



## Trends in food consumption by degree of processing and diet quality over 17 years: results from the Framingham Offspring Study

Filippa Juul<sup>1</sup>, Yong Lin<sup>2,3</sup>, Andrea L. Deierlein<sup>4,5</sup>, Georgeta Vaidean<sup>6</sup> and Niyati Parekh<sup>4,5,7\*</sup>

<sup>1</sup>Department of Public Health Policy and Management, School of Global Public Health, New York University, New York, USA

<sup>2</sup>Department of Biostatistics and Epidemiology, School of Public Health, Rutgers University, New Brunswick, NJ, USA

<sup>3</sup>Biometrics Division, Rutgers Cancer Institute of New Jersey, Rutgers University, New Brunswick, NJ, USA

<sup>4</sup>Program of Public Health Nutrition, School of Global Public Health, New York University, New York, USA

<sup>5</sup>Department of Population Health, Grossman School of Medicine, New York University, New York, USA

<sup>6</sup>School of Pharmacy and Health Sciences, Fairleigh Dickinson University, Teaneck, NJ, USA

<sup>7</sup>Rory Meyers College of Nursing, New York University, New York, USA

(Submitted 30 August 2020 – Final revision received 17 December 2020 – Accepted 9 February 2021 – First published online 19 February 2021)

### Abstract

Ultraprocessed foods provide the majority of energy content in the American diet, yet little is known regarding consumption trends over time. We determined trends in diet processing level and diet quality from 1991 to 2008 within the prospective Framingham Offspring Cohort. Dietary intakes were collected by FFQ quadrennially 1991–2008 (total of four examinations). The analytical sample included 2893 adults with valid dietary data for  $\geq 3$  examinations (baseline mean age = 54 years). Based on the NOVA framework, we classified foods as: unprocessed/minimally processed foods; processed culinary ingredients (salt/sugar/fats/oils); and processed foods and ultraprocessed foods. We evaluated diet quality using the Dietary Guidelines for Americans Adherence Index (DGAI) 2010. Trends in consumption of foods within each processing level (servings/d) and diet quality over the four examinations were evaluated using mixed effects models with subject-specific random intercepts. Analyses were stratified by sex, BMI ( $< 25$  kg/m<sup>2</sup>, 25–29.9 kg/m<sup>2</sup>,  $\geq 30$  kg/m<sup>2</sup>) and smoking status. Over 17 years of follow-up, ultraprocessed food consumption decreased from 7.5 to 6.0 servings/d and minimally processed food consumption decreased from 11.9 to 11.3 servings/d ( $P_{\text{trend}} < 0.001$ ). Changes in intakes of processed foods, culinary ingredients and culinary preparations were minimal. Trends were similar by sex, BMI and smoking status. DGAI-2010 score increased from 60.1 to 61.5,  $P < 0.001$ . The current study uniquely describes trends in diet processing level in an ageing US population, highlighting the longstanding presence of ultraprocessed foods in the American diet. Given the poor nutritional quality of ultraprocessed foods, public health efforts should be designed to limit their consumption.

**Key words:** Framingham Heart Study; Ultra-processed food; NOVA; Diet quality; Dietary Guidelines for Americans Adherence Index

Ultraprocessed foods are defined as industrially manufactured, ready-to-eat/heat formulations made with additives, such as dyes, flavourings and preservatives, that contain little, if any, whole foods. National and international studies have consistently found that diets high in ultraprocessed foods are higher in total energy, total fat, saturated fat, *trans*-fat, added/free sugars and Na while providing less protein, fibre and several essential vitamins and minerals than diets containing less ultraprocessed foods<sup>(1–4)</sup>. Ultraprocessed foods have also been associated with multiple chronic conditions including obesity, type 2 diabetes, hypertension, CVD and cancer<sup>(5–9)</sup>.

Few studies have investigated changes in diet processing level over time in the USA<sup>(10–12)</sup>. US food purchasing survey data suggest that households' grocery purchases of highly processed foods, defined as multi-ingredient industrially formulated mixtures, remained stable at about 61% of purchased energy content from 2000 to 2012, while purchases of minimally processed foods increased slightly<sup>(11)</sup>. In contrast, national retail data show that total volume sales of ultraprocessed foods and beverages decreased by 11.5% from 2002 to 2016<sup>(12)</sup>. To date, only one study has evaluated trends in diet processing level using self-reported dietary intake data in a US population.

**Abbreviations:** DGAI, Dietary Guidelines for Americans Adherence Index; FOS, Framingham Offspring Cohort; NHANES, National Health and Nutrition Examination Survey.

\* **Corresponding author:** Niyati Parekh, email [niyati.parekh@nyu.edu](mailto:niyati.parekh@nyu.edu)

Analyses within the cross-sectional National Health and Nutrition Examination Survey (NHANES) showed that the average consumption of ultraprocessed foods in the general US population aged  $\geq 2$  years increased from 57.6% to 59.7% of daily energy content between 2007 and 2012, while minimally processed foods, defined as single-ingredient whole foods, only accounted for 27.5% of daily energy content during this time<sup>(10)</sup>. Ultraprocessed food intake was inversely associated with age and income and increased over time among men, adolescents and adults with high-school education<sup>(10)</sup>. Older, highly educated and high-income adults consumed less ultraprocessed foods (range: 53–55% of daily energy content), and their intake levels remained stable over the study period<sup>(10)</sup>.

Trends in processed food intakes over longer time periods, and corresponding changes in diet quality, have not yet been evaluated. The objective of the present study was to examine longitudinal trends in food consumption according to degree of processing and diet quality from 1991 to 2008 within an ageing US population, using data from the Framingham Offspring Cohort (FOS). Spanning over a 17-year period, this study uniquely investigates dietary changes during middle through older adulthood, which represents a critical window of exposure to chronic disease risk factors.

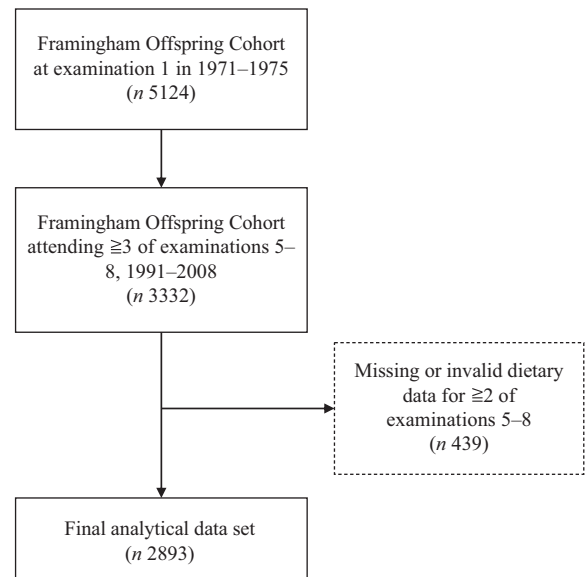
## Methods

### Study population

The Framingham Heart Study (FHS) is an ongoing prospective cohort study in Framingham, MA, initiated by the National Heart, Lung, and Blood Institute with the objective to investigate CVD risk factors<sup>(13)</sup>. The current study uses data from the FOS, which was enrolled as the second familial generation in 1971–1975 (age range 5–70 years; mean age 36 years), with approximate 4-year follow-up examinations thereafter<sup>(14,15)</sup>. Details regarding FOS have been published previously<sup>(16)</sup>. The FOS was conducted according to the Declaration of Helsinki guidelines, and written informed consent was obtained from all subjects enrolled in the FOS. The current study was approved by the University Committee on Activities Involving Human Subjects at New York University (IRB No.: IRB-FY2017-681).

### Analytical data set

Dietary data collection for the FOS was initiated at the 5th examination in 1991–1995, which was considered the baseline for the current analyses. Participants who attended at least three examinations between 1991 and 2008 were eligible for the current analyses ( $n$  3332). We excluded participants with missing or invalid dietary data for two or more examinations ( $n$  439). In accordance with FHS criteria, dietary data were considered invalid if the food frequency questionnaire (FFQ) contained  $>12$  blanks, or if total energy content was  $<600$  (2510.4 kJ), or exceeded 3999 kcal (16731.8 kJ) for females and 4199 kcal (17,568.6 kJ) for males ( $n$  329)<sup>(17)</sup>. The creation of the analytical data set is presented in Fig. 1.



**Fig. 1.** Creation of the final analytical data set from the Framingham Offspring Cohort (1971–1975). Examination 5 (1991–1995) was used as baseline in the present analyses.

### Assessment of dietary intake

Diet was assessed at each examination using the 131-item Harvard semi-quantitative FFQ, which has been validated for forty foods/food groups, energy, macronutrients, fibre, cholesterol, ten vitamins and seven minerals<sup>(18,19)</sup>. Participants reported the frequency of consumption of specific foods in the previous year, with options ranging from never or  $<1$  serving/month to  $\geq 6$  servings/d. Trained study personnel reviewed the FFQ together with participants at each examination to ensure accuracy of self-reported diet. Total energy and nutrient intakes were estimated from the FFQ using the US Department of Agriculture Nutrient Database for Standard Reference, which was updated regularly to reflect changes in the food supply over time<sup>(20)</sup>.

### Ascertainment of the exposure

**Processing level.** All FFQ items were classified based on the extent and purpose of the industrial food processing applied, in accordance with the NOVA food classification<sup>(21)</sup>. NOVA (not an acronym) distinguishes four mutually exclusive levels of processing: (1) 'unprocessed or minimally processed foods' including fresh, dry or frozen plant and animal foods; (2) 'processed culinary ingredients' including table sugar, oils, fats, salt and other constituents used in kitchens to make culinary preparations; (3) 'processed foods' including foods such as canned fish and vegetables, simple breads and artisanal cheeses which are manufactured by adding processed culinary ingredients to unprocessed or minimally processed foods and (4) 'ultra-processed foods'; industrial formulations made with no or minimal whole foods and produced with substances extracted from foods or synthesised in laboratories such as dyes, flavourings and preservatives, often using processing techniques with no domestic equivalent<sup>(21)</sup>.

FFQ line items that included foods of potentially different processing levels were classified according to the most frequently consumed form of the food among adult participants in NHANES or based on literature regarding US dietary intakes ( $n = 8, 6.25\%$ )<sup>(22,23)</sup>. For example, the FFQ item 'yoghurt' was classified as ultraprocessed as 86% of yogurt consumed by adults in NHANES 2001–2002 was ultraprocessed. Likewise, breads were classified as ultraprocessed as previous investigations in NHANES indicate that the majority of breads consumed in the US population are industrially manufactured and ultraprocessed<sup>(23)</sup>. In cases where the most commonly consumed form could not be determined with certainty ( $n = 2, 1.56\%$ ), we classified the foods as the lowest potential processing level. FFQ items indicated to be homemade (e.g. home-baked cakes, cookies and sweet rolls) or assumed to be homemade due to lack of detailed information (e.g. soup/chowder) were classified as minimally processed foods.

The absolute consumption of foods (servings/d) from each NOVA processing level was calculated for each participant, that is, (1) unprocessed or minimally processed foods, (2) processed culinary ingredients, (3) processed foods and (4) ultra-processed foods. We calculated the weekly consumption of the specific food groups (servings/week) included in each NOVA processing level. An overview of the FFQ items included in each NOVA processing level and food group is presented in online Supplementary Table S1.

**Diet quality.** Diet quality was assessed using the Dietary Guidelines for Americans Adherence Index (DGAI) 2010<sup>(24)</sup>. Similar to the Healthy Eating Index 2010<sup>(25)</sup>, the DGAI-2010 measures adherence to the key recommendations of the 2010 Dietary Guidelines for Americans<sup>(24)</sup>. The DGAI-2010 was updated from the previous version, DGAI-2005, which was developed for the FOS in reference to the 2005 Dietary Guidelines for Americans<sup>(26)</sup>. The DGAI-2010 evaluates intakes of fourteen food groups (fruit; dark green vegetables, orange and red vegetables; starchy vegetables; other vegetables; grains; milk; meat, protein and eggs; seafood; nuts; legumes; sugar; variety in protein choices and variety of fruits and vegetables) and eleven healthy choice or nutrient intake recommendations (amounts of total fat, saturated fat, *trans*-fat, cholesterol, Na, fibre, alcohol; and percentage of protein that is lean, milk that is low-fat, grains that are whole grains, and fruits that are whole fruits)<sup>(27)</sup>. The maximum score of the DGAI-2010 is 100, and higher scores indicate greater adherence to the dietary guidelines and higher diet quality.

#### Assessment of other variables

Age, physical activity and smoking status (smokers *v.* non-smokers) were self-reported during interviews at each examination. Years of education were self-reported once at examination 2 (1979–1983). A physical activity index was calculated by first multiplying the average daily number of hours in each activity (resting or sleeping, or in sedentary, light, moderate or heavy physical activities) with the activity-specific metabolic costs, and then summing the weighted hours, as previously described

in FHS<sup>(28)</sup>. Based on this index, physical activity level was categorised as low (<30), moderate (30–33) and high (>33)<sup>(29)</sup>. Trained personnel measured weight and height at each clinical examination, using standardised methods. BMI ( $\text{kg}/\text{m}^2$ ) was calculated from measured height and weight and categorised as normal weight (<25  $\text{kg}/\text{m}^2$ ), overweight (25–29.9  $\text{kg}/\text{m}^2$ ) and obese ( $\geq 30 \text{ kg}/\text{m}^2$ )<sup>(30)</sup>.

#### Statistical analyses

We calculated descriptive statistics (means, standard deviations for continuous variables and frequencies and percentage for discrete variables) for demographic and clinical characteristics of the sample at baseline (examination 5; 1991–1995). We examined trends in the intake of each NOVA processing level (servings/d), specific food groups within each NOVA processing level (servings/week), total energy content, macronutrients, fibre, Na and diet quality in the full sample, and among males and females separately, using means, standard deviations and *P*-values for trends over the four examinations (examinations 5–8, 1991–2008). Trends were reported separately for males and females, as previous studies have identified sex differences in dietary patterns in the FOS and the general US population<sup>(9,31)</sup>. In exploratory analyses, trends in NOVA processing levels were stratified by BMI and smoking status, as food choices and eating patterns may differ between these subgroups. As a sensitivity analysis, we examined trends for participants with and without prevalent chronic diseases (CVD, diabetes and hypertension) to assess whether dietary behaviours may change in response to disease diagnosis. We performed trend analyses using mixed effects models with subject-specific random intercepts to account for within-subject correlation across examinations. Non-linear trends were assessed by adding quadratic or higher-order time variables to the models. Analyses were performed using Stata/SE 15.1 (StataCorp).

## Results

### Participant characteristics at first dietary assessment (1991–1995)

Participant characteristics at the first dietary assessment (examination 5, 1991–1995) are summarised in Table 1. Participants were predominantly middle-aged (mean age = 54.1 years), overweight (mean BMI = 27.3  $\text{kg}/\text{m}^2$ ) and college-educated (mean years of education = 14.1). The majority of participants had a high level of physical activity (52.6%) and were non-smokers (81.8% and 82.5% of females and males, respectively). Over a fourth (26.2%) of males and a fifth of females (20.4%) had obesity. Prevalence of diabetes (8.1 *v.* 4.6%) and CVD (10.2 *v.* 4.8%) was significantly higher among males than among females ( $P < 0.001$ ).

### Trends in food consumption according to processing level among males and females

Trends in food consumption by NOVA processing level in the overall sample and among males and females are presented in



**Table 1.** Characteristics of participants in the Framingham Offspring Cohort in 1991–1995 (examination 5) (Mean values and standard deviations, numbers and percentages, *n* 2741)

Characteristics	Overall sample ( <i>n</i> 2741)				Females ( <i>n</i> 1491)				Men ( <i>n</i> 1250)			
	Mean	SD	%	<i>n</i>	Mean	SD	%	<i>n</i>	Mean	SD	%	<i>n</i>
Age (years)	54.1	9.5			53.9	9.4			54.3	9.5		
Education (years)	14.1	2.6			13.8	2.3			14.6	2.8		
Current smokers (%)			17.9	490			18.2	271			17.5	219
Physical activity level (%)												
Low			15.8	423			17.3	253			13.9	170
Medium			31.6	849			38.5	563			23.4	286
High			52.6	1412			44.2	647			62.7	765
BMI (kg/m <sup>2</sup> )	27.3	4.9			26.5	5.3			28.2	4.0		
Prevalence of:												
Obesity (BMI ≥ 30) (%)			23.0	629			20.4	302			26.2	327
Diabetes mellitus (%)			6.2	169			4.6	68			8.1	101
Hypertension (%)*			17.3	471			16.0	237			18.8	234
CVD (%)			7.3	199			4.8	72			10.2	127

Missing values: Education, *n* 333; current smoking, *n* 2; physical activity, *n* 57; BMI, *n* 10; diabetes mellitus, *n* 8; hypertension, *n* 13.  
\*% of participants receiving treatment for hypertension.

**Fig. 2.** Participants consumed the majority of daily servings in the form of minimally processed foods, followed by ultraprocessed foods in 1991–2008. Compared with men, women consumed significantly more minimally processed foods at exams 5 ( $P < 0.001$ ) and 8 ( $P = 0.025$ ) and less processed food and ultraprocessed foods at all time points ( $P < 0.001$ ). Ultraprocessed food consumption declined significantly in the whole sample and among females and males between 1991 and 2008 ( $-1.5$  servings/d,  $P_{\text{trend}} < 0.001$ ). A trend towards decreased consumption of minimally processed food was also identified in the overall sample and among males and females; however, the magnitude of change was minimal ( $-0.6$  servings/d in the overall sample,  $P_{\text{trend}} < 0.001$ ). In contrast, there was a small yet statistically significant increase in the consumption of processed foods among both females ( $+0.3$  servings/d,  $P_{\text{trend}} < 0.001$ ) and males ( $+0.1$  serving/d,  $P_{\text{trend}} = 0.013$ ). Consumption of culinary ingredients increased minimally among females ( $+0.2$  servings/d,  $P_{\text{trend}} < 0.001$ ), while no change was observed among males ( $P_{\text{trend}} = 0.391$ ).

#### Trends in intakes of specific food groups within each processing level

Intakes of foods included within each processing level (servings/week) and *P*-values for trends over time in the overall sample, and among females and males, are presented in [Table 2](#). Among minimally processed foods, consumption of fruits, nuts, and meat, fish and eggs increased, while intakes of fruit juices, skimmed and whole milk, and coffee and tea decreased in the overall sample and among males and females. Consumption of minimally processed grains, vegetables and legumes also decreased among females, but not among males. Of culinary ingredients, consumption of butter, cream, sour cream and oil and vinegar dressing increased among females only, while the addition of sugar to beverages decreased among both males and females. Intakes of homemade baked goods, soups and sauces decreased among females but not among males. Finally, consumption of all ultraprocessed foods, except for ultraprocessed meat products and yoghurt, decreased in the overall sample, and

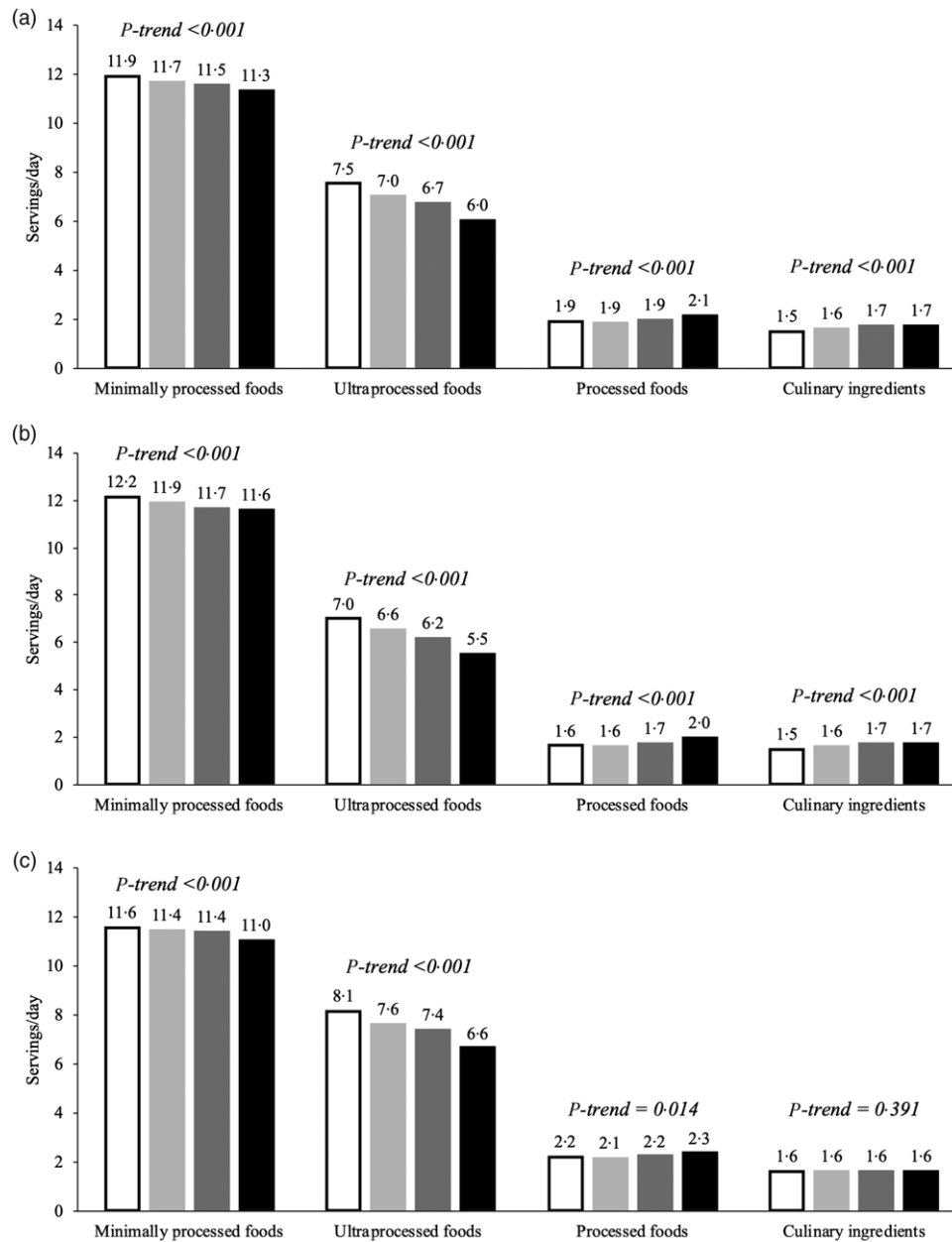
among females and males. Intake of ultraprocessed breakfast cereals increased among males but not among females.

#### Trends in diet quality and energy and nutrient intakes

Trends in energy and nutrient intakes and diet quality in the overall sample and among males and females are presented in [Table 3](#). The DGAI-2010 score increased in the overall sample and among females ( $62.9$ – $63.9$ ,  $P_{\text{trend}} = 0.013$ ) and males ( $56.8$ – $58.6$ ,  $P_{\text{trend}} < 0.001$ ) over the study period. DGAI-2010 scores were lower among males than females at all time points ( $P < 0.001$ ). Total energy intake remained stable between 1991 and 2008, while the percentage of energy provided by total carbohydrates, sucrose and fructose decreased among both females and males ( $P_{\text{trend}} < 0.001$ ). Intake of total sugar (% energy) decreased from 1998 to 2008 among females and males ( $P_{\text{trend}} < 0.001$ ); however, data regarding total sugar intake were not available for 1991–1998. The percentage of energy provided by protein, total fat, saturated fat, monounsaturated fat and polyunsaturated fat also increased among both males and females ( $P_{\text{trend}} < 0.001$ ), while percentage of energy from *trans*-fat decreased ( $P_{\text{trend}} < 0.001$ ). Fibre intakes increased in the overall sample and among males and females ( $P_{\text{trend}} < 0.001$ ), while Na intakes decreased slightly from  $1158.1$  to  $1083.9$  mg/1000 kcal ( $P_{\text{trend}} < 0.001$ ).

#### Trends in food consumption according to processing level and diet quality by BMI category

Over the study period, the consumption of minimally processed foods decreased slightly among participants with normal weight ( $-0.4$  servings/d), overweight ( $-0.7$  servings/d) and obesity ( $-0.5$  servings/d) ( $P < 0.001$ ) ([Fig. 3](#)). The intake of ultraprocessed foods also declined among participants with obesity ( $-1.9$  servings/d), overweight ( $-1.7$  servings/d) and normal weight ( $-1.2$  servings/d) ( $P_{\text{trend}} < 0.001$ ). While the consumption of ultraprocessed foods remained higher among participants with obesity compared with participants with normal weight at all time points ( $P < 0.001$ ), the magnitude of the difference declined over time ( $8.3$  *v.*  $6.9$  servings/d in 1991–1995, and  $6.4$



**Fig. 2.** Trends in food consumption (servings/d) by NOVA processing level from 1991 to 2008 in (a) the overall sample and in (b) females and (c) males, in the Framingham Offspring Cohort. ■, 1991/1995; ■, 1995/1998; ■, 1998/2001; ■, 2005/2008.

v. 5.8 servings/d in 2005–2008). There were trends towards increased consumption of culinary ingredients and processed foods, and decreased consumption of culinary preparations among participants with normal weight, overweight and obesity, but changes in intakes were minor ( $\pm 0.2$  or fewer servings/d). Diet quality increased among participants with normal weight (61.8–63.3,  $P_{\text{trend}} < 0.001$ ), overweight (59.9–61.5,  $P_{\text{trend}} < 0.001$ ) and obesity (58.1–59.9,  $P_{\text{trend}} = 0.009$ ) over the study period (data not shown).

#### Subgroup and sensitivity analyses

Trends in food consumption according to processing level did not differ between smokers and non-smokers and were

comparable to those in the overall population (data not shown). Diet quality was higher among non-smokers than smokers at all time points ( $P < 0.001$ ) and increased among non-smokers (61.4–62.1,  $P_{\text{trend}} = 0.001$ ), but not among smokers (54.4–55.0,  $P_{\text{trend}} = 0.117$ ) over the study period (data not shown). Likewise, trends in diet processing level intake did not differ when the analyses were repeated among individuals with and without chronic diseases (CVD, diabetes mellitus and hypertension) and were similar to those in the overall population (data not shown). Diet quality did not differ between individuals with and without chronic diseases at baseline ( $P = 0.074$ ) and improved over time among disease-free participants (59.9–62.1,  $P < 0.001$ ) but not among those with chronic diseases (60.8–61.0,  $P = 0.878$ ) (data not shown).



**Table 2.** Trends in mean intake of specific food groups (servings/week) by NOVA processing level from 1991 to 2008 among males and females, Framingham Offspring Cohort (Mean values and standard deviations, *n* 2893)

	Overall sample					Females					Men				
	1991–1995 ( <i>n</i> 2741)		2005–2008 ( <i>n</i> 2438)		<i>P</i> <sub>trend</sub>	1991–1995 ( <i>n</i> 1491)		2005–2008 ( <i>n</i> 1339)		<i>P</i> <sub>trend</sub>	1991–1995 ( <i>n</i> 1250)		2005–2008 ( <i>n</i> 1099)		<i>P</i> <sub>trend</sub>
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
<b>Minimally processed foods</b>															
Vegetables & legumes*	20.2	12.4	20.2	12.5	0.143	22.2	13.5	21.7	13.1	0.015	17.9	10.4	18.4	11.5	0.524
Fruit†	11.1	9.0	12.4	8.9	<0.001	11.6	8.8	13.4	9.1	<0.001	10.5	9.1	11.3	8.6	<0.001
Fruit juice‡	6.1	6.6	5.1	5.5	<0.001	5.8	6.7	4.7	5.4	<0.001	6.4	6.5	5.5	5.6	<0.001
Meat, fish & eggs§	8.1	3.3	8.8	3.5	<0.001	8.0	3.3	8.7	3.4	<0.001	8.2	3.2	9.0	3.6	<0.001
Milk (skimmed & whole)	5.4	6.1	4.7	5.6	<0.001	5.3	5.8	4.8	5.4	<0.001	5.6	6.4	4.6	5.7	<0.001
Grains	4.4	4.0	4.2	3.9	<0.001	4.6	4.1	4.3	4.1	<0.001	4.2	3.8	4.1	3.6	0.192
Nuts	0.6	1.5	2.0	3.9	<0.001	0.5	1.2	2.1	4.0	<0.001	0.8	1.8	1.9	3.7	<0.001
Coffee & tea	18.6	12.1	14.4	10.2	<0.001	18.8	12.2	14.3	10.2	<0.001	18.5	11.9	14.5	10.3	<0.001
Homemade baked goods¶	1.9	3.2	1.7	3.0	<0.001	1.9	3.2	1.6	2.9	0.001	2.0	3.3	1.8	3.2	0.063
Soups & sauces**	2.2	1.8	2.0	2.0	<0.001	2.1	1.7	1.8	1.7	<0.001	2.4	1.9	2.2	2.2	0.087
<b>Culinary ingredients</b>															
Cream, butter & sour cream	4.7	8.6	5.3	8.2	0.002	4.4	8.1	5.5	8.4	<0.001	5.1	9.1	5.1	7.9	0.749
Oil & vinegar dressing	2.3	3.1	2.6	3.0	<0.001	2.4	3.0	2.8	3.3	0.001	2.2	3.2	2.3	2.7	0.077
Salt††	5.6	8.9	5.1	7.9	0.030	5.7	8.7	5.3	7.7	0.113	5.4	9.1	4.9	8.1	0.137
Sugar††	6.3	12.1	4.0	9.6	<0.001	5.2	10.8	3.4	8.8	<0.001	7.7	13.4	4.9	10.4	<0.001
<b>Processed foods</b>															
Cheese‡‡	3.1	3.4	4.0	4.3	<0.001	3.0	3.2	4.1	4.5	<0.001	3.2	3.6	3.8	4.0	<0.001
Canned/cured meat & fish§§	1.5	1.5	1.4	1.7	0.769	1.4	1.3	1.3	1.6	0.794	1.6	1.7	1.5	1.9	0.892
Wine & beer	4.0	7.1	4.2	6.6	0.751	2.5	4.8	2.9	5.0	0.060	5.8	8.9	5.7	7.9	0.393
Other processed foods	6.8	6.2	7.4	6.8	<0.001	6.6	6.1	7.2	6.4	0.002	7.1	6.4	7.6	7.2	0.011
<b>Ultraprocessed foods</b>															
Bread¶¶	11.8	9.5	8.2	7.5	<0.001	11.2	8.7	7.5	6.9	<0.001	12.4	10.4	9.1	8.1	<0.001
Sweets & desserts***	9.9	9.6	9.0	9.3	<0.001	8.8	8.6	8.3	8.3	<0.001	11.1	10.6	9.9	10.3	<0.001
Ultraprocessed meats†††	2.5	2.7	2.4	2.6	0.707	1.9	1.9	2.0	2.3	0.739	3.1	3.2	3.1	2.9	0.484
Salty snack foods‡‡‡	5.8	8.4	4.7	7.0	<0.001	6.2	8.8	4.8	7.2	<0.001	5.3	7.8	4.6	6.8	0.004
Sugarsweetened beverages§§§	2.8	5.2	1.7	4.0	<0.001	2.1	4.6	1.2	3.0	<0.001	3.6	5.8	2.3	4.9	<0.001
Low-energy soft drinks	4.3	7.5	3.0	5.9	<0.001	4.3	6.9	2.5	4.9	<0.001	4.4	8.2	3.6	6.9	<0.001
Fast foods¶¶¶	4.3	2.6	3.8	2.2	<0.001	3.7	2.0	3.3	1.7	<0.001	5.0	3.0	4.4	2.5	<0.001
Breakfast cereals****	2.2	2.9	2.5	2.9	0.004	2.1	2.7	2.3	2.8	0.117	2.4	3.2	2.7	3.0	0.013
Yogurt	0.9	1.9	1.3	2.9	<0.001	1.1	2.1	1.8	3.4	<0.001	0.6	1.5	0.8	2.0	0.006
Other ultraprocessed foods††††	9.5	10.3	6.5	9.0	<0.001	8.8	9.7	5.9	8.0	<0.001	10.3	10.9	7.4	10.0	<0.001

\* Includes broccoli, cabbage/coleslaw, cauliflower, Brussels sprouts, alfalfa sprouts, carrots (raw/cooked), mixed vegetables, winter squash, summer squash, beets, celery, spinach (raw/cooked), iceberg/head lettuce, romaine/leaf lettuce, tomatoes, yams/sweet potatoes, kale/mustard greens/chard, garlic, beets, maize, potatoes, string beans, peas/lima beans and beans/lentils.

† Includes apples and pears, bananas, raisins, prunes, cantaloupe, watermelon, oranges, grapefruit, strawberries, blueberries and peaches.

‡ Includes orange juice, grapefruit juice, tomato juice, apple juice/cider and other fruit juices.

§ Includes chicken/turkey (with/without skin), liver, meat as main dish, dark meat fish, other fish, shellfish (e.g. shrimp, lobster, scallops) and eggs.

|| Includes oatmeal, rice (brown and white), pasta, bran, wheat germ, minimally processed hot and cold breakfast cereals and other grains.

¶ Includes homemade sweet rolls, cookies, cakes, pies and granola.

\*\* Includes fried food made at home, soup/chowder and tomato sauce (assumed homemade).

†† Added to foods and beverages by participant at time of consumption.

‡‡ Includes cottage cheese/ricotta and other cheese.

§§ Includes canned tuna and bacon.

||| Includes peanut butter, mustard, jams/jellies, tofu, mayonnaise and processed breakfast cereals (cereals with added salt and/or sugar but without additives).

¶¶ Includes white and dark bread and English muffins/bagels.

\*\*\* Includes ready-made sweet rolls, pies, cookies, doughnuts, brownies, pancakes/waffles, muffins/biscuits, ice cream, sherbet/ice milk, candy bars, chocolate and candy without chocolate.

††† Includes processed meats (e.g. sausage, bologna, salami), hot dogs and meat sandwiches.

‡‡‡ Includes chips, crackers and popcorn.

§§§ Includes cola and non-cola carbonated drinks with sugar, punch, lemonade and other non-carbonated fruit drinks.

|||| Includes low-energy cola and non-cola carbonated beverages (with/without caffeine).

¶¶¶ Includes, pizza, hamburgers, French fries and fried foods away from home.

\*\*\*\* Includes breakfast cereals containing additives such as flavours, colours and preservatives not used in domestic cooking.

†††† Includes non-dairy coffee whitener, margarine, cream cheese, liquor and chilli sauce.

## Discussion

Ultraprocessed foods were frequently consumed in this predominantly Caucasian population of ageing adults over the 17-year study period (1991–2008), although intakes decreased modestly over time. Trends in diet processing level were similar in males and females and irrespective of weight and smoking

status. Diet quality, measured by DGAI-2010, improved modestly over time for the entire study population, except for current smokers and participants with chronic disease.

Our results are consistent with, and extend, findings from NHANES, 2007–2012, showing that ultraprocessed foods provided 55–53% of energy content in the diet of middle-aged

**Table 3.** Trends in mean energy intake, nutrient intakes and diet quality from 1991 to 2008 among males and females, Framingham Offspring Cohort (Mean values and standard deviations, *n* 2893)

	1991–1995		1995–1998		1998–2001		2005–2008		<i>P</i> <sub>trend</sub>
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
<b>Whole sample</b>									
<i>n</i>	2741		2733		2730		2438		
Total energy intake (kcal)	1865.2	612.2	1851.9	608.0	1825.4	587.2	1875.5	636.3	0.479
%Energy from									
Protein	16.8	3.3	17.1	3.3	17.3	3.4	17.9	3.6	<0.001
Carbohydrates, of which:	51.0	8.5	51.8	8.6	50.0	8.9	46.8	8.6	<0.001
Total sugar*					23.1	7.5	21.6	7.2	<0.001
Sucrose	9.8	4.1	10.0	3.7	9.3	3.7	8.8	3.7	<0.001
Fructose	5.4	2.7	5.6	2.5	5.3	2.4	4.7	2.2	<0.001
Total fat, of which:	30.0	6.4	29.1	6.5	30.7	6.6	33.0	6.5	<0.001
Saturated fat	10.4	2.8	10.1	2.8	10.7	2.9	11.1	2.7	<0.001
Monounsaturated fat	5.9	1.7	5.6	1.6	5.8	1.7	6.3	1.8	<0.001
Polyunsaturated fat	11.1	2.6	10.8	2.6	11.3	2.7	12.4	2.8	<0.001
Trans-fat†	1.5	0.7			1.3	0.5	1.2	0.4	<0.001
Alcohol	4.0	5.8	4.0	5.7	3.9	5.7	3.9	5.6	0.773
Fibre, g/1000kcal	9.8	3.1	10.3	3.2	10.2	3.3	10.4	3.2	<0.001
Na, mg/1000kcal	1158.1	231.7	1176.6	234.8	1125.8	221.9	1083.9	213.2	<0.001
DGAI-2010‡	60.1	11.4			60.6	11.6	61.5	11.3	<0.001
<b>Females</b>									
<i>n</i>	1491		1474		1480		1339		
Total energy intake (kcal)	1752.1	562.8	1748.9	560.1	1716.1	525.9	1787.8	594.7	0.329
%Energy from									
Protein	17.4	3.3	17.6	3.3	17.9	3.3	18.5	3.6	<0.001
Carbohydrates, of which:	51.7	8.3	52.8	8.5	50.8	9.0	47.4	8.6	<0.001
Total sugar*					23.8	7.4	22.3	7.3	<0.001
Sucrose	9.9	4.0	10.2	3.7	9.5	3.7	9.0	3.7	<0.001
Fructose	5.4	2.7	5.6	2.4	5.4	2.4	4.9	2.2	<0.001
Total fat, of which:	29.9	6.3	28.9	6.4	30.6	6.7	33.0	6.6	<0.001
Saturated fat	10.3	2.8	10.0	2.8	10.7	2.9	11.1	2.8	<0.001
Monounsaturated fat	6.0	1.7	5.7	1.6	5.9	1.8	6.4	1.9	<0.001
Polyunsaturated fat	10.9	2.6	10.6	2.6	11.0	2.7	12.3	2.8	<0.001
Trans-fat†	1.5	0.7			1.2	0.5	1.2	0.4	<0.001
Alcohol	2.9	4.7	2.9	4.7	2.8	4.6	2.9	4.4	0.445
Fibre, g/1000kcal	10.3	3.2	10.9	3.2	10.7	3.5	11.0	3.3	<0.001
Na, mg/1000kcal	1188.5	232.6	1202.1	232.9	1136.7	224.3	1094.7	221.5	<0.001
DGAI-2010‡	62.9	10.9			63.0	11.4	63.9	11.0	0.013
<b>Men</b>									
<i>n</i>	1250		1259		1250		1099		
Total energy intake (kcal)	2000.0	641.1	1972.5	639.2	1954.9	628.5	1982.4	668.4	0.055
%Energy from									
Protein	16.1	3.2	16.5	3.1	16.7	3.3	17.3	3.4	<0.001
Carbohydrates, of which:	50.1	8.5	50.7	8.6	49.1	8.6	46.1	8.5	<0.001
Total sugar*					22.4	7.5	20.8	7.0	<0.001
Sucrose	9.6	4.2	9.7	3.6	9.1	3.6	8.7	3.6	
Fructose	5.4	2.7	5.7	2.6	5.2	2.5	4.6	2.2	
Total fat, of which:	30.2	6.4	29.4	6.5	30.8	6.5	32.9	6.5	<0.001
Saturated fat	10.5	2.9	10.2	2.8	10.7	2.8	11.1	2.7	<0.001
Monounsaturated fat	5.7	1.7	5.5	1.5	5.7	1.6	6.2	1.7	<0.001
Polyunsaturated fat	11.3	2.6	11.1	2.7	11.5	2.7	12.5	2.8	<0.001
Trans-fat†	1.6	0.8			1.3	0.5	1.2	0.4	<0.001
Alcohol	5.3	6.7	5.3	6.5	5.3	6.5	5.3	6.4	0.796
Fibre, g/1000kcal	9.1	2.9	9.7	3.0	9.6	2.9	9.6	3.0	<0.001
Na, mg/1000kcal	1121.9	225.3	1146.9	233.5	1112.9	218.5	1070.8	201.9	<0.001
DGAI-2010‡	56.8	11.1			57.8	11.2	58.6	11.0	<0.001

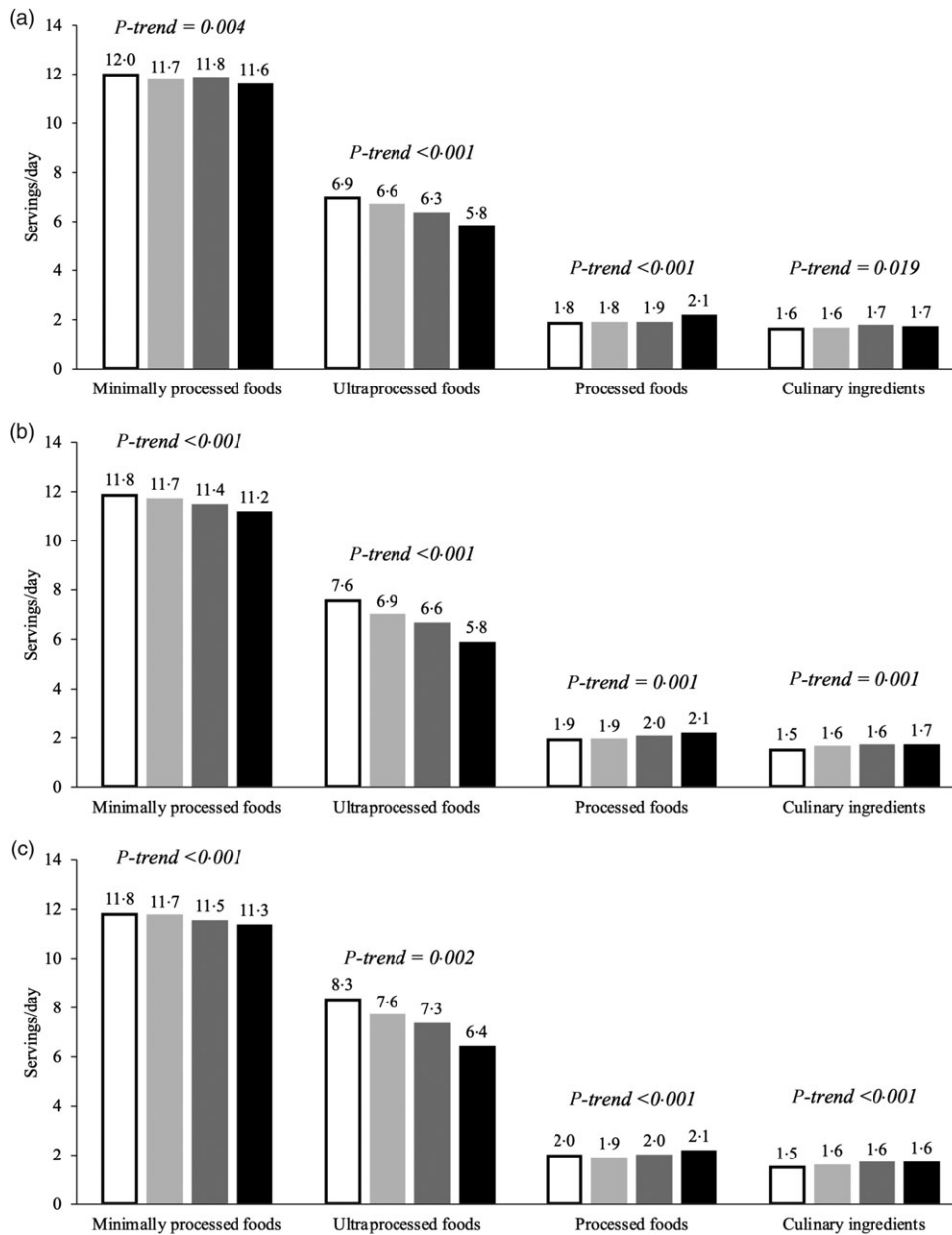
\* Data regarding total sugar intake not available for examinations 5 (1991–1995) and 6 (1995–1998).

† Data regarding trans-fat intake not available for examination 6 (1995–1998).

‡ 2010 Dietary Guidelines for Americans Adherence Index (continuous, range 0–100), higher scores indicate higher diet quality. Data regarding DGAI-2010 were not available for examination 6 (1995–1998).

and older US adults ( $\geq 40$  years of age)<sup>(10)</sup>. In the FOS, the observed trend towards reduced consumption of ultraprocessed foods over time is also in line with analyses of Euromonitor volume sales data, documenting that US sales of ultraprocessed foods declined from 401.0 to 354.6 kg per capita between 2002 and 2016<sup>(12)</sup>. However, analyses within the

Nielsen Homescan Panel suggest that US households' purchases of highly processed foods, defined as multi-ingredient industrially formulated mixtures, remained stable, at approximately 61% of purchased energy content, between 2002 and 2012<sup>(11)</sup>, a period that coincides with FOS dietary data collection.



**Fig. 3.** Trends in food consumption (servings/d) by NOVA processing level from 1991 to 2008 among participants in the Framingham Offspring Cohort with (a) normal weight, (b) overweight and (c) obesity. ■, 1991/1995; ■, 1995/1998; ■, 1998/2001; ■, 2005/2008.

In the FOS, the declining intake of ultraprocessed foods occurred in parallel to modest improvements in diet quality and reductions in the intakes of *trans* fats and Na, as well as sucrose and fructose, the predominant added sugars in the US food supply<sup>(32)</sup>. Our findings align with previous observations in NHANES that the quality of the US diet improved from 1999 to 2011<sup>(33)</sup>. In the FOS, we observed decreased intakes of margarine, fast foods, salty snacks, breads and sweet ultraprocessed foods (baked goods, sweets, desserts and sugar-sweetened beverages), which are major sources of *trans* fats, Na and added sugars in the US diet<sup>(32,34,35)</sup>. Our findings contribute to the existing evidence suggesting that limiting ultraprocessed foods may be an effective strategy to improve diet quality<sup>(4)</sup>.

The observed changes in nutrient intakes in the FOS may reflect shifts in dietary behaviours in response to national dietary guidelines, from recommending low-fat diets (<30 % of energy) in the 1990s to moderate-fat diets (25–35 % of energy) in 2005<sup>(36,37)</sup>, as well as the growing popularity of low-carbohydrate diets in the early 2000s<sup>(38)</sup>. Increased marketing and availability of ultraprocessed low-fat products in the 1990s and low-carbohydrate products in the 2000s may also have promoted and facilitated the observed trends in macronutrient intakes. For example, in 1996, over 3400 novel low-fat or fat-free ultraprocessed products were introduced to the US market, and in 2004, 3400 new ‘low-carb’ and ‘no-carb’ ultraprocessed products were launched<sup>(38)</sup>. In this context, the nutrient-focused





approach of national dietary guidelines in the 1990s and 2000s may have enabled, and unintentionally promoted, continued high consumption of ultraprocessed foods<sup>(39)</sup>. While the current DGA (2015–2020) emphasises the importance of healthy dietary patterns based on nutrient-dense foods, processing level is still not explicitly addressed<sup>(40)</sup>. Future investigations should determine if food-based dietary guidelines that distinguish ultraprocessed from moderately and minimally processed foods facilitate healthier food choices and improve diet quality.

The current findings should be interpreted in the light of several limitations. The reduced consumption of ultraprocessed foods over the study period may, in part, be explained by diminishing food intake, as ageing is associated with reduced appetite and decreased energy intake<sup>(41)</sup>. The Harvard FFQ queries a comprehensive, although not exhaustive, list of foods, and we can only draw conclusions regarding intake trends of foods included in the FFQ. We were unable to calculate the relative energy provided by the foods in each processing level since the FOS only provides data regarding total energy and nutrient intakes per day, and not per food. As a result, consumption estimates are reported in servings/d and are not directly comparable to consumption estimates from NHANES, which are reported as percentages of total energy intake. Although it is well documented that dietary assessment by FFQ provides an imperfect measure of diet<sup>(42)</sup>, the Harvard FFQ is widely used in research and has been validated in US populations<sup>(18,19)</sup>. Processing level may have been misclassified as certain FFQ line items included foods of potentially different processing levels. However, we attempted to minimise misclassification by basing assumptions of processing level of FFQ items on the current literature and on actual consumption data from adults in NHANES 2001–2002 with similar demographics to the FOS cohort. The Harvard FFQ differentiates between homemade and ready-made cookies, cakes, pies and pastries; distinguishes between homemade and commercially prepared fried foods and allow respondents to specify the type and brand of breakfast cereals consumed, which enabled a more precise classification of these foods. Dietary data in the FOS were not available beyond year 2008 at the time of writing. Nevertheless, the FOS is an ongoing cohort study, and more recent dietary data have been collected, which, when made available, will enable determination of consumption trends during the 2010s. Finally, the FOS is an older cohort with higher education and income levels than the average US population, which may limit the generalisability of our findings. Given that age, education and income are inversely associated with ultraprocessed food intake<sup>(10)</sup>, consumption may have been lower in the FOS cohort as compared with the average US population. FOS participants may also be more health conscious than the general population given their voluntary participation in a longitudinal health study.

The present study also has important strengths, including its longitudinal design, nearly 20-year follow-up, and serially collected dietary and anthropometric data by trained study personnel during in-person study examinations. Food processing level was determined according to the standardised and objective criteria of NOVA. The NOVA framework is a comprehensive,

specific and coherent classification that has been internationally recognised as a valid tool for public health and nutrition research and policy<sup>(43)</sup>. Additionally, diet quality was evaluated using an objective and multi-dimensional index that considers food and nutrient intakes, as well as healthy food choices (e.g. choosing whole grains over refined grains), variety in protein and vegetable intakes, and overconsumption of energy-dense foods and discretionary energy content<sup>(27)</sup>.

### Conclusion

The current study uniquely adds to the literature by describing longitudinal trends in diet processing level and diet quality in an ageing US population, highlighting the longstanding presence of ultraprocessed foods in the American diet. Further research is warranted to elucidate trends in diet processing level in racially/ethnically diverse populations and across socio-economic strata and to clarify the role of diet processing level in existing disparities in diet quality. Given the accumulating evidence of the poor nutritional quality and potential harms of ultraprocessed foods, public health efforts and policies should be designed to limit the consumption of ultraprocessed foods and encourage healthier food choices. It is also imperative to educate health professionals and the population at large about what ultraprocessed foods are in order to enable selection of less processed products.

### Acknowledgements

We thank Dr Euridice Martinez Steele for guidance in classifying the dietary data according to the NOVA framework.

The Framingham Heart Study is conducted and supported by the National Heart, Lung, and Blood Institute (NHLBI) in collaboration with Boston University (Contract No. N01-HC-25195). Funding support for the Framingham Food Frequency Questionnaire data sets was provided by ARS Contract No. 53-3k06-5-10, ARS Agreement No.'s 58-1950-9-001, 58-1950-4-401 and 58-1950-7-707. This manuscript was not prepared in collaboration with investigators of the Framingham Heart Study and does not necessarily reflect the opinions or views of the Framingham Heart Study, Boston University, or NHLBI.

The authors' responsibilities were as follows: F. J. and N. P. designed the overall research plan within the existing dataset; F. J. constructed the analytical data set and performed the statistical analyses; Y. L. and N. P. provided expertise regarding statistical analyses, F. J. took lead in writing the manuscript; Y. L., A. L. D., G. V. and N. P. aided in the interpretation of the data and revised the manuscript for important intellectual content. N. P. oversaw the research project as senior author. All authors have read and approved the final manuscript and take full responsibility for the final content.

The authors declare that there are no conflicts of interest.

### Supplementary material

For supplementary material referred to in this article, please visit <https://doi.org/10.1017/S000711452100060X>

## References

- Moubarac JC, Batal M, Louzada ML, *et al.* (2017) Consumption of ultra-processed foods predicts diet quality in Canada. *Appetite* **108**, 512–520.
- Julia C, Martinez L, Alles B, *et al.* (2017) Contribution of ultra-processed foods in the diet of adults from the French NutriNet-Sante study. *Public Health Nutr* 1–11.
- Rauber F, da Costa Louzada ML, Steele EM, *et al.* (2018) Ultra-processed food consumption and chronic non-communicable diseases-related dietary nutrient profile in the UK (2008–2014). *Nutrients* **10**, 587.
- Martinez Steele E, Popkin BM, Swinburn B, *et al.* (2017) The share of ultra-processed foods and the overall nutritional quality of diets in the US: evidence from a nationally representative cross-sectional study. *Popul Health Metr* **15**, 6.
- Fiolet T, Srour B, Sellem L, *et al.* (2018) Consumption of ultra-processed foods and cancer risk: results from NutriNet-Sante prospective cohort. *BMJ* **360**, k322.
- Srour B, Fezeu LK, Kesse-Guyot E, *et al.* (2019) Ultra-processed food intake and risk of cardiovascular disease: prospective cohort study (NutriNet-Sante). *BMJ* **365**, l1451.
- Srour B, Fezeu LK, Kesse-Guyot E, *et al.* (2019) Ultraprocessed food consumption and risk of type 2 diabetes among participants of the Nutrinet-Sante prospective cohort. *JAMA Intern Med* **180**, 283–291.
- Mendonca RD, Lopes AC, Pimenta AM, *et al.* (2017) Ultra-processed food consumption and the incidence of hypertension in a Mediterranean cohort: the seguimiento universidad de navarra project. *Am J Hypertens* **30**, 358–366.
- Juul F, Martinez-Steele E, Parekh N, *et al.* (2018) Ultra-processed food consumption and excess weight among US adults. *Br J Nutr* **120**, 90–100.
- Baraldi LG, Martinez Steele E, Canella DS, *et al.* (2018) Consumption of ultra-processed foods and associated socio-demographic factors in the USA between 2007 and 2012: evidence from a nationally representative cross-sectional study. *BMJ Open* **8**, e020574.
- Poti JM, Mendez MA, Ng SW, *et al.* (2015) Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *Am J Clin Nutr* **101**, 1251–1262.
- Vandevijvere S, Jaacks LM, Monteiro CA, *et al.* (2019) Global trends in ultraprocessed food and drink product sales and their association with adult body mass index trajectories. *Obes Rev* **20**, 10–19.
- Dawber TR, Meadors GF & Moore FE (1951) Epidemiological approaches to heart disease: the Framingham Study. *Am J Public Health Nations Health* **41**, 279–281.
- Larson MG, Atwood LD, Benjamin EJ, *et al.* (2007) Framingham Heart Study 100K project: genome-wide associations for cardiovascular disease outcomes. *BMC Med Genet* **8**, S5.
- Kannel WB, Feinleib M, McNamara PM, *et al.* (1979) An investigation of coronary heart disease in families. The Framingham offspring study. *Am J Epidemiol* **110**, 281–290.
- Feinleib M, Kannel WB, Garrison RJ, *et al.* (1975) The Framingham offspring study. Design and preliminary data. *Prev Med* **4**, 518–525.
- McKeown NM, Troy LM, Jacques PF, *et al.* (2010) Whole- and refined-grain intakes are differentially associated with abdominal visceral and subcutaneous adiposity in healthy adults: the Framingham Heart Study. *Am J Clin Nutr* **92**, 1165–1171.
- Hu FB, Rimm E, Smith-Warner SA, *et al.* (1999) Reproducibility and validity of dietary patterns assessed with a food-frequency questionnaire. *Am J Clin Nutr* **69**, 243–249.
- Rimm EB, Giovannucci EL, Stampfer MJ, *et al.* (1992) Reproducibility and validity of an expanded self-administered semiquantitative food frequency questionnaire among male health professionals. *Am J Epidemiol* **135**, 1114–1126.
- Wolongevicz DM, Brown LS & Millen BE (2010) Nutrient database development: a historical perspective from the Framingham Nutrition Studies. *J Am Diet Assoc* **110**, 898–903.
- Monteiro CA, Cannon G, Levy RB, *et al.* (2019) Ultra-processed foods: what they are and how to identify them. *Public Health Nutr* **22**, 936–941.
- Nielsen SJ, Siega-Riz AM & Popkin BM (2002) Trends in energy intake in U.S. between 1977 and 1996: similar shifts seen across age groups. *Obes Res* **10**, 370–378.
- Martinez Steele E, Baraldi LG, Louzada ML, *et al.* (2016) Ultra-processed foods and added sugars in the US diet: evidence from a nationally representative cross-sectional study. *BMJ Open* **6**, e009892.
- Troy LM & Jacques PF (2012) Diets that follow the 2010 Dietary Guidelines for Americans (DGA) are associated with higher intakes of nutrients of concern. *FASEB J* **26**, 267.
- Guenther PM, Kirkpatrick SI, Reedy J, *et al.* (2014) The Healthy Eating Index-2010 is a valid and reliable measure of diet quality according to the 2010 Dietary Guidelines for Americans. *J Nutr* **144**, 399–407.
- Fogli-Cawley JJ, Dwyer JT, Saltzman E, *et al.* (2006) The 2005 Dietary Guidelines for Americans Adherence Index: development and application. *J Nutr* **136**, 2908–2915.
- Sauder KA, Proctor DN, Chow M, *et al.* (2015) Endothelial function, arterial stiffness and adherence to the 2010 Dietary Guidelines for Americans: a cross-sectional analysis. *Br J Nutr* **113**, 1773–1781.
- Kannel WB & Sorlie P (1979) Some health benefits of physical activity: the Framingham Study. *Arch Intern Med* **139**, 857–861.
- Jonker JT, De Laet C, Franco OH, *et al.* (2006) Physical activity and life expectancy with and without diabetes: life table analysis of the Framingham Heart Study. *Diabetes Care* **29**, 38–43.
- WHO (2020) Obesity and overweight. <https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight>. (accessed April 2020).
- Millen BE, Quatromoni PA, Gagnon DR, *et al.* (1996) Dietary patterns of men and women suggest targets for health promotion: the Framingham Nutrition Studies. *Am J Health Promot* **11**, 42–52; discussion 52–43.
- Marriott BP, Cole N & Lee E (2009) National estimates of dietary fructose intake increased from 1977 to 2004 in the United States. *J Nutr* **139**, 1228S–1235S.
- Wilson MM, Reedy J & Krebs-Smith SM (2016) American diet quality: where it is, where it is heading, and what it could be. *J Acad Nutr Diet* **116**, 302–310.
- IOM (2010) *Strategies to Reduce Sodium Intake in the United States*. Washington, DC: Institute of Medicine (US) Committee on Strategies to Reduce Sodium Intake.
- Kris-Etherton PM, Lefevre M, Mensink RP, *et al.* (2012) Trans fatty acid intakes and food sources in the U.S. population: NHANES 1999–2002. *Lipids* **47**, 931–940.
- USDA & HHS (1990) *Nutrition and Your Health: Dietary Guidelines for Americans*, 3rd ed. Washington, DC: USDA, US Department of Health and Human Services.
- USDA & HHS (2005) *Dietary Guidelines for Americans*. Washington, DC: USDA, US department of Health and Human Services.
- Kuchler F, Golan E, Variyam J, *et al.* (2005) Obesity policy and the law of unintended consequences. *Amber Waves* **3**, 26–33.



39. Mozaffarian D & Ludwig DS (2010) Dietary guidelines in the 21st century—a time for food. *JAMA* **304**, 681–682.
40. USDA (2015) *2015–2020 Dietary Guidelines for Americans*, 8th ed. Washington, DC: US Department of Health and Human Services and US Department of Agriculture.
41. Giezenaar C, Chapman I, Luscombe-Marsh N, *et al.* (2016) Ageing is associated with decreases in appetite and energy intake—a meta-analysis in healthy adults. *Nutrients* **8**, 28.
42. Schatzkin A, Kipnis V, Carroll RJ, *et al.* (2003) A comparison of a food frequency questionnaire with a 24-hour recall for use in an epidemiological cohort study: results from the biomarker-based Observing Protein and Energy Nutrition (OPEN) study. *Int J Epidemiol* **32**, 1054–1062.
43. FAO (2015) *Guidelines on the Collection of Information on Food Processing through Food Consumption Surveys*. Rome: The Food and Agriculture Organization of the United Nations.