Trends in Orange Juice Consumption and Nutrient Adequacy in Children 2003-2016

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Abstract: This study aimed to examine secular trends in 100% orange juice (OJ) consumption and trends in nutrient adequacy in children 2-18 years participating in the 2003-2016 National Health and Nutrition Examination Survey. The National Cancer Institute method was used to estimate the usual intake. Ten deciles of OJ consumption were determined based on intakes with non-consumers in the first decile. Nutrient adequacy was determined using the percentage below the Estimated Average Requirement (EAR) or the Adequate Intake (AI) percentage. Linear regression coefficients for changes in intake over time and across deciles of OJ were generated. Approximately 14% of the total sample consumed OJ with a mean intake of 40.0 g/d (77 KJ [0.9% of total energy intake]). Amounts of all 100% fruit juices consumed decreased by 44%, and whole fruit intake increased by approximately 32% from 2003-2016. Consumption of total energy, total carbohydrates, added sugars, and saturated fatty acids decreased. Intakes of folate, riboflavin, zinc, and vitamin C decreased from 2003-2016. The percentage of children below the EAR increased for vitamin C and zinc and decreased for vitamin A from 2003-2016. Percent of children above the AI increased for fiber. Across the deciles of OJ consumption, the percent of children with an inadequate vitamin D intake, calcium, iron, and phosphorus decreased. OJ and other 100% juices were major food sources of many nutrients consumed at levels below recommendations. One strategy to reduce inadequate intake of calcium, phosphorus, and potassium intake is to maintain or increase the consumption of OJ and other 100% juices.

Keywords: Orange juice consumption, 100% fruit juice consumption, secular trends, nutrient intake, nutrient adequacy, NHANES.

1. INTRODUCTION

One hundred percent fruit juices (FJ) contribute various key vitamins, minerals, and other bioactive compounds to the diet. FJ provides, in varying amounts depending on the type of juice [1, 2], vitamin C, potassium, thiamin, folate, vitamin B6, and magnesium as well as numerous phytochemicals. Several studies have investigated the effects of 100 % FJ on nutrient intakes [2-7], diet quality [2, 8, 9], and the health status of consumers [2-4, 9].

Crowe-White *et al*. [3] concluded that "consumption of 100 % FJ within the context of an overall healthy dietary pattern may play a role in preventing nutrient inadequacy without contributing to excess weight gain." Twenty-two studies have provided evidence that did not support an association between 100 % FJ consumption and weight status in children. Limited evidence suggested that children consuming 100% FJ had higher intake and adequacy of vitamin C, potassium, magnesium, and dietary fiber. Similarly, Auerbach *et al*. [4] recently published a meta-analysis on the subject of FJ and childhood and adolescent obesity. Specific to children, no association of FJ consumption was found with a clinically significant weight gain among FJ consumers compared to non-consumers. The same research group published a second meta-analysis examining the connection between 100% FJ consumption and risks for chronic health conditions in children and adults [10]. The results showed no negative health effects of 100% FJ on blood lipids, blood pressure, glucose homeostasis, and no higher risk of cardiovascular disease or diabetes.

The American Academy of Pediatrics (AAP) has recommended that children 1 to 6 years (y) of age should be limited to 113.4 g to 170.1 g/d (4 to 6 fl oz) 100 % FJ, and children 7 to 18 y-old should be limited to 226.8 g to 340.2 g/d (8 to 12 fl oz/d) [11]; however, the scientific basis for these limits have not been clearly established. A recent analysis of the National Health and Nutrition Examination Survey (NHANES) 2003-2010 revealed that usual daily mean fruit consumption by Americans ≥4 y was ~1 cup equivalent, one-third of which was 100 % FJ [12]. A majority (79.6%) of Americans ≥2 y did not meet fruit recommendations [13]. Among 19- to 30-y females, 92.7 % did not meet fruit recommendations [13, 14], and 60 % of 1- to 18-y-old children fell short of meeting the recommendations [15]. However, one study

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showed that the mean daily consumption of 100% FJ was 116.2 g (4.1 fl oz), which contributed a mean intake of 242 KJ (58 kcal) (3.3 % of total energy intake) [5] which is consistent with AAP recommendations [11].

There has been some concern among the scientific community that consumption of 100% FJ may have the unintended consequence of replacing whole fruit consumption, thus impacting nutrient intake. One study found that children who consumed 100% FJ also consumed significantly more servings of total whole fruit than non-consumers [5]. This study suggested that children consuming 100% juice may have an increased preference for fruit overall; thus, helping children to be closer to the fruit recommendations. The US Department of Agriculture conducted a special modeling study for the 2005 Dietary Guidelines Advisory Committee (DGAC) [16] that looked at the effect of removing 100% FJ from the fruit intake and substituting a composite of the whole fruit. The Committee concluded that 100% FJ provided higher amounts of several vitamins and minerals, including vitamin C, folate, Mg, and K, than whole fruits. Dietary fiber was lower when whole fruit was removed from the diet, which led to the recommendation by the DGAC that no more than one-third of fruit servings should come from 100% FJ and two-thirds should come from whole fruit [16]. The 2015 Dietary Guidelines for Americans (DGA) endorsed the same recommendation for 100% FJ consumption, emphasizing that “the majority of the fruit recommendation should come from whole fruit” [17].

Although considerable work has been published regarding 100% FJ consumption, few studies are available on specific types of 100% FJ. One study did find that among types of 100% FJ examined, citrus juices were the most nutrient-dense regardless of the type of density measures used in the evaluation [1]. Orange juice (OJ) is one of the most popular 100% FJ in the United States. A 226 g (8 ounce) serving of OJ provides the following nutrient content; 498 kilojoules (KJ) (119 kilocalories (kcals)), sugars, 20.6 g, 0.74 g dietary fiber, calcium 139 mg, phosphorus 69.4 mg, magnesium 27.3 mg, potassium 441 mg, folate DFE (dietary folate equivalents) 47.1 µg, vitamin C 83.3 mg, and vitamin A RAE (Retinol Activity Equivalents) 4.7 µg [18, 19]. Orange juice provides nearly 100% of the daily value (DV) of vitamin C and approximately 10% of the DV of folate and potassium for children 4-y of age and older. Vitamin C and potassium are among the under-consumed nutrients identified by the 2015-2020 DGA [17].

Few studies have looked at the association between OJ consumption on macronutrient intake, nutrient adequacy, diet quality, and body composition [20-22] in children and adolescents using cross-sectional associations. In a critical review [23], the studies confirmed that moderate consumption of 100% citrus juices, specifically OJ might provide meaningful nutritional benefits without negatively impacting body weight.

To determine nutrient adequacy, the 2015 DGAC [24] examined the intake distribution for eleven vitamins and nine minerals using nutrient intake data from a representative sample of the US population. Data showed that vitamins A, D, E, and C, folate, calcium, and magnesium were under-consumed relative to the Estimated Average Requirement (EAR). Iron was under-consumed by adolescents. Potassium and fiber were under-consumed relative to the Adequate Intake (AI). Calcium, potassium, dietary fiber, and vitamin D were considered nutrients of public health concern because low intakes were associated with health concerns. While OJ, the predominant 100% FJ consumed, contributes to higher intakes of some of these key nutrients in the diets of children [25] per capita consumption has decreased over the past ten years [26], no studies have looked at secular trends in OJ consumption and nutrient adequacy in children over that time. This study's objective was to examine secular trends in OJ consumption along with trends in nutrient intake adequacy from 2003-2016 in children 2-18 years of age (y).

2. METHODS

2.1. Study Design, Subjects, and Demographics

Data from the NHANES were used to assess dietary intakes of children aged 2-18 y. The NHANES is a cross-sectional survey that uses a complex, multistage, probability sampling procedure to provide nationally representative estimates of the non-institutionalized US civilian population's nutritional status. Full details of the sampling framework and analytical considerations can be found elsewhere [27, 28]. NHANES 2003-2016 data age 2-18 y (n=25,295) was used after exclusions of unreliable data (n=3,218) and pregnant or lactating females (n=85); resulting in a total sample of (n=21,995) Sample-weighted data were used in all statistical analyses [28], and all analyses were performed using SAS 9.4 (SAS Institute, Cary, NC) to adjust the variance for the clustered sample design. Means±SEs were determined for nutrient intake and food group consumption for each two-year cycle of NHANES from 2003-2016.

Written informed consent was obtained for all participants, as described in the NHANES interviewer procedures manual [25]. The NHANES protocols were approved by the National Center for Health Statistics ethics review board [29]. Because this was a secondary data analysis with a lack of personal identifiers, this study was exempted by the Institutional Review Boards associated with the co-authors.

To obtain an adequate sample size to produce reliable estimates within this age group, data from seven cycles of NHANES (2003-2016) were combined [30, 31]. Most demographic information was collected via interviews using appropriate cycle questionnaires [32, 33]. Poverty Income Ratio (PIR) was classified into three categories: <1.35, 1.35≤1.85, and >1.85. Weight and height were obtained using the NHANES Anthropometry Procedures Manual [34]. Body mass index (BMI) was calculated as body weight (kilograms) divided by height (meters) squared. Centers for Disease Control and Prevention growth chart programs were used to determine BMI z-scores; children with a BMI≥ the 85th but < 95th, and ≥ the 95th percentiles were considered overweight or obese, respectively [35]. The parent/caregiver self-reported the study child's race or ethnic group according to pre-defined categories used in the NHANES.

2.2. Dietary Intake

An in-person 24-h dietary recall was administered by trained interviewers using an Automated Multiple-Pass Method [25], and a second recall was collected via a telephone interview 3-10 days after the in-person interview. Food intake was assessed using USDA food codes/categories corresponding to What We Eat in America (WWEIA), the dietary component of NHANES [36]. Energy and nutrient intake from foods was determined using the respective Food and Nutrient Database for Dietary Studies (FNDDS) for each NHANES cycle [37] available from total nutrient intake files. The use of supplements was not included in the analyses.

Caretakers of children 2 to 5 y provided the 24-h dietary recalls for their children; children 6 to 11 y were assisted by an adult, and all others provided their own recall. Only recall data judged to be complete and reliable by the National Center for Health Statistics staff were included in these analyses. Detailed descriptions of the dietary recall and data collection are available in the NHANES Dietary Interviewer's Training Manual [38].

Orange juice consumption was determined using the OJ food codes in WWEIA: 61210000 (orange juice, not further specified; 61210010 orange juice freshly squeezed, 61210220 orange juice, canned, bottled or in a carton, 61210250 orange juice with calcium added, canned, bottled or in a carton, 61210620 orange juice, frozen (reconstituted with water), 61210720 orange juice, frozen, not reconstituted, 61210820 orange juice, frozen, with calcium added (reconstituted with water), 67205000 orange juice, baby food. Other 100% juices were defined as other citrus juices other than orange juice (food category: 7002), apple juices (food category: 7004), and other juices (food category: 7006).

2.3. Food Groupings

The What We Eat In America (WWEIA) food category classification system was used to classify all foods consumed [39]. Categorization at the subgroup level (n=48) was used to determine the significant contributors to total nutrient intake. Energy and nutrients from each subgroup of foods were summed across the single 24-h dietary recall for all subjects. Total dietary intakes were obtained by summing intakes across all foods. Sources of energy and nutrients were compared for 2003-2004 and 2015-2016 among and between OJ consumers and non-consumers.

2.4. Statistical Analyses

Usual Intake (UI) of OJ and nutrients was determined using the preferred National Cancer Institute (NCI) method [40]. The NCI macros (Mixtran and Distrib) were used to generate parameter effects after covariate adjustments and estimate UI distribution. The one part NCI model was used for nutrients since most subjects consumed these substances on most days. The two-part model (frequency and amount) was used for OJ usual intakes. Covariates for these analyses were the day of the week of the 24-h recall [coded as a weekend (Friday-Sunday) or weekday (Monday-Thursday)] and sequence of dietary recall (first or second); variance estimates were obtained using the two days of intake with one-day sampling weights. Deciles of OJ consumption were determined based on usual individual intakes with non-consumers in the first decile, and consumers of OJ separated into nine relatively equal intake groups.

Mean intakes and standard errors were generated separately for each survey cycle for OJ, FJ, other juices, total fruit, whole fruit, macronutrients, and 15 vitamins and minerals associated with OJ intake. Linear regression coefficients for changes over time from 2003-2016 were generated. Usual nutrient intake distribution was generated for each decile of OJ consumption, and nutrient adequacy was determined as a percentage below the EAR using the cut-point method [41]. The EAR is the amount of a nutrient that is estimated to meet the requirement for a specific criterion of the adequacy of half of the healthy individuals of a specific age and life stage. Where an EAR was not available, the AI cut-points were used to determine the percent at or below a certain level of intake [41]. Regression analyses using the mean OJ consumption of each decile was generated to assess changes across OJ consumption levels. P-values for statistical significance were set at $p< 0.05$.

3. RESULTS

3.1. Demographics of Consumers and Non-consumers of Orange Juice in Children 2-18 y (Table 1)

Of the total sample (n=21,995), approximately 14% reported consuming OJ with an average mean intake of 40.0 ± 1.7 g/d (1.33 ± 0.06 fl oz); which was equivalent to 77.0 ± 3.3 KJ (18.4 ± 0.8 kcal) or 0.96 ± 0.04% of total energy intake. OJ consumers were more likely to be younger (p=<0.0001), male (p=0.0275), Mexican American (p=<0.0001), Non-Hispanic Black (p=0.0004) and other Hispanic (p=0.0001) and less likely to be Non-Hispanic White (p=<0.0001). OJ consumers were more likely to have a PIR < 1.35% (p=0.0004) and less likely to have a PIR > 1.85% (p=0.0044). OJ consumers reported an additional 669.44 KJ/day (160 kcal/day) compared to non-consumers (p=<0.0001). No significant differences were found in physical activity level and body weight status (i.e., % overweight or obese and BMI z-score).

3.2. Linear Trends in Fruits and Nutrient Intakes among Children from NHANES 2003 to 2016 (Table 2)

Fruits

Although there was no significant trend over time in consumption of total fruits, there was an increase in consumption of whole fruits (β=0.03 cup eq/cycle, p=0.0005) and a decrease in consumption of FJ (β=-0.04 cup eq/cycle, p=< 0.0001), specifically for both OJ (β=-4.46 g/cycle, p=< 0.0001) and other 100 % juices (β=-3.24 g/cycle, p=0.0002).

Macronutrients

Total energy (KJ) intake decreased from 2003-2016 (β=8.98 KJ/cycle, p=<0.0001). This was reflected in a decreased intake of total protein (β=-0.70 g/cycle, p=0.0034), carbohydrate (β=-6.47 g/cycle, p=<0.0001) and total sugars (β=-5.85 g/cycle, p=<0.0001), specifically added sugars (β=-1.12 tsp eq/cycle, p=<0.0001). Total fiber intake increased (β=0.26 g/cycle, p=<0.0001). Total fat intake decreased (β=-0.97 g/cycle, p=<0.0001), specifically saturated fat (β=-0.38 g/cycle, p=0.0001).

Vitamins

There was a significant decrease in intakes of folate (β=- 7.90 μg/cycle, p=0.0006), riboflavin (β=- 0.05 mg/cycle, p=<0.0001), thiamin (β=- 0.01 mg/cycle, p=0.0090), vitamin C (β=- 3.06 mg/cycle, p=<0.0001), and vitamin D (β=-0.08 μg /cycle, p=0.0325) from 2003-2016. For all other vitamins studied, no significant trends were found in intakes.

Minerals

There was a significant decrease in intakes of sodium (β=- 45.3 mg/cycle, p=<0.0001), potassium (β=- 25.1 mg/cycle, p=0.0020), iron (β=- 0.22 mg/cycle, p=0.0001), and zinc (β=- 0.24 mg/cycle, p=<0.0001) from 2003-2016. For all 0.22 minerals studied, no significant trends were found in intakes.

3.3. Linear Trends in Nutrient Adequacy among Children from NHANES 2003-2016 (Table 3)

The percentage of children below the EAR increased for vitamin C (β=1.13 mg/cycle, p=0.0085) and zinc (β=0.85 mg/cycle, p=0.0116) from 2003-2016. However, the percent below the EAR decreased for vitamin A (β=-1.03 μg/cycle, p=0.0195). The percentage of children above the AI increased for dietary fiber (β=0.13 g/cycle, p=0.0364) from 2003-2016.

3.4. Percent below EAR or above AI by Decile of OJ Consumption

Deciles of OJ consumption were determined based on dietary intake data with non-consumers in the first decile and consumers of OJ separated into nine relatively equal groups; mean OJ consumptions of

Table 1: Demographics of Consumers and Non-Consumers of Orange Juice in Children (NHANES 2003-2016)

Variables	Total Population			Non-consumers, OJ			Consumers, OJ			Cons vs Non-Cons		
	N	Mean	SE	N	Mean	SE	N	Mean	SE	Beta	SE	P
Orange Juice Cons (%)	21,995	14.29	0.51	18,465	0.00	0.00	3,530	100.00	0.00	.	.	.
Age (Years)	21,995	10.08	0.07	18,465	10.20	0.07	3,530	9.39	0.12	-0.81	0.14	<0.0001
Gender = Male (%)	21,995	50.77	0.55	18,465	50.29	0.59	3,530	53.68	1.41	3.39	1.52	0.0275
Ethnicity												
Mexican American (%)	21,995	14.34	1.05	18,465	13.50	0.99	3,530	19.35	1.77	5.85	1.20	<0.0001
Other Hispanic (%)	21,995	6.53	0.56	18,465	6.07	0.51	3,530	9.30	1.08	3.24	0.81	0.0001
Non-Hispanic White (%)	21,995	56.84	1.68	18,465	58.55	1.65	3,530	46.58	2.54	-11.98	1.87	<0.0001
Non-Hispanic Black (%)	21,995	14.36	0.94	18,465	13.90	0.92	3,530	17.11	1.32	3.21	0.88	0.0004
Other (%)	21,995	7.93	0.47	18,465	7.98	0.47	3,530	7.66	0.85	-0.32	0.74	0.6648
Poverty Income Ratio (PIR)												
< 1.35 (%)	20,591	34.18	1.16	17,296	33.36	1.16	3,295	39.13	1.85	5.76	1.57	0.0004
1.35 <= 1.85 (%)	20,591	10.81	0.48	17,296	10.85	0.49	3,295	10.53	0.97	-0.32	0.96	0.7367
> 1.85 (%)	20,591	55.01	1.28	17,296	55.79	1.25	3,295	50.35	2.23	-5.44	1.87	0.0044
Physical Activity												
Sedentary	21,520	12.20	0.39	18,092	12.10	0.43	3,428	12.77	0.97	0.67	1.05	0.5256
Moderate	21,520	20.82	0.48	18,092	21.10	0.48	3,428	19.16	1.22	-1.93	1.22	0.1159
Vigorous	21,520	66.98	0.62	18,092	66.80	0.63	3,428	68.07	1.54	1.27	1.54	0.4123
Weight Status												
Overweight (%)	21,712	15.64	0.38	18,222	15.64	0.41	3,490	15.67	1.00	0.03	1.08	0.9800
Overweight or Obese (%)	21,712	32.50	0.68	18,222	32.70	0.72	3,490	31.27	1.47	-1.44	1.54	0.3516
Obese (%)	21,712	16.85	0.52	18,222	17.06	0.56	3,490	15.60	1.03	-1.46	1.09	0.1802
Kilojoules consumed (KJ)	21,995	8140.52	42.26	18,465	8044.70	41.88	3,530	8715.23	106.06	670.49	103.93	<0.0001
Grams of Food	21,995	2156.13	16.49	18,465	2140.87	17.00	3,530	2247.63	28.83	106.76	27.80	0.0002
BMI z score	21,697	0.50	0.02	18,211	0.50	0.02	3,486	0.49	0.03	-0.01	0.03	0.8593

Table 2: Linear Trends in Fruits and Nutrient Intakes Among Children from NHANES 2003 to 2016

	2003-2004		2005-2006		2007-2008		2009-2010		2011-2012		2013-2014		2015-2016		Linear Trend		
Variable	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Beta	SE	P
Total fruits (cup eq)	1.08	0.06	1.05	0.03	1.11	0.06	1.14	0.06	1.17	0.05	1.03	0.04	0.98	0.04	-0.01	0.01	0.2493
Whole fruits (cup eq)	0.49	0.04	0.55	0.02	0.69	0.06	0.71	0.04	0.72	0.04	0.66	0.03	0.65	0.04	0.03	0.01	0.0005
Fruit juices (cup eq)	0.59	0.03	0.50	0.02	0.42	0.02	0.43	0.03	0.45	0.03	0.38	0.02	0.33	0.02	-0.04	0.01	<0.0001
Orange Juice (g)	61.35	7.32	41.19	2.90	39.44	3.79	41.08	5.12	38.75	3.81	33.56	3.35	24.99	3.43	-4.46	0.94	<0.0001
Other 100% Juice (g)	68.66	4.43	69.71	5.25	60.62	3.39	55.89	4.09	59.88	6.53	52.67	4.09	49.99	4.08	-3.24	0.84	0.0002
Total Energy (kJ)	506	6	484	8	456	6	456	6	462	6	447	6	445	6	-8.98	1.14	<0.0001
Protein (g)	72.68	1.33	70.47	1.42	67.61	1.09	68.41	1.18	68.27	1.18	69.10	1.26	66.82	1.05	-0.70	0.23	0.0034
Carbohydrate (g)	286	4	271	4	255	3	258	4	261	3	245	3	240	3	-6.47	0.64	<0.0001
Total sugars (tsp eq)	147	2	137	3	128	2	126	1	127	2	114	2	108	2	-5.85	0.43	<0.0001
Added sugars (g)	23.13	0.58	21.20	0.68	19.64	0.35	18.67	0.44	18.59	0.42	16.76	0.42	15.93	0.43	-1.12	0.10	<0.0001
Dietary fiber (g)	12.82	0.29	12.82	0.25	12.70	0.34	13.64	0.24	14.19	0.22	13.84	0.23	14.07	0.22	0.26	0.05	<0.0001
Total fat (g)	78.36	0.86	75.68	1.42	70.65	1.26	69.10	1.07	70.75	1.19	70.29	1.30	72.75	1.18	-0.97	0.23	<0.0001
Saturated fat (g)	27.58	0.34	26.81	0.52	24.92	0.45	24.09	0.38	24.68	0.46	24.60	0.50	25.58	0.53	-0.38	0.09	0.0001
Folate, DFE (µg)	566	13	529	11	499	10	521	15	517	9	507	14	501	10	-7.90	2.23	0.0006
Niacin (mg)	21.25	0.50	21.58	0.53	20.82	0.55	20.90	0.36	21.01	0.41	21.77	0.48	21.27	0.41	0.02	0.09	0.7928
Riboflavin (mg)	2.26	0.05	2.15	0.05	2.04	0.04	1.96	0.04	1.95	0.02	1.98	0.04	1.90	0.04	-0.05	0.01	<0.0001
Thiamin (mg)	1.65	0.03	1.58	0.02	1.49	0.02	1.54	0.04	1.53	0.03	1.55	0.03	1.52	0.02	-0.01	0.01	0.0090
Vitamin A, RAE (µg)	560	23	583	17	592	15	589	15	597	11	595	15	591	18	4.27	3.61	0.2400
Vitamin B6 (mg)	1.73	0.05	1.72	0.05	1.72	0.05	1.66	0.03	1.71	0.03	1.78	0.04	1.68	0.04	0.00	0.01	0.9012
Vitamin C (mg)	89.86	3.55	81.70	2.10	82.99	3.11	79.13	2.87	80.07	4.35	73.52	1.87	67.82	3.23	-3.06	0.59	<0.0001
Vitamin D (D2 + D3) (µg)	6.19	0.22	5.63	0.18	5.29	0.12	6.01	0.13	5.99	0.15	5.36	0.12	5.37	0.22	-0.08	0.04	0.0325
Calcium (mg)	1029	27	994	22	985	19	1064	19	1065	18	1022	21	977	26	-0.76	4.63	0.8702
Iron (mg)	15.37	0.29	14.92	0.25	13.49	0.27	13.81	0.26	14.13	0.23	13.80	0.29	13.85	0.31	-0.22	0.05	0.0001
Magnesium (mg)	232	4	230	4	224	4	238	3	238	3	233	3	231	4	0.65	0.73	0.3746
Phosphorus (mg)	1291	24	1240	23	1204	18	1292	21	1286	17	1269	18	1234	23	-1.14	4.25	0.7892
Potassium (mg)	2326	54	2208	42	2117	42	2227	36	2236	31	2154	31	2088	30	-25.09	7.91	0.0020
Sodium (mg)	3267	44	3214	54	3050	70	3056	65	3025	67	2999	43	2994	37	-45.32	8.70	<0.0001
Zinc (mg)	11.55	0.21	10.75	0.24	10.21	0.18	10.23	0.15	9.87	0.20	9.98	0.19	9.92	0.20	-0.24	0.04	<0.0001

Table 3: Linear Trends in Percentage of the Population below the EAR*/above the AI* among Children from NHANES 2003-2016

	Cutoff	2003-2004		2005-2006		2007-2008		2009-2010		2011-2012		2013-2014		2015-2016		Linear Trend		
Variable	%	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Beta	SE	P
Protein (g)	EAR (% Below)	0.38	0.17	0.43	0.20	0.63	0.30	0.06	0.07	0.18	0.09	1.01	0.67	0.46	0.22	-0.02	0.05	0.7127
Carbohydrate (g)	EAR (% Below)	0.08	0.06	0.21	0.09	0.24	0.13	0.07	0.06	0.02	0.03	0.19	0.10	0.32	0.09	0.00	0.02	0.9223
Dietary fiber (g)	AI (% Above)	0.41	0.19	0.29	0.13	0.39	0.12	0.77	0.12	0.93	0.35	1.41	0.44	0.78	0.25	0.13	0.05	0.0364
Niacin (mg)	EAR (% Below)	0.31	0.17	0.39	0.15	0.31	0.20	0.11	0.12	0.03	0.04	0.68	0.54	0.30	0.23	-0.07	0.03	0.0909
Thiamin (Vitamin B1) (mg)	EAR (% Below)	1.13	0.43	1.05	0.35	1.66	0.55	0.85	0.31	0.54	0.40	2.53	1.11	0.81	0.35	-0.06	0.07	0.4434
Vitamin A, RAE (µg)	EAR (% Below)	29.42	2.36	26.92	1.72	24.08	2.61	22.63	2.66	23.50	1.79	24.78	2.92	22.50	3.20	-1.03	0.30	0.0195
Vitamin B6 (mg)	EAR (% Below)	3.00	0.67	2.08	0.48	1.69	0.52	1.98	0.74	1.02	0.54	2.85	1.53	1.82	0.72	-0.18	0.12	0.1780
Vitamin C (mg)	EAR (% Below)	18.33	2.29	15.87	1.65	17.66	2.43	18.85	1.84	19.26	2.51	21.30	2.36	23.82	2.13	1.13	0.27	0.0085
Vitamin D (D2 + D3) (µg)	EAR (% Below)	86.93	1.73	91.18	1.49	93.42	0.85	90.86	0.81	90.90	1.47	93.25	1.28	94.09	0.98	0.62	0.37	0.1569
Calcium (mg)	EAR (% Below)	47.11	1.99	48.81	1.40	49.69	1.62	41.17	2.15	39.48	1.16	45.97	2.12	49.46	3.48	-1.44	0.94	0.1854
Iron (mg)	EAR (% Below)	1.38	0.31	1.28	0.20	2.80	0.47	1.99	0.35	1.73	0.49	3.64	0.93	2.34	0.43	0.21	0.10	0.0867
Magnesium (mg)	EAR (% Below)	36.92	1.88	36.63	1.52	38.05	1.41	33.93	1.61	32.23	1.01	36.84	1.84	35.33	2.24	-0.69	0.52	0.2405
Phosphorus (mg)	EAR (% Below)	15.22	1.63	16.48	1.45	18.23	1.46	9.76	1.69	11.46	1.17	16.28	2.18	14.18	2.73	-0.77	0.68	0.3108
Potassium (mg)	AI (% Above)	41.68	2.83	34.60	2.14	29.91	2.05	35.98	2.34	36.90	1.70	31.64	1.72	27.63	2.48	-1.10	0.81	0.2325
Riboflavin (Vitamin B2) (mg)	EAR (% Below)	0.69	0.27	0.53	0.21	0.63	0.22	0.72	0.27	0.49	0.32	1.61	0.94	0.67	0.36	0.01	0.04	0.7260
Sodium (mg)	AI (% Above)	99.91	0.06	99.91	0.07	99.76	0.13	99.97	0.04	99.98	0.02	99.79	0.19	99.92	0.05	0.01	0.01	0.5040
Zinc (mg)	EAR (% Below)	4.02	0.94	5.29	0.90	7.40	1.54	5.43	1.37	7.28	1.24	11.88	2.72	9.02	1.77	0.85	0.22	0.0116

*EAR: Estimated Average Requirement; AI: Adequate Intake.

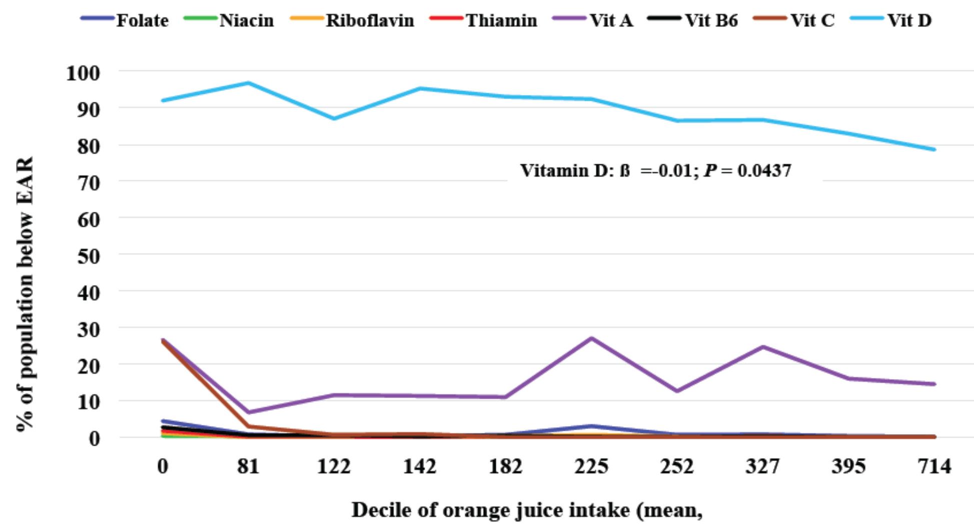

Figure 1: Percentage of Children 2-18 y (National Health And Nutrition Examination Survey 2003–2016) with Intakes Below the Estimated Average Requirement (EAR) for Select Vitamins by Decile of Orange Juice (OJ) Consumption. Regression Analysis (ß: regression coefficient) was Used to Assess if a Linear Association Existed with OJ Consumption. Only Associations Significant at $p < 0.05$ are Presented.

decile 1, decile 5, and decile 10 were 0, 182, and 714 g/d. All regression coefficients for assessing change in percentage below the EAR/above the AI across deciles of OJ consumption are presented in Supplemental Table **1**.

Vitamin D

For every gram of OJ consumed, the percent of the population with inadequate vitamin D intake decreased by 0.01 percentage units (Figure **1**). In other words, for every 120 g (4 fl oz) of OJ consumed, the percent of the population with inadequate intake decreased 1.2 percentage points.

Calcium

For every gram of OJ consumed, the percent of the population with an inadequate intake of calcium decreased 0.07 percentage units (Figure **2**); for every 120 g (4 fl oz) of OJ consumed the percent of the population with inadequate intake decreased 8.4 percentage units. The most significant drop in the percent with inadequate intake was between decile 1 (0

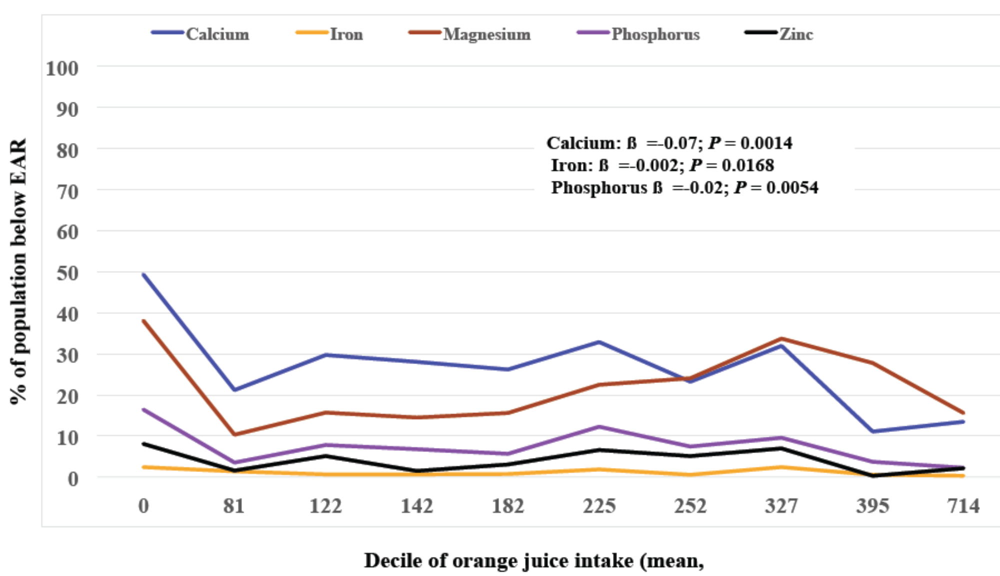

Figure 2: Percentage of Children 2-18 y (National Health And Nutrition Examination Survey 2003–2016) with Intakes Below the Estimated Average Requirement (EAR) for Select Minerals by Decile of Orange Juice (OJ) Consumption. Regression Analysis (ß: regression coefficient) was Used to Assess if a Linear Association Existed with OJ Consumption. Only Associations Significant at $p < 0.05$ are Presented.

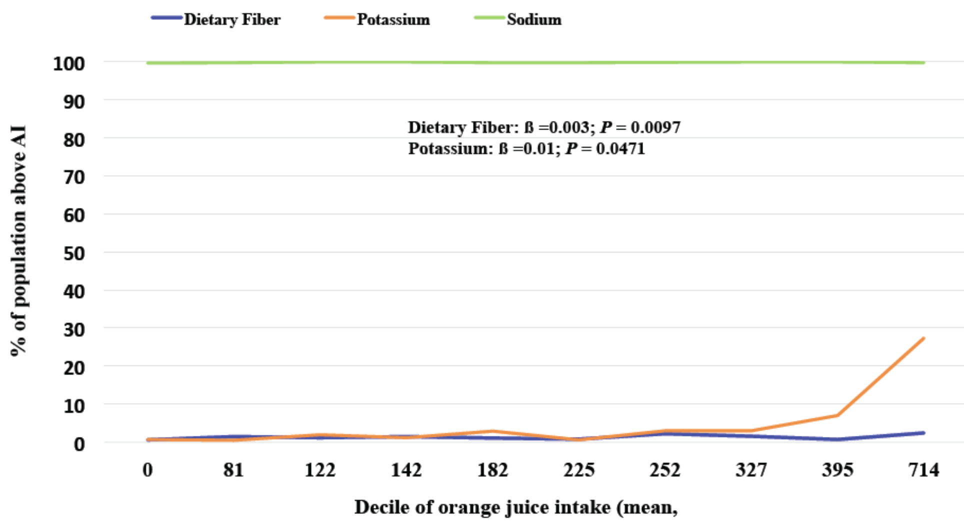

Figure 3: Percentage of Children 2-18 y (National Health And Nutrition Examination Survey 2003–2016) with Intakes Above Adequate Intake (AI) of Orange Juice (OJ) Consumption. Regression Analysis (ß: regression coefficient) was used to Assess if a Linear Association Existed with OJ Consumption. Only Associations Significant at $p < 0.05$ are Presented.

g of OJ consumed; 49%) and decile 2 (81-122 g of OJ consumed; 21%) with only 14% with inadequate intake in decile 10 (>714 g of OJ consumed).

Iron

For every gram of OJ consumed, the percent of the population with an inadequate intake of iron decreased 0.002 percentage units (Figure **2**). In other words, for every 120 g (4 fl oz) of OJ consumed, the percent of the population with inadequate intake decreased by 0.24 percentage units. The largest drop in the percent with inadequate intake was between decile 1 (0 g; 2%) and decile 2 (81-122 g; 1%) with only 0.3% with inadequate intake in decile 10 (714 g of OJ consumed).

Phosphorus

For every gram of OJ consumed, the percent of the population with an inadequate intake of phosphorus decreased by 0.02 percentage units (Figure **2**); for every 120 g (4 fl oz) of OJ consumed the percent of the population with inadequate intake decreased 2.4 percentage units. The largest drop in the percent with inadequate intake was between decile 1 (16%) and decile 2 (4%), with only 2% with inadequate intake in decile 10.

Dietary Fiber

For every gram of OJ consumed, the percent of the population above the AI for dietary fiber increased by 0.003 percentage units (Figure **3**). Thus, for every 120 g (4 fl oz) of OJ consumed, the population's percent with the adequate intake increased 0.36 percentage units.

Potassium

For every gram of OJ consumed, the percent of the population with adequate intake of potassium increased 0.01 percentage units (Figure **3**); for every 120 g (4 fl oz) of OJ consumed the percent of the population with the adequate intake increased 1.2 percentage units.

For other nutrients evaluated (niacin, riboflavin, thiamine, vitamins A, C, magnesium, and zinc), there were no significant associations of changes in the percentage of the population below the EAR/above the AI across deciles of OJ intake.

3.5. Major Food Sources of Energy and Nutrient Intake by Orange Juice Consumption and Survey Year

Energy

The food sources of energy intake by OJ consumption that were significantly different for NHANES survey years 2003-2004 and 2015-2016 are presented in Table **4**. Only the food sources of energy intake that were significantly different among OJ consumers and non-consumers are presented. Of the increased energy in 2003-2004 among OJ consumers (431 KJ) as compared to non-consumers, mostly was due to consumption of OJ (594 KJ) and other 100% juices (512 KJ) with a concomitant decrease in consumption of sweetened beverages (-276 KJ), candy (-72 KJ), white potatoes (-72 KJ) and coffee and tea (-25 KJ). In 2015-2016, the increased energy among OJ consumers (653 KJ) as compared to non-consumers

Table 4: Significant Food Sources of Energy Intake (KJ) of Children 2-18 y of Age by Orange Juice Consumption and by Survey Year

Significant food groups	2003-2004 Energy Intake (KJ) of Children 2-18 Years of Age						
	OJ consumers		OJ non-consumers		OJ consumers vs OJ non-consumers		
	Mean	SE	Mean	SE	Beta	SE	P value
All Foods	9216.50	207.11	8785.40	103.76	431.12	226.19	0.0760
Orange Juice	594.30	42.10	0.00	0.00	594.30	42.09	<0.0001
100% Juice	667.70	40.54	155.90	10.54	511.79	40.79	<0.0001
Sweetened Beverages	620.00	30.04	896.30	38.03	-276.35	40.79	<0.0001
Diet Beverages	1.10	0.33	4.60	1.09	-3.56	1.26	0.0118
Candy	161.40	30.17	234.10	20.71	-72.76	28.49	0.0221
Coffee and Tea	22.20	8.12	46.80	6.61	-24.60	10.17	0.0286
White Potatoes	260.80	25.44	333.10	30.46	-72.26	32.89	0.0442
2015-2016 Energy Intake (KJ) of Children 2-18 Years of Age							
All Foods	8372.90	184.05	7719.70	105.31	653.21	189.95	0.0037
Orange Juice	465.90	16.69	0.00	0.00	465.89	16.69	<0.0001
100% Juice	520.80	19.92	104.60	8.95	416.22	18.41	<0.0001
Diet Beverages	0.30	0.13	0,70	0.29	-1.42	0.25	0.0001
Coffee and Tea	32.60	6.32	73.80	12.30	-41.17	11.00	0.0020
Sweetened Beverages	296.00	29.71	408.10	15.61	-112.09	31.34	0.0027
Eggs	229.00	41.42	109.70	10.29	119.29	44.18	0.0165

was mostly due to consumption of OJ and other 100% juice (416 KJ) with a concomitant decrease in consumption of sweetened beverages (-112 KJ) and coffee and tea (-41 KJ), but with also an increase in consumption of eggs (119 KJ).

Significant food sources for all nutrients that showed a significant association of changes in the percentage of the population below the EAR/above the AI across deciles of OJ consumption are presented by survey year in Supplemental Tables **2-7**. The significant differences in food sources of iron (<1 g), fiber (<1 g), and vitamin D intake (<1 µg) among OJ consumers and non-consumers were very small. The most notable differences were found in the food sources of calcium, potassium, and phosphorus.

Calcium

Of the increase in calcium intake in 2003-2004 among OJ consumers (232 mg) as compared to non-consumers, most was due to consumption of OJ (176 mg) and 100% juice (173 mg) with a concomitant decrease in calcium from sweetened beverages (-9 mg) and sweet bakery products (-3 mg). In 2015-2016, the increased calcium intake among OJ consumers (170 mg) as compared to non-consumers was mostly due to consumption of OJ (134), 100% juice (130 mg), eggs (13 mg) and fruits (4 mg) with a concomitant decrease in consumption of coffee/tea (-3 g).

Potassium

Of the increase in potassium intake in 2003-2004 among OJ consumers (684 mg) as compared to non-consumers, most was due to consumption of OJ (593 mg) and 100% juice (414 mg) with a concomitant decrease in consumption of coffee/tea (-15 mg) and candy (-7 mg). In 2015-2016, the increased potassium intake among OJ consumers (508 mg) as compared to non-consumers, most was due to consumption of OJ (514 mg), 100% juice (387 mg), eggs (28 mg), and fruits (40 mg) with a concomitant decrease in consumption of coffee/tea (-17 mg).

Phosphorus

Of the increase in phosphorus intake in 2003-2004 among OJ consumers (120 mg) as compared to non-consumers, most was due to consumption of OJ (48 mg) and 100% juice (45 mg) with a concomitant decrease in consumption of candy (-4 mg). In 2015-2016, the increased phosphorus intake among OJ consumers (147 mg) as compared to non-consumers, most was due to consumption of OJ (66 mg), 100% juice (64 mg), eggs (31 mg) and fruits (4 mg) with a concomitant decrease in consumption of sweetened beverages (-8 mg) and coffee/tea (8 mg).

4. DISCUSSION

Approximately 14% of the total sample of children 2-18 y reported consuming OJ with an average mean intake of 40.0 g/d (1.33 fl oz), equivalent to 77 KJ (18.4 kcal) or 0.9% of total energy intake. On average, children consumed OJ well below the AAP recommendation [11]. OJ consumers were more likely to be younger, confirmed in a previous study [20]. No significant differences were found in weight status, which also agrees with that found in previous studies relevant to OJ consumption in children [20, 21].

The intake of fruits and nutrients has significantly changed in the diets of children from 2003-2016. The amount of all 100% FJ consumed decreased 44% from 2003 (0.59 cup eq) to 2016 (0.33 cup eq), while whole fruit increased about 32% (0.49 cup eq in 2003 to 0.65 cup eq in 2015-2016). The proportion of total fruit from whole fruit increased from approximately 45% (2003) to approximately 65% in 2016. This is consistent with the latest vital signs report by the Centers for Disease Control and Prevention [12]. The most recent intake of whole fruit is consistent with the 2015 DGA recommendation that approximately two-thirds of total fruit should come from whole fruit [17] concomitant with an increase in whole fruit the consumption of FJ, 100% FJ and specifically OJ, significantly decreased (~44 and ~59%, respectively); thus explaining why there was no significant trend over time in consumption of total fruits. The current amount of total fruit consumed (0.99 cup eq) is well below the recommended intake of fruit for children [17] thus while the proportion of total fruit as FJ was in line with recommendations total fruit intake needs to increase 50-100% depending on age and gender [42]. Sixty percent of children do not eat enough fruit to meet daily recommendations [12].

The nutrient intake has also significantly changed from 2003 to 2016. Total energy intake decreased, reflected in the reduced intake of total carbohydrates, total sugars (specifically added sugars), and total fat (specifically saturated fatty acids). The total intake of fiber increased with no significant change in total protein. Intakes of folate, riboflavin, zinc, and vitamin C decreased from 2003-2016. Two of these nutrients, folate, and vitamin C, were identified as being under-consumed relative to the EAR [17]. On a positive note, intakes of sodium decreased; however, 90% of children still exceed the current sodium recommendation [43]. To our knowledge, this is the first study to report on linear trends in nutrient adequacy among children from 2003-2016. The percentage of children below the EAR increased for vitamin C and zinc but decreased for vitamin A. The percent of children above the AI increased for dietary fiber.

Given that this paper's major focus was on trends in OJ consumption and nutrient adequacy from 2003-2016, the most notable trends were found in the percent below the EAR or above AI for six nutrients: vitamin D, calcium, iron, phosphorus, dietary fiber, and potassium. Across the deciles of OJ consumption, the percent of children with an inadequate intake of vitamin D, calcium, iron, and phosphorus decreased. The largest drop in the percent of children with insufficient intake was between decile 1 (0 g of OJ consumed) and decile 2 (81-122 g of OJ consumed). The percent of children above the AI increased for fiber and potassium; however, the increases were minimal and likely insignificant clinically.

To better understand the trends in nutrient adequacy by OJ consumption, food sources of the significant nutrients were explored for the survey year 2003-2004 compared to survey the year 2015-2016. Of the increased energy in 2003-2004 among OJ consumers compared to non-consumers was mostly due to OJ consumption and other 100% FJ with a concomitant decrease in consumption of sweetened beverages, candy, white potatoes, and coffee/tea. In 2015-2016, the increase in energy among OJ consumers compared to non-consumers was mostly due to OJ's consumption, other 100% FJ and eggs with a concomitant decrease in consumption of sweetened beverages and coffee/tea.

The significant food sources of iron, fiber, and vitamin D intake among OJ consumers and non-consumers were very small. The most notable differences were found in the food sources of calcium, potassium, and phosphorus. For the most part, the increase in calcium, potassium, and phosphorus was mostly due to increased OJ consumption and other 100% FJ, with small increases in the consumption of eggs and fruits. These increases were reflected in a decreased consumption of sweetened beverages and coffee/tea. Smaller decreases were shown in intakes of sweet bakery products and candy depending on the nutrient and survey year.

Strengths of this study include that it encompassed a large nationally representative sample achieved through combining several sets of NHANES releases, use of 2-days of intake, and the NCI method to assess UI of OJ and the percentage of the population below recommended levels over time and across levels of OJ consumption. Identifying food sources of energy and nutrients for 2003-2004 and 2015-2016 for OJ consumers and non-consumers provided greater insight into the dietary patterns of these groups and strengthened the identification of OJ as the likely sources of changes in intake while also identify major pattern shifts (e.g., lower sweetened beverage consumption in OJ consumers).

This study's limitations are that NHANES is a cross-sectional study; thus, cause and effect relationships cannot be determined. Intake was self-reported, and subjects or caregivers relied on the memory of what they ate and underreporting, or over-reporting of intake could have occurred. Caregivers reported or assisted with the 24-hour recalls of children 2 to 11 y. However, parents may often report accurately what children eat at home [44], they may not know what their children eat outside the home [45], which could result in reporting errors [46]. The possibility that self-reported data may include other juice cocktails and drinks that are not in the definition of 100% juice is possible, and it is also well documented that energy intakes are under-reported, particularly among overweight individuals [47-50]. Finally, examining linear trends in nutrient intake and nutrient adequacy across OJ deciles does not imply that OJ consumption was solely associated with some nutrients' nutrient adequacy. It can be seen that there were differences in other food sources of nutrients among OJ consumers.

In conclusion, there were changes in intake and nutrient adequacy from 2003-2004 to 2015-2016. There were also changes in the percentage of population below EAR/above AI across OJ consumption levels for some nutrients. These results suggest that consumption of OJ and other 100% FJ were major food sources of select nutrients that were inadequate among children. The data also suggest that significant food sources of vitamin D, calcium, iron, and phosphorus varied among OJ consumers compared to non-consumers. Among OJ consumers compared to non-consumers, there was a concomitant decrease in the intake of coffee/tea and sweetened beverages, and to a lesser degree, for sweet bakery products, candy, eggs, and fruits. One possible strategy to decrease inadequate intake of calcium, potassium, and phosphorus is to increase the consumption of OJ and other 100% FJ and decrease the consumption of sweetened beverages and coffee/tea.

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APPENDIX

AAP = American Academy of Pediatrics

BMI = Body Mass Index

cup eq = Cup equivalent

DGA = Dietary Guidelines for Americans

DGAC = Dietary Guidelines Advisory Committee

DFE = Dietary Folate Equivalents

EAR = Estimated Average Requirement

FJ = Fruit juice

Fl oz = Fluid ounce

g = Grams

h = hour

Kcal = kilocalorie

KJ = kilojoule

mg = milligram

μg = microgram

NCI = National Cancer Institute

NHANES = National Health and Nutrition Examination Survey

OJ = Orange juice

PIR = Poverty income ratio

UI = Usual intake

WWEIA = What We Eat In America

y = year/s

SUPPLEMENTAL TABLES

The supplemental tables can be downloaded from the journal website along with the article.

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