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Ultra-processed foods and added sugars in the US diet

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Keywords: ultra-processed, added sugars, dietary intake, NHANES, US.

ABSTRACT

Objectives: To investigate the contribution of ultra-processed foods to the intake of added sugars in the US.

Food items were classified according to extent and purpose of industrial food processing. Ultra-processed foods were defined as formulations manufactured mostly or entirely from substances extracted from foods or obtained from further processing of constituents of foods.

Design: Cross- sectional study.

Setting: *National Health and Nutrition Examination Survey* 2009-2010.

Participants: We evaluated 9,317 participants aged 1+ years with at least one 24-hour dietary recall.

Main outcome measures: Average dietary content of added sugars and proportion of individuals consuming more than 10% of total energy from added sugars.

Data analysis: Gaussian and Poisson regressions estimated the association between consumption of ultra-processed foods and intake of added sugars. All models incorporated survey sample weights and adjusted for age, sex, race/ethnicity, and family income.

Results: Ultra-processed foods comprised 57.5% of energy intake, and contributed 89.7% of the energy intake from added sugars. The content of added sugars in ultra-processed foods (20.8% of calories) was 9-fold higher than in processed foods (2.3%) and 5-fold higher than in unprocessed or minimally processed foods and processed culinary ingredients grouped together (3.6%). In both unadjusted and adjusted models, each increase of 5 percentage points in proportional energy intake from ultra-processed foods increased the proportional energy intake from added sugars by 1 percentage point. Consumption of added sugars increased linearly across quintiles of ultra-processed food consumption: from 7.8% of total energy in the lowest quintile to 19.2% in the highest. A total of 85.8% of Americans in the highest quintile exceeded the recommended limit of 10% energy from added sugars, compared with 28.9% in the lowest.

Conclusions: Decreasing the consumption of ultra-processed foods could be an effective way of reducing the excessive intake of added sugars in the US.

Strengths and limitations of this study:

- Use of a large, nationally representative sample of the US population, increasing generalizability.
- Use of data on added sugars rather than total sugars or sugar-sweetened beverages, which corresponds to guidelines relevant area of prioritization.
- Unlike most articles which have focused on specific food items such as soft drinks or fast food, our study evaluates the impact of a comprehensive group of products whose consumption is increasing exponentially in most countries.
- Dietary data obtained by 24-hour recalls is subjected to potential error and bias.

- Information indicative of food processing is not consistently determined for all food items in NHANES, which could lead to modest over or underestimation of the consumption of ultra-processed foods.

INTRODUCTION

Increasing policy attention has focused on added sugars, including by the World Health Organization (WHO)(1), the United Kingdom National Health System(2), the Canadian Heart and Stroke Foundation(3), the American Heart Association (AHA)(*4*), and the US Dietary Guidelines Advisory Committee (USDGAC)(*5*).

These reports concluded that a high intake of added sugars increases risk for weight gain(1,4,5), excess body weight(5) and obesity(3,5); type 2 diabetes mellitus(3,5); higher serum triglycerides(5) and high blood cholesterol(3); higher blood pressure(5) and hypertension(5); stroke(3,5); coronary heart disease(3,5); cancer(3); and dental caries(1,3,5). Moreover, foods higher in added sugars are often a source of empty calories with minimum essential nutrients or dietary fiber(6-8), which displace more nutrient-dense foods(9) and lead, in turn, to simultaneously overfed and undernourished individuals.

All reports recommended limiting intake of added sugars(1,3-5*)*. In the US, the USDGAC recommended limiting added sugars to no more than 10% of total calories. This is a challenge, as recent consumption of added sugars in the US amounted to almost 15% of total calories in 2005-2010(10,11).

To design and implement effective measures to reduce added sugars, their dietary sources must be clearly identified. Added sugars can be consumed either as ingredients of dishes or drinks prepared from scratch by consumers or cook, or as ingredients of food products manufactured by the food industry. According to market disappearance data from 2014, more than three quarters of the sugar and high fructose corn syrup available for human consumption in the US were used by the food industry(12). This suggests food products manufactured by the industry could have an important role in the excess added sugars consumption in the US. However, to assess this role, it is essential to consider the contribution of manufactured food products to both total energy intake and the energy intake from added sugars, and, more relevantly, to quantify the relationship between their consumption and the total dietary content of added sugars. To address these questions, we performed an investigation utilizing 2009-2010 *National Health and Nutrition Examination Survey (NHANES).*

SUBJECTS AND METHODS

Data source, population and sampling

We utilized nationally representative data from the 2009-2010 *National Health and Nutrition Examination Survey (NHANES),* specifically the dietary component *What we eat in America (WWEIA)*(13).

NHANES is a continuous, nationally representative, cross-sectional survey of the non-institutionalized, civilian US residents(14). NHANES sample was obtained by using a complex, stratified, multi-stage probability cluster sampling design, based on the selection of counties, blocks, households, and the number of people within households(14). In order to improve the estimate precision and reliability, NHANES 2009-2010 oversampled the following subgroups: Hispanic, Non-Hispanic black, Non-Hispanic white and Other persons at or below 130% of the federal poverty level and Non-Hispanic white and Other persons aged 80 + years(14).

All NHANES examinees were eligible for two 24-hour dietary recall interviews. The first dietary recall interview was collected in-person in the mobile examination center (MEC)(15) while the second was collected by telephone 3 to 10 days later(16). Dietary interviews were conducted by trained interviewers using the validated(17-19) *US Department of Agriculture Automated Multiple-Pass Method (AMPM)*(20).

Among the 13,272 people screened in NHANES 2009-2010, 10,537 (79.4%) participated in the household interview and 10253 (77.3%) also participated in the MEC health examination(21). Of these, 9,754 individuals provided one day of complete dietary intakes and 8,406 provided two days(22).

We evaluated 9,317 survey participants aged 1 year and above who had one day 24-hour dietary recall data and had not been breast-fed on either of the two days. These individuals had similar socio-demographic characteristics to the full sample of 10,109 participants interviewed.

Food classification according to processing

We classified all recorded food items (N=280,132 Food Codes) according to NOVA, a food classification based on the extent and purpose of industrial food processing(23-25). This classification includes 4 groups: “unprocessed or minimally processed foods” (such as fresh, dry or frozen fruits or vegetables, grains, legumes, meat, fish and milk); “processed culinary ingredients” (including table sugar, oils, fats, salt, and other substances extracted from foods or from nature, and used in kitchens to make culinary preparations), “processed foods” (foods manufactured with the addition of salt or sugar or other substances of culinary use to unprocessed or minimally processed foods, such as simple cheese, bread and canned food), and “ultra-processed foods” (formulations manufactured mostly or entirely from starches, sugars, oils, fats, proteins, and other substances extracted from foods or obtained from the further processing of constituents of foods or other organic sources, with little if any whole foods). A detailed definition of each food group and examples of food items classified in each group are shown in **Supplementary Table 1**. The rationale underlying the classification is described elsewhere(26-29).

For all food items (Food Codes) judged to be a handmade recipe, the classification was applied to the underlying ingredients (Standard Reference Codes -SR Codes-) obtained from the USDA Food and Nutrient Database for

Dietary Studies (FNDDS) 5.0(30). Refer to Online Supplementary Material (OSM) for further details.

Assessing energy and added sugar contents

For this study, we used Food Code energy values as provided by NHANES.

For handmade recipes, we calculated the underlying ingredient (SR Code) energy values using variables from both *FNDDS 5.0*(30) and *USDA National Nutrient Database for Standard Reference, Release 24 (SR24)*(31). Refer to OSM for further details.

Data on added sugars per Food Code and per SR Code were obtained by merging the Food Patterns Equivalents Database (FPED) 2009-2010 and the Food Patterns Equivalents Ingredients Database (FPID) 2009-2010(32). Added sugars are defined in these databases as “sugars that are added to foods as an ingredient during preparation, processing, or at the table. Added sugars do not include naturally occurring sugars (e.g., lactose in milk, fructose in fruits). Examples of added sugars include brown sugar, cane sugar, confectioners’ sugar, granulated sugar, dextrose, white sugar, corn syrup and corn syrup solids, molasses, honey, and all types of syrups such as maple syrup, table syrups, and pancake syrup”(32). These two databases express the content of added sugars in teaspoons per 100 g. Teaspoons were converted into grams using the factor 4.2 g/teaspoon and into kcal using the factor 3.87 kcal/g.

Data Analysis

We utilized all available dietary data for each participant, using means of both recall days when available (86% of participants). Food items were sorted into mutually exclusive food subgroups within Unprocessed or minimally processed foods (n= 11), Processed culinary ingredients (n=4), Processed foods (n=4) and Ultra-processed foods (n=18), as shown in Table 1. First, we evaluated the contributions of each of the NOVA food groups and subgroups to total energy and to the energy from added sugars. Next, we calculated the average content of added sugars in the overall US diet and in fractions of this diet composed by each of the NOVA food groups and subgroups. We also calculated the dietary content of added sugars in the group of unprocessed or minimally processed foods combined with the group of processed culinary ingredients, as foods belonging to these two groups are usually combined together in culinary preparations and therefore consumed together.

We used Gaussian regression to estimate the association between the dietary contribution of ultra-processed foods and the dietary content of added sugars, each expressed as proportions of total energy. This association was also explored after adjusting for the proportion of added sugars in non-ultra-processed energy intake. Dietary contribution of ultra-processed foods was transformed using restricted cubic spline functions to allow for nonlinearity.

The average content of added sugars in the overall diet was compared across quintiles of the dietary contribution of ultra-processed foods. Poisson regression was used to assess whether the percentage of diets with more than 10% or 20% of total energy from added sugars increased across quintiles. This increase was also evaluated across demographic subgroups in stratified analysis. Tests of linear trend were performed in order to evaluate the effect of quintiles as a single continuous variable.

All regression models were adjusted for age (1-5 years, 6-11 years, 12-19 years, 20–39 years, 40–59 years, 60 + years), sex, race/ethnicity (Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Other Race including Multi-Racial) and ratio of family income to poverty (categorized based on Supplemental Nutrition Assistance Program (SNAP) eligibility as 0.00–1.30, >1.30–3.50, and >3.50 and above)(14). As 833 participants had missing values on income to poverty, adjusted analysis included 8,484 individuals.

NHANES survey sample weights were used in all analyses to account for differential probabilities of selection for the individual domains, nonresponse to survey instruments, and differences between the final sample and the total US population. The Taylor series linearization variance approximation procedure was used for variance estimation in all analysis in order to account for the complex sample design and the sample weights(14).

To minimize chance findings from multiple comparisons, statistical hypotheses were tested using a two-tailed $p<0.001$ level of significance. Data were analyzed using Stata statistical software package version 12.1.

RESULTS

Distribution of total energy intake by food groups

The average US daily energy intake in 2009-2010 was 2044.6 kcal, and nearly 3 in 5 calories (57.5%) came from ultra-processed foods (**Table 1**).

Unprocessed or minimally processed foods contributed 30.3% of total calories, processed foods an additional 9.3%, and processed culinary ingredients the remaining 2.9%. The most common ultra-processed foods in terms of energy contribution were breads; soft drinks, fruit drinks, and milk drinks; cakes, cookies, and pies; salty-snacks; frozen and shelf-stable plates; pizza; and breakfast cereals. Meat, fruit, and milk provided the most calories among unprocessed or minimally processed foods; ham and cheese, the most calories among processed foods; and table sugar and plant oils, the most calories among processed culinary ingredients.

Table 1. Distribution of the total energy intake and of the energy intake from added sugars according to food groups, and the mean content of added sugars of each food group. US population aged 1 + years (NHANES 2009-2010) (N=9,317)

	Mean energy intake		Mean energy intake from added sugars		Mean content of added sugars
Food groups	Absolute (kcal/day)	Relative (% of total energy intake)	Absolute (kcal/day)	Relative (% of total energy intake from added sugars)	% of energy from added sugars
Unprocessed or minimally processed foods	***591.1***	***30.3***	***0.0***	***0.0***	**0.0**
Meat (includes poultry)	170.3	8.3	0.0	0.0	0.0
Fruit[1]	96.8	5.2	0.0	0.0	0.0
Milk and plain yoghurt	96.8	5.1	0.0	0.0	0.0
Grains	54.5	2.9	0.0	0.0	0.0
Roots and tubers	32.2	1.6	0.0	0.0	0.0
Eggs	29.1	1.5	0.0	0.0	0.0
Pasta	29.3	1.4	0.0	0.0	0.0
Legumes	16.7	0.8	0.0	0.0	0.0
Fish and sea food	15.7	0.8	0.0	0.0	0.0
Vegetables	13.9	0.8	0.0	0.0	0.0
Other unprocessed or minimally processed foods[2]	35.6	1.7	0.0	0.0	0.0
Processed culinary ingredients	***62.9***	***2.9***	**23.9**	***8.7***	***38.3***
Table sugar[3]	24.2	1.1	23.9	8.7	98.4

Plant oils	26.8	1.2	0.0	0.0	0.0
Animal fats[4]	10.9	0.5	0.0	0.0	0.0
Other processed culinary ingredients[5]	0.9	0.04	0.0	0.0	0.0
Unprocessed or minimally processed foods + Processed culinary ingredients	***653.9***	***33.2***	***23.9***	***8.7***	***3.6***
Processed foods	***203.2***	***9.3***	***2.4***	***1.6***	**2.3**
Cheese	77.7	3.7	0.0	0.0	0.0
Ham and other salted, smoked or canned meat or fish	26.2	1.3	0.3	0.2	1.4
Vegetables and other plant foods preserved in brine	13.3	0.7	1.5	0.9	13.5
Other processed foods[6]	86	3.7	0.6	0.4	1.3
Ultra-processed foods	***1187.4***	***57.5***	***254.5***	***89.7***	**20.8**
Breads[7]	190.5	9.6	10.4	7.8	5.6
Cakes, cookies and pies	117.2	5.5	28	10.9	23.9
Salty-snacks	90.7	4.4	1.2	0.8	1.4
Frozen and shelf-stable plate meals	79.7	3.9	1.1	0.8	1.7
Soft drinks, carbonated	77.2	3.6	70.9	16.5	69.6
Pizza (ready-to-eat/heat)	77.2	3.3	2.3	1.4	2.9
Fruit drinks[8]	65	3.2	51.9	13.5	67.3
Breakfast cereals	56.1	3	13.7	7.1	23.5

Sauces, dressings and gravies	52.4	2.5	4.5	3	9.8
Reconstituted meat or fish products	49.6	2.3	0.7	0.6	1.9
Ice cream and ice pops	49.3	2.3	18.2	6.1	36.9
Sweet-snacks	48.3	2.3	17.9	6.7	37.8
Milk drinks[9]	35.7	1.9	11.1	4.8	33.3
Desserts[10]	35.7	1.8	17.8	7.3	48.1
French fries and other potatoe products[11]	37.7	1.7	0.0	0.0	0.0
Sandwiches and hamburgers on bun (ready-to-eat/heat)	31.9	1.4	1.3	0.6	4.3
Instant and canned soups	15.1	0.9	0.2	0.1	0.8
Other ultra-processed foods[12]	78.2	3.7	3	1.5	7.9
Total	**2044.6**	**100.0**	**280.8**	**100.0**	**13.4**

1Including freshly squeezed juices

2Including nuts and seeds (unsalted); yeast; dried fruits (without added sugars) and vegetables; non pre-sweetened, non-whitened, non-flavored coffee and tea; coconut water and meat; homemade soup and sauces (with no underlying ingredients); flours; tapioca

3Including honey, molasses, maple syrup (100%)

4Including unsalted butter, lard and cream

5Including starches; coconut and milk cream; unsweetened baking chocolate, cocoa powder and gelatin powder; vinegar; baking powder and baking soda

6Including salted or sugared nuts and seeds; peanut, sesame, cashew and almond butter or spread; beer and wine

[7]Including all types of bread. Processed bread made of flour, water, salt, leavening agents and possibly walnuts, dried fruits and other whole foods, were included under this group as well, because of the low consumption

[8]Including fruit and fruit-flavored, non-carbonated and other sweetened drinks, including presweetened tea and coffee, energy drinks, sports drinks with no milk added, nonalcoholic wine

[9]Including flavored yogurt sweetened with sugar or with low-calorie sweetener, milk-shake, soymilk

[10]Including ready-to-eat and dry-mix desserts such as pudding; sugar based ingredients such as whipped cream; sweetened canned fruit and fruit sauce

[11]Including hash browns, potato puffs, stuffed potatoes, onion rings (ready-to-eat/heat)

[12]Including soy products such as meatless patties and fish sticks; babyfood and baby formula; dips, spreads, mustard and catsup; salted butter and margarine; sugar substitutes, sweeteners and all syrups (excluding 100% maple syrup); distilled alcoholic drinks

Distribution of energy intake from added sugars by food groups

The average US daily intake of added sugars was 280.8 kcal (Table 1). Notably, almost 90% of this (89.7%) came from ultra-processed foods. The main sources of added sugars among ultra-processed foods were: soft drinks (16.5% of US intake of added sugars), fruit drinks (13.5%), milk drinks (4.8%); cakes, cookies, and pies (10.9%); breads (7.8%); desserts (7.3%); breakfast cereals (7.1%); sweet snacks (6.7%), and ice creams and ice pops (6.1%). In contrast, only 8.7% of the added sugars in the US diet came from processed culinary ingredients (table sugar consumed as part of dishes or drinks prepared from scratch by consumers or cook), and only 1.6% from processed foods.

The average content of added sugars in ultra-processed foods (20.8% of calories) was 9-fold higher than in processed foods (2.3%) and 5-fold higher than in unprocessed or minimally processed foods and processed culinary ingredients grouped together (3.6%) (Table 1).

Association between consumption of ultra-processed foods and added sugar intake

In both unadjusted and multivariable-adjusted restricted cubic splines Gaussian regression analyses, a strong linear association was identified between the dietary contribution (percentage of calories) of ultra-processed foods and the dietary content (percentage of calories) in added sugars (unadjusted coefficient for linear term=0.21, 95% CI: 0.18 to 0.24) **(Figure 1)**.

Figure 1.

There was little evidence of nonlinearity in the restricted cubic spline model (Wald test for linear term $p<0.0001$; Wald test for all non-linear terms $p=0.19$ –unadjusted model-). The strength of the association remained fairly the same after adjusting for the proportion of added sugars in non-ultra-processed energy intake (coefficient for linear term=0.19, 95% CI: 0.17 to 0.23) and for age, sex, race/ethnicity, and family income (coefficient for linear term=0.22, 95% CI: 0.18 to 0.26).

Overall, each increase in 5 percentage points of energy in consumption of ultra-processed foods was associated with 1 higher percentage point of energy in the consumption of added sugars.

Across quintiles of energy-adjusted ultra-processed food consumption, the intake of added sugars increased substantially and monotonically, from 7.8% of total calories in the lowest quintile to 19.2% in the highest. Across the same quintiles, the proportion of individuals consuming more than 10% of total energy from added sugars (61.5% in the total population) increased from 28.9% to 85.8%, respectively. An even more pronounced increase was seen in the proportion of individuals consuming more than 20% of their total energy from added sugars: from 3.6% in the lowest quintile to 41.1% in the highest **(Table 2)**. Similar increases were seen in stratified analysis by major demographic subgroups **(Supplementary Table 2)**. The magnitude and the statistical significance of the association between the dietary contribution of ultra-processed foods and the dietary content in added sugars did not change with adjustment for sex, age, race/ethnicity, and family income.

Table 2. Indicators of the dietary content in added sugars according to the dietary contribution of ultra-processed foods. US population aged 1 + years (NHANES 2009-2010)

Dietary contribution of ultra-processed foods (% of total energy intake)		Indicators: % of total energy intake from added sugars	Participants with more than 10% of total energy intake from added sugars			Participants with more than 20% of total energy intake from added sugars		
Quintiles	Mean (range)	Mean	%	PR[1]	PRadj[2]	%	PR[1]	PRadj[2]
1st (n=1,955)	32.5 (0 to 42.7)	7.8	28.9	1	1	3.6	1	1
2nd (n=1,901)	48.6 (42.7 to 53.9)	11.2	50.1	1.7	1.8	8.5	2.4	2.5
3rd (n=1,774)	58.3 (53.9 to 62.6)	13.3	65.1	2.2	2.3	15.2	4.3	4.3
4th (n=1,784)	67.2 (62.6 to 72.1)	15.7	77.7	2.7	2.7	23.9	6.7	6.5
5th (n=1,903)	80.7 (72.1 to 100)	19.2*	85.8	2.9*	2.9*	41.1	11.5*	10.9*
Total (n=9,317)	57.5 (0 to 100.0)	13.4	61.5	_	_	18.5	_	_

*Significant linear trend across all quintiles (p<=0.001), both in unadjusted and models adjusted for sex, age group (1-5, 6–11, 12–19, 20–39, 40–59, 60 + years), race/ethnicity (Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black and Other Race - Including Multi-Racial-), and ratio of family income to poverty (SNAP 0.00–1.30, >1.30–3.50, and >3.50 and over).

1PR=Prevalence ratios estimated using Poisson regression (N=9,317)

2PRadj=Prevalence ratios adjusted for sex, age groups, race/ethnicity and ratio of family income to poverty, as above (N=8,484)

DISCUSSION

In this analysis of nationally representative data, we confirmed the excessive consumption of added sugars in the US(10,11). We also provide new evidence that ultra-processed foods represent more than half of all calories in the US diet, and contribute nearly 90% of all added sugars. Added sugars represented 1 of every 5 calories in the average ultra-processed food (20.8%), far higher than the content of added sugars in processed foods (2.3%) and in unprocessed or minimally processed foods, and processed culinary ingredients grouped together (3.6%). A strong linear relationship was found between the dietary contribution of ultra-processed foods and the dietary content of added sugars. Moreover, the risk of exceeding the recommended upper limit of 10% energy from added sugars was far higher when ultra-processed food consumption was high, and risk differences were even more pronounced for exceeding a limit of 20% energy. Notably, only those Americans in the lowest quintile of ultra-processed food consumption met the recommended limit of <10% energy from added sugars. To our knowledge, this is the first study to assess the consumption of ultra-processed foods and establish its relationship with excessive added sugar intake in the US.

The high consumption of added sugars in the US is likely contributing to excess obesity, type 2 diabetes, dyslipidemia, hypertension and coronary heart disease(1,3-5). Consequently, most dietary guidelines now recommend limiting added sugar consumption. However, such guidelines are not always clear on how to put this recommendation into practice. Our study suggests that in the US, limiting the consumption of ultra-processed foods may be a highly effective way to decrease added sugars. A reduction in ultra-processed foods should also increase the intake of more healthful, minimally processed foods such as milk, fruits, and nuts, and freshly-prepared dishes based on whole grains and vegetables, which would produce additional health benefits beyond the reduction in added sugar. Consistent with this approach, in Brazil, where the consumption of added sugars is as high as in the US(33), the new dietary guidelines launched in 2014 emphasize the importance of not replacing unprocessed or minimally processed foods and freshly prepared dishes by ultra-processed foods(34).

Few studies have assessed the impact of levels of food processing on the nutrient profile of the US diet. One analysis using data from NHANES 2003-2008(35) used a food classification system(36) including "Mixtures of combined Ingredients" and "Ready-to-eat", which are mostly ultra-processed foods and together, contributed to about half of total energy intake and three-quarters of energy intake from added sugars. Another study evaluated household barcoded purchasing data from 2000-2012 using a classification system guided by the one used in our study(37). In 2012, the mean per capita purchase of "highly processed foods", a category similar to ultra-processed foods, corresponded to 61.0% of all calories and had higher adjusted median total sugar content than "less processed foods". This report did not evaluate added sugars nor the contribution of processed foods to sugar intake. It also did not capture non-barcoded items such as unpackaged fresh fruit, vegetables and meat, or highly processed foods such as ready-to-eat store-prepared items. An investigation in Canada, using 2001 household purchasing data, found that ultra-processed foods are high in free sugars and that only households in the lowest quintile of ultra-processed food purchasing might have met the recommended limit of <10% energy from free sugars (9.2%)(38). Being based on household purchasing data, these two prior studies and others based on the NOVA classification system(23, 39-42) could not evaluate fraction of wasted food nor purchases at restaurants, which represent a substantial proportion of US calories. Our findings build upon and considerably extend these prior reports by evaluating food processing and added sugar intake using contemporary, nationally representative dietary intake data in the US.

Our study has several strengths. We studied a large, nationally representative sample of the US population, increasing generalizability. Use of data on added sugars rather than total sugars or sugar-sweetened beverages, corresponds to the relevant area of prioritization of recent national and international guidelines. Our investigation was based on individual consumption data, rather than market disappearance or household purchasing data which cannot account for differences between amounts purchased and amounts actually consumed.

Potential limitations should be considered. As with most population measures, dietary data obtained by 24-hour recalls is imperfect. However, the standardized methods and approach of NHANES and use of two recalls per person minimize potential error and bias, particularly for assessing population averages as focused upon in the present study. Previous studies suggest that people with obesity may underreport consumption of foods with caloric sweeteners(43) such as desserts and sweet baked goods(44, 45). If so, these biases may lead to an underestimation of the dietary contribution of ultra-processed foods and the overall intake of added sugars, but should have much less effect on the association between these. Although NHANES collects some information indicative of food processing (i.e. place of meals, product brands), these data are not consistently determined for all food items, which could lead to modest over or underestimation of the consumption of ultra-processed foods.

In conclusion, we found that ultra-processed foods contribute almost 60% of calories and 90% of added sugars consumed in the US. Only Americans in the lowest quintile of ultra-processed food consumption met the recommended guidelines for intake of added sugars. Decreasing the consumption of ultra-processed foods could be an effective way of reducing the excessive intake of added sugars in the US.

Competing Interests.

"All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; DM reports ad hoc honoraria or consulting from Bunge, Haas Avocado Board, Nutrition Impact, Amarin, Astra Zeneca, Boston Heart Diagnostics, GOED, and Life Sciences Research Organization; and scientific advisory boards, Unilever North America and Elysium Health; no other relationships or activities that could appear to have influenced the submitted work."

Contributorship statement.

CAM, EMS, DM designed research; EMS, LB, ML data management; EMS, J-CM, ML analyzed data; EMS, DM, CAM wrote paper; CAM, EMS had primary responsibility for final content. All authors read and approved the final manuscript.

All authors had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Transparency declaration.

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data sharing.

No additional data available.

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Ethics approval.

No protocol approval was necessary because data were obtained from secondary sources.

Figure 1. The dietary content in added sugars regressed on the dietary contribution of ultra-processed foods evaluated by restricted cubic splines. US population aged 1 + years (NHANES 2009-2010) (N=9,317)

Legend: The values shown on the x-axis correspond to the 5th, 27.5th, 50th, 72.5th, and 95th percentiles for percentage of total energy from ultra-processed foods (knots). Coefficient for linear term=0.21 95% CI: 0.18 to 0.24. There was little evidence of nonlinearity in the restricted cubic spline model (Wald test for linear term $p<0.0001$; Wald test for all non-linear terms $p=0.19$).

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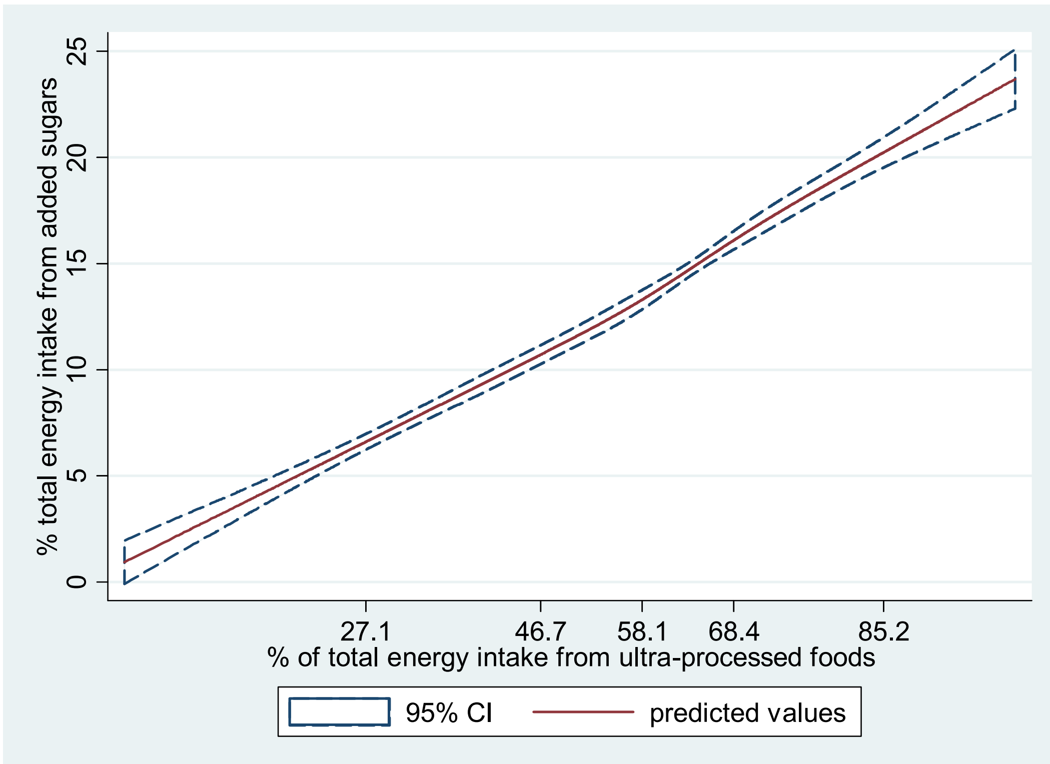
Figure 1. The dietary content in added sugars regressed on the dietary contribution of ultra-processed foods evaluated by restricted cubic splines. US population aged 1 + years (NHANES 2009-2010) (N=9,317)



Online Supplementary Material

Food classification according to processing

Food items were initially classified into four groups shown in Table 1. This was accomplished by taking into account, the following three variables from the NHANES recall databases: “Main Food Description”, “Additional Food Description” and “SR Code Description”. Thereafter, the food item classification was modified, if necessary, taking two variables into account: “Combination Food Type” and “Source of food”. Thus, most “Frozen meals" or "Lunchables" or food items consumed in “Restaurant fast food/pizza” or acquired at a “Vending machine", were classified as ultra-processed foods.

As explained in the Subjects and Methods section, when Food Codes were judged to be a handmade recipe, the classification was applied to the underlying ingredients (SR Codes), to enable a more precise food item classification (1).

It must be noted, however, that SR Codes and their proportions are not necessarily the ingredients and proportions consumed by the participant. One of the reasons is that links between FNDDS 5.0 and SR24 were developed to estimate the nutrient content of a Food Code and not the ingredient intake (2). Furthermore, when assigning SR Codes to a Food Code the individual-specific variable “Modification Code” (“adjustments to predefined recipe ingredients that reflect more closely the food as described by the respondent” (2)) was not taken into account, as manual changes would have had been necessary to do so.

Absence of data or discrepancies regarding degree of processing were solved opting for the lesser degree of processing (conservative criterion), which could have led to a slight underestimation of ultra-processed food consumption.

Online Supplementary Material

We classified homemade recipes with unknown ingredients based on expected principal ingredients, which could slightly underestimate ultra-processed food consumption.

Regarding bread, the classification distinguishes between handmade bread (either homemade or made in restaurants or artisanal bakeries), and industrial bread (made in industrial bakeries or factories), either processed (when made only of ingredients used in the making of handmade breads -flour, yeast, water, salt, and, sometimes, walnuts, dried fruits and other whole foods-) or ultra-processed (when adding substances not commonly used in the making of handmade breads -such as hydrogenated fat, sugars, starches, and additives). In our study, because of the large amount of industrial breads with unknown ingredients (approximately 3.7% of all industrial bread had fully known ingredients) and the very low consumption of processed breads when ingredients were reported (approximately 2.3% of industrial breads were processed), we ended up classifying all industrial bread as ultra-processed foods. This could slightly overestimate ultra-processed food consumption.

Assessing energy and added sugar contents

For some handmade recipes, the sum of the "calorie intake per SR Code" (calculated by us) of all underlying SR Codes did not add up exactly to the "calorie intake per Food Code" (provided by NHANES). In these cases, the "final calorie intake per SR code" was calculated as follows:

$$\text{Final calorie intake per SR code} = \text{NHANES Calorie intake per Food Code} * \left(\frac{\text{Calculated Calorie intake per SR code}}{\sum_{n=1}^{\infty} \text{Calculated Calorie intake per SR Code}}\right)$$

The same was done for added sugars:

Online Supplementary Material

$$\text{Final added sugars intake per SR code} = \text{Added sugars intake per Food Code} * \left(\frac{\text{Added sugars intake per SR code}}{\sum_{n=1}^{\infty} \text{Added sugars intake per SR code}}\right)$$

where n = each of the Food Code underlying SR Codes

Online Supplementary Material

Supplementary Table 1. NOVA food classification based on the extent and purpose of industrial processing (adapted from 3,4)

Food groups and definition	Examples
1 Unprocessed or minimally processed foods Natural foods are those obtained directly from plants or animals (such as green leaves and fruits, or eggs and milk) and purchased for consumption without having undergone any alteration following their removal from nature. Minimally processed foods are natural foods that have been submitted to cleaning, removal of inedible or unwanted parts, fractioning, grinding, drying, fermentation, pasteurisation, cooling, freezing, or other processes which do not add substances to the original food. Purpose of minimum processes is to preserve foods and make it possible to store them and, sometimes, also to decrease stages of food preparation (cleaning and removing inedible parts) or facilitate their digestion, or render them more palatable (grinding or fermentation).	Natural, packaged, cut, chilled or frozen vegetables, fruits, potatoes, cassava, and other roots and tubers; bulk or packaged white, parboiled and wholegrain rice; whole or separated corn; grains of wheat and other cereals that are dried, polished, or ground as grits or flour; dried or fresh pasta made from wheat flour and water; all types of beans; lentils, chickpeas, and other legumes; dried fruits, fruit juices fresh or pasteurized without added sugar or other substances; nuts, peanuts, and other oilseeds without salt or sugar; fresh and dried mushrooms and other fungi; fresh and dried herbs and spices; fresh, frozen, dried beef, pork, poultry and other meat and fish; pasteurized, 'long-life' and powdered milk; fresh and dried eggs, yoghurt without sugar; and tea, herbal infusions, coffee, and tap, spring and mineral water.
2 Processed culinary ingredients These are substances extracted from natural foods or from nature itself by processes such as pressing, grinding, crushing, pulverising, and refining. Purpose of processing here is to obtain ingredients used in homes and restaurants kitchens to season and cook natural or minimally processed foods and to create with them varied and enjoyable dishes such as soups and broths, salads, rice and beans dishes, grilled or roasted vegetables and meat, and homemade breads, pies, cakes, and desserts.	Plant oils; coconut and animal fats (including butter and lard); table sugar, maple syrup (100%), molasses and honey; and table salt.
3 Processed foods These are relatively simple products manufactured essentially with the addition of salt or sugar or other substance of common culinary use, such as oil or vinegar, to natural or minimally processed foods. Purpose here is to prolong duration of foods and modify their palatability. If alcoholic beverages should be classified, drinks produced by the fermentation of group 1 food items such as wine, beer and cider will be classified in this group.	Canned and bottled vegetables, legumes or fruits; salted nuts or seeds; salted, smoked or cured meat or fish; canned sardine and tuna; cheeses, and breads made of wheat flour, yeast, water, and salt.
4 Ultra-processed foods These are food and drink products whose manufacture involves several stages and various processing techniques and ingredients, many of which are used exclusively by industry. Purpose of processing here is to create durable, accessible, convenient, and highly palatable, ready-to-drink, ready-to-eat, or ready-to-heat products typically consumed as snacks or desserts or as fast meals which replace dishes prepared from scratch.	Confectionery, soft drinks, sweetened juices and dairy drinks, powders for juices, sausages, chicken and fish nuggets or sticks and other pre-prepared frozen dishes, dried products such as cake mix, powdered soup, instant noodles, ready-seasonings, and an infinity of new products including packaged snacks, morning cereals, cereal bars, and 'energy' drinks. Sugar substitutes, sweeteners and all syrups (excluding 100% maple syrup). Breads and baked goods become ultra-processed products when, in addition to wheat flour,

Online Supplementary Material

If alcoholic beverages should be classified, drinks produced by fermentation of group 1 food items followed by distillation and eventual addition of sugars or other substances, such as rum, whiskey, vodka, gin, and liqueurs, will be classified in this group.	yeast, water, and salt, their ingredients include substances such as hydrogenated vegetable fat, sugar, starch, whey, emulsifiers, and other additives.

Online Supplementary Material

Supplementary Table 2. Percentage of participants with more than 10% of total energy intake from added sugars, by demographic subgroups, according to quintiles of the dietary contribution of ultra-processed foods. US population aged 1 + years (NHANES 2009-2010)

		Quintiles of the dietary contribution of ultra-processed foods (% of total energy intake)				
		1st (n=1955)	2nd (n=1901)	3rd (n=1774)	4th (n=1784)	5th (n=1903)
Gender	Men (n=4,634)	25.8	49.9	67.2	77.3	86.0*
	Women (n=4,683)	32.1	50.2	63.4	78.0	85.7*
Age (years)	1 to 5 (n=1,136)	23.8	47.6	60.1	71.5	90.7*
	6 to 11 (n=1,154)	39.5	59.6	71.6	84.5	91.0*
	12 to 19 (n=1,265)	43.1	69.1	73.4	78.0	89.0*
	20 to 39 (n=1,928)	26.7	52.7	71.5	76.7	86.9*
	40 to 59 (n=1,935)	32.1	46.6	59.5	79.6	81.7*
	60 and over (n=1,899)	24.6	44.4	60.4	72.6	74.7*
Race/ethnicity	Mexican American (n=2,064)	32.9	55.9	70.4	78.7	85.0*
	Other Hispanic (n=988)	37.7	55.4	72.4	80.9	90.6*
	Non-Hispanic White (n=3,984)	24.4	47.0	62.1	77.4	84.8*
	Non-Hispanic Black (n=1,726)	34.8	66.6	74.1	81.6	88.9*
	Other Race (including Multi-Racial) (n=555)	35.1	35.8	68.1	65.0	88.8*

Online Supplementary Material

Income to poverty*	0.00–1.30 (n=3,322)	33.4	59.8	73.6	83.9	86.9*
	>1.30–3.50 (n=3,062)	30.8	49.0	69.5	78.3	88.0*
	>3.50 and above (n=2,100)	22.6	45.0	54.5	73.3	81.6*

*Significant linear trend across quintiles (P<=0.001), both in unadjusted and Poisson models adjusted for sex, age group (1-5, 6–11, 12–19, 20–39, 40–59, 60 + years), race/ethnicity (Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black and Other Race - Including Multi-Racial-), and ratio of family income to poverty (SNAP 0.00–1.30, >1.30–3.50, and >3.50 and over).

Online Supplementary Material

References (for Online Supplementary Material).

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (Cross- sectional study; p.2)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (p.2-3)
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported (p.4-5)
Objectives	3	State specific objectives, including any prespecified hypotheses (p.5)
Methods		
Study design	4	Present key elements of study design early in the paper (p.6)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (p.6-7)
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (nap) *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls (nap) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants (p.6-7)
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed (nap) *Case-control study*—For matched studies, give matching criteria and the number of controls per case (nap)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (p.7-10)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (p.7-10)
Bias	9	Describe any efforts to address potential sources of bias (lines 60-61)
Study size	10	Explain how the study size was arrived at (lines 54-60; lines 134-136)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (p.8-10)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (p.9-10)
		(*b*) Describe any methods used to examine subgroups and interactions (p.9-10)
		(*c*) Explain how missing data were addressed (lines 134-136)
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed (nap) *Case-control study*—If applicable, explain how matching of cases and controls was addressed (nap) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy (lines 137-142)
		(*e*) Describe any sensitivity analyses (nap)

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (lines 54-61, lines 134-136)
		(b) Give reasons for non-participation at each stage (lines 54-61, lines 134-136)
		(c) Consider use of a flow diagram (nap)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (lines 147-158; Table 1)
		(b) Indicate number of participants with missing data for each variable of interest (lines 134-136)
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) (nap)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time (nap)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure (nap)
		Cross-sectional study—Report numbers of outcome events or summary measures (lines 180-193; Table 1)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (lines 194-224; Figure 1; Table 2)
		(*b*) Report category boundaries when continuous variables were categorized (Table 2)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period (nap)
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (lines 220-221; Supplementary Table 2)
Discussion		
Key results	18	Summarise key results with reference to study objectives (lines 233-247)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (lines 296-308)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (lines 309-314)
Generalisability	21	Discuss the generalisability (external validity) of the study results (lines 265-288)
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based (nap)

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Ultra-processed foods and added sugars in the US diet: evidence from a nationally representative cross-sectional study

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Ultra-processed foods and added sugars in the US diet: evidence from a nationally representative cross-sectional study

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ABSTRACT

Objectives: To investigate the contribution of ultra-processed foods to the intake of added sugars in the US.

Ultra-processed foods were defined as industrial formulations which, besides salt, sugar, oils and fats, include substances not used in culinary preparations, in particular additives used to imitate sensorial qualities of minimally processed foods and their culinary preparations.

Design: Cross- sectional study.

Setting: *National Health and Nutrition Examination Survey* 2009-2010.

Participants: We evaluated 9,317 participants aged 1+ years with at least one 24-hour dietary recall.

Main outcome measures: Average dietary content of added sugars and proportion of individuals consuming more than 10% of total energy from added sugars.

Data analysis: Gaussian and Poisson regressions estimated the association between consumption of ultra-processed foods and intake of added sugars. All models incorporated survey sample weights and adjusted for age, sex, race/ethnicity, family income and educational attainment.

Results: Ultra-processed foods comprised 57.9% of energy intake, and contributed 89.7% of the energy intake from added sugars. The content of added sugars in ultra-processed foods (21.1% of calories) was 8-fold higher than in processed foods (2.4%) and 5-fold higher than in unprocessed or

minimally processed foods and processed culinary ingredients grouped together (3.7%). In both unadjusted and adjusted models, each increase of 5 percentage points in proportional energy intake from ultra-processed foods increased the proportional energy intake from added sugars by 1 percentage point. Consumption of added sugars increased linearly across quintiles of ultra-processed food consumption: from 7.5% of total energy in the lowest quintile to 19.5% in the highest. A total of 82.1% of Americans in the highest quintile exceeded the recommended limit of 10% energy from added sugars, compared with 26.4% in the lowest.

Conclusions: Decreasing the consumption of ultra-processed foods could be an effective way of reducing the excessive intake of added sugars in the US.

Strengths and limitations of this study:

- Use of a large, nationally representative sample of the US population, increasing generalizability.
- Use of data on added sugars rather than total sugars or sugar-sweetened beverages, which corresponds to guidelines relevant area of prioritization.
- Unlike most articles which have focused on specific food items such as soft drinks or fast food, our study evaluates the impact of a comprehensive group of products whose consumption is increasing exponentially in most countries.
- Dietary data obtained by 24-hour recalls is subjected to potential error and bias.

- Information indicative of food processing is not consistently determined for all food items in NHANES, which could lead to modest over or underestimation of the consumption of ultra-processed foods.

INTRODUCTION

Increasing policy attention has focused on added sugars, including by the World Health Organization (WHO)(1), the United Kingdom National Health System(2), the Canadian Heart and Stroke Foundation(3), the American Heart Association (AHA)(*4*), and the US Dietary Guidelines Advisory Committee (USDGAC)(*5*).

These reports concluded that a high intake of added sugars increases risk for weight gain(1,4,5), excess body weight(5) and obesity(3,5); type 2 diabetes mellitus(3,5); higher serum triglycerides(5) and high blood cholesterol(3); higher blood pressure(5) and hypertension(5); stroke(3,5); coronary heart disease(3,5); cancer(3); and dental caries(1,3,5). Moreover, foods higher in added sugars are often a source of empty calories with minimum essential nutrients or dietary fiber(6-8), which displace more nutrient-dense foods(9) and lead, in turn, to simultaneously overfed and undernourished individuals.

All reports recommended limiting intake of added sugars(1,3-5*).* In the US, the USDGAC recommended limiting added sugars to no more than 10% of total calories. This is a challenge, as recent consumption of added sugars in the US amounted to almost 15% of total calories in 2005-2010(10,11).

To design and implement effective measures to reduce added sugars, their dietary sources must be clearly identified. Added sugars can be consumed either as ingredients of dishes or drinks prepared from scratch by consumers or cook, or as ingredients of food products manufactured by the food industry. According to market disappearance data from 2014, more than three quarters of the sugar and high fructose corn syrup available for human consumption in the US were used by the food industry(12). This suggests food products manufactured by the industry could have an important role in the excess added sugars consumption in the US. However, to assess this role, it is essential to consider the contribution of manufactured food products to both total energy intake and the energy intake from added sugars, and, more relevantly, to quantify the relationship between their consumption and the total dietary content of added sugars. To address these questions, we performed an investigation utilizing 2009-2010 *National Health and Nutrition Examination Survey (NHANES).*

SUBJECTS AND METHODS

Data source, population and sampling

We utilized nationally representative data from the 2009-2010 *National Health and Nutrition Examination Survey (NHANES),* specifically the dietary component *What we eat in America (WWEIA)*(13*)*.

NHANES is a continuous, nationally representative, cross-sectional survey of the non-institutionalized, civilian US residents(14). NHANES sample was obtained by using a complex, stratified, multi-stage probability cluster sampling design, based on the selection of counties, blocks, households, and the number of people within households(14). In order to improve the estimate precision and reliability, NHANES 2009-2010 oversampled the following subgroups: Hispanic, Non-Hispanic black, Non-Hispanic white and Other persons at or below 130% of the federal poverty level and Non-Hispanic white and Other persons aged 80 + years(14).

The survey included an interview conducted in the home and a subsequent health examination performed at a mobile examination center (MEC). All NHANES examinees were eligible for two 24-hour dietary recall interviews. The first dietary recall interview was collected in-person in the MEC(15) while the second was collected by telephone 3 to 10 days later but never on the same day of the week as the MEC interview(16). Dietary interviews were conducted by trained interviewers using the validated(17-19) *US Department of Agriculture Automated Multiple-Pass Method (AMPM)*(20). For children under 9 years of age, the interview was conducted with a proxy; for children between 6 and 8 years of age, in the presence of the child. Children 9 to 11 years old provided their own data assisted by an adult household member (assistant). The preferred proxy/assistant was the most knowledgeable person about the child's consumption the day before the interview. If the child had more than one caregiver, several individuals could contribute to the intake data(15; 16).

Among the 13,272 people screened in NHANES 2009-2010, 10,537 (79.4%) participated in the household interview and 10253 (77.3%) also participated in the MEC health examination(21). Of these, 9,754 individuals provided one day of complete dietary intakes and 8,406 provided two days(22).

We evaluated 9,317 survey participants aged 1 year and above who had one day 24-hour dietary recall data and had not been breast-fed on either of the two days. These individuals had similar socio-demographic characteristics (gender, age, race/ ethnicity, family income and educational attainment) to the full sample of 10,109 participants interviewed.

Food classification according to processing

We classified all recorded food items (N=280,132 Food Codes for both recall days) according to NOVA, a food classification based on the extent and purpose of industrial food processing(23-25). This classification includes 4 groups: "unprocessed or minimally processed foods" (such as fresh, dry or frozen fruits or vegetables, grains, legumes, meat, fish and milk); "processed culinary ingredients" (including table sugar, oils, fats, salt, and other substances extracted from foods or from nature, and used in kitchens to make culinary preparations), "processed foods" (foods manufactured with the addition of salt or sugar or other substances of culinary use to unprocessed or minimally processed foods, such as simple cheese, bread and canned food), and "ultra-processed foods" (formulations of several ingredients which, besides salt, sugar, oils and fats, include food substances not used in culinary preparations. In particular flavors, colors, sweeteners, emulsifiers and other additives used to imitate sensorial qualities of unprocessed or minimally processed foods and their culinary preparations or to disguise undesirable qualities of the final product). A detailed definition of each food group and examples of food items classified in each group are shown in **Supplementary Table 1**. The rationale underlying the classification is described elsewhere(26-29).

For all food items (Food Codes) judged to be a handmade recipe, the classification was applied to the underlying ingredients (Standard Reference Codes -SR Codes-) obtained from the USDA Food and Nutrient Database for Dietary Studies (FNDDS) 5.0(30). Refer to Online Supplementary Material (OSM) for further details.

Assessing energy and added sugar contents

For this study, we used Food Code energy values as provided by NHANES.

For handmade recipes, we calculated the underlying ingredient (SR Code) energy values using variables from both *FNDDS 5.0*(30) and *USDA National Nutrient Database for Standard Reference, Release 24 (SR24)*(31). Refer to OSM for further details.

Data on added sugars per Food Code and per SR Code were obtained by merging the Food Patterns Equivalents Database (FPED) 2009-2010 and the Food Patterns Equivalents Ingredients Database (FPID) 2009-2010(32). Added sugars are defined in these databases as "sugars that are added to foods as an ingredient during preparation, processing, or at the table. Added sugars do not include naturally occurring sugars (e.g., lactose in milk, fructose in fruits). Examples of added sugars include brown sugar, cane sugar, confectioners' sugar, granulated sugar, dextrose, white sugar, corn syrup and corn syrup solids, molasses, honey, and all types of syrups such as maple syrup, table syrups, and pancake syrup"(32). These two databases express the content of added sugars in teaspoons per 100 g. Teaspoons were converted into grams using the factor 4.2 g/teaspoon and into kcal using the factor 3.87 kcal/g.

Data Analysis

We utilized all available day 1 dietary data for each participant. Food items were sorted into mutually exclusive food subgroups within Unprocessed or minimally processed foods (n= 11), Processed culinary ingredients (n=4), Processed foods (n=4) and Ultra-processed foods (n=18), as shown in Table 1. First, we evaluated the contributions of each of the NOVA food groups and subgroups to total energy and to the energy from added sugars. Next, we calculated the average content of added sugars in the overall US diet and in fractions of this diet composed by each of the NOVA food groups and subgroups. We also calculated the dietary content of added sugars in the group of unprocessed or minimally processed foods combined with the group of processed culinary ingredients, as foods belonging to these two groups are usually combined together in culinary preparations and therefore consumed together.

We used Gaussian regression to estimate the association between the dietary contribution of ultra-processed foods and the dietary content of added sugars, each expressed as proportions of total energy. This association was also explored after adjusting for the proportion of added sugars in non-ultra-processed energy intake. Dietary contribution of ultra-processed foods was transformed using restricted cubic spline functions to allow for nonlinearity.

The average content of added sugars in the overall diet was compared across quintiles of the dietary contribution of ultra-processed foods. Poisson regression was used to assess whether the percentage of diets with more than 10% or 20% of total energy from added sugars increased across quintiles. This increase was also evaluated across demographic subgroups in stratified analysis. Tests of linear trend were performed in order to evaluate the effect of quintiles as a single continuous variable.

All regression models were adjusted for age (1-5 years, 6-11 years, 12-19 years, 20–39 years, 40–59 years, 60 + years), sex, race/ethnicity (Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Other Race including Multi-Racial), ratio of family income to poverty (categorized based on Supplemental Nutrition Assistance Program (SNAP) eligibility as 0.00–1.30, >1.30–3.50, and >3.50 and above)(14) and educational attainment of respondents, for participants aged 20 + years, and of household reference person otherwise (<12, 12 years and >12 years). As 908 participants had missing values on family income and/or educational attainment, multivariable-adjusted analysis included 8,409 individuals. Analysis which also adjusted for the added sugar content of all non-ultra-processed foods grouped together included 8,335 individuals.

NHANES survey sample weights were used in all analyses to account for differential probabilities of selection for the individual domains, nonresponse to survey instruments, and differences between the final sample and the total US population. The Taylor series linearization variance approximation procedure was used for variance estimation in all analysis in order to account for the complex sample design and the sample weights(14).

To minimize chance findings from multiple comparisons, statistical hypotheses were tested using a two-tailed p<0.001 level of significance. Data were analyzed using Stata statistical software package version 12.1.

RESULTS

Distribution of total energy intake by food groups

The average US daily energy intake in 2009-2010 was 2069.5 kcal, and nearly 3 in 5 calories (57.9%) came from ultra-processed foods (**Table 1**).

Unprocessed or minimally processed foods contributed 29.6% of total calories, processed foods an additional 9.4%, and processed culinary ingredients the remaining 2.9%. The most common ultra-processed foods in terms of energy contribution were breads; soft drinks, fruit drinks, and milk-based drinks; cakes, cookies, and pies; salty-snacks; frozen and shelf-stable plates; pizza; and breakfast cereals. Meat, fruit, and milk provided the most calories among unprocessed or minimally processed foods; ham and cheese, the most calories among processed foods; and table sugar and plant oils, the most calories among processed culinary ingredients.

Table 1. Distribution of the total energy intake and of the energy intake from added sugars according to food groups, and the mean content of added sugars of each food group. US population aged 1 + years (NHANES 2009-2010) (N=9,317)

	Mean energy intake		Mean energy intake from added sugars		Mean content of added sugars
Food groups	Absolute (kcal/day)	Relative (% of total energy intake)	Absolute (kcal/day)	Relative (% of total energy intake from added sugars)	% of energy from added sugars
Unprocessed or minimally processed foods	***585.5***	***29.6***	***0.0***	***0.0***	**0.0**
Meat (includes poultry)	165.3	7.9	0.0	0.0	0.0
Fruit[1]	97.5	5.2	0.0	0.0	0.0
Milk and plain yoghurt	96.4	5.1	0.0	0.0	0.0
Grains	53.3	2.8	0.0	0.0	0.0
Roots and tubers	32.2	1.6	0.0	0.0	0.0
Eggs	28.8	1.4	0.0	0.0	0.0
Pasta	28.4	1.4	0.0	0.0	0.0
Legumes	16.2	0.8	0.0	0.0	0.0
Fish and sea food	17.2	0.8	0.0	0.0	0.0
Vegetables	13.5	0.7	0.0	0.0	0.0
Other unprocessed or minimally processed foods[2]	36.7	1.8	0.0	0.0	0.0
Processed culinary ingredients	***64.3***	***2.9***	**24.4**	***8.7***	***38.8***

Table sugar[3]	24.7	1.1	24.4	8.7	98.5
Plant oils	27.5	1.3	0.0	0.0	0.0
Animal fats[4]	11.2	0.5	0.0	0.0	0.0
Other processed culinary ingredients[5]	0.9	0.04	0.0	0.0	0.0
Unprocessed or minimally processed foods + Processed culinary ingredients	***649.8***	***32.6***	***24.4***	***8.7***	***3.7***
Processed foods	***209.7***	***9.4***	***2.5***	***1.6***	**2.4**
Cheese	80.1	3.7	0.0	0.0	0.0
Ham and other salted, smoked or canned meat or fish	26.4	1.2	0.3	0.2	1.4
Vegetables and other plant foods preserved in brine	13.4	0.7	1.6	0.9	13.7
Other processed foods[6]	89.8	3.8	0.6	0.5	1.2
Ultra-processed foods	***1209.8***	***57.9***	***265.2***	***89.7***	**21.1**
Breads[7]	191.6	9.5	10.6	7.6	5.7
Cakes, cookies and pies	122.8	5.7	29.8	11.2	24.2
Salty-snacks	93.2	4.6	1.2	0.7	1.4
Frozen and shelf-stable plate meals	80.6	4.02	1.1	0.7	1.6
Soft drinks, carbonated	81.8	3.7	75.2	17.1	69.9
Pizza (ready-to-eat/heat)	81.8	3.5	2.4	1.4	2.9
Fruit drinks[8]	69.2	3.3	55.7	13.9	67.5

Breakfast cereals	50.9	2.8	12.4	6.4	23.3
Sauces, dressings and gravies	49.8	2.4	4.4	2.8	10.0
Reconstituted meat or fish products	51.5	2.4	0.7	0.6	2.0
Sweet-snacks	50.9	2.4	19.4	7.1	38.9
Ice cream and ice pops	48.7	2.3	18.3	5.9	36.9
Milk-based drinks[9]	34.6	1.8	10.8	4.6	34.1
Desserts[10]	36.4	1.8	18.5	7.3	48.5
French fries and other potatoe products[11]	37.8	1.7	0.0	0.0	0.0
Sandwiches and hamburgers on bun (ready-to-eat/heat)	32.5	1.4	1.3	0.6	4.4
Instant and canned soups	14.3	0.8	0.1	0.1	0.7
Other ultra-processed foods[12]	81.5	3.8	3.1	1.5	7.8
Total	**2069.5**	**100.0**	**292.2**	**100.0**	**13.8**

1Including freshly squeezed juices

2Including nuts and seeds (unsalted); yeast; dried fruits (without added sugars) and vegetables; non pre-sweetened, non-whitened, non-flavored coffee and tea; coconut water and meat; homemade soup and sauces; flours; tapioca

3Including honey, molasses, maple syrup (100%)

4Including unsalted butter, lard and cream

5Including starches; coconut and milk cream; unsweetened baking chocolate, cocoa powder and gelatin powder; vinegar; baking powder and baking soda

6Including salted or sugared nuts and seeds; peanut, sesame, cashew and almond butter or spread; beer and wine

7Including all types of bread. Processed bread made of flour, water, salt, leavening agents and possibly walnuts, dried fruits and other whole foods, were included under this group as well, because of the low consumption

8Including fruit and fruit-flavored, non-carbonated and other sweetened drinks, including presweetened tea and coffee, energy drinks, sports drinks with no milk added, nonalcoholic wine

9Including flavored yogurt sweetened with sugar or with low-calorie sweetener, milk-shake, soymilk

10Including ready-to-eat and dry-mix desserts such as pudding; sweetened canned fruit and fruit sauce

11Including hash browns, potato puffs, stuffed potatoes, onion rings (ready-to-eat/heat)

12Including soy products such as meatless patties and fish sticks; babyfood and baby formula; dips, spreads, mustard and catsup; salted butter and margarine; sugar substitutes, sweeteners and all syrups (excluding 100% maple syrup); distilled alcoholic drinks

Distribution of energy intake from added sugars by food groups

The average US daily intake of added sugars was 292.2 kcal (Table 1). Notably, almost 90% of this (89.7%) came from ultra-processed foods. The main sources of added sugars among ultra-processed foods were: soft drinks (17.1% of US intake of added sugars), fruit drinks (13.9%), milk-based drinks (4.6%); cakes, cookies, and pies (11.2%); breads (7.6%); desserts (7.3%); sweet snacks (7.1%); breakfast cereals (6.4%); and ice creams and ice pops (5.9%). In contrast, only 8.7% of the added sugars in the US diet came from processed culinary ingredients (table sugar consumed as part of dishes or drinks prepared from scratch by consumers or cook), and only 1.6% from processed foods.

The average content of added sugars in ultra-processed foods (21.1% of calories) was 8-fold higher than in processed foods (2.4%) and 5-fold higher than in unprocessed or minimally processed foods and processed culinary ingredients grouped together (3.7%) (Table 1).

Association between consumption of ultra-processed foods and added sugar intake

In unadjusted restricted cubic splines Gaussian regression analysis, a strong linear association was identified between the dietary contribution (percentage of calories) of ultra-processed foods and the dietary content (percentage of calories) in added sugars (coefficient for linear term=0.20, 95% CI: 0.17 to 0.23) **(Figure 1)**.

Figure 1.

There was little evidence of nonlinearity in the restricted cubic spline model (Wald test for linear term p<0.0001; Wald test for all non-linear terms p=0.27). The strength of the association remained fairly the same after adjusting for age, sex, race/ethnicity, family income, educational attainment and proportion of added sugars in non-ultra-processed energy intake (coefficient for linear term=0.19, 95% CI: 0.17 to 0.22). Overall, each increase in 5 percentage points of energy in consumption of ultra-processed foods was associated with 1 higher percentage point of energy in the consumption of added sugars.

Across quintiles of energy-adjusted ultra-processed food consumption, the intake of added sugars increased substantially and monotonically, from 7.5% of total calories in the lowest quintile to 19.5% in the highest. Across the same quintiles, the proportion of individuals consuming more than 10% of total energy from added sugars (59.6% in the total population) increased from 26.4% to 82.1%, respectively. An even more pronounced increase was seen in the proportion of individuals consuming more than 20% of their total energy from added sugars: from 4.7% in the lowest quintile to 41.2% in the highest **(Table 2)**. Similar increases were seen in stratified analysis by major demographic subgroups **(Supplementary Table 2)**. The magnitude and the statistical significance of the association between the dietary contribution of ultra-processed foods and the dietary content in added sugars did not change with adjustment for sex, age, race/ethnicity, family income and educational attainment.

238 **Table 2.** Indicators of the dietary content in added sugars according to the dietary contribution of ultra-processed foods. US
239 population aged 1 + years (NHANES 2009-2010)

Dietary contribution of ultra-processed foods (% of total energy intake)		Indicators						
		% of total energy intake from added sugars	Participants with more than 10% of total energy intake from added sugars			Participants with more than 20% of total energy intake from added sugars		
Quintiles	Mean (range)	Mean	%	PR[1]	PRadj[2]	%	PR[1]	PRadj[2]
1st (n=1,937)	28.9 (0 to 40.1)	7.5	26.4	1	1	4.7	1	1
2nd (n=1,888)	47.3 (40.1 to 53.3)	11.1	50	1.9	1.9	10.5	2.2	2.2
3rd (n=1,814)	58.7 (53.3 to 64.1)	13.8	62.7	2.4	2.3	21.1	4.5	4.3
4th (n=1,779)	69.7 (64.1 to 75.7)	16.9	76.6	2.9	2.8	29.9	6.4	5.9
5th (n=1,899)	85.1 (75.7 to 100)	19.5*	82.1	3.1*	2.9*	41.2	8.8*	7.9*
Total (n=9,317)	57.9 (0 to 100.0)	13.8	59.6	_	_	21.5	_	_

240 *Significant linear trend across all quintiles (p<=0.001), both in unadjusted and models adjusted for sex, age group (1-5, 6–11, 12–
241 19, 20–39, 40–59, 60 + years), race/ethnicity (Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black and
242 Other Race - Including Multi-Racial-), ratio of family income to poverty (SNAP 0.00–1.30, >1.30–3.50, and >3.50 and over) and
243 educational attainment (<12, 12 years and >12 years).

[1]PR=Prevalence ratios estimated using Poisson regression (N=9,317)

[2]PRadj=Prevalence ratios adjusted for sex, age groups, race/ethnicity, ratio of family income to poverty and educational attainment, as above (N=8,409)

DISCUSSION

In this analysis of nationally representative data, we confirmed the excessive consumption of added sugars in the US(10,11). We also provide new evidence that ultra-processed foods represent more than half of all calories in the US diet, and contribute nearly 90% of all added sugars. Added sugars represented 1 of every 5 calories in the average ultra-processed food (21.1%), far higher than the content of added sugars in processed foods (2.4%) and in unprocessed or minimally processed foods, and processed culinary ingredients grouped together (3.7%). A strong linear relationship was found between the dietary contribution of ultra-processed foods and the dietary content of added sugars. Moreover, the risk of exceeding the recommended upper limit of 10% energy from added sugars was far higher when ultra-processed food consumption was high, and risk differences were even more pronounced for exceeding a limit of 20% energy. Notably, only those Americans in the lowest quintile of ultra-processed food consumption met the recommended limit of <10% energy from added sugars. To our knowledge, this is the first study to assess the consumption of ultra-processed foods and establish its relationship with excessive added sugar intake in the US.

The high consumption of added sugars in the US is likely contributing to excess obesity, type 2 diabetes, dyslipidemia, hypertension and coronary heart disease(1,3-5). Consequently, most dietary guidelines now recommend limiting added sugar consumption. However, such guidelines are not always clear on how to put this recommendation into practice. Our study suggests that in the US, limiting the consumption of ultra-processed foods may be a highly effective way to decrease added sugars. A reduction in ultra-processed foods should also increase the intake of more healthful, minimally processed foods such as milk, fruits, and nuts, and freshly-prepared dishes based on whole grains and vegetables, which would produce additional health benefits beyond the reduction in added sugar. Consistent with this approach, in Brazil, where the consumption of added sugars is as high as in the US(33), the new dietary guidelines launched in 2014 emphasize the importance of not replacing unprocessed or minimally processed foods and freshly prepared dishes by ultra-processed foods(34).

Few studies have assessed the impact of levels of food processing on the nutrient profile of the US diet. One analysis using data from NHANES 2003-2008(35) used a food classification system(36) including "Mixtures of combined Ingredients" and "Ready-to-eat", which are mostly ultra-processed foods and together, contributed to about half of total energy intake and three-quarters of energy intake from added sugars. Another study evaluated household barcoded purchasing data from 2000-2012 using a classification system guided by the one used in our study(37). In 2012, the mean per capita purchase of "highly processed foods", a category similar to ultra-processed foods, corresponded to 61.0% of all calories and had higher adjusted median total sugar content than "less processed foods". This report did not evaluate added sugars nor the contribution of processed foods to sugar intake. It also did not capture non-barcoded items such as unpackaged fresh fruit, vegetables and meat, or highly processed foods such as ready-to-eat store-prepared items. An investigation in Canada, using 2001 household purchasing data, found that ultra-processed foods are high in free sugars and that only households in the lowest quintile of ultra-processed food purchasing might have met the recommended limit of <10% energy from free sugars (9.2%)(38). Being based on household purchasing data, these two prior studies and others based on the NOVA classification system(23, 39-42) could not evaluate fraction of wasted food nor purchases at restaurants, which represent a substantial proportion of US calories. Our findings build upon and considerably extend these prior reports by evaluating food processing and added sugar intake using contemporary, nationally representative dietary intake data in the US.

Our study has several strengths. We studied a large, nationally representative sample of the US population, increasing generalizability. Use of data on added sugars rather than total sugars or sugar-sweetened beverages, corresponds to the relevant area of prioritization of recent national and international guidelines. Our investigation was based on individual consumption data, rather than market disappearance or household purchasing data which cannot account for differences between amounts purchased and amounts actually consumed.

Potential limitations should be considered. As with most population measures, dietary data obtained by 24-hour recalls is imperfect. However, the standardized methods and approach of NHANES minimize potential error and bias, particularly for assessing population averages as focused upon in the present study. Previous studies suggest that people with obesity may underreport consumption of foods with caloric sweeteners(43) such as desserts and sweet baked goods(44, 45). If so, these biases may lead to an underestimation of the dietary contribution of ultra-processed foods and the overall intake of added sugars, but should have much less effect on the association between these. Although NHANES collects some information indicative of food processing (i.e. place of meals, product brands), these data are not consistently determined for all food items, which could lead to modest over or underestimation of the consumption of ultra-processed foods.

In conclusion, we found that ultra-processed foods contribute almost 60% of calories and 90% of added sugars consumed in the US. Only Americans in the lowest quintile of ultra-processed food consumption met the recommended guidelines for intake of added sugars. Decreasing the consumption of ultra-processed foods could be an effective way of reducing the excessive intake of added sugars in the US.

Competing Interests.

"All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; DM reports ad hoc honoraria or consulting from Bunge, Haas Avocado Board, Nutrition Impact, Amarin, Astra Zeneca, Boston Heart Diagnostics, GOED, and Life Sciences Research Organization; and scientific advisory boards, Unilever North America and Elysium Health; no other relationships or activities that could appear to have influenced the submitted work."

Contributorship statement.

CAM, EMS, DM designed research; EMS, LB, ML data management; EMS, J-CM, ML analyzed data; EMS, DM, CAM wrote paper; CAM, EMS had primary responsibility for final content. All authors read and approved the final manuscript.

All authors had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Transparency declaration.

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data sharing.

No additional data available.

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Exclusive licence.

Ethics approval.

No protocol approval was necessary because data were obtained from secondary sources.

Figure 1. The dietary content in added sugars regressed on the dietary contribution of ultra-processed foods evaluated by restricted cubic splines. US population aged 1 + years (NHANES 2009-2010) (N=9,317)

Legend: The values shown on the x-axis correspond to the 5th, 27.5th, 50th, 72.5th, and 95th percentiles for percentage of total energy from ultra-processed foods (knots). Coefficient for linear term=0.20 95% CI: 0.17 to 0.23. There was little evidence of nonlinearity in the restricted cubic spline model (Wald test for linear term $p<0.0001$; Wald test for all non-linear terms $p=0.27$).

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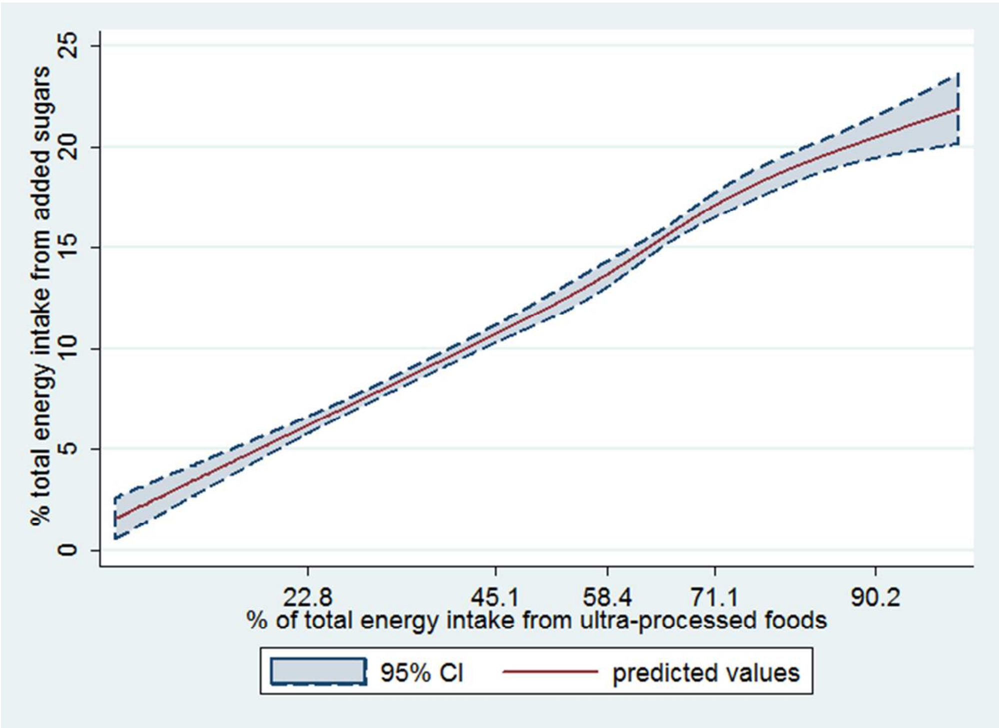

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Online Supplementary Material

Food classification according to processing

Food items were initially classified into four groups shown in Table 1. This was accomplished by taking into account, the following three variables from the NHANES recall databases: “Main Food Description”, “Additional Food Description” and “SR Code Description”. Thereafter, the food item classification was modified, if necessary, taking two variables into account: “Combination Food Type” and “Source of food”. Thus, most “Frozen meals" or "Lunchables" or food items consumed in “Restaurant fast food/pizza” or acquired at a “Vending machine", were classified as ultra-processed foods.

As explained in the Subjects and Methods section, when Food Codes were judged to be a handmade recipe, the classification was applied to the underlying ingredients (SR Codes), to enable a more precise food item classification (1).

It must be noted, however, that SR Codes and their proportions are not necessarily the ingredients and proportions consumed by the participant. One of the reasons is that links between FNDDS 5.0 and SR24 were developed to estimate the nutrient content of a Food Code and not the ingredient intake (2). Furthermore, when assigning SR Codes to a Food Code the individual-specific variable “Modification Code” (“adjustments to predefined recipe ingredients that reflect more closely the food as described by the respondent” (2)) was not taken into account, as manual changes would have had been necessary to do so.

Absence of data or discrepancies regarding degree of processing were solved opting for the lesser degree of processing (conservative criterion), which could have led to a slight underestimation of ultra-processed food consumption.

Online Supplementary Material

We classified homemade recipes with unknown ingredients based on expected principal ingredients, which could slightly underestimate ultra-processed food consumption.

Regarding bread, the classification distinguishes between handmade bread (either homemade or made in restaurants or artisanal bakeries), and industrial bread (made in industrial bakeries or factories), either processed (when made only of ingredients used in the making of handmade breads -flour, yeast, water, salt, and, sometimes, walnuts, dried fruits and other whole foods-) or ultra-processed (when adding substances not commonly used in the making of handmade breads -such as hydrogenated fat, sugars, starches, and additives). In our study, because of the large amount of industrial breads with unknown ingredients (approximately 3.7% of all industrial bread had fully known ingredients) and the very low consumption of processed breads when ingredients were reported (approximately 2.3% of industrial breads were processed), we ended up classifying all industrial bread as ultra-processed foods. This could slightly overestimate ultra-processed food consumption.

Assessing energy and added sugar contents

For some handmade recipes, the sum of the "calorie intake per SR Code" (calculated by us) of all underlying SR Codes did not add up exactly to the "calorie intake per Food Code" (provided by NHANES). In these cases, the "final calorie intake per SR code" was calculated as follows:

$$\text{Final calorie intake per SR code} = \text{NHANES Calorie intake per Food Code} * \left(\frac{\text{Calculated Calorie intake per SR code}}{\sum_{n=1}^{\infty} \text{Calculated Calorie intake per SR Code}}\right)$$

The same was done for added sugars:

Online Supplementary Material

$$\text{Final added sugars intake per SR code} = \text{Added sugars intake per Food Code} * \left(\frac{\text{Added sugars intake per SR code}}{\sum_{n=1}^{\infty} \text{Added sugars intake per SR code}}\right)$$

where n = each of the Food Code underlying SR Codes

Online Supplementary Material

Supplementary Table 1. NOVA food classification based on the extent and purpose of industrial processing (adapted from 3,4)

Food groups and definition	Examples
1 Unprocessed or minimally processed foods Unprocessed foods are those obtained directly from plants or animals (such as green leaves and fruits, or eggs and milk) and purchased for consumption without having undergone any alteration following their removal from nature. Minimally processed foods are natural foods that have been submitted to cleaning, removal of inedible or unwanted parts, fractioning, grinding, drying, fermentation, pasteurisation, cooling, freezing, or other processes which do not add substances to the original food. Purpose of minimum processes is to preserve foods and make it possible to store them and, sometimes, also to decrease stages of food preparation (cleaning and removing inedible parts) or facilitate their digestion, or render them more palatable (grinding or fermentation).	Natural, packaged, cut, chilled or frozen vegetables, fruits, potatoes, cassava, and other roots and tubers; bulk or packaged white, parboiled and wholegrain rice; whole or separated corn; grains of wheat and other cereals that are dried, polished, or ground as grits or flour; dried or fresh pasta made from wheat flour and water; all types of beans; lentils, chickpeas, and other legumes; dried fruits, fruit juices fresh or pasteurized without added sugar or other substances; nuts, peanuts, and other oilseeds without salt or sugar; fresh and dried mushrooms and other fungi; fresh and dried herbs and spices; fresh, frozen, dried beef, pork, poultry and other meat and fish; pasteurized, 'long-life' and powdered milk; fresh and dried eggs, yoghurt without sugar; and tea, herbal infusions, coffee, and tap, spring and mineral water.
2 Processed culinary ingredients These are substances extracted from natural foods or from nature itself by processes such as pressing, grinding, crushing, pulverising, and refining. Purpose of processing here is to obtain ingredients used in homes and restaurants kitchens to season and cook natural or minimally processed foods and to create with them varied and enjoyable dishes such as soups and broths, salads, rice and beans dishes, grilled or roasted vegetables and meat, and homemade breads, pies, cakes, and desserts.	Plant oils; coconut and animal fats (including butter and lard); table sugar, maple syrup (100%), molasses and honey; and table salt.
3 Processed foods These are relatively simple products manufactured essentially with the addition of salt or sugar or other substance of common culinary use, such as oil or vinegar, to natural or minimally processed foods. Purpose here is to prolong duration of foods and modify their palatability. If alcoholic beverages should be classified, drinks produced by the fermentation of group 1 food items such as wine, beer and cider will be classified in this group.	Canned and bottled vegetables, legumes or fruits; salted nuts or seeds; salted, smoked or cured meat or fish; canned sardine and tuna; cheeses, and breads made of wheat flour, yeast, water, and salt.
4 Ultra-processed foods These are food and drink products whose manufacture involves several stages and various processing techniques and ingredients, many of which are used exclusively by industry. Purpose of processing here is to create durable, accessible, convenient, and highly palatable, ready-to-drink, ready-to-eat, or ready-to-heat products typically consumed as snacks or desserts or as fast meals which replace dishes prepared from scratch.	Confectionery, soft drinks, sweetened juices and dairy drinks, powders for juices, sausages, chicken and fish nuggets or sticks and other pre-prepared frozen dishes, dried products such as cake mix, powdered soup, instant noodles, ready-seasonings, and an infinity of new products including packaged snacks, morning cereals, cereal bars, and 'energy' drinks. Sugar substitutes, sweeteners and all syrups (excluding 100% maple syrup). Breads and baked goods become ultra-processed products when, in addition to wheat flour,

Online Supplementary Material

If alcoholic beverages should be classified, drinks produced by fermentation of group 1 food items followed by distillation and eventual addition of sugars or other substances, such as rum, whiskey, vodka, gin, and liqueurs, will be classified in this group.	yeast, water, and salt, their ingredients include substances such as hydrogenated vegetable fat, sugar, starch, whey, emulsifiers, and other additives.

Online Supplementary Material

Supplementary Table 2. Percentage of participants with more than 10% of total energy intake from added sugars, by demographic subgroups, according to quintiles of the dietary contribution of ultra-processed foods. US population aged 1 + years (NHANES 2009-2010)

		Quintiles of the dietary contribution of ultra-processed foods (% of total energy intake)				
		1st (n=1,937)	2nd (n=1,888)	3rd (n=1,814)	4th (n=1,779)	5th (n=1,899)
Gender	Men (n=4,634)	24.5	48.6	61.7	78.1	78.5*
	Women (n=4,683)	28.3	51.4	63.7	75.3	85.6*
Age (years)	1 to 5 (n=1,136)	17.0	45.5	61.3	71.0	84.3*
	6 to 11 (n=1,154)	33.1	54.0	76.5	82.4	90.0*
	12 to 19 (n=1,265)	39.9	62.8	66.2	83.0	87.1*
	20 to 39 (n=1,928)	28.8	53.4	64.1	79.7	82.7*
	40 to 59 (n=1,935)	26.0	49.1	59.6	71.7	76.7*
	60 and over (n=1,899)	22.8	43.6	58.6	71.9	71.1*
Race/ethnicity	Mexican American (n=2,064)	28.5	52.8	64.5	79.4	84.7*
	Other Hispanic (n=988)	41.7	59.4	62.2	80.1	85.2*
	Non-Hispanic White (n=3,984)	22.9	47.3	60.1	75.3	80.4*
	Non-Hispanic Black (n=1,726)	33.0	60.3	76.5	82.1	89.0*
	Other Race (including Multi-Racial) (n=555)	25.8	45.0	64.5	73.0	79.2*

Online Supplementary Material

Income to poverty*	0.00–1.30 (n=3,322)	31.1	58.8	72.3	81.0	86.5*
	>1.30–3.50 (n=3,062)	26.4	50.0	67.1	77.4	84.9*
	>3.50 and above (n=2,100)	23.0	46.1	52.0	72.8	75.2*
Educational attainment	<12 years (n=2,669)	32.9	50.6	68.7	76.8	86.4*
	12 years (n=2,136)	29.3	56.2	66.0	81.8	83.7*
	>12 years (n=4,398)	23.4	47.7	59.1	74.2	79.9*

*Significant linear trend across quintiles (P<=0.001), both in unadjusted and Poisson models adjusted for sex, age group (1-5, 6–11, 12–19, 20–39, 40–59, 60 + years), race/ethnicity (Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black and Other Race - Including Multi-Racial-), ratio of family income to poverty (SNAP 0.00–1.30, >1.30–3.50, and >3.50 and over) and educational attainment (<12, 12 years and >12 years).

Online Supplementary Material

References (for Online Supplementary Material).

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (Cross- sectional study; p.2)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (p.2-3)
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported (p.4-5)
Objectives	3	State specific objectives, including any prespecified hypotheses (p.5)
Methods		
Study design	4	Present key elements of study design early in the paper (p.6)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (p.6-7)
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (nap) *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls (nap) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants (p.6-7)
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed (nap) *Case-control study*—For matched studies, give matching criteria and the number of controls per case (nap)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (p.7-10)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (p.7-10)
Bias	9	Describe any efforts to address potential sources of bias (lines 60-61)
Study size	10	Explain how the study size was arrived at (lines 54-60; lines 134-136)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (p.8-10)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (p.9-10)
		(*b*) Describe any methods used to examine subgroups and interactions (p.9-10)
		(*c*) Explain how missing data were addressed (lines 134-136)
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed (nap) *Case-control study*—If applicable, explain how matching of cases and controls was addressed (nap) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy (lines 137-142)
		(*e*) Describe any sensitivity analyses (nap)

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (lines 54-61, lines 134-136)
		(b) Give reasons for non-participation at each stage (lines 54-61, lines 134-136)
		(c) Consider use of a flow diagram (nap)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (lines 147-158; Table 1)
		(b) Indicate number of participants with missing data for each variable of interest (lines 134-136)
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) (nap)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time (nap)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure (nap)
		Cross-sectional study—Report numbers of outcome events or summary measures (lines 180-193; Table 1)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (lines 194-224; Figure 1; Table 2)
		(*b*) Report category boundaries when continuous variables were categorized (Table 2)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period (nap)
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (lines 220-221; Supplementary Table 2)
Discussion		
Key results	18	Summarise key results with reference to study objectives (lines 233-247)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (lines 296-308)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (lines 309-314)
Generalisability	21	Discuss the generalisability (external validity) of the study results (lines 265-288)
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based (nap)

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.