* **27**, 821–826.
18. Papandreou D, Andreou E, Heraclides A *et al.* (2013) Is beverage intake related to overweight and obesity in school children? *Hippokratia* **17**, 42–46.
19. Tam CS, Garnett SP, Cowell CT *et al.* (2006) Soft drink consumption and excess weight gain in Australian school students: results from the Nepean study. *Int J Obes* **30**, 1091–1093.
20. Beck AL, Tschann J, Butte NF *et al.* (2014) Association of beverage consumption with obesity in Mexican American children. *Public Health Nutr* **17**, 338–344.
21. Fiorito LM, Marini M, Francis LA *et al.* (2009) Beverage intake of girls at age 5 year predicts adiposity and weight status in childhood and adolescence. *Am J Clin Nutr* **90**, 935–942.
22. LaRowe T, Moeller S & Adams A (2007) Beverage patterns, diet quality, and body mass index of US preschool and school-aged children. *J Am Diet Assoc* **107**, 1124–1133.
23. Nicklas TA, O'Neil CE & Kleinman R (2008) Association between 100 % juice consumption and nutrient intake and weight of children aged 2 to 11 years. *Arch Pediatr Adolesc Med* **162**, 557–565.
24. Nicklas T, O'Neil C & Fulgoni III V (2015) Consumption of 100 % fruit juice is associated with better nutrient intake and diet quality but not with weight status in children: NHANES 2007–2010. *Int J Child Heal Nutr* **4**, 112–121.
25. O'Neil CE, Nicklas TA & Kleinman R (2010) Relationship between 100 % juice consumption and nutrient intake and weight of adolescents. *Am J Heal Promot* **24**, 31–37.
26. O'Neil CE, Nicklas TA, Rampersaud GC *et al.* (2011) One hundred percent orange juice consumption is associated with better diet quality, improved nutrient adequacy, and no increased risk for overweight/obesity in children. *Nutr Res* **31**, 673–682.
27. Skinner JD, Carruth BR, Moran J *et al.* (1999) Fruit juice intake is not related to children's growth. *Pediatrics* **103**, 58–64.
28. Skinner JD & Carruth BR (2001) A longitudinal study of children's juice intake and growth. *J Am Diet Assoc* **101**, 432–437.
29. Taber DR, Stevens J, Poole C *et al.* (2012) State disparities in time trends of adolescent body mass index percentile and weight-related behaviors in the United States. *J Commun Health* **37**, 242–252.
30. Vanselow MS, Pereira MA, Neumark-Sztainer D *et al.* (2009) Adolescent beverage habits and changes in weight over time: findings from project EAT. *Am J Clin Nutr* **90**, 1489–1495.
31. Heyman MB & Abrams SA (2017) Fruit juice in infants, children, and adolescents: current recommendations. *Pediatrics* **139**, e20170967.
32. U.S. Department of Health and Human Services; U.S. Department of Agriculture (2015) *2015–2020 Dietary*

*Guidelines for Americans*, 8th ed. http://health.gov/dietaryguidelines/2015/guidelines/ (accessed May 2020).
33. Ogden CL, Carroll MD, Kit BK *et al.* (2012) Prevalence of obesity and trends in body mass index among US children and adolescents, 1999–2010. *JAMA* **307**, 483–490.
34. Foehr UG (2006) *Media Multitasking among American Youth: Prevalence, Predictors and Pairings (Report No. 7592)*. Menlo Park, CA: Kaiser Family Foundation.
35. Setty AR, Curhan G & Choi HK (2007) Obesity, waist circumference, weight change, and the risk of psoriasis in women. *Arch Intern Med* **167**, 1670–1675.
36. Goodman E, Hinden BR & Khandelwal S (2000) Accuracy of teen and parental reports of obesity and body mass index. *Pediatrics* **106**, 52–58.
37. Strauss R (1999) Comparison of measured and self-reported weight and height in a cross-sectional sample of young adolescents. *Int J Obes* **23**, 904–908.
38. Elgar FJ, Roberts C, Tudor-Smith C *et al.* (2005) Validity of self-reported height and weight and predictors of bias in adolescents. *J Adolesc Heal* **37**, 371–375.
39. Kuczmarski R, Ogden C, Guo S *et al.* (2002) 2000 CDC growth charts for the United States: methods and development. *Vital Heal Stat* **11**, 1–190.
40. Centers for Disease Control and Prevention: US Department of Health and Human Services (2018) About Child & Teen BMI. https://www.cdc.gov/healthyweight/assessing/bmi/childrens_bmi/about_childrens_bmi.html (accessed June 2020).
41. Yang M, Lee SG, Wang Y *et al.* (2013) Orange juice, a marker of diet quality, contributes to essential micronutrient and antioxidant intakes in the United States population. *J Nutr Educ Behav* **45**, 340–348.
42. Ainsworth BE, Haskell WL, Herrmann SD *et al.* (2011) Second update of codes and MET values. *Med Sci Sport Exerc* **43**, 1575–1581.
43. Cornier M-A, Després J-P, Davis N *et al.* (2011) Assessing adiposity. *Circulation* **124**, 1996–2019.
44. Freedman DS & Sherry B (2009) The validity of BMI as an indicator of body fatness and risk among children. *Pediatrics* **124**, S23–S34.
45. Sakaki JR, Melough MM, Li J *et al.* (2019) Associations between 100 % orange juice consumption and dietary, lifestyle and anthropometric characteristics in a cross-sectional study of U.S. children and adolescents. *Nutrients* **11**, 2687.
46. Field AE, Gillman MW, Rosner B *et al.* (2003) Association between fruit and vegetable intake and change in body mass index among a large sample of children and adolescents in the United States. *Int J Obes* **27**, 821–826.
47. Grasgruber P, Sebera M, Hrazdíra E *et al.* (2016) Major correlates of male height: a study of 105 countries. *Econ Hum Biol* **21**, 172–195.
48. Berkey CS, Colditz GA, Rockett HRH *et al.* (2009) Dairy consumption and female height growth: prospective cohort study. *Cancer Epidemiol Biomarkers Prev* **18**, 1881–1887.
49. Khazai N, Judd SE & Tangpricha V (2008) Calcium and vitamin D: skeletal and extraskeletal health. *Curr Rheumatol Rep* **10**, 110–117.
50. Lee S, Yang M, Wang Y *et al.* (2014) Impact of orange juice consumption on bone health of the U.S. population in the National Health and Nutrition Examination Survey 2003–2006. *J Med Food* **17**, 1142–1150.
51. Fang A, Li K, Li H *et al.* (2017) Low habitual dietary calcium and linear growth from adolescence to young adulthood: results from the China Health and Nutrition Survey. *Sci Rep* **7**, 1–10.
52. Silventoinen K (2003) Determinants of variation in adult body height. *J Biosoc Sci* **35**, 263–285.
53. Allen L (1994) Nutritional influences on linear growth: a general review. *Eur J Clin Nutr* **48**, S75–S89.
54. US Department of Agriculture (2018) What We Eat in America, NHANES 2015–2016. http://www.ars.usda.gov/nea/bhnrc/fsrg (accessed August 2020).
55. Sakaki J, Melough M, Lee S *et al.* (2018) Blackcurrant supplementation improves trabecular bone mass in young but not aged mice. *Nutrients* **10**, 1671.
56. Pasco JA, Henry MJ, Wilkinson LK *et al.* (2006) Antioxidant vitamin supplements and markers of bone turnover in a community sample of nonsmoking women. *J Women's Heal* **15**, 295–300.
57. Sugiura M, Nakamura M, Ogawa K *et al.* (2008) Bone mineral density in post-menopausal female subjects is associated with serum antioxidant carotenoids. *Osteoporos Int* **19**, 211–219.