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Identifying and Estimating Ultraprocessed Food Intake in the US NHANES According to the Nova Classification System of Food Processing

Eurídice Martínez Steele [1,2,*,†], Lauren E. O'Connor [3,†], Filippa Juul [4], Neha Khandpur [1,2,5], Larissa Galastri Baraldi [2,6], Carlos A. Monteiro [1,2], Niyati Parekh [7,8,9], Kirsten A. Herrick [3]

[1] *Department of Nutrition, School of Public Health, University of São Paulo, São Paulo, Brazil;* [2] *Center for Epidemiological Studies in Health and Nutrition, University of São Paulo, São Paulo, Brazil;* [3] *Risk Factor Assessment Branch, Epidemiology and Genomics Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, National Institutes of Health, Rockville, MD, USA;* [4] *Department of Public Health Policy and Management, School of Global Public Health, New York University, New York, NY, USA;* [5] *Department of Nutrition, Harvard T.H. Chan School of Public Health, Boston, MA, USA;* [6] *Center for Food Studies and Research (NEPA), University of Campinas, Campinas, Brazil;* [7] *Public Health Nutrition Program, School of Global Public health, New York University, New York, NY, USA;* [8] *Department of Population Health Sciences, NYU Grossman School of Medicine, New York University, New York, NY, USA;* [9] *Rory Meyers School of Nursing, New York University, New York, NY, USA*

A B S T R A C T

Background: The degree of food processing may be an important dimension of diet in how it relates to health outcomes. A major challenge is standardizing food processing classification systems for commonly used datasets.

Objectives: To standardize and increase transparency in its application, we describe the approach used to classify foods and beverages according to the Nova food processing classification in the 24-h dietary recalls from the 2001–2018 cycles of What We Eat in America (WWEIA), NHANES, and investigate variability and potential for Nova misclassification within WWEIA, NHANES 2017–2018 data via various sensitivity analyses.

Methods: First, we described how the Nova classification system was applied to the 2001–2018 WWEIA, NHANES data using the reference approach. Second, we calculated the percentage energy from Nova groups [1: unprocessed or minimally processed foods, 2: processed culinary ingredients, 3: processed foods, and 4: ultraprocessed foods (UPFs)] for the reference approach using day 1 dietary recall data from non-breastfed participants aged ≥1 y from the 2017–2018 WWEIA, NHANES. We then conducted 4 sensitivity analyses comparing potential alternative approaches (e.g., opting for more vs. less degree of processing for ambiguous items) to the reference approach, to assess how estimates differed.

Results: The energy contribution of UPFs using the reference approach was 58.2% ± 0.9% of the total energy; unprocessed or minimally processed foods contributed 27.6% ± 0.7%, processed culinary ingredients contributed 5.2% ± 0.1%, and processed foods contributed 9.0% ± 0.3%. In sensitivity analyses, the dietary energy contribution of UPFs ranged from 53.4% ± 0.8% to 60.1% ± 0.8% across alternative approaches.

Conclusions: We present a reference approach for applying the Nova classification system to WWEIA, NHANES 2001–2018 data to promote standardization and comparability of future research. Alternative approaches are also described, with total energy from UPFs differing by ~6% between approaches for 2017–2018 WWEIA, NHANES.

Keywords: degree of processing, Nova, ultraprocessed, NHANES, dietary intake, 24-hour recalls, WWEIA

Abbreviations: AMPM, Automated Multiple-Pass Method; FNDDS, Food and Nutrient Database for Dietary Studies; MEC, Mobile Examination Center; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference; WWEIA, What We Eat in America.

* Corresponding author. *E-mail address:* emar_steele@hotmail.com (E.M. Steele).
† Joint first authors.

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Introduction

There is increasing interest in how the degree of food processing affects human health [1–3]. The Nova classification is a system that classifies foods and beverages based on the extent and purpose of the industrial processing that they undergo and accounts for the physical, biological, and chemical methods used in their manufacture, including the use of additives [4]. Ultraprocessed foods, 1 of the 4 groups that make up the Nova classification system, are industrial formulations of processed food substances (oils, fats, sugars, starch, protein isolates) that contain little or no whole foods and typically include flavorings, colorings, emulsifiers, and other cosmetic additives [4]. Studies using the ongoing US nationally representative NHANES found that ultraprocessed food consumption was associated with poorer overall dietary quality [5,6], lower nonnutrient lignan intake/-bioavailability [7], and water intake [8]. Other studies have observed that high intake of ultraprocessed food are associated with an increased exposure to phthalates and bisphenol [9,10]. In US adults, higher ultraprocessed food consumption has been associated with an increased prevalence of overweight/obesity and metabolic syndrome, higher excess heart age and abdominal and visceral adiposity, and lower cardiovascular health [11–15]. Among US adolescents, higher ultraprocessed food consumption was associated with increased total, abdominal, and visceral adiposity [16]. Another study using NHANES estimated that reducing ultraprocessed food consumption has the potential to substantially reduce obesity rates among children and adolescents in the United States [17]. Trend analyses have consistently observed increases in ultraprocessed food consumption in both US youth and adults in the past 2 decades [18,19].

Ensuring a standardized application of the Nova classification system to nationally representative datasets, such as NHANES, is needed as the Nova classification system is increasingly recognized by global health organizations as a tool for measuring diet quality [20–22]. Standardization is critical so that the studies investigating associations between the Nova classification system and health outcomes are both replicable and comparable. A major challenge in standardizing the Nova classification system for datasets like NHANES is the lack of detail on processing levels of foods, as that was not the objective of the dietary data collection. For example, during dietary interviews, interviewers generally do not probe participants about food preparation (whether a food was handmade or not) or the degree of food processing (that may be ascertained by asking about the brand name of the product). Even if they are probed, it may be difficult for the participants to understand or recall the degree to which a food that they reported is processed. Second, food composition databases without brand-specific data may lack the necessary descriptive information (e.g., food labels and package ingredients) to determine the Nova classification. As a result, assumptions regarding the degree of processing are needed for certain food items when applying the Nova classification system to self-reported dietary intake data in nutrition surveillance and epidemiology. Different approaches can be used (resorting to the least degree of processing or relying on metadata like food source) to address the lack of detail or clarity present in NHANES and other large dietary datasets. Understanding the impact that these different approaches can have on the estimated intakes of Nova groups is an important component in interpreting variability and potential misclassification when using the Nova classification system. This research will help address concerns about the reproducibility of the Nova classification system to dietary databases and promote the standardization of this approach [23–25].

The first objective of this study was to describe how the Nova classification system was applied to the 2001–2018 What We Eat in America (WWEIA) data, the dietary intake component of the NHANES, using the reference approach to provide transparency of its application. The second objective was to estimate the percentage energy from Nova groups (1: unprocessed or minimally processed foods, 2: processed culinary ingredients, 3: processed foods, and 4: ultraprocessed foods) for WWEIA, NHANES 2017–2018 in individuals aged ≥1 y using the reference approach. We then conducted a series of 4 sensitivity analyses, comparing potential alternative approaches (e.g., opting for more vs. less degree of processing for ambiguous items) to the reference approach, to assess how the percentage of energy from Nova groups differed between approaches.

Methods

In this section, we start by providing some background about WWEIA, NHANES and its structure and explain how potential homemade or artisanal mixed dishes were disaggregated into a list of constituent ingredients to obtain more accurate Nova estimates. Thereafter, we explain how the Nova classification system was originally applied to WWEIA, NHANES 2001–2018, and decisions made to do so, in what we call the reference approach, that has been used in prior research [5–9,11–19,26]. Lastly, we describe alternative approaches to applying the Nova classification to WWEIA, NHANES and sensitivity analyses to explore the variability of alternative approaches, compared with the reference approach, in estimating the percentage of total energy from Nova groups consumed by the US population aged ≥1y in WWEIA, NHANES 2017–2018.

Background on WWEIA, NHANES

Data source

NHANES is a series of nationally representative, cross-sectional surveys, conducted by the US CDC's NCHS that aim to assess the health and nutritional status of the noninstitutionalized, civilian US population [27]. The survey uses a complex, stratified, multistage probability cluster sampling design based on the selection of counties, blocks, households, and the number of people within households. The data have been released every 2 y since 1999 [28]. The survey includes an in-person household interview followed by a physical examination conducted at a Mobile Examination Center (MEC).

NHANES protocols are approved by the NCHS Research Ethics Review Board. Written informed consent is obtained from participants aged ≥18 y, written parental informed consent is obtained for all children aged 2–17 y, and child assent is obtained from all children aged 7–17 y.

Collection of dietary information

The dietary intake component of NHANES is referred to as WWEIA, NHANES [29]. Since 2003, all NHANES participants are eligible to complete two 24-h dietary recall interviews; 1 interview was completed before 2003. The first interview-administered dietary recall is collected in-person in the MEC [30], whereas the second is collected by telephone 3–10 d later and ideally not on the same day of the week as the MEC interview [31]. All dietary recalls are collected using the USDA's Automated Multiple-Pass Method (AMPM) [32]—a 5-step dietary interview—during which the respondents receive cues to help them remember and describe foods that they consumed during the 24 h of the previous day. Although AMPM aims to prompt complete reporting and several studies support the utility of the AMPM in assessing total energy intake at the population level [32], it was not specifically designed to probe participants about food preparation (whether a food was handmade or not) or degree of food processing (e.g., brand names consumed). Participants aged ≥12 y complete the dietary recall on their own, those aged 6–11 years are assisted by a proxy, and proxies report intakes for those aged ≤5 y.

General structure of the WWEIA dietary data

Each food or beverage in WWEIA, NHANES is uniquely identified by an 8-digit food code. The first digit of the food code refers to 1 of the 9 major food commodity groups in the United States, and the second digit refers to the commodity food subgroups [33]. Data from WWEIA, NHANES are linked to data on energy and nutrient values in the Food and Nutrient Database for Dietary Studies (FNDDS) using the 8-digit food codes [29,33]. In FNDDS, the energy and nutrient values of food codes are estimated using the USDA National Nutrient Database for Standard Reference based on standard reference codes (SR codes), or ingredient code(s) in the 2015–2018 cycles (hereafter SR codes) (NDB_No as named in USDA National Nutrient Database for Standard Reference) [33]. Energy and nutrient values in the SR database are derived from analyses, calculations, or the literature, and are an estimate of the average exposure of that food or beverage across the United States [29].

The SR codes are compiled and linked to food codes to obtain an appropriate nutrient content that is representative of the food code but do not serve as a list of exact ingredients of that food code [33]. Some food codes link to single SR codes (Fig. 1), whereas other food codes link to multiple SR codes. Multiple SR codes may be used when a single SR code is not enough to define the nutrient profile of the food code (Fig. 2), to represent a composite of variants of a food or beverage when the food code is nonspecific as to type (Fig. 3), or to represent constituent ingredients from a composite recipe/mixed dish (Fig. 4). Some 8-digit food codes link to other 8-digit food codes instead of SR codes (as a way of simplifying database maintenance), which then link further to SR codes; eventually all 8-digit food codes can be broken down into underlying SR codes only (Fig. 5).

For the 2015–2016 and 2017–2018 cycles, FNDDS used what are referred to as "ingredient codes" to generate the nutrient profile of each food code. The ingredient codes can be any of the following: SR code (4–5 digit), FNDDS food code (8 digit), or the Food Surveys Research Group (FSRG) generated code based on another SR code (6 digits). FNDDS 2017–2018 also included Foundation Food codes from Food Data Central as ingredient codes.

Linking food codes from WWEIA, NHANES with SR codes using FNDDS

As a prior step to applying the Nova classification to WWEIA, NHANES we linked each 8-digit food code to its underlying SR codes (and SR code weights per 100 g of food code) by consecutive merges of FNDDS "main food description" and "SR link"/"ingredient" files (Fig. 5). The intention behind linking food codes to SR codes (the smallest unit of underlying components of each food code) was that some food codes may be homemade dishes made from scratch ingredients; thus, we disaggregated them into their SR codes to obtain more accurate estimates of constituent scratch ingredients (as is recommended by the proponents of the Nova classification system). We refer to these as "disaggregated food codes."

Consecutive merges are needed because in FNDDS some food codes are linked to food codes instead of SR codes as a way of simplifying database maintenance. At each merge, the gram weight of each food code/SR code was recalculated so that the food code/SR code amount was proportional to the parent food code that was being disaggregated into subcomponents at each merge (Fig. 5). After the food codes were linked to the underlying SR codes, the dataset was merged with FNDDS "additional food descriptions" (occasionally including brand names) to provide additional qualitative information to inform the Nova classification.

The consecutive merges disaggregated all food codes (including recipes and mixed dishes) into underlying SR codes. Some mixed dishes may not be disaggregated into constituent ingredients after the consecutive merges because only a single recipe SR code is provided in FNDDS to calculate the nutrient profile and not a composite of SR codes representing constituent ingredients (referred to as "nondisaggregated food codes"). For example, food code "Sesame chicken" is linked to SR code "Restaurant, Chinese, sesame chicken" and, thus, not disaggregated into constituent ingredients after the consecutive merges.

The Nova classification system

The Nova classification includes 4 groups: group 1 (unprocessed or minimally processed foods) includes foods such as fresh, dry, or frozen fruits or vegetables, grains, legumes, meat, fish, and milk that have undergone no processing or processing like grinding, roasting, pasteurization, freezing; group 2 (processed culinary ingredients) includes table sugar, oils, fats, salt, and other substances that have been extracted, pressed, or centrifuged from group 1 foods or from nature, which are used to make culinary preparations; group 3 (processed foods) includes foods that are manufactured using unprocessed or minimally processed foods with the addition of group 2 ingredients to prolong the durability and modify their palatability (e.g., canned fruits; artisanal breads and cheese; and salted, smoked, or cured meat or fish); and group 4 (ultraprocessed foods) foods are industrial formulations of several ingredients, including group 2 ingredients and small or no amounts of whole foods, that typically contain food cosmetic additives not used in culinary preparations, like flavors, colors, sweeteners, emulsifiers, and other substances used to disguise undesirable qualities of the final product or imitate the sensorial qualities of group 1 culinary preparations [4]. Table 1 provides definition and examples of each Nova food group.

Application of the Nova classification system to WWEIA, NHANES

Each WWEIA, NHANES food item (food code and SR code) was classified into 1 of 4 Nova groups and 1 of 37 mutually

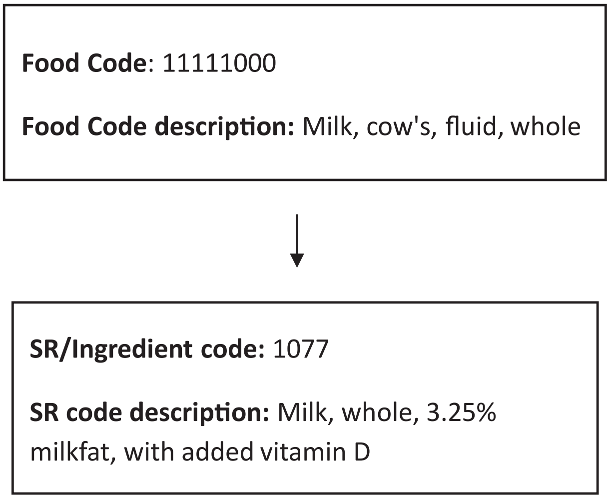

Fig. 1. Example of a food code linked to a single ingredient/SR code. Food code, 8-digit food code from the USDA Food and Nutrient Database for Dietary Studies; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference.

exclusive food subgroups within unprocessed or minimally processed foods ($n = 11$ subgroups), processed culinary ingredients ($n = 4$ subgroups), processed foods ($n = 4$ subgroups), or ultra-processed foods ($n = 18$ subgroups), based on use, main ingredient/type of food, and degree of consumption. Foods with a low prevalence of consumption were grouped as "others" within each of the 4 Nova groups. Food code and SR code descriptions classified in each Nova group and subgroup are listed in Supplemental Table 1.

Reference approach to guide the Nova classification of food items in WWEIA, NHANES

Here, we describe what we call the "reference approach" of classifying WWEIA, NHANES data according to the Nova classification system. We considered this the reference approach because it was developed by the creators of the Nova classification system and has been used in most previous studies [5–9, 11–19,26].

The decisions made to classify WWEIA, NHANES according to the Nova classification system in the reference approach including examples are displayed in Table 2.

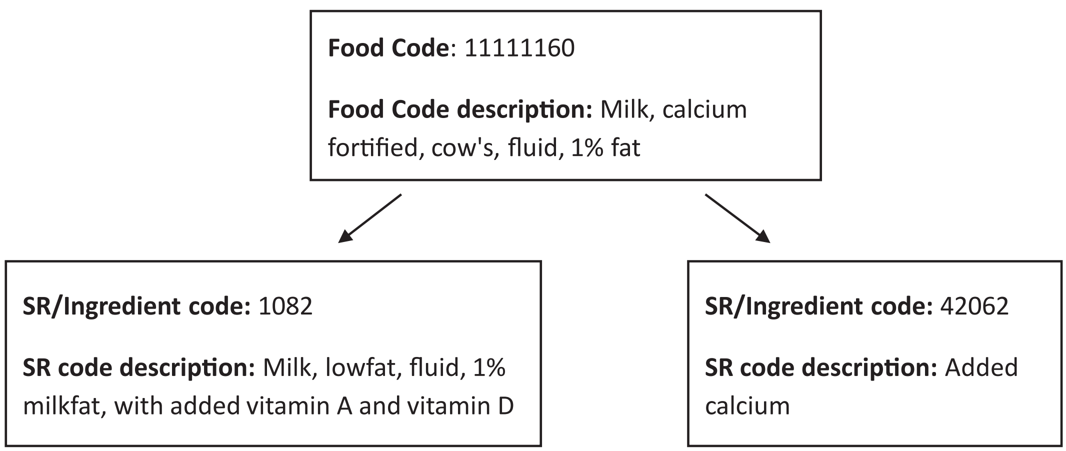

Fig. 2. Example of a food code linked to multiple ingredient/SR codes when a single ingredient/SR code is not enough to define the nutrient profile of the food code. Food code, 8-digit food code from the USDA Food and Nutrient Database for Dietary Studies; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference.

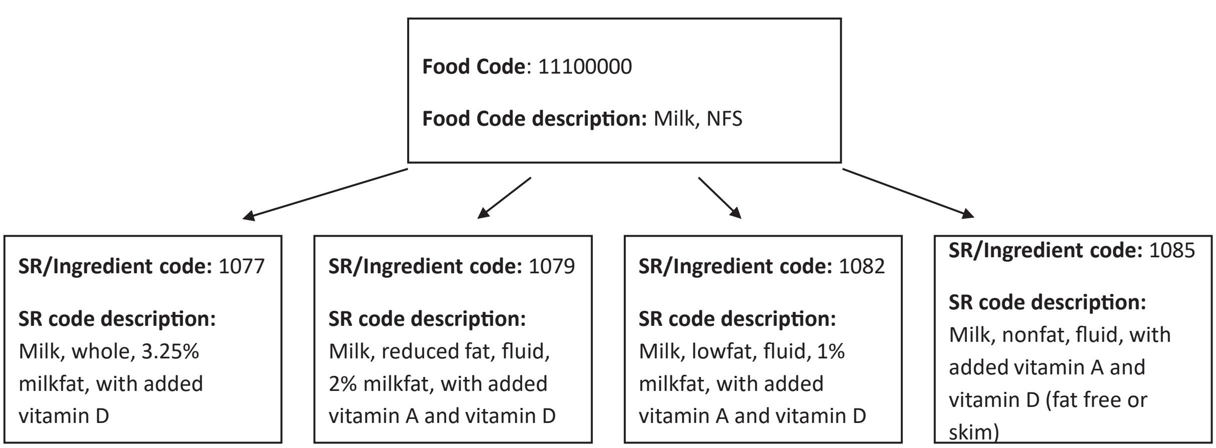

Fig. 3. Example of a food code linked to multiple ingredient/SR codes when food code is nonspecific as to type. Food code, 8-digit food code from the USDA Food and Nutrient Database for Dietary Studies; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference; NFS, not further specified.

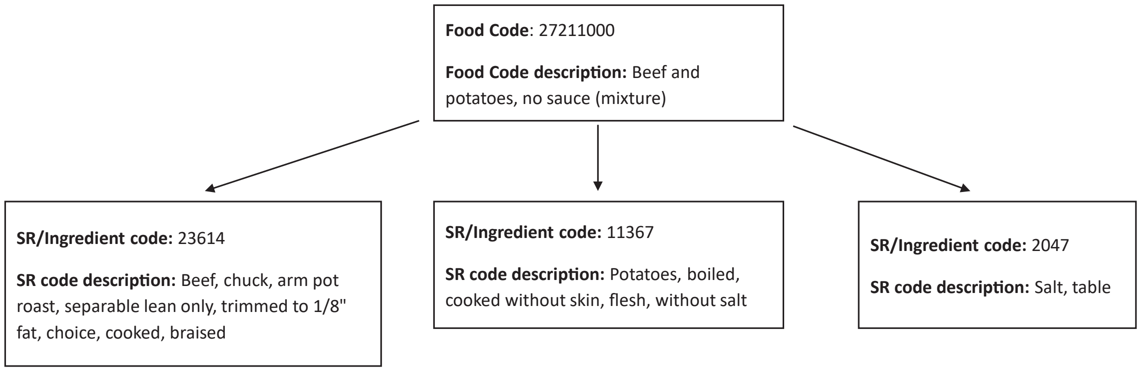

Fig. 4. Example of a food code linked to multiple ingredient/SR codes to represent ingredients from a composite recipe/mixed dish. Food code, 8-digit food code from the USDA Food and Nutrient Database for Dietary Studies; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference.

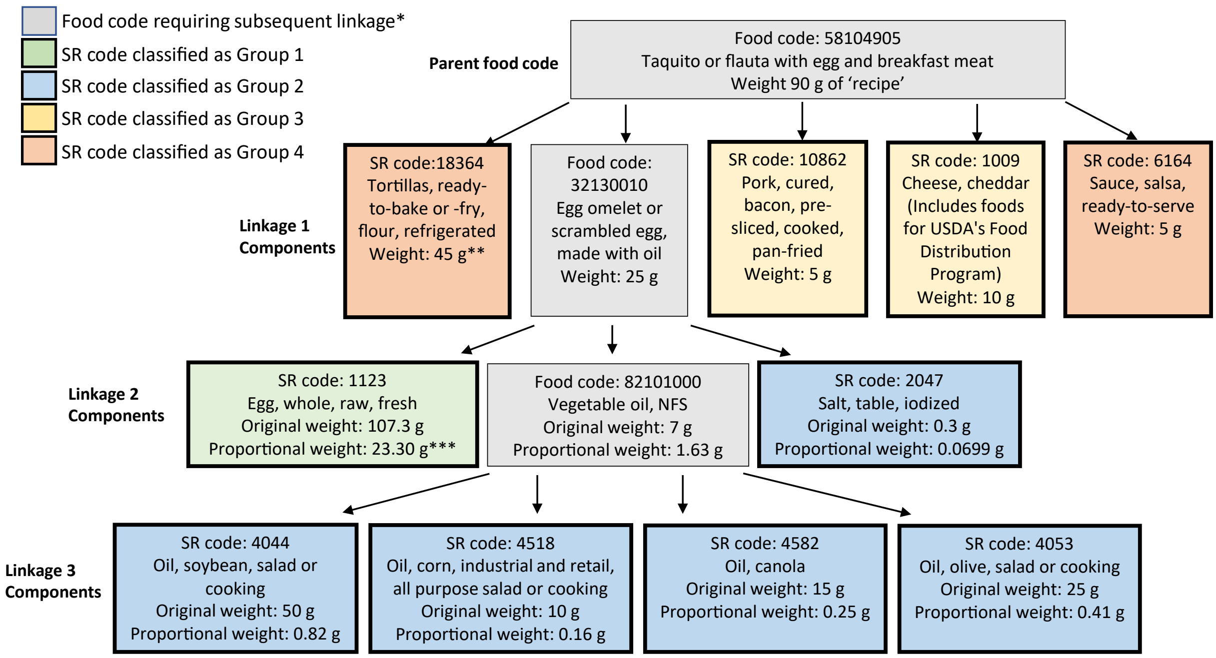

Fig. 5. Example of disaggregating a food code into SR codes and applying the Nova classification system. *Consecutive merges were needed because in USDA Food and Nutrient Database for Dietary Studies (FNDDS), some food codes were linked to food codes instead of SR codes as a way of simplifying database maintenance. At each merge, the gram weight of each food code/SR code was recalculated so that the food code/SR code amount is proportional to the parent food code that is being disaggregated into subcomponents at each merge. **The component weights in linkage 1 sum to the weight of the parent food code. ***The component weights in subsequent linkages are proportional weights based on the "recipe" for the food code being further linked. For example, the "recipe" for food code: 32130010 is 100.0 g of SR 1123, 0.3 g of SR 2047, and 7.0 g of food code 82101000. Therefore, the proportional weight for SR 1123 in linkage 2 is 25 g $\times$ (100.0/100.0 + 0.3 + 7.0). These steps use the FNDDS database before the participant-level data from NHANES are merged. Therefore, the weight corresponds to the weight of the parent food code in the database and not the amount of the parent food code reported by the participant. The weights shown here will be further multiplied by the amount of the parent food code that the participant reported. Minor additional adjustments, such as accounting for moisture and fat content of cooked vs. raw components, may be made for the more complex parent food codes. In this hypothetical example, this food was considered homemade; therefore, the Nova classification system was applied to the SR codes after the third linkage, rather than at the parent food code level. If a participant reported that the source of the food code was a frozen meal, the original amount reported for the parent food code 58104905 would have been all classified as group 4. Food code, 8-digit food code from the USDA FNDDS; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference; NFS, not further specified.

The Nova classification was determined by taking into account the following 3 variables from the NHANES recall databases: "main food description," "additional food description," which qualitatively describes food codes, and "SR code description," which qualitatively describes each of the underlying SR codes. For each food code, a decision was made on whether food codes or underlying SR codes would be used to estimate Nova group energy contributions. The decision to use an SR code rather than a food code depended on whether there was any indication that the food code could have been homemade. Food codes that were likely to be homemade or artisanal and linked to a list of scratch ingredient SR codes, such as "Beef stroganoff" and "Cookie, chocolate chip, made from home recipe or purchased at a bakery," were classified at the SR code level

Table 1
The Nova classification system: Definition and examples of each Nova food group

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 unprocessed foods that have been submitted to cleaning, removal of inedible or unwanted parts, fractioning, grinding, drying, fermentation, pasteurization, cooling, freezing, or other processes that do not add substances to the original food. The purpose of minimum processing is to preserve foods and make it possible to store them and, sometimes, also to reduce the stages of food preparation (cleaning and removing inedible parts), to facilitate their digestion, or to 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 • Yogurt without sugar • Tea, herbal infusions, coffee, and tap, spring, and mineral water
2 Processed culinary ingredients These are substances extracted from unprocessed foods or from the nature itself using processes such as pressing, grinding, crushing, pulverizing, and refining. The purpose of processing is to obtain ingredients used in home and restaurant kitchens to season and cook unprocessed or minimally processed foods and to create with them varied and enjoyable dishes such as soups and broths; salads; rice and bean 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 • Table salt
3 Processed foods These are relatively simple products manufactured essentially with the addition of salt or sugar or other substances of common culinary use, such as oil or vinegar, to unprocessed or minimally processed foods. Breads made with wheat flour, yeast, water, sugar and salt, or other ingredients used in culinary preparations are classified in this group. Processed foods also include alcoholic drinks produced by the fermentation of group 1 food items. The purpose here is to prolong the durability of foods and to modify their palatability.	• Canned and bottled vegetables, legumes, or fruits • Salted nuts or seeds • Salted, smoked, or cured meat or fish • Canned sardine and tuna • Cheeses • Wine, beer, and cider • Breads that comply with the processed food definition
4 Ultraprocessed foods Food products made up from several ingredients (formulations) including sugar, oils, fats, and salt (generally in combination and in higher amounts than in processed foods) and food substances of no or rare culinary use (such as high fructose corn syrup, hydrogenated oils, modified starches and protein isolates). Group 1 foods are absent or represent a small proportion of the ingredients in the formulation. These are food and drink products whose manufacturing involves several stages and various processing techniques and ingredients, many of which are used exclusively by industry. The purpose of processing 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. Alcoholic beverages produced by fermentation of group 1 food items followed by distillation and eventual addition of sugars or other substances are also classified in this group. Breads and baked goods become ultraprocessed products when, in addition to wheat flour, yeast, water, sugar, and salt, their ingredients include substances that are not used in culinary preparations, such as hydrogenated vegetable fat, whey, emulsifiers, and other additives.	• Confectionery • Soft drinks, energy drinks, sweetened juices, and powders for juices • Dairy drinks • Sausages, chicken and fish nuggets or sticks • Pre-prepared frozen dishes • Dried products such as cake mix, powdered soup, instant noodles, ready-to-eat seasonings • Packaged snacks • Ready-to-eat cereals and cereal bars • Sugar substitutes, sweeteners, and all syrups (excluding 100% maple syrup) • Breads and baked goods that comply with ultraprocessed food definition

(referred to as "disaggregated food codes" or "disaggregated mixed dishes") (decision A in Table 2). Conversely, foods likely purchased as ready-to-eat/heat/drink items, such as "Milk, fat-free (skim)," "Cereal (Kellogg's Apple Jacks)" or "Lasagna with meat, canned" were classified at the food code level (referred to as "nondisaggregated food code" or "nondisaggregated mixed dishes"). Mixed dishes were assumed to be homemade unless the food item description or SR codes clearly suggested that it was ready-to-eat.

When necessary, the list of ingredients of branded food products, obtained through supermarket, Amazon, and Fooducate websites [34] and from the USDA Branded Food Products Database (available from 2019 onward and relevant to the 2017–2018 WWEIA, NHANES cycles only) [35,36] were used to

Table 2
Decisions made to classify What We Eat in America, NHANES, according to the Nova classification system in the reference approach

Decision	Description	Examples
Decision A: Likely homemade dishes classified at the SR code level	Food codes that were likely to be homemade or artisanal and linked to a list of scratch ingredient SR codes were classified at the SR code level (referred to as "disaggregated mixed dishes"). Mixed dishes were assumed to be homemade unless the food item description or SR codes clearly suggested that it was ready-to-eat.	- "Beef stroganoff" and "Cookie, chocolate chip, made from home recipe or purchased at a bakery" were classified at the SR code level - Foods likely purchased as ready-to-eat/heat/drink items, such as "Milk, fat-free (skim)," "Cereal (Kellogg's Apple Jacks)" or "Lasagna with meat, canned," were classified at the food code level
Decision B: More conservative classification	Absence of needed descriptive data for food codes or discrepancies between coders regarding the degree of processing were generally solved by opting for the lesser degree of processing (conservative criterion), with some exceptions including bread, ready-to-eat cereal, and salty snacks.	- Cured meats were classified as processed (group 3), as guided by the Nova classification system, although some would be considered ultraprocessed. Food code "Pork bacon, NS as to fresh, smoked or cured, cooked" was classified as processed, although some brands such as "Sliced bacon, hickory smoked" should be considered ultraprocessed because of sodium nitrite and flavorings in the following ingredient list: pork cured with water, salt, cane, and brown sugar, sodium phosphate, sodium erythorbate, sodium nitrite, flavorings (source: USDA Branded Food Products Database) - Jellies, jams, and applesauce were classified as processed foods (although some brands could be ultraprocessed) - Animal fats such as creams and evaporated milks were classified as processed culinary ingredients (although some brands could be ultraprocessed) - Cottage and cream cheese were classified as processed cheese (although some brands could be ultraprocessed)
Decision C: Classifying breakfast cereals and salty snacks as ultraprocessed	Ready-to-eat breakfast cereals and salty snacks were generally classified as ultraprocessed, as guided by the Nova classification system, although some specific brands may be processed.	- For example, food code "Cereal, Corn Flakes" was classified as ultraprocessed consistent with the ingredient list of Kellogg's Corn Flakes containing malt flavor (milled corn, sugar, contains ≤2% of malt flavor, salt, BHT for freshness, vitamins, and minerals) or Springfield Cereal, Corn Flakes containing high fructose corn syrup (milled corn, sugar, salt, malt syrup, high fructose corn syrup, vitamins and minerals), although some brands might be processed, such as Barbara's Cereal, Corn Flakes (organic corn, organic fruit juice concentrate (pear or apple), sea salt) - Regarding salty snacks, although Corn Nuts Crunchy Corn Kernels are ultraprocessed because of monosodium glutamate and natural flavor in their ingredient list (corn, salt, corn oil, contains <2% of maltodextrin, spice, onion powder, garlic powder, tomato powder, monosodium glutamate, citric acid, paprika extract (for color), natural flavor), Corn Nuts Original Crunchy Corn Kernels (corn, corn oil, salt) would be processed
Decision D: Classifying industrial bread as ultraprocessed	Regarding bread, the Nova 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 manufactured with ingredients used in culinary preparations) or ultraprocessed (when manufactured with food substances not used in culinary preparations). Because of the large amount of industrial breads with unknown ingredients in the NHANES dietary data (~3.7% of all industrial bread had fully known ingredients in cycle 2009–2010) and the very low consumption of processed breads when ingredients were reported (~2.3% of industrial breads were processed in cycle 2009–2010), all industrial bread were classified as ultraprocessed foods [26].	—
Decision E: Classifying nondisaggregated mixed dishes based on principal ingredient	Potential homemade mixed dishes with unlisted scratch ingredients (because Food Code was linked to recipe/mixed dish and not to a list of scratch ingredient SR codes) were classified based on expected principal ingredients.	- For example, an SR code "Restaurant, Chinese, sesame chicken" (36633) used to code the "Sesame chicken" (food code 27146360), was classified as "meat" within unprocessed/minimally processed foods

(*continued on next page*)

Table 2 (*continued*)

Decision	Description	Examples
Decision F: Using "combination food type" and "source of food" to review Nova classification	Participant-specific "Combination Food Type" and "Source of food" variables from the dietary recall were used to check the appropriateness of Nova classification. Some items were reclassified based on the information provided by these variables, if needed. Some food codes (mainly mixed dishes, including sauces and cakes, cookies, and pies) initially classified at the SR code level were reclassified as ultraprocessed foods at the food code level if consumed as "frozen meals" or "lunchables" (combination food types) or from "restaurant fast food/pizza" or "vending machine" (food source). The classification of most food items, however, did not change (e.g., a raw apple from a fast food place or vending machine remained classified as an unprocessed/minimally processed food).	- For example, "Rice with vegetables (including carrots, broccoli, and/or dark-green leafy), no sauce, NS as to fat added in cooking" was initially classified at the SR code level under the assumption that it was a homemade recipe. This was reclassified at the food code level as an ultra-processed ready-to-eat meal when reported as a "frozen meal" - "Coffee cake, yeast type, made from home recipe or purchased at a bakery" coded according to SR codes was reclassified as ultraprocessed "cake" when consumed at a "restaurant fast food/pizza"

NS, not specified. SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference.

decide upon the most appropriate Nova group and subgroup. The USDA Branded Food Products Database is the result of a public–private partnership, furnishing private label data of branded foods provided by the food industry [29,35,36]. For example, food code "Salsa, red, cooked, not homemade" linked with SR code "Sauce, ready-to-serve, salsa" was classified as ultraprocessed (rather than processed) based on the list of ingredients of branded products such as Lizano Salsa [water, sugar, iodized salt, vegetables, chili, pepper, molasses, spices (mustard, celery), modified corn starch, acetic acid, hydrolyzed corn protein, and sodium benzoate (used to protect quality); treated with ionizing energy and contains traces of soy and milk]. In contrast, food code "Salsa, red, cooked, homemade," which is linked to a list of scratch ingredient SR codes ["Peppers, hot chile, sun-dried" (unprocessed/minimally processed), "Tomatoes, red, ripe, canned, packed in tomato juice" (processed), "Onions, raw" (unprocessed/minimally processed), "Garlic, raw" (unprocessed/minimally processed), "Vegetable oil, not further specified" (processed culinary ingredient), "Salt, table" (processed culinary ingredient), and "Water, tap, drinking" (unprocessed/minimally processed)] was classified at the SR code level.

This reference approach of Nova application to NHANES generally used a conservative approach, with some exceptions such as ready-to-eat cereal, salty snacks, and bread. This meant that ambiguous food items, where a brand name or further details would have been needed to assign a Nova group with certainty, were classified into a lower degree of processing (conservative criteria) (such as cured meats, jellies, jams, applesauce, cottage and cream cheese, creams, and evaporated milks) (decision B in Table 2). Ready-to-eat breakfast cereals, salty snacks, and industrial bread were classified as ultraprocessed (although some specific brands could have been processed or minimally processed) because most foods that fall into these categories met the Nova criteria for ultraprocessed, and these foods are not commonly homemade in the United States (decisions C and D in Table 2).

Potential homemade recipes with unlisted constituent ingredients (SR codes) were classified into 1 of the 4 Nova groups based on the expected principal ingredients (i.e., food code "Sesame chicken" linked to SR code "Restaurant, Chinese, sesame chicken" was classified as "unprocessed/minimally processed meat") (decision E in Table 2).

Finally, the participant-specific variables of "combination food type" and "source of food" from the dietary recall were used to check the appropriateness of the Nova group. Some items were reclassified based on the information provided by these variables (decision F in Table 2). For instance, some food codes (mainly mixed dishes, including sauces and cakes, cookies, and pies) initially classified at the SR code level were reclassified as ultraprocessed foods at the food code level in participants who consumed the food code as "Frozen meals" or "Lunchables" (combination food types) or from "Restaurant fast food/pizza" or "Vending machine" (food source). The classification of most food items, however, did not change (e.g., raw apple from a fast food place or vending machine remained classified as an unprocessed/minimally processed food). Fig. 6 describes the overall classification process.

Application of the Nova classification system to 2009–2010 WWEIA, NHANES

The classification was first manually applied to 2009–2010 WWEIA, NHANES data because this was the most recent available data cycle at inception [26]. Two researchers worked independently to manually classify both food code and underlying SR codes according to the Nova classification system and decided for each food code whether food codes or underlying SR codes would be used to estimate Nova category group energy contributions, in Microsoft Excel. Discordant classifications between the researchers were resolved by discussion.

The manual coding of the NHANES, WWEIA 2009–2010 cycle was then coded into Stata, reviewed by a third researcher, and compared with the initial manual classification (completed in Excel) for accuracy.

Application of the Nova classification system to the remaining WWEIA, NHANES cycles

FNDDS is updated every 2 y and tied to the relevant release cycle of WWEIA, NHANES data. New food codes are added, whereas others are discontinued to reflect new food items, portion sizes, and changes in the food production and supply. The Stata

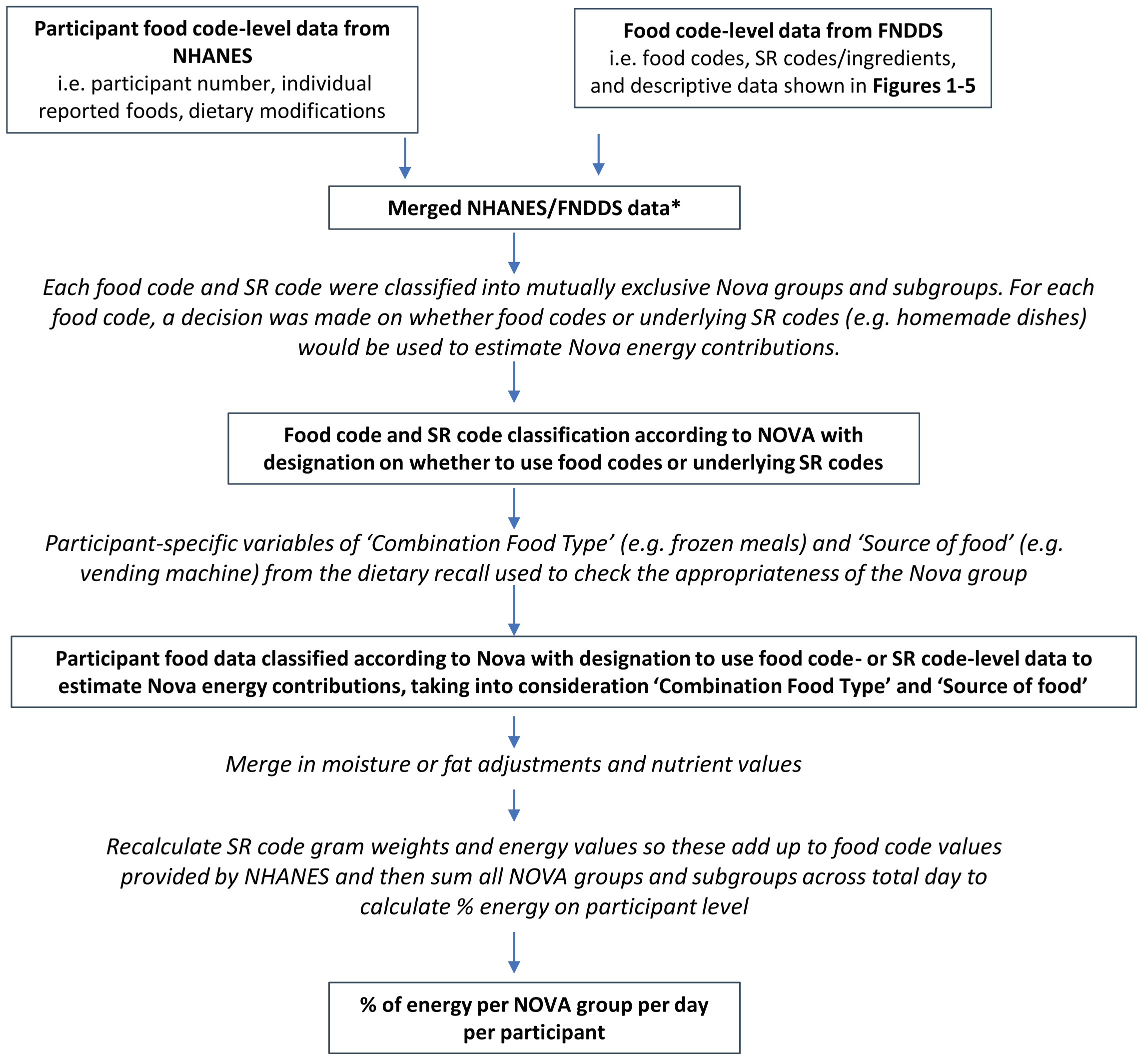

Fig. 6. Overview of the Nova classification process for NHANES. The boxes represent datasets, and the italicized text describes the action completed at each step by the program. *Food codes are disaggregated into SR codes at this step. More information of each step is described in the article. Food code, 8-digit food code from the USDA Food and Nutrient Database for Dietary Studies; SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference; FNDDS, USDA Food and Nutrient Database for Dietary Studies.

code developed for the Nova classification of 2009–2010 WWEIA, NHANES cycle was updated to include food and SR codes used in cycles spanning 2001–2018 to allow researchers to assess intakes from different data cycles and map trends over time of Nova groups. To apply and update the 2009–2010 classification code in Stata for its application in the remaining cycles from 2001–2002 to 2017–2018, the food codes used in each cycle were first linked with SR codes following the steps previously described (see "Linking food codes from WWEIA, NHANES with SR codes using FNDDS"). The SR codes for each cycle were obtained from the corresponding FNDDS versions—FNDDS 1.0, 2.0, 3.0, 4.0, 2011–2012, 2013–2014, 2015–2016 and 2017–2018. The Stata file was updated with any new food codes or SR codes not coded in the previously classified cycles.

Alternative approaches to guide the Nova classification of food items

In the current section, we describe 4 alternative approaches to the reference approach for Nova classification. These alternative approaches were used in sensitivity analyses to assess how the estimates differed between approaches (see "Data analysis").

In the first alternative approach (most conservative), we coded items with uncertain classification using the lowest potential processing level. In this alternative approach, some salty snacks and breakfast cereals classified as ultraprocessed in the reference approach (as per decision C in Table 2) were reclassified as processed foods, whereas a few were reclassified as minimally processed foods. Some breads coded as ultraprocessed foods in the reference approach (as per decision D in Table 2) were reclassified as processed foods (group 3), whereas a small number were disaggregated into underlying ingredients (SR codes). In this alternative approach, potential homemade recipes with unlisted constituent ingredients classified into 1 of the 4 Nova groups based on the expected principal ingredients in the reference approach (as per decision E in Table 2) were classified separately in a group without a Nova assignation (named "non-disaggregated mixed dishes").

In the second alternative approach (least conservative), we coded items with uncertain classification using the highest

Table 3
Examples (nonexhaustive list) of Nova coding of food items in the reference and alternative approaches in What We Eat in America, NHANES 2017–2018

		Nondisaggregated mixed dish (i.e., restaurant, Mexican, Spanish rice)	Oil, PAM[5] cooking spray, original	Cream and sour cream	Evaporated milk, coconut cream, stevia	Cottage, cream, and ricotta cheese	Bacon, smoked or cured pork, pork chop, or pork roast	Apple pie filling; chili with beans, canned; tomato products, canned, sauce	Jellies, jams, applesauce, honey-roasted nuts, mustard	Breads (nonhomemade) with uncertain classification (i.e., Injera, Ethiopian bread; tortilla)	Ready-to-eat cereals with uncertain classification (i.e., corn flakes; Post Shredded Wheat)	Salty snacks (unflavored) with uncertain classification (i.e., corn chips, plain; crackers, matzo, plain)
Reference approach		Grains (unprocessed /minimally processed food) (coded according to the main ingredient)	Plant oils (processed culinary ingredient)	Animal fats (processed culinary ingredient)	Other processed culinary ingredients	Cheese (processed)	Ham and other salted, smoked or canned meat or fish (processed)	Vegetables and other plant foods preserved in brine (processed)	Other processed foods	Bread (ultraprocessed)	Breakfast cereals (ultraprocessed)	Salty snacks (ultraprocessed)
Alternative approach	Approach 1 (most conservative)[1]	Nondisaggregated mixed dishes (additional separate group without a Nova assignation)	Plant oils (processed culinary ingredient)	Animal fats (processed culinary ingredient)	Other processed culinary ingredients	Cheese (processed)	Ham and other salted, smoked or canned meat or fish (processed)	Vegetables and other plant foods preserved in brine (processed)	Other processed foods	- Injera, Ethiopian bread: disaggregated into underlying ingredients - Tortilla: other processed foods	- Corn flakes: other processed foods - Post Shredded Wheat: grains (unprocessed/ minimally processed food)	- Corn chips, plain: other processed foods - Crackers, matzo, plain: other unprocessed/ minimally processed food
	Approach 2 (least conservative)[2]	Nondisaggregated mixed dishes (additional separate group without a Nova assignation)	Other ultraprocessed	Other ultraprocessed	Other ultraprocessed	Other ultraprocessed	Reconstituted meat (ultraprocessed)	- Apple pie filling: desserts and other sugary products (ultraprocessed) - Chili with beans, canned: frozen and shelf-stable plate meals (ultraprocessed) - Tomato products, canned, sauce: sauces, dressings and gravies (ultraprocessed)	- Jellies and jams and applesauce: desserts (ultraprocessed) - Honey-roasted nuts: salty snacks (ultraprocessed) - Mustard: sauces, dressings, and gravies (ultraprocessed)	Bread (ultraprocessed)	Breakfast cereals (ultraprocessed)	Salty snacks (ultraprocessed)
	Approach 3 (not accounting for Food Source/ Combination Food type)[3]	Grains (unprocessed/ minimally processed food) (coded according to the main ingredient)	Plant oils (processed culinary ingredient)	Animal fats (processed culinary ingredient)	Other processed culinary ingredients	Cheese (processed)	Ham and other salted, smoked or canned meat or fish (processed)	Vegetables and other plant foods preserved in brine (processed)	Other processed foods	Bread (ultraprocessed)	Breakfast cereals (ultraprocessed)	Salty snacks (ultraprocessed)
	Approach 4 (using SR codes only)[4]	Grains (unprocessed /minimally processed food) (coded according to the main ingredient)	Plant oils (processed culinary ingredient)	Animal fats (processed culinary ingredient)	Other processed culinary ingredients	Cheese (processed)	Ham and other salted, smoked or canned meat or fish (processed)	Vegetables and other plant foods preserved in brine (processed)	Other processed foods	Bread (ultraprocessed)	Breakfast cereals (ultraprocessed)	Salty snacks (ultraprocessed)

[1] Items with uncertain classification were classified using the lowest potential processing level.

[2] Items with uncertain classification were coded using the highest potential processing level.

[3] Energy contributions were recalculated using the reference approach without taking into consideration participant-specific variables of "Combination Food Type" and "Source of food" from the dietary recall.

[4] Energy contributions were recalculated using SR codes only for all food items (instead of only using SR codes for potential homemade dishes or when indifferent). Reference approach was used taking into consideration participant-specific variables of "Combination Food Type" and "Source of food" from the dietary recall. SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference.

[5] PAM, Product of Arthur Meyerhoff.

potential processing level and coded nondisaggregated mixed dishes as a separate group without a Nova assignation ("non-disaggregated mixed dishes"). In this approach, some food items initially classified as non-ultraprocessed (as per decision B in Table 2) were reclassified as ultraprocessed.

In a third approach, we coded items making the same decisions as in the reference approach, except decision F in Table 2; thus, without taking into consideration participant-specific variables of "combination food type" and "source of food" from the dietary recall.

Last of all, in a fourth approach, we coded items making the same decisions as in the reference approach (including taking into consideration participant-specific variables of "combination food type" and "source of food" from the dietary recall) but used SR codes for all food items. In the reference approach, SR codes were used for potential homemade dishes (decision A in Table 2) or when indifferent, only; in this fourth alternative approach, SR codes were used for all food codes. Comparing estimates using SR codes only with those using the reference approach gives a sense of the variability of Nova estimates associated with the decision to use food or SR codes and to some extent the degree of consistency in the classification of food code and SR codes.

The examples of Nova coding of food items in the reference and alternative approaches are provided in Table 3.

Calculation of dietary metrics to capture Nova group intake

One way of utilizing the Nova classification system for WWEIA, NHANES is to report the percentage of total daily energy intake from the Nova main groups and subgroups [26]. Food code energy values provided by WWEIA, NHANES and FNDDS were used to calculate energy intakes from each Nova food group and subgroup. For homemade or disaggregated food codes, energy and nutrient values of the underlying SR codes were calculated using variables from both FNDDS and the USDA National Nutrient Database for Standard Reference. In this case, SR code gram weights and energy values were recalculated taking into consideration moisture or fat adjustments, so these add up to food code values provided by NHANES. All Nova groups and subgroup intakes (food code or SR code as appropriate) were summed across total day to calculate percentage energy on participant level.

Data analysis

The second objective of this study was to estimate the percentage energy from Nova groups using the reference approach (described in "Reference approach to guide the Nova classification of food items in WWEIA, NHANES" and Table 2). We also conducted a series of 4 sensitivity analyses, comparing potential alternative approaches to the reference approach (described in "Alternative approaches to guide the Nova classification of food items"), to assess how percentage energy from Nova groups differed between approaches.

The analytical sample used to compare these approaches consisted of non-breastfed NHANES participants aged $\geq$1 y from the 2017–2018 cycle. Among the 7640 individuals who provided 1 d of complete and reliable dietary intake based on USDA assessment [27], we excluded 332 participants who were aged <1 y and an additional 24 participants who were breastfed, yielding a final sample size of 7284. The breastfed participants were excluded because of the absence of data on quantities of breastfed milk intake [27].

We calculated the mean contributions of each of the Nova groups and subgroups to total energy intake using the mean proportion method. The mean proportion method calculates a ratio (e.g., percentage energy from ultraprocessed food and beverages = energy from ultraprocessed foods/total energy intake) at the individual level, which was then averaged [37,38]. NHANES sample weights were used 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 analyses to account for the complex sample design and sample weights [39]. All analyses were conducted using the Stata statistical software package version 14.2 (Stata).

Results

Results using the reference approach of Nova classification

A list of 4713 unique food codes from day 1 dietary recall data was compiled for WWEIA, NHANES 2017–2018 (the latest classified cycle). In 2746 (58.3%) of these food codes, SR codes were used to estimate Nova energy contributions instead of the parent food code. Ultraprocessed foods constituted 1942 of the list of 3065 unique food or beverage items (food code and SR codes) consumed on day 1 in 2017–2018, whereas unprocessed or minimally processed foods, processed culinary ingredients, and processed foods comprised 703, 73, and 347 of the unique food or beverage items, respectively (Supplementary Table 2). The average US daily energy intake in 2017–2018 for the non-breastfed population aged $\geq$1 y was 2085 kcal, and 58.2% on average came from ultraprocessed foods when using the reference approach of Nova classification (Table 4). Unprocessed or minimally processed foods contributed 27.6% of total energy intake, processed culinary ingredients contributed additional 5.2%, and processed foods contributed the remaining 9%. The most common ultraprocessed foods in terms of energy contribution were breads (10%); soft drinks, fruit drinks, and milk-based drinks (7.3%); cakes, cookies, and pies (5.8%); reconstituted meat or fish products (5.6%); and salty snacks (4.8%). Meat, fruit, and milk provided the most energy among unprocessed or minimally processed foods; plant oils and animal fats provided the most energy among processed culinary ingredients; and ham and cheese provided the most energy among processed foods.

A total of 7.0% food items (215 of 3065) from the food and beverage list had uncertain classification due to the lack of needed data for Nova classification (as per decisions B, C, and D in Table 2) and 1.1% (33 of 3065) were nondisaggregated mixed dishes classified based on expected main ingredient (as per decision E in Table 2) (Supplementary Tables 1 and 2). Food items with uncertain classification corresponded to 6.7% of the daily intake, whereas 1.7% came from nondisaggregated mixed dishes. These items from the food and beverage list (248 of 3065) were flagged for sensitivity analysis 1 and 2.

Sensitivity analyses

In alternative approach 1 (most conservative), items with uncertain classification (215 items) were classified into the most

Table 4

Distribution of the total energy intake[14] according to food groups using reference and alternative approaches; US population aged ≥1 y (NHANES day 1 dietary recall data 2017–2018) ($N = 7284$)

Food groups	Reference approach		Alternative approaches							
	Absolute (kcal/d)	Relative (% of total energy intake)	Approach 1 (most conservative)		Approach 2 (least conservative)		Approach 3 (not accounting for food source/combination food type)		Approach 4 (using only SR codes)	
			Absolute (kcal/d)	Relative (% of total energy intake)	Absolute (kcal/d)	Relative (% of total energy intake)	Absolute (kcal/d)	Relative (% of total energy intake)	Absolute (kcal/d)	Relative (% of total energy intake)
Unprocessed or minimally processed foods	547.0 (12.1)	27.6 (0.7)	510.6 (11.5)	26.0 (0.6)	507.3 (11.3)	25.8 (0.6)	548.7 (12.1)	27.6 (0.7)	583.1 (12.3)	29.3 (0.7)
Meat (includes poultry)	136.2 (5.5)	6.5 (0.3)	125.3 (5.4)	6.0 (0.2)	125.3 (5.4)	6.0 (0.2)	136.3 (5.4)	6.5 (0.3)	142.5 (5.4)	6.8 (0.3)
Fruit[1]	82.9 (3.2)	4.4 (0.1)	82.9 (3.2)	4.4 (0.2)	82.9 (3.2)	4.4 (0.2)	82.9 (3.2)	4.4 (0.1)	84.6 (3.2)	4.5 (0.2)
Milk and plain yogurt	70.7 (2.8)	3.7 (0.2)	70.7 (2.8)	3.7 (0.2)	70.7 (2.8)	3.7 (0.2)	71.3 (2.8)	3.8 (0.2)	74.5 (3.1)	4.0 (0.2)
Grains	59.3 (4.6)	3.0 (0.2)	48.4 (4.1)	2.6 (0.2)	47.5 (3.9)	2.5 (0.2)	59.4 (4.6)	3.0 (0.2)	61.9 (4.5)	3.2 (0.2)
Roots and tubers	32.4 (1.1)	1.6 (0.1)	29.1 (1.4)	1.5 (0.1)	27.9 (1.2)	1.4 (0.1)	32.8 (1.1)	1.7 (0.1)	33.0 (1.1)	1.7 (0.1)
Eggs	33.3 (1.6)	1.7 (0.1)	33.3 (1.6)	1.7 (0.1)	33.3 (1.6)	1.7 (0.1)	33.5 (1.6)	1.7 (0.1)	33.8 (1.6)	1.7 (0.1)
Pasta	38.4 (3.2)	1.9 (0.2)	35.8 (2.9)	1.8 (0.2)	35.0 (2.9)	1.7 (0.2)	38.4 (3.2)	1.9 (0.2)	41.6 (3.2)	2.1 (0.2)
Legumes	16.6 (1.7)	0.8 (0.1)	15.2 (1.6)	0.7 (0.1)	15.2 (1.6)	0.7 (0.1)	16.6 (1.7)	0.8 (0.1)	16.7 (1.7)	0.8 (0.1)
Fish and sea food	13.8 (1.1)	0.7 (0.1)	13.8 (1.1)	0.7 (0.1)	13.8 (1.1)	0.7 (0.1)	13.8 (1.1)	0.7 (0.1)	16.9 (1.7)	0.9 (0.1)
Vegetables	17.3 (1.3)	0.9 (0.1)	13.0 (0.9)	0.7 (0.0)	13.0 (0.9)	0.7 (0.0)	17.4 (1.3)	0.9 (0.1)	17.6 (1.4)	0.9 (0.1)
Other unprocessed or minimally processed foods[2]	46.0 (2.9)	2.2 (0.2)	43.0 (3.2)	2.1 (0.2)	42.7 (3.1)	2.1 (0.2)	46.3 (2.9)	2.2 (0.2)	60.2 (3.8)	2.8 (0.2)
Processed culinary ingredients	108.3 (3.1)	5.2 (0.1)	108.3 (3.1)	5.2 (0.1)	98.5 (2.8)	4.7 (0.1)	110.4 (2.9)	5.3 (0.1)	133.2 (2.5)	6.4 (0.1)
Table sugar[3]	21.0 (1.0)	1.0 (0.1)	21.0 (1.0)	1.0 (0.1)	21.0 (1.0)	1.0 (0.1)	21.5 (1.0)	1.1 (0.1)	35.3 (1.1)	1.7 (0.1)
Plant oils	51.5 (2.4)	2.4 (0.1)	51.5 (2.4)	2.4 (0.1)	51.4 (2.4)	2.4 (0.1)	52.3 (2.3)	2.5 (0.1)	59.0 (2.6)	2.8 (0.1)
Animal fats[4]	34.6 (1.8)	1.7 (0.1)	34.6 (1.8)	1.7 (0.1)	25.2 (1.5)	1.2 (0.1)	35.3 (1.8)	1.7 (0.1)	37.3 (1.7)	1.8 (0.1)
Other processed culinary ingredients[5]	1.2 (0.2)	0.07 (0.01)	1.3 (0.2)	0.1 (0.0)	1.0 (0.2)	0.1 (0.0)	1.3 (0.2)	0.07 (0.01)	1.6 (0.2)	0.1 (0.0)
Processed foods	197.1 (6.8)	9.0 (0.3)	299.7 (9.8)	13.7 (0.4)	169.1 (5.7)	7.7 (0.2)	197.7 (6.8)	9.0 (0.3)	176.1 (8.0)	8.1 (0.4)
Cheese	71.4 (3.9)	3.3 (0.2)	70.0 (3.9)	3.2 (0.2)	65.0 (3.4)	3.0 (0.1)	71.9 (3.9)	3.3 (0.2)	70.0 (3.5)	3.3 (0.1)
Ham and other salted, smoked or canned meat or fish	18.5 (1.8)	0.9 (0.1)	18.5 (1.8)	0.9 (0.1)	3.4 (0.6)	0.2 (0.0)	18.5 (1.8)	0.9 (0.1)	16.6 (1.4)	0.8 (0.1)
Vegetables and other plant foods preserved in brine	11.3 (0.6)	0.56 (0.03)	11.3 (0.6)	0.6 (0.0)	10.1 (0.6)	0.5 (0.0)	11.3 (0.6)	0.57 (0.03)	10.0 (0.6)	0.5 (0.0)
Other processed foods[6]	95.8 (3.7)	4.3 (0.1)	199.9 (7.0)	9.0 (0.3)	90.6 (3.5)	4.0 (0.1)	95.9 (3.7)	4.3 (0.1)	79.5 (5.5)	3.5 (0.2)
Ultraprocessed foods	1232.8 (18.9)	58.2 (0.9)	1127.3 (16.0)	53.4 (0.8)	1271.1 (20.0)	60.1 (0.8)	1228.5 (18.8)	58.0 (0.9)	1192.8 (18.5)	56.2 (0.8)
Breads[7]	207.4 (6.1)	10.0 (0.3)	149.1 (5.2)	7.4 (0.3)	207.4 (6.1)	10.0 (0.3)	207.3 (6.1)	10.0 (0.3)	200.0 (6.0)	9.7 (0.3)
Cakes, cookies and pies	128.8 (3.8)	5.8 (0.2)	128.8 (3.8)	5.8 (0.2)	128.8 (3.8)	5.8 (0.2)	127.3 (4.0)	5.7 (0.2)	124.4 (3.4)	5.6 (0.2)
Reconstituted meat or fish products	121.9 (4.2)	5.6 (0.2)	121.9 (4.2)	5.6 (0.2)	137.1 (3.9)	6.3 (0.2)	121.9 (4.2)	5.6 (0.2)	96.5 (2.3)	4.4 (0.1)
Salty snacks	98.6 (4.4)	4.8 (0.2)	56.6 (2.2)	2.9 (0.1)	99.1 (4.4)	4.8 (0.2)	98.6 (4.4)	4.8 (0.2)	93.9 (4.3)	4.6 (0.2)
Frozen and shelf-stable plate meals	58.8 (4.3)	2.8 (0.2)	58.8 (4.3)	2.8 (0.2)	59.7 (4.2)	2.8 (0.2)	58.2 (4.3)	2.7 (0.2)	64.5 (4.2)	3.0 (0.2)
Soft drinks, carbonated	69.0 (5.0)	3.1 (0.3)	69.0 (5.0)	3.1 (0.3)	69.0 (5.0)	3.1 (0.3)	69.0 (5.0)	3.1 (0.3)	68.8 (5.0)	3.1 (0.3)
Pizza (ready-to-eat/heat)	74.9 (2.8)	3.4 (0.2)	74.9 (2.8)	3.4 (0.2)	74.9 (2.8)	3.4 (0.2)	74.9 (2.8)	3.4 (0.2)	73.9 (2.5)	3.3 (0.2)
Fruit drinks[8]	58.3 (3.3)	2.9 (0.2)	58.3 (3.3)	2.9 (0.2)	58.3 (3.3)	2.9 (0.2)	58.3 (3.3)	2.9 (0.2)	53.8 (3.4)	2.7 (0.2)
Breakfast cereals	42.8 (1.4)	2.2 (0.1)	37.4 (1.3)	1.9 (0.1)	42.8 (1.4)	2.2 (0.1)	42.8 (1.4)	2.2 (0.1)	39.2 (1.3)	2.0 (0.1)

(continued on next page)

Table 4 (*continued*)

Food groups	Reference approach		Alternative approaches							
	Absolute (kcal/d)	Relative (% of total energy intake)	Approach 1 (most conservative)		Approach 2 (least conservative)		Approach 3 (not accounting for food source/combination food type)		Approach 4 (using only SR codes)	
			Absolute (kcal/d)	Relative (% of total energy intake)	Absolute (kcal/d)	Relative (% of total energy intake)	Absolute (kcal/d)	Relative (% of total energy intake)	Absolute (kcal/d)	Relative (% of total energy intake)
Sauces, dressings, and gravies	67.8 (2.8)	3.2 (0.1)	67.8 (2.8)	3.2 (0.1)	69.5 (2.8)	3.2 (0.1)	67.1 (2.7)	3.1 (1.1)	69.1 (2.8)	3.2 (0.1)
Ice cream and ice pops	40.3 (2.6)	1.9 (0.1)	40.3 (2.6)	1.9 (0.1)	40.3 (2.6)	1.9 (0.1)	41.4 (2.8)	1.9 (0.1)	35.9 (2.3)	1.7 (0.1)
Sweet snacks	57.4 (3.0)	2.8 (0.1)	57.4 (3.0)	2.8 (0.1)	57.4 (3.0)	2.8 (0.1)	57.4 (3.0)	2.8 (0.1)	61.5 (2.7)	3.0 (0.1)
Milk drinks[9]	28.3 (2.3)	1.3 (0.1)	28.3 (2.3)	1.4 (0.1)	28.3 (2.3)	1.4 (0.1)	26.7 (1.6)	1.3 (0.1)	24.0 (2.2)	1.2 (0.1)
Desserts[10]	24.4 (2.2)	1.2 (0.1)	24.4 (2.2)	1.2 (0.1)	28.5 (2.2)	1.4 (0.1)	24.5 (2.1)	1.2 (0.1)	25.3 (2.2)	1.2 (0.1)
French fries and other potatoe products[11]	34.0 (2.2)	1.5 (0.1)	34.0 (2.2)	1.5 (0.1)	34.0 (2.2)	1.5 (0.1)	33.7 (2.1)	1.5 (0.1)	34.4 (2.5)	1.6 (0.1)
Sandwiches and hamburgers on bun (ready-to-eat/heat)	36.9 (3.7)	1.7 (0.2)	36.9 (3.7)	1.7 (0.2)	36.9 (3.7)	1.7 (0.2)	36.8 (3.7)	1.7 (0.2)	38.0 (3.8)	1.8 (0.2)
Instant and canned soups	17.8 (1.6)	1.0 (0.1)	17.8 (1.6)	1.1 (0.1)	19.1 (1.6)	1.1 (0.1)	17.8 (1.6)	1.0 (0.1)	15.4 (1.2)	0.9 (0.1)
Other ultraprocessed foods[12]	65.5 (2.9)	2.9 (0.1)	65.6 (2.9)	2.9 (0.1)	80.3 (2.5)	3.6 (0.1)	64.6 (3.1)	2.9 (0.1)	74.2 (2.7)	3.3 (0.1)
Nondisaggregated mixed dishes (without a Nova assignation)[13]	—	—	39.3 (3.8)	1.7 (0.2)	39.3 (3.8)	1.7 (0.2)	—	—	—	—
Total	2085.2 (14.1)	100.0	2085.2 (14.1)	100.0	2085.2 (14.1)	100.0	2085.2 (14.1)	100.0	2085.2 (14.1)	100.0

[1] Including freshly squeezed juices.
[2] Including nuts and seeds (unsalted); yeast; dried fruits (without added sugars) and vegetables; nonpresweetened, non-whitened, non-flavored coffee and tea; coconut water and meat; homemade soup and sauces (with no underlying ingredients); flours; tapioca.
[3] Including honey, molasses, and maple syrup (100%).
[4] Including unsalted butter, lard, and cream.
[5] Including starches; coconut and milk cream; unsweetened baking chocolate, cocoa powder and gelatin powder; vinegar; baking powder and baking soda.
[6] Including salted or sugared nuts and seeds; peanut, sesame, cashew, and almond butter or spread; beer and wine; some baby foods.
[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, noncarbonated and other sweetened drinks, including presweetened tea and coffee, energy drinks, sports drinks with no milk added, and nonalcoholic wine.
[9] Including flavored yogurt sweetened with sugar or with low-calorie sweetener, milk shake, and soymilk.
[10] Including ready-to-eat and dry-mix desserts such as pudding, sugar-based ingredients such as whipped cream, and sweetened canned fruit and fruit sauce.
[11] Including hash browns, potato puffs, stuffed potatoes, and onion rings (ready-to-eat/heat).
[12] Including soy products such as meatless patties and fish sticks; dips, spreads, mustard, and catsup; margarine; sugar substitutes, sweeteners, and all syrups (excluding 100% maple syrup); distilled alcoholic drinks; infant formula.
[13] See decision E in Table 2. SR code, standard reference code or ingredient code from the USDA National Nutrient Database for Standard Reference.
[n] Values presented are Mean (SE).

conservative Nova group possible, i.e., the least processed group, whereas nondisaggregated mixed dishes (33 items) were placed in a separate group without a Nova assignation (as “non-disaggregated mixed dishes”). Thus, 125 ultraprocessed food items were reclassified as processed or minimally processed. The energy contribution of ultraprocessed foods dropped from 58.2% to 53.4% (~5% points), driven by the decrease in ultraprocessed breads (down from 10% to 7.4%), salty snacks (down from 4.8% to 2.9%), and breakfast cereals (down from 2.2% to 1.9%) (Table 4). Using this approach, unprocessed or minimally processed foods contributed 26%, processed culinary ingredients contributed 5.2%, and processed foods contributed 13.7% of total energy intake.

In alternative approach 2, items with uncertain classification were classified into the least conservative Nova group possible (215 items), i.e., the most processed group, whereas non-disaggregated mixed dishes (33 items) were placed in a separate group without a Nova assignation. Thus, 2 minimally processed food items, 16 processed culinary ingredients, and 72 processed foods were reclassified as ultraprocessed foods. The energy contribution of ultraprocessed foods rose from 58.2% in the reference approach to 60.1% (~2% points). This energy contribution rise was mainly driven by the increase in ultraprocessed reconstituted meat (up from 5.6% to 6.3%), desserts (up from 1.2% to 1.4%), and “other ultraprocessed foods” (up from 2.9% to 3.6%). Using this approach, unprocessed or minimally processed foods contributed 25.8% of total energy intake, processed culinary ingredients contributed 4.7%, and processed foods contributed 7.7%.

In alternative approach 3, using the reference classification without accounting for participant-specific variables of “combination food type” and “source of food,” contributions remained practically unchanged compared with the reference approach. Ultraprocessed foods contributed on average 58.0% of total energy intake, unprocessed or minimally processed foods contributed 27.6%, processed culinary ingredients contributed additional 5.3%, and processed foods contributed the remaining 9.0%.

In alternative approach 4, we used the reference approach but recalculated energy contributions using SR codes only (instead of using SR codes for potential homemade dishes or when indifferent, only). There were minimal changes in energy contribution from the 4 Nova groups using alternative approach 4 compared with the reference approach. Ultraprocessed foods contributed on average 56.2% of total energy intake, unprocessed or minimally processed foods contributed 29.3% of total energy intake, processed culinary ingredients contributed an additional 6.4%, and processed foods contributed the remaining 8.1%.

Discussion

We described in detail the approach of classifying foods from the 2001–2018 cycles of WWEIA, NHANES 24-h dietary recalls according to the Nova processed food classification system. Using the reference approach, the energy contribution of ultraprocessed foods in WWEIA, NHANES 2017–2018 represents more than half of the energy intake in the US diet (58.2%). Conducting sensitivity analyses to assess variability and potential misclassification of ultraprocessed foods showed that the energy contribution ranged from 53.4% under the most conservative approach up to 60.1% under the least conservative approach. This up to 6% variation range provides confidence in the current approach used to classify foods according to the degree of processing using the Nova classification system with information currently captured in NHANES 24-h recalls.

The results of our sensitivity analyses suggest that <10% of individual foods and beverages reported in WWEIA, NHANES are at a potential risk of misclassification using the Nova classification system. In 2017–2018, 63.4% of the unique foods (not energy contribution) were classified as ultraprocessed, whereas the remaining 22.9%, 2.4%, and 11.3% were assigned to unprocessed or minimally processed foods, processed culinary ingredients, and processed foods, respectively. A total of 8.0% from the food list were flagged for sensitivity analysis, constituting <10% of total energy intake, because they were likely to be classified in >1 way. In a similar methodological approach using a semiquantitative food frequency questionnaire rather than 24-h recalls, Khandpur et al. [40] attributed 36.1% of food items from the Nurses' Health Study and the Health Professionals Follow-up Study and 43.5% from the Growing Up Today Studies to ultraprocessed foods and 50.2% and 40.1% of food items, respectively, to unprocessed or minimally processed foods; 4.4% and 9.3% of food items were flagged for sensitivity analysis, respectively. Although the FFQ appeared to have a more balanced distribution across the Nova groups, the proportion of foods earmarked for sensitivity analysis was similar to the proportion from our study using 24-h recalls. Thus, these results align with our conclusion that ~10% of foods and beverages from WWEIA, NHANES data pose challenges due to lack of needed detail and are likely to be classified in >1 way. Sensitivity analysis using SR codes in all cases provided similar estimates to those in our reference approach, suggesting that *1)* our classification of food code and SR codes was fairly consistent and *2)* estimates using SR codes alone are good proxies of Nova estimates using both food code and SR codes. The advantage of using SR codes alone is that they are more straightforward, requiring less decision making and might be less prone to arbitrariness, avoiding potential inconsistencies in the food code and SR code classifications and in the decision of when to use food code or SR codes.

Data collection protocols for WWEIA, NHANES, such as AMPM and linked databases, are not designed to assess Nova or degree of food processing of foods and beverages reported by participants a priori. Thus, a post hoc assessment of the Nova classification system, as we described, faces several challenges. First, the number of food items reported in NHANES is a small, although representative, proportion of the number of items available in the marketplace. Further, national food composition data are not updated as required for accurate Nova classification to include all brand-specific information (ingredient lists, labels) or to examine differences in dietary profiles sensitive to brand preferences [41]. The current approach to classification based on FNDDS with limited information on food brands may not capture diversity or changes in diversity or reformulation of product profiles through the years. Moreover, because the links between FNDDS and SR were developed to estimate nutrient contents and not ingredient intakes, the use of standardized recipes may not reflect the ingredients and proportions consumed by participants [33]. The individual-specific variable "modification code" (adjustments to predefined recipe ingredients that reflect more closely the food as described by the respondent) used in cycles before 2013–2014 was not considered when assigning SR codes to a food code, as manual changes would have been necessary to do so. Taken together, the above factors may lead to group and subgroup classification errors.

The main intention of this article was to provide a detailed and transparent description of the approaches used to apply the Nova classification to WWEIA, NHANES data to estimate the energy intake contribution of each Nova group. This is impactful because WWEIA, NHANES is a nationally representative, continuously updated, ongoing survey of the US population that is publicly available to answer a wide array of research questions related to dietary patterns and health. Describing this in detail is an important contribution to the scientific community because the use of a standardized approach will ensure that studies can be compared with one another during literature reviews and evidence syntheses. Transparency is also essential to ensure that the approach evolves appropriately as the scientific community critiques and applies it to their own data. To instill confidence in the use of this approach for future research, we conducted robust sensitivity analyses that compared multiple alternative approaches of Nova classification within the same sample of WWEIA, NHANES. The limited change in percentage energy from each Nova group across sensitivity analyses shows that misclassification is likely low.

The potential limitations of our reference approach must be taken into consideration by researchers who choose to use this approach for future research. First, it is largely applied to self-reported dietary data, which have noted limitations [42,43]. However, 24-h recalls are the least-biased self-report instrument available, and the standardized methods and approach of NHANES have been shown to produce acceptable intake estimates [32,44,45] and are suitable for assessing food group contributions in the overall diet as used in this study. The underreporting of foods high in caloric sweeteners or fats [46], such as desserts and sweet baked goods [47,48], is possible because of social desirability bias. This could lead to the underestimation of the dietary contribution of ultraprocessed foods, as many of these foods might be considered ultraprocessed. Another consideration is that our current approach assumed no changes in the data collection process (i.e., AMPM). However, trend analyses conducted in children and adults show that the intake of Nova groups is relatively stable over time; thus, influences of these noted limitations may be minimal [18,19]. Our approach also assumed no changes in the classification of food processing over time because of reformulation. Additionally, product ingredient lists from supermarkets and Fooducate websites or USDA Branded Food Products Database from 2012 onward were used to reflect the processing of food items from all cycles. Reformulations, however, will not necessarily affect the Nova classification, especially because the food industry generally needs to find an equivalent substitute for the reduced ingredient [49,50].

A central challenge of our approach is determining whether dishes were homemade from scratch ingredients or not. This is because a dietary interviewer using AMPM does not probe respondents about home food preparation or to what extent the food is homemade, partly because "homemade" or "handmade" has different meanings to different people [51]. Some may consider adding ground beef to jarred spaghetti sauce as homemade, whereas others would consider making the sauce from raw ingredients (tomatoes, garlic, beef, etc.) to be homemade. The interviewer does, however, ask whether each food reported was consumed at or away from home, as well as where the food was acquired (e.g., from a grocery store, vending machine, or restaurant). This provided additional information was used to help determine when an item was homemade or not. Further, mixed dishes that were not acquired at a vending machine, fast food place, or frozen were generally considered handmade, which may have underestimated the proportion of ultraprocessed ready-to-eat meals. One interesting finding is that a study using the US grocery purchasing data from the National Household Food Acquisition and Purchase Survey 2012–2013 [52] obtained similar ultraprocessed food estimates to the ones from our study using a similar approach to ours in classifying the food purchased. Although grocery purchasing data do not account for energy from meals eaten away from home and present the same limitation as NHANES in terms of the lack of product label ingredients, they provide more certainty on the nature of the composite dishes purchased, as they were purchased, they were necessarily ready-to-eat.

In our study, potentially homemade dishes were disaggregated into underlying SR codes to obtain a list of constituent scratch ingredients. However, the FNDDS linkage of SR codes to food codes is intended to obtain appropriate nutrient content and not a list of exact ingredients for that food code [33]. Thus, there is likely a degree of error associated with using SR codes that may not correspond to true consumed ingredients for Nova classification. However, this degree of error is probably lower than the inaccuracy associated with classifying mixed dishes as a whole (at the food code level) into a Nova group and subgroup. Further, if the linkage of SR codes to food codes is intended to obtain appropriate nutrient content, it is likely that ingredients that contribute minimally to the nutrient profile will generally not be included as SR codes. If these ingredients are likely those that would make a food ultraprocessed (such as artificial sweeteners, emulsifiers, etc.), this could cause potential underestimation of ultraprocessed foods. Future studies should seek to investigate variability and potential for Nova group misclassification across population subgroups, which was beyond the scope of the current study.

Future applications of the Nova classification system to dietary data would be enhanced by probing for more detailed information during dietary data collection, such as brand names, ingredient lists from packaged foods, and more information about whether meals were prepared at home from minimally processed ingredients or were purchased as processed, prepared, or ready-to-eat meals. At the same time, the linking with food composition databases that provide both nutrient contents and list of ingredients of brand-specific packaged foods and are updated at an ongoing basis as soon as products are released into the market would be desirable.

In conclusion, current datasets do not capture all the needed information to classify foods according to the Nova classification system with certainty. This work contributes to a better understanding of variability and potential misclassification of Nova for

WWEIA, NHANES data and encourages researchers to use this standardized approach for future investigation of Nova food processing and human health to ensure that future studies are replicable and comparable. This approach could be applied to NHANES or other datasets that link to FNDDS, such as those collected via the Automated Self-Administered 24-h Dietary Assessment Tool, to be used for nutrition monitoring and surveillance, food pattern modeling, risk assessment, or policy analyses.

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Disclosures

The authors report no conflicts of interest.

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Data sharing Data described in the manuscript, code book, and analytic code will be made available upon request pending.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tjnut.2022.09.001.

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