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Ultra-processed foods and recommended intake levels of nutrients linked to non-communicable diseases in Australia: evidence from a nationally representative cross-sectional study

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ABSTRACT

Objective This study aimed to describe the consumption of ultra-processed foods in Australia and its association with the intake of nutrients linked to non-communicable diseases (NCDs).

Design Cross-sectional study.

Setting National Nutrition and Physical Activity Survey (2011-2012).

Participants 12,153 participants aged 2+ years.

Main outcome measures Average dietary content of nutrients linked to NCDs and the prevalence of intake outside levels recommended for the prevention of NCDs.

Data analysis Food items were classified according to the NOVA system, a classification based on the nature, extent and purpose of industrial food processing. The contribution of each NOVA food group and their subgroups to total energy intake was calculated. Mean nutrient content of ultra-processed food and non-ultra-processed food fractions of the diet were compared. Across quintiles of the energy contribution of ultra-processed foods, differences in the intake of nutrients linked to NCDs as well as in the prevalence of intakes outside levels recommended for the prevention of NCDs were examined.

Results Ultra-processed foods had the highest dietary contribution (42.0% of energy intake), followed by unprocessed or minimally processed foods (35.4%), processed foods (15.8%) and processed culinary ingredients (6.8%). A positive and statistically significant linear trend was found between quintiles of ultra-processed food consumption and intake levels of free sugars (standardised β 0.43, p<0.001); total (β 0.08, p<0.001), saturated (β 0.18, p<0.001) and trans fats (β 0.10, p<0.001); sodium (β 0.21, p<0.001) and diet energy density (β 0.41, p<0.001), while an inverse relationship was observed for dietary fibre (β -0.21, p<0.001) and potassium (β -0.27, p<0.001). The prevalence of non-recommended intake levels of all studied nutrients increased linearly across quintiles of ultra-processed food intake, notably from 22% to 82% for free sugars, from 6% to 11% for trans fat and from 2% to 25% for dietary energy density, from the lowest to the highest ultra-processed food quintile.

Conclusion The high energy contribution of ultra-processed foods impacted negatively on the intake of non-ultra-processed foods and on all nutrients linked to NCDs in Australia. Decreasing the dietary share of ultra-processed foods would substantially improve the diet quality in the country and help the population achieve recommendations on critical nutrients linked to NCDs.

Strengths and limitations of this study

- Use of the most up-to-date, individual-level dietary survey data taken from a nationally representative sample of Australian children and adults, increasing generalisability.
- Use of the NOVA food classification system applied to disaggregated food codes, enabling to assess underestimated food groups and comparisons among different countries.
- The assessment of the contribution of foods according to the level of processing to daily intake of nutrients linked to non-communicable diseases provided novel evidence to improve the diet quality in Australia.
- Dietary data obtained by 24-hour recalls are subject to errors.
- Some items may have been misclassified due to inconsistencies of information indicative of food processing in the data sets.

INTRODUCTION

Obesity and chronic non-communicable diseases (NCDs), such as cardiovascular diseases, type 2 diabetes and some cancers, are the main causes of premature death and disability in Australia and the world.[1–3] Important risk factors driving most NCDs are dietary nutritional imbalances,[4] which appear to be due to changes in global food systems.[5–7] The increasing supply, distribution and consumption of cheap, palatable, accessible, convenient and highly marketed mass-produced products have led to the

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displacement of dietary patterns based on fresh and minimally processed foods.[8 9]

The NOVA system, a food classification based on the nature, extent and purpose of industrial food processing, has been applied worldwide to understand the impact of modern industrial food systems on human health.[10] Considered the most specific, coherent and comprehensive food classification system based on food processing,[11] NOVA classifies foods into four groups: unprocessed and minimally processed foods, processed culinary ingredients, processed foods and ultra-processed foods.[12] Ultra-processed foods are formulations of low-cost ingredients, many of non-culinary use, that result from a sequence of industrial processes (hence 'ultra-processed'). Examples of ultra-processed foods include soft drinks; sweet and savoury snacks such as fruit straps, potato crisps, confectionery; many breakfast cereals; microwaveable frozen meals; instant soups; fast food dishes and a myriad of new products launched in the market every year.[9 12] High amounts of salt, added sugars, fat and/or additives make them extremely palatable and habit-forming.[13] They dispense with the necessity of culinary preparation and are omnipresent, which make them convenient and accessible. The aggressive and sophisticated marketing of ultra-processed foods amplifies their 'advantages' (convenience, branding, pricing) over unprocessed or minimally processed foods.[8 14]

In Australia, an increase in the consumption of high energy-dense, nutrient-poor foods has been observed over the years.[15–17] Sales data provided by the market research firm Euromonitor show that in 2013 Australia had the sixth highest per capita sales among the evaluated ultra-processed foods behind the USA, Canada, Germany, Mexico and Belgium.[14] Data from a nationally representative sample of the Australian households also showed that expenditure (as a percentage of the home food budget) on ultra-processed foods increased around 5% between 1989 and 2010.[18]

Despite the evidence that indicates that the degree of food processing effectively predicts the nutritional quality of diets and their impact on obesity and NCDs,[10 14] the consumption of ultra-processed foods and their impact on the dietary nutrient profile have not been studied in Australia. This study aimed to characterise the overall and different patterns of ultra-processed food consumption in Australia, compare the nutrient profiles of ultra-processed and non-ultra-processed fractions of the diet and describe the association between ultra-processed food consumption and intake of nutrients linked to NCDs.

METHODS

Data source

The data source for this study was the National Nutrition and Physical Activity Survey (NNPAS) 2011–2012, part of the 2011–2013 Australian Health Survey. This nationally representative cross-sectional survey studied a randomly selected, national sample of the Australian population using a complex, stratified, multistage probability cluster sampling design with selection of strata, households and people within households. The NNPAS was conducted between May 2011 and June 2012 on 9519 households where 12153 Australians aged 2 years and above were interviewed.[19]

Data on food intake were collected as part of NNPAS based on two 24-hour dietary recalls administered by trained and experienced interviewers using the Automated Multiple-Pass Method. The first recall was applied through a face-to-face interview (n=12153), while the second recall (n=7735) was applied via a telephone interview conducted 8 days or more after the first interview.[19] For children under 15 years of age, parents/guardians were used as proxies, previously found to be valid instruments to assess energy intake among children aged 4 to 10 years.[20] Where permission was granted by a parent/guardian, adolescents aged 15–17 years were interviewed in person. If permission was not granted, questions were answered by an adult. Energy and nutrient intakes were estimated based on the Australian Food and Nutrient Database (AUSNUT 2011–2013), which contains information for 5740 foods and beverages consumed during the survey.[21]

Food classification

Reported single food items and the underlying ingredients of culinary preparations (handmade recipes) were classified according to NOVA food classification system into the following four groups (and subgroups within these groups): group 1—unprocessed or minimally processed foods (eg, rice and other cereals, meat, fish, milk, eggs, fruit, roots and tubers, vegetables, nuts and seeds); group 2—processed culinary ingredients (eg, sugar, plant oils and butter); group 3—processed foods (eg, processed breads and cheese, canned fruit and fish, and salted and smoked meats); group 4—ultra-processed foods (eg, confectioneries, savoury snacks, fast food dishes, mass-produced packaged breads, frozen and ready meals and soft drinks).[10 12]

Ultra-processed foods, which are the focus of interest in this study, as previously mentioned, are formulations of low-cost ingredients, many of non-culinary use, that result from a sequence of industrial processes. Processes underlying the manufacture of ultra-processed foods start with the extraction of substances existing in intact foods, such as oils, fats, sugars, starches and protein. Intermediate processes may involve hydrolysis, hydrogenation and other chemical modifications of the extracted substances. Other steps include the assembling of modified (eg, hydrogenated oils) and unmodified (eg, sugar) substances using processes such as extrusion and prefrying, the addition of additives and sophisticated packaging with the frequent employment of novel synthetic materials.[10 12]

Food items were ultimately classified as ultra-processed if they contained ingredients found exclusively in these products. These ingredients are substances derived from foods but of non-culinary use (eg, protein

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isolates, modified starches, hydrogenated or interesterified oils) and classes of additives with cosmetic functions (eg, colourants, flavourings, artificial sweeteners, emulsifiers, thickeners and bleaching, bulking, firming, gelling, glazing, foaming and carbonating agents). The presence or absence of these ingredients was identified from auxiliary AUSNUT data sources (Food details file and Food recipe file)[21] and from list of ingredients obtained from food packages or from company websites (see online supplementary appendix 1 to 2). More information regarding how to identify ultra-processed foods can be found elsewhere.[10 12]

For all food items judged to be a culinary preparation, the recipes were disaggregated using the AUSNUT 2011–2013 Food Recipe File,[21] enabling the classification of composite foods into all NOVA food groups. A total of 2585 (45%) food codes were subject to disaggregation, and this process was continued until all ingredients were single food items.

To classify all food items, two experts with Australian food and dietary intake knowledge applied the NOVA system to the AUSNUT 2011–2013. All classifications were checked by another two independent food assessment experts, and where classification discrepancies arose, these were discussed until consensus was reached among all researchers. The NOVA system was applied to the AUSNUT classification system that considers a major (two-digit), submajor (three-digit) or minor (five-digit) food group. The survey ID (eight-digit) assigned to each food item was used when it was not possible to discriminate the degree of food processing within a minor group (table 1).

When the classification of a food item was not clear (eg, cake or cupcake, honey, commercial or homemade), the conservative alternative was chosen (homemade in this case, and thus disaggregated). Additional procedures were applied to classify breads with generic food item descriptions based on the sampling details information comprised in the AUSNUT 'Food details file'. Unlike other countries, many commercially produced breads in Australia are processed rather than ultra-processed, that is, their ingredients do not include neither food substances of no culinary use nor cosmetic additives. Of the 62 generic bread codes where the NOVA classification was not easily apparent, there were two generic bread codes that contributed the most to total bread energy intake (25% combined): (1) bread, from white flour, commercial; (2) bread roll, from white flour, commercial. They were classified as ultra-processed foods since the samples that composed the AUSNUT 2011–2013 were mostly of mass-produced branded breads with cosmetic additives. All the remaining infrequent breads were classified as processed as the conservative hypothesis (see details in the online supplementary appendix 1 to 2).

Data analysis

The mean daily contribution of each NOVA food group and their subgroups to the total energy intake was calculated. Thereafter, the population was stratified into quintiles of the energy share of ultra-processed foods, with the lowest consumers belonging to the first quintile and the highest consumers to the fifth. The energy share of each NOVA food group and subgroup was estimated across those quintiles.

Considering the nutrients included in international guidelines (WHO and World Cancer Research Fund) for the prevention of NCDs among all age groups, we assessed the percentage of energy from free sugars and from fats (total, saturated and trans), the density of dietary fibre (g per 1000 kcal), sodium (mg per 1000 kcal) and potassium (mg per 1000 kcal) and the dietary energy density (calculated as kcal per g, excluding beverages).[22–26] The mean nutrient intake levels were calculated for the overall diet and for two diet fractions, one made up entirely of the ultra-processed foods and the other made up of all the non-ultra-processed foods (ie, the sum of unprocessed or minimally processed foods, processed culinary ingredients and processed foods). Differences between the two diet fractions were analysed using tests of means for independent samples (t-test).

The mean nutrient intake levels for the overall diet were then compared across quintiles of the dietary energy provided by ultra-processed foods. Crude and adjusted standardised linear regression models were used to assess the direction and the statistical significance of the association of these quintiles with the nutrient intake levels. Standardised adjusted regression coefficients were obtained by regressing the nutrient intake levels on the quintiles of the dietary share of ultra-processed foods and expressed in SD units. For these analyses, the first 24-hour recall was used, which is suitable to estimate group means.[27 28]

Finally, we estimated, for the overall population and for quintiles of the dietary share of ultra-processed foods, the prevalence of nutrient intake levels that were outside

Table 1 Example of the AUSNUT 2011–2013 food group classification and application of the NOVA system

Major food group: two-digit food code	Submajor food group: three-digit food code	Minor food group: five-digit food code	Survey ID: eight-digit food code	NOVA system classification
16 Fruit products and dishes	161 Pome fruit	16104 Pears, commercially sterile	16104009 Pears, canned in sugar syrup	Group 3 Processed foods
			16104010 Pears, canned in intense sweetened liquid	Group 4 Ultra-processed foods

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the recommended levels for the prevention of NCDs: ≥10% of total energy intake for free sugar, ≥30% of total energy intake for total fat, ≥10% of total energy intake for saturated fat, ≥1% of total energy intake for trans fat, ≤12.5 g/1000 kcal for dietary fibre, ≥1000 mg/1000 kcal for sodium, ≤1755 mg/1000 kcal for potassium and ≥2.25 kcal/g for dietary energy density.[22–26] For this analysis, intakes were adjusted by the Multiple Source Method[29] to account for intraperson variability by considering the data from the second 24-hour recall, which is the recommended approach to evaluate dietary adequacy.[27] Prevalence ratios from Poisson regression models were used to assess the magnitude of the associations between quintiles of energy contribution of ultra-processed foods and nutrient intakes. Wald and linear tests were used to assess the significance of variables in the models and to test trends across quintiles of ultra-processed food intake, respectively.

All regression models were adjusted for the following potential confounders: sex (male/female), age groups (2–5, 6–9, 10–18, 19–30, 31–50, 51–69 and ≥70 years), SocioEconomic Index of Disadvantage for Areas (SEIFA—quintiles), educational attainment of respondents, for participants ≥18 years old and of household reference persons otherwise (completed 9 years or below including never attended, completed 10–12 years with no graduate degree, completed 12 years with graduate degree) and geographical location (major cities of Australia, inner regional and other, which includes outer regional, remote and very remote Australia).

Sensitivity analyses were carried out to account for exposure misclassification of breads. The counterfactual scenario simulated the effect in the direction, magnitude and the statistical significance of the association between the dietary share of ultra-processed foods and dietary content of nutrients linked to NCDs if all breads were classified in the processed food group.

Weighted analyses were performed using Stata survey module (V.14) to consider the effect of complex sampling procedures adopted in the NNPAS 2011–2012 and in order to allow extrapolation of results for the Australian population (Stata Corp).[19]

Patient and public involvement

This research was done without patient involvement.

RESULTS

In 2011–2012, Australians aged 2 years and above consumed an average of 1968 kcal per day, 35.4% of which were from the NOVA group of unprocessed or minimally processed foods, 6.8% from processed culinary ingredients, 15.8% from processed foods and 42.0% from the ultra-processed food group (table 2).

Meat, milk, cereal grains and flours, and fruits accounted for most of the energy of unprocessed or minimally processed foods consumed in Australia. Within processed culinary ingredients, most of the energy came

Table 2 Mean absolute and relative daily energy intake according to NOVA food groups (Australian population aged 2+ years (NNPAS 2011–2012) (n = 12 153))

NOVA food groups	Kcal	% of total energy intake
Unprocessed or minimally processed foods	675.4	35.4
Red meat and poultry	155.3	8.1
Milk and plain yoghurt	123.9	6.6
Cereal grains and flours	120.3	5.9
Fruits*	86.8	4.9
Vegetables	50.5	2.8
Pasta	45.4	2.3
Nuts and seeds	21.3	1.2
Potatoes and other tubers and roots	21.8	1.0
Eggs	19.2	1.0
Fish	15.2	0.8
Legumes	9.2	0.5
Other†	6.8	0.4
Processed culinary ingredients	133.8	6.8
Plant oils	59.2	3.0
Animal fats	37.6	1.8
Table sugar	30.8	1.6
Other‡	6.2	0.3
Processed foods	310.5	15.8
Processed breads	123.3	6.8
Beer and wine	80.1	3.6
Cheese	50.5	2.6
Bacon and other salted, smoked or canned meat or fish	22.6	1.2
Vegetables and other plant foods preserved in brine	8.6	0.5
Other§	25.5	1.2
Ultra-processed foods	842.4	42.0
Mass-produced packaged breads	89.3	4.8
Frozen and shelf stable ready meals¶	70.8	3.7
Fast foods dishes**	75.8	3.5
Pastries, buns and cakes	72.6	3.3
Breakfast cereals	62.0	3.2
Biscuits	59.0	3.1
Fruit drinks and iced teas	58.7	3.0
Confectionery	58.6	2.9
Sausage and other reconstituted meat products	49.0	2.4
Carbonated soft drinks	44.0	2.1
Milk-based drinks	42.8	2.1

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Table 2 Continued

NOVA food groups	Kcal	% of total energy intake
Sauces, dressing and gravies	36.3	1.8
Salty snacks	34.1	1.6
Ice cream, ice pops and frozen yoghurts	34.2	1.6
Margarine and other spreads	26.9	1.4
Alcoholic distilled drinks	12.2	0.5
Other††	16.8	0.9
Total	1968.0	100.0

kcal = 4.18 kJ.
*Including freshly squeezed juices.
†Including meat from other animals, teas, coffees and dried spices.
‡Including honey, maple syrup (100%) and vinegar.
§Including salted or sugared nuts, seeds and dried fruits.
¶Including frozen lasagna, pizza and other pastas and meals, and instant soups and noodles.
**Including hamburger, pizza and French fries from fast food places.
††Including ultra-processed cheese, baby food and baby formula.
NNPAS, National Nutrition and Physical Activity Survey.

from plant oils. Processed breads, beer and wine were the highest contributors of energy among processed foods. Mass-produced packaged breads (4.8% of total daily intake), frozen and shelf stable ready meals (3.7%), fast food dishes (3.5%), and pastries, buns and cakes (3.3%) contributed most to dietary energy intake from ultra-processed foods (table 2).

The mean dietary share of ultra-processed foods ranged from 12.8% of total daily intake for those in the lowest quintile of ultra-processed food intake to 74.5% for those in the upper quintile of ultra-processed food intake (table 3). The energy share of all subgroups belonging to the ultra-processed food group increased linearly across quintiles of ultra-processed food intake, in particular fast food dishes and ready meals showed a substantial increase (114 times and 22 times, respectively). An opposite trend for subgroups from the three remaining groups indicates that ultra-processed foods tend to progressively displace all other foods and culinary preparations as ultra-processed food intake increases (table 3).

A comparison of the nutrient profiles between the ultra-processed and non-ultra-processed fractions of the Australian diet can be seen in table 4. The dietary fraction made up exclusively of ultra-processed items that contained significantly more free sugars (4.7 times), sodium (2.9 times), was higher in diet energy density (1.9 times) and was lower in potassium (1.7 times) and fibre content (1.4 times) than the non-ultra-processed fraction. The average content of fats in the diet fraction made of ultra-processed items was higher than in the dietary fraction made of non-ultra-processed items, except for trans fat content, although the magnitude of the differences was small: 32.1% versus 30.4% for total fats, 12.7% versus 11.6% for saturated fats and 0.5% versus 0.6% for trans fats.

Table 5 presents the average nutrient content of the overall diet across quintiles of ultra-processed food intake. Both crude and adjusted regression coefficients show a positive and statistically significant linear trend between the dietary share of ultra-processed foods and the intake of free sugars; total, saturated and trans fats; sodium and the dietary energy density, while an inverse relationship was observed for the intake of dietary fibre and potassium. Stronger associations were found with free sugars (β=0.43, p<0.001), energy density (β=0.41, p<0.001), sodium (β=0.21, p<0.001), potassium (β=−0.27, p<0.001) and dietary fibre (β=−0.21, p<0.001). Stratified analyses showed that the association between the dietary share of ultra-processed foods and the intake of nutrients remained statistically significant among most age groups and both sex strata (data not shown).

Table 6 shows the prevalence of non-recommended nutrient intake levels across quintiles of the dietary energy share of ultra-processed foods. In the highest quintile of ultra-processed food consumption, about 80% of the Australian population exceeded the upper limits recommended for free sugars, saturated fats and sodium and over 85% did not meet the recommendation for dietary fibre and potassium. The prevalence of non-recommended intake levels of all nutrients increased linearly across quintiles of the dietary share of ultra-processed foods (p<0.001). Notably, from the lower to the upper quintile, the proportion of non-recommended intake levels increased from 22% to 82% for free sugars, from 6% to 11% for trans fat and from 2% to 25% for dietary energy density.

The direction, magnitude and the statistical significance of the associations between the dietary share of ultra-processed foods and the risk of non-recommended intake levels of all studied nutrients did not change with adjustment for age, sex, educational attainment, socioeconomic status and geographical location. We also categorised individuals with diet energy density higher than 1.25 kcal/g (World Cancer Research Fund recommends lowering this value as a public health goal),[26] and the proportion of non-recommended intake levels increased from 82% to 98% from the lower to the upper quintile (PR: 1.2; p<0.001—data not shown).

Tables S1–S3 (available in the online supplementary appendix 3) show results from the sensitivity analyses that considered all breads in the processed food group (11.6% of total energy intake from processed breads). Results show that potential ultra-processed bread misclassification may have led to a 4.8% maximum overestimation of energy intake from ultra-processed foods and to slight underestimations of the strength of associations between ultra-processed foods and free sugars, fats and dietary fibre, and overestimation of the association with sodium, potassium and diet energy density.

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Table 3 Percentage of total energy intake according to NOVA food groups across quintiles of the dietary share of ultra-processed foods (Australian population aged 2+years (NNPAS 2011–2012) (n = 12 153))

	Quintiles of the dietary contribution of ultra-processed foods (% of total dietary energy)†				
NOVA food groups	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**
Unprocessed or minimally processed foods	54.8	43.3	36.0	27.6	15.3*
Red meat and poultry	12.2	10.0	8.3	6.4	3.4*
Milk and plain yoghurt	7.7	7.7	6.9	6.3	4.2*
Cereal grains and flours	12.0	7.3	5.4	3.6	1.2*
Fruits‡	7.1	5.8	5.2	4.1	2.4*
Vegetables	4.3	3.4	2.9	2.0	1.2*
Pasta	3.0	3.0	2.5	1.8	0.9*
Nuts and seeds	2.5	1.3	0.8	0.4	0.2*
Potatoes and other tubers and roots	1.5	1.5	1.3	1.1	0.6*
Eggs	1.4	1.2	1.0	0.9	0.5*
Fish	1.6	1.1	0.7	0.5	0.3*
Legumes	0.9	0.6	0.5	0.3	0.2*
Other§	0.7	0.5	0.4	0.3	0.2*
Processed culinary ingredients	9.7	8.4	7.1	5.4	3.1*
Plant oils	5.0	3.7	3.2	2.2	1.1*
Animal fats	2.3	2.3	1.9	1.6	0.8*
Table sugar	1.9	2.0	1.7	1.4	1.0*
Other¶	0.5	0.4	0.3	0.2	0.1*
Processed foods	22.7	19.8	16.5	12.9	7.1*
Processed breads	9.0	8.1	7.1	6.1	3.6*
Beer and wine	6.8	4.8	3.5	1.9	0.8*
Cheese	3.0	3.2	2.8	2.5	1.5*
Bacon and other salted, smoked or canned meat or fish	1.6	1.5	1.3	1.0	0.5*
Vegetables and other plant foods preserved in brine	0.7	0.4	0.5	0.5	0.2*
Others**	1.6	1.6	1.3	0.9	0.6*
Ultra-processed foods	12.8	28.4	40.4	54.1	74.5*
Mass-produced packaged breads	1.6	3.8	5.1	6.1	7.3*
Frozen and shelf stable ready meals††	0.4	1.4	2.7	5.1	8.7*
Fast foods dishes‡‡	0.1	0.6	1.3	4.0	11.4*
Pastries, buns and cakes	0.6	2.2	3.5	4.7	5.6*
Breakfast cereals	1.4	3.1	4.0	4.0	3.6*
Biscuits	1.1	2.3	3.2	4.0	4.7*
Fruit drinks and iced teas	1.1	2.3	3.1	3.9	4.8*
Confectionery	0.9	2.2	3.0	3.5	4.7*
Sausage and other reconstituted meat products	0.9	1.6	2.4	3.3	3.9*
Carbonated soft drinks	0.4	1.1	1.8	2.6	4.6*
Milk-based drinks	0.9	1.6	2.0	2.7	3.5*
Sauces, dressing and gravies	1.1	1.9	1.9	2.2	1.9*
Salty snacks	0.3	0.7	1.6	2.3	3.1*

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Table 3 Continued

NOVA food groups	Quintiles of the dietary contribution of ultra-processed foods (% of total dietary energy)†				
	Q1	Q2	Q3	Q4	Q5
Ice cream, ice pops and frozen yoghurts	0.3	1.1	1.9	2.3	2.6*
Margarine and other spreads	0.9	1.4	1.5	1.7	1.5*
Alcoholic distilled drinks	0.1	0.3	0.3	0.6	1.2*
Other§§	0.5	0.8	1.1	0.8	1.3*
Total	100.0	100.0	100.0	100.0	100.0

*p<0.05 for linear trend across quintiles of dietary share of ultra-processed foods.
†Percentage of total energy intake from ultra-processed foods. Mean (range): Q1= 12.8 (0 to 21.8); Q2= 28.4 (21.8 to 34.6); Q3= 40.4 (34.6 to 46.6); Q4= 54.1 (46.6 to 62.1); Q5= 74.5 (62.1 to 100).
‡Including freshly squeezed juices.
§Including meat from other animals, teas, coffees and dried spices.
¶Including honey, maple syrup (100%) and vinegar.
**Including salted or sugared nuts, seeds and dried fruits.
††Including frozen lasagna, pizza and other pastas and meals, and instant soups and noodles.
‡‡Including hamburger, pizza and French fries from fast food places.
§§Including ultra-processed cheese, baby food and baby formula.
NNPAS, National Nutrition and Physical Activity Survey.

DISCUSSION

In this analysis of nationally representative data, we found that ultra-processed foods contribute to more than 40% of total daily energy intake of Australians. These foods are predominantly mass-produced packaged breads, ready meals, fast food dishes and pastries, buns and cakes. As ultra-processed food consumption increases, these foods tend to displace unprocessed and minimally processed foods and their culinary preparations, including the five core food groups recommended by the Australian Dietary Guidelines (ADGs).[30] The dietary content of free sugars; total, saturated and trans fats; sodium and the dietary energy density, all increased significantly as the energy share of ultra-processed foods increased, while an inverse association was found for the dietary content of fibre and potassium. The prevalence of non-recommended intake levels of all studied nutrients linked to NCDs increased linearly across quintiles of ultra-processed food intake.

In other high-income countries, ultra-processed foods also dominate the diet: 57.9% of total energy intake in the USA,[31] 56.7% in the UK[32] and 47.7% in Canada.[33] In Latin American high-income and middle-income countries, such as Chile,[34] Brazil[35] and Mexico,[36] unprocessed and minimally processed foods are still the basis of the population's diet and ultra-processed foods made up between 20% and 30% of total energy intake. This is

Table 4 Average nutrient content of the overall diet and of two diet fractions (Australian population aged 2+years (NNPAS 2011–2012) (n=12 153))

Nutrients	Overall diet	Ultra-processed food diet fraction	Non-ultra-processed food diet fraction†
	Mean (SE)	Mean (SE)	Mean (SE)
Free sugars (% of total energy)	11.7 (0.1)	21.6 (0.2)	4.6* (0.1)
Total fats (% of total energy)	31.1 (0.1)	32.1 (0.2)	30.4* (0.1)
Saturated fat (% of total energy)	12.0 (0.1)	12.7 (0.1)	11.6* (0.1)
Trans fat (% of total energy)	0.6 (0.0)	0.5 (0.0)	0.6* (0.0)
Dietary fibre (g/1000 kcal)	11.5 (0.1)	9.7 (0.1)	13.2* (0.1)
Sodium (mg/1000 kcal)	1213 (6.4)	2475 (90.8)	859* (6.3)
Potassium (mg/1000 kcal)	1444 (6.)	1055 (8.6)	1813* (10.5)
Energy density (kcal/g)‡	1.7 (0.0)	2.7 (0.0)	1.4* (0.0)

*p<0.001 for significant mean differences between the two fractions of the diet.
†It includes NOVA unprocessed or minimally processed foods, processed culinary ingredients and processed foods.
‡Beverages excluded.
NNPAS, National Nutrition and Physical Activity Survey.

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Table 5 Average nutrient content of the overall diet according to quintiles of the dietary share of ultra-processed foods (Australian population aged 2+ years (NNPAS 2011–2012) (n=12 153))

	Quintiles of the dietary contribution of ultra-processed foods (% of total dietary energy)†					Standardised regression coefficients‡	
Nutrients	Q1	Q2	Q3	Q4	Q5	Crude	Adjusted§
Free sugars (% of total energy)	5.8	9.2	11.7	14.0	17.7	0.45*	0.43*
Total fats (% of total energy)	30.1	31.1	30.5	31.6	32.2	0.08*	0.08*
Saturated fat (% of total energy)	10.3	11.7	12.0	12.8	13.1	0.21*	0.18*
Trans fat (% of total energy)	0.52	0.58	0.59	0.63	0.64	0.11*	0.10*
Dietary fibre (g/1000 kcal)	13.3	12.3	11.8	10.7	9.4	−0.24*	−0.21*
Sodium (mg/1000 kcal)	1053	1142	1216	1275	1384	0.21*	0.21*
Potassium (mg/1000 kcal)	1674	1542	1465	1346	1177	−0.30*	−0.27*
Energy density (kcal/g)¶	1.5	1.6	1.7	1.8	2.1	0.43*	0.41*

*Statistically significant p<0.001.
†Percentage of total energy intake from ultra-processed foods. Mean (range): Q1= 12.8 (0 to 21.8); Q2= 28.4 (21.8 to 34.6); Q3= 40.4 (34.6 to 46.6); Q4= 54.1 (46.6 to 62.1); Q5= 74.5 (62.1 to 100).
‡Obtained with linear regression of the dietary nutrient content on the quintiles of the dietary share of ultra-processed foods and expressed in SD units.
§Adjusted for age, sex, educational attainment,socio-economic status and geographical location.
¶Beverages excluded.
NNPAS, National Nutrition and Physical Activity Survey.

despite sales of ultra-processed foods in Latin American countries rising rapidly.[14]

The strong association between the energy share of ultra-processed foods and dietary nutrient profiles predictive of increased risk of diet-related NCDs is seen across several high-income and middle-income countries.[31–34 37 38] In Australia, the prevalence ratios of non-recommended nutrient intake levels among people in the fifth quintile of ultra-processed food consumption were higher in comparison with the USA (2.9 times more likely to exceed added sugars intake than the first quintile)[31] and the UK (1.1 times more likely to exceed free sugars and fibre intake).[32] This is probably explained by differences in the dietary share of ultra-processed foods and also by the types of non-ultra-processed foods most consumed by first quintile ultra-processed food consumers in the countries (rather than by differences among higher consumers). While in Australia ultra-processed foods account for 13% of total energy intake in the lowest quintile of ultra-processed food consumption, in the USA and the UK this figure surpasses 30%.[31 32] Australians with the lowest consumption of ultra-processed foods also consume more grains and vegetables than Americans and British.

To our knowledge, this is the first study to evaluate the association between the dietary contribution of ultra-processed foods and the overall NCD-related nutrient profile of diets in Australia and the first to analyse the 2011–2012 survey data with this focus. In Australia, one-third (35%) of total daily energy consumed is from discretionary foods—defined as foods that are unnecessary in a healthy diet and which are generally energy dense and nutrient poor.[30 39] The ADGs emphasise the importance of limiting the consumption of discretionary foods.[30] Although most discretionary foods are likely to be classified as ultra-processed foods, a considerable number of foods from the Five Food Groups recommended by the ADGs are classified as ultra-processed foods, including many breads, breakfast cereals, flavoured yoghurts and margarines.

Australia is experiencing a high prevalence of NCDs—more than 90% of the deaths are due to chronic diseases, notably cardiovascular diseases and cancer,[3] and Australia has the fifth highest rate of obesity in the OECD (28% of the population aged +15 years).[40] The evidence so far, from cross-sectional or cohort studies conducted in middle-income and high-income countries, has shown a direct association between ultra-processed food consumption and obesity,[41–45] cancer,[46] hypertension,[47]

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Table 6 Prevalence (%) of non-recommended nutrient intake levels according to quintiles of the dietary share of ultra-processed foods (Australian population aged 2+years (NNPAS 2011–2012) (n=12 153))

Quintiles of the dietary contribution of ultra-processed foods (% of total dietary energy)‡	Non-recommended nutrient intake levels of:															
	Free sugars		Total fat		Saturated fat		Trans fat		Dietary fibre		Sodium		Potassium		Energy density	
	≥10% of energy		≥30% of energy		≥10% of energy		≥1% of energy		≤12.5 g/1000 kcal		≥1000 mg/1000 kcal		≤1755 mg/1000 kcal		≥2.25 kcal/g	
	%	PR	%	PR	%	PR	%	PR	%	PR	%	PR	%	PR	%	PR
Q1 (lowest)	21.7	1.0	53.4	1.0	57.5	1.0	5.6	1.0	55.0	1.0	66.6	1.0	75.6	1.0	1.9	1.0
Q2	47.3	2.1	53.0	1.0	67.5	1.2	4.5	1.0	65.0	1.2	75.5	1.1	82.4	1.0	2.3	1.2
Q3	58.5	2.6	60.0	1.1	77.8	1.3	7.0	1.2	70.4	1.3	79.4	1.2	87.0	1.1	5.0	2.5
Q4	69.8	3.1	64.0	1.2	81.7	1.4	7.6	1.4	75.1	1.3	83.1	1.2	91.3	1.2	7.2	3.5
Q5 (highest)	82.1	3.6*†	69.7	1.3*†	84.3	1.4*†	10.9	1.9*†	85.6	1.5*†	84.7	1.3*†	93.1	1.2*†	24.8	11.7*†
Total	55.9	–	60.0	–	73.8	–	7.2	–	70.2	–	77.9	–	86.1	–	8.3	–

*Significant linear trend across quintiles (p<0.001) in both unadjusted (coefficients not shown) and adjusted models.
†Wald test at 5% significance level.
‡Percentage of total energy intake from ultra-processed foods. Mean (range): Q1= 12.8 (0 to 21.8); Q2= 28.4 (21.8 to 34.6); Q3= 40.4 (34.6 to 46.6); Q4= 54.1 (46.6 to 62.1); Q5= 74.5 (62.1 to 100).
NNPAS, National Nutrition and Physical Activity Survey; PR, prevalence ratios adjusted for age, sex, educational attainment, socioeconomic status and geographical location.

dyslipidaemias,[48] metabolic syndrome[49 50] and myocardial infarction and stroke.[51]

Considering the mounting body of research linking inadequate intake of critical nutrients and risk of chronic diseases,[7 26] and the persistent increase in the purchase of ultra-processed foods by the Australian population,[18] our findings have implications for policy and practice. We showed that Australians who based their diet on unprocessed and minimally processed foods, and on culinary preparations made up with these foods, are more likely to achieve the nutrient intake levels internationally recommended for the prevention of NCDs. Therefore, there is a need for initiatives that combine the promotion of healthy foods with the reduction of ultra-processed food consumption.[5 7 52 53]

The presence of misleading nutrition and health claims on ultra-processed food labels in Australia,[54 55] the limitations of the Australian Health Star Rating System to support healthy choices in agreement with the ADGs[56] and the limits of the ultra-processed food reformulation to address unhealthy diets[57] reinforce the need for targeted strategies to reduce the consumption of ultra-processed foods.[52] Australia could adopt some of the lessons from its successful antismoking intervention[58] to the consumption of ultra-processed foods to help tackle the epidemic of chronic disease. This could entail restricting the sale of ultra-processed foods in schools, healthcare and other settings, considering taxation and pricing interventions, limiting promotion and advertising, particularly to children, improving food labelling and improving the retail environment.[24 52 59–61]

The main strength of our study is the use of the most up-to-date, individual-level dietary survey data taken from a nationally representative sample of Australian children and adults, which increases the generalisability of our findings. The food classification system we used (NOVA) has been recognised as a relevant approach for linking dietary intakes and incidence of obesity and NCDs.[10 14] In addition, we applied the classification to several disaggregated food codes in the AUSNUT 2011–2013, enabling the assessment of food groups whose consumption has previously been underestimated,[62] and comparisons with studies in different countries that applied the NOVA system.[31 32 34 37] It is also important to highlight that the AUSNUT 2011–2013 food composition database was specifically developed to reflect the food supply and food preparation practices during the period of the NNPAS 2011-2012.[21]

Nevertheless, potential limitations should be considered. Although we used the most recent, individual-level national survey to analyse Australian dietary intake, these data may not account for recent changes in the food supply or dietary habits in the country. Though household expenditure in ultra-processed foods increased from 2010 to 2016 in Australia,[63] as well as the supply of those foods,[9] no substantial changes in their nutrient profile could be identified.[54 64] Therefore, the observed associations in our study will unlikely have changed in more

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recent years. Dietary data obtained by 24-hour recalls are subject to errors given the tendency for people to misreport their food intake. Analysis of the NNPAS 2011–2012 suggests sizeable misreporting,[19] but the impact in the assessment of ultra-processed food consumption is unknown. Some studies suggest that unhealthy foods are more likely to be under-reported,[65] which could have led to an underestimation of overall dietary contribution of ultra-processed foods or the prevalence of inadequate nutrient intake or may attenuate the magnitude of the association between both variables (should differential information bias exist).

Another potential limitation is that both the 24-hour recall instrument and the food composition tables were not designed to evaluate the food consumption according to industrial processing. Therefore, despite the effort and systematic approach to apply the NOVA system properly into the AUSNUT 2011–2013 data set, some items may have been misclassified. However, to reduce misclassification, several independent researchers reviewed the classification and any areas of misclassification were resolved by discussion and consensus. Additionally, in the case of breads, we carried out sensitivity analyses given their high contribution to the total energy intake in Australia, especially those types of breads with generic food descriptions in the AUSNUT data set. Including information to characterise the processing of foods in dietary surveys, like brand and product name, preferably linked to a list of ingredients provided by a food supply survey or by the food industry, would help to assess dietary intake considering food processing.[66]

CONCLUSION

In conclusion, ultra-processed foods accounted for more than 40% of energy consumed in Australia and they tend to displace all other foods and culinary preparations. The dietary share of ultra-processed foods impacted negatively on the intake of all nutrients linked to NCDs, being therefore a key metric to evaluate dietary patterns. The high dietary energy share of ultra-processed foods in Australia calls for actions targeting those products in order to increase the healthiness of food environments and reduce obesity and diet-related NCDs. Decreasing the dietary share of ultra-processed foods would substantially improve the diet quality in Australia and help the population achieve recommendations on critical nutrients linked to NCDs and foods recommended by the ADGs.

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Contributors CAM, EMS, PPM and RBL designed the research; EMS, JW, PPM and ZS took care of data management and analyses; AR, CAM, EMS, GS, JW, PPM, RBL, TG and ZS interpreted the data; PPM wrote the first draft of the manuscript; AR, CAM, EMS, GS, JW, PPM, RBL, TG and ZS revised each draft for important intellectual content. All authors read and approved the final manuscript.

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