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Micronutrients or processing? An analysis of food and drink items from the UK National Diet and Nutrition Survey based on micronutrient content, the Nova classification and front of package traffic light labelling

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Abstract

Increased ultra-processed food (UPF) intake is associated with adverse health outcomes. However, with limitations in UPF evidence, and partial overlap between UK front of package labelling (FOPL) and degree of food processing, the value of food processing within dietary guidance is unclear. This study compared food and drink from the UK National Diet and Nutrition Survey (NDNS) database based on micronutrient content, Nova classification and FOPL. The aim was to examine the micronutrient contributions of UK food and drink to UK government dietary micronutrient recommendations for adult females and males, aged 19-64 years, based on the degree of food processing and FOPL. NDNS items were coded into minimally processed food (MPF), processed culinary ingredients (PCI), processed food (PF) and UPF, and FOPL traffic lights. MPF, PF and UPF provided similar average contributions per 100g to micronutrient recommendations. Per 100kcal, MPF provided the greatest average contribution to micronutrient recommendations (14.4% [interquartile range (IQR):8.2-28.1]), followed by PF (7.7% [IQR:4.6-10.9], then UPF (5.8% [IQR:3.1-9.7]). After adjusting for healthy/unhealthy items (presence of 1+ red FOPL), MPF had higher odds of an above average micronutrient contribution per 100kcal than UPF (odds ratio (OR): 5.9x (95%CI:4.9, 7.2)), and PF (OR:3.2 (95%CI:2.4, 4.2)). MPFs were more likely to provide greater contributions to dietary micronutrient recommendations than PF or UPF per 100kcal. These findings suggest that UPF or PF diets are less likely to meet micronutrient recommendations than an energy-matched MPF diet. The results are important for understanding how consumers perceive the healthiness of products based on FOPL.

Key words: Front of package labelling, ultra-processed food, NOVA classification, micronutrients, dietary guidelines, diet recommendations

Introduction

For centuries, food processing has provided people around the world with a safe and long-lasting food supply (1). However, recent evidence suggests the degree of food processing may also be an important dietary determinant of health (2,3). Most commonly defined by the Nova classification (4), ultra-processed foods (UPFs) are industrially formulated, typically with five or more ingredients, resulting in highly palatable, long lasting, readily accessible, and more affordable products (5). The Nova classification also categorises foods and drinks into three other groups with increasing degrees of processing: minimally processed food (MPF), processed culinary ingredients (PCI), and processed food (PF).

Prospective studies suggest increased risks of several non-communicable diseases with increasing UPF intake, generally with low or very-low quality of evidence (3). However, scientific debate continues regarding the role of food processing alongside existing dietary guidance, such as those in the UK (6,7). Ultra-processing may impact on health beyond nutrient content or dietary pattern (2), such as from additives or neo-formed contaminants (8), and influence dietary behaviours through changes in food texture, palatability, portion size, energy density and eating rate (9,10). However, the exact mechanisms are yet to be confirmed.

Dietary advice in the UK is provided to the public via the Eatwell Guide (EWG) (11). The EWG is communicated in the retail environment through multiple traffic light (MTL) front of package labels (FOPL) (11,12), which assigns a green, amber or red FOPL colour based on low, medium or high fat, saturated fat, salt or sugar content, respectively (12). A previous meta-analysis reported that diets higher in UPF tend to be higher in fat, saturated fat and free sugar, and lower in fibre, protein and micronutrients including potassium, zinc, magnesium and vitamins A, C, D, E, B12 and niacin (13). However, assessment of UPF intake with dietary recalls, often limited to a single day (13), may not fairly represent and reflect the wide range of foods and drink within each food processing group, or consumed by an individual over time. To do so requires assessment of a national food/drink and nutrient database. A recent analysis of the nationally-representative UK National Diet and Nutrition Survey (NDNS) nutrient database demonstrated partial overlap between macronutrient content, MTL FOPL and the degree of food processing (14). UPFs tended to have an unhealthier nutrient profile and were more likely to have a worse

MTL FOPL score e.g. higher in fat, saturated fat, salt, sugar and/or energy, but some UPFs were considered healthy according to their macronutrient profile and MTL FOPL, which aligned with previously reported data (5). However, no study has comprehensively assessed the micronutrient content of a representative supply of food and drink in the UK based on FOPL MTL and Nova classification, and their relative contributions to governmental dietary recommendations (11).

The aim of this study was to assess the micronutrient content of the NDNS food/drink database; first, to determine the contributions of food and drink to recommended micronutrient intakes overall and across processing groups according to Nova; second, whether contributions differed according to FOPL MTL; and third, whether contributions differed according to Nova, independent of FOPL MTL.

Methods

Data sources

Details on the methods used have been reported elsewhere (14). Briefly, NDNS is a repeated cross-sectional survey, that since 2008, provides comprehensive assessment of dietary intake from a nationally-representative UK sample living in private households and aged 1.5 years and older (15). From 2008-19, the survey was conducted using four-day food diaries completed across consecutive days. In 2019/20, four-day food diaries were replaced with four non-consecutive, multiple-pass, 24-hour dietary recalls using Intake24 (16). Intake24 is an online, automated, self-reported 24-hour dietary recall (https://intake24.co.uk) (17). This analysis used nutrient composition data of food and drink items in the Year 12 survey, and reported nutrient intakes from participant food diaries from the Year 9-11 survey (2016/17-2018/19). Food and drink names and subgroups were obtained via the Intake24 team. The matching nutrient databank from NDNS with the latest publicly available data on the nutrient content for each item was obtained from the UK Data Service (https://beta.ukdataservice.ac.uk), as well as the latest publicly available data on reported nutrient intakes from Years 9-11. Nutrient content in the nutrient databank was determined from multiple sources. Primarily, the UK Composition of Foods Integrated Dataset (18). This is supplemented with manufacturer data from food labels and the web, and from the Food Standards Agency (FSA) Food Recipes Database (19), and manufacturers' data gathered through food labels and web information. Nutrient values are

assigned to all foods, ensuring no missing values. For nutrients without reliable information, values are extrapolated from similar foods. Finally, all nutrient values are inspects before being added to the databank (20). Detail on Intake24 and NDNS have been previously published (16).

Nova classification

Coding of food and drink items into the Nova classification (see Supplementary Materials for definitions) (4) has been described in detail elsewhere (14). Each item in the Year 12 NDNS dataset was individually coded and conducted with authors blind to the nutrient database. Classification was determined based on definitions of each processing group in the Nova classification (4), item name, subgroup code, representative products from UK supermarkets, and the assigned Nova group of the corresponding item in the NDNS database from Years 1-11 (21). Of the 3105 items in the database; 109 items were coded outside of the NOVA classification (e.g., fish oil supplements and multivitamins) and were removed before analysis as in previous publications (14). An additional 16 items had no corresponding item in the NDNS nutrient databank. Of the 2,980 remaining items, 55.4% were UPF (n=1650), 33.1% were MPF (n=986), 9.5% were PF (n=283), and 2.0% (n=61) were PCI.

FOPL classification

Coding of food and drink items into MTL FOPL according to the Department of Health and Food Standards Agency guidance for fat, saturated fat, total sugar and salt content (12), has been also been described in detail elsewhere (14). For each nutrient, items with low content are coded green, with moderate content as amber, and with high content as red (thresholds are outlined in Supplementary Table 1). For comparability, items were coded per 100g. Drinks were coded using the lower threshold guidance for amber or red coding per 100g, which was assumed equivalent to 100ml of drink.

Micronutrient content

The NDNS nutrient databank includes data on micronutrient content (vitamins and minerals) per 100g for foods and drinks, including: retinol; total carotene; alpha-carotene; beta-carotene; beta cryptoxanthin; vitamins A (retinol equivalents); D; C; E; B6; B12; thiamin; riboflavin; niacin equivalent; folate; pantothenic acid; biotin; potassium; calcium; magnesium; phosphorus; iron; haem iron; non-haem iron; copper; zinc; sodium (Na); chloride (Cl); iodine; manganese and

selenium. Micronutrient content was also calculated per 100kcal by dividing the micronutrient value per 100g for each item by its energy content per 100g, and then multiplying by 100. A total of 25 items contained zero energy content per 100g (i.e., water, weak teas, salts, and no-calorie sweeteners), and were removed from the per 100kcal analysis.

Percent contributions to meeting daily reference nutrient intakes (RNIs) (the quantity considered to meet 97.5% of the population's requirements) for key micronutrients were calculated from the UK government dietary recommendations for females and males aged 19-64 years in the general population, respectively (11). These recommendations are based on the Committee on Medical Aspects of Food Policy (COMA) and the Scientific Advisory Committee on Nutrition (SACN) reports on Dietary Reference Values (22–24). Micronutrient dietary recommendations are provided for: vitamin A (retinol equivalents); D; C; E; B6; B12; thiamin; riboflavin; niacin equivalent; folate; potassium; calcium; magnesium; phosphorus; iron; copper; zinc; sodium; chloride; iodine and selenium (Supplementary Table 2). For females, 14.8mg was used for iron, as the daily recommendation for 19-49 year olds (with 8.7mg recommended for females aged 50-64) (11). Percent contributions to meeting government daily micronutrient intakes were reported per 100g and per 100kcal of each food and drink. This represents the quantity of each micronutrient per 100g and per 100kcal from compositional data, as a proportion of the recommended intake. Two UPF items were missing data on selenium content: low-protein pasta (e.g. Loprofin) and crunchy, cluster type cereal (e.g. Kellogg's/Nestle) – they were included in analyses for other micronutrients, but excluded from overall micronutrient calculations.

To calculate overall average percent contributions to government dietary micronutrient recommendations for males and females, the percent contribution per 100g and 100kcal of each food or drink to each micronutrient recommendation was averaged (i.e., the percentage values for each individual micronutrient were averaged to provide a composite micronutrient value, per 100g and per 100kcal). Sodium and chloride were excluded from the overall average as sodium is a nutrient to limit, and consumption of chloride as it is most commonly consumed as sodium chloride. Vitamin E was excluded from overall contributions as it is reported in NHS guidance (25), but not in UK government guidance (11).

For comparison to actual UK adult intakes, the average percent contributions to government dietary micronutrient recommendations from micronutrient intakes obtained from participant food diaries from the NDNS Year 9-11 survey for males and females, aged 19-64, were reported, as well as the percent contributions per 100kcal of reported total daily energy intake. Total diet weight was not available in the publicly available NDNS dataset.

Statistical analysis

Given the sex-specific government micronutrient recommendations, analyses were conducted separately for males and females. Analysis by weight (100g) was conducted as the unit used for creating MTL FOPL. However, this does not reflect energy content. Analysis by energy content (100kcal) was conducted, given the evidence linking UPF with increased energy intake and the importance of energy intake for weight management and obesity-related non-communicable disease (24). Non-parametrically distributed variables were described using medians and interquartile ranges (IQR), and categorical variables using counts and percentages. Comparisons of non-parametrically distributed micronutrient variables between Nova groups were analysed using Kruskal-Wallis analysis of variance. Categorical variables were analysed using chi-square tests. Comparisons of two non-parametrically distributed micronutrient variables (healthy and unhealthy foods within each Nova group (e.g. ultra-processed foods with or without a red FOPL traffic light)) were analysed using Mann-Whitney U tests. Bonferroni correction was used for multiple comparisons.

The average micronutrient content and percent contributions to government micronutrient recommendations per 100g and per 100kcal were described for all food and drinks, and for each Nova group, for males and females, separately. The proportion of items with zero content for each micronutrient were also reported overall, and for each Nova group.

As in a previous analysis of the UK NDNS and Nova classification (14), items were classified into ‘healthy’ or ‘unhealthy’ based on the presence or absence of a red FOPL traffic light for fat, saturated fat, total sugar or salt. This is based on research that when identifying healthier products, UK consumers are more cautious to avoid items with red traffic lights, than to select items with green traffic lights (26,27). Subgroup analyses were then used to compare the average

micronutrient content and percent contributions to government dietary recommendations of 'healthy' vs. 'unhealthy' food and drink items per 100g and per 100kcal across the NDNS database, for each Nova group (i.e., healthy vs. unhealthy UPFs), and then between NOVA food groups within healthy' vs. 'unhealthy' subgroups (i.e., comparing the micronutrient content of healthy products across Nova groups). The number of items across quartiles of average percentage contributions to daily government micronutrient recommendations of food and drink items per 100g and per 100kcal were then compared by Nova group, and by healthy/unhealthy FOPL score.

Regression analysis was then used to examine the relationship between NOVA group and micronutrient content, accounting for MTL FOPL score. Binary regression was used to model the odds of a food or drink item containing above average percent contribution to government micronutrient recommendations per 100g and per 100kcal (i.e., an above median vs. median or below percent contribution to government dietary recommendations), with Nova group (categorical: MPF, PCI, PF, UPF) and FOPL score (categorical: healthy vs. unhealthy) as explanatory variables.

Sensitivity analysis

Overall average percent contributions to government micronutrient recommendations of each food or drink per 100g and 100kcal for each micronutrient was repeated including sodium and chloride into the overall estimate. Statistical significance was set at <0.05. Data analysis was conducted in SPSS V29.0, and R Version 2024.04.1+748.

Results

Contributions of food and drink to recommended micronutrient intakes overall and by Nova group.

Given the similarities in results between females and males, results for females are presented in the main Tables, and males in the Supplementary Materials. The average percent contributions to government dietary micronutrient recommendations from micronutrient intakes obtained from

participant food diaries from the NDNS Year 9-11 survey for males and females, aged 19-64, are reported in Supplementary Table 2, including the percentage of adults meeting the government dietary micronutrient recommendations. From the food diaries in NDNS Year 9-11, on average, females met 10 (IQR: 7, 13), and males, 12 (IQR: 8, 15) out of 18 micronutrient recommendations. From the nutrient database for the 2980 food and drink items, average percentage contributions to daily micronutrient recommendations of each key vitamin and mineral per 100g for females aged 19-64 years across each Nova group are reported in Figure 1 and Supplementary Table 3. The nutrient content of food and drink items from the nutrient database on average would provide 11.3% [IQR: 6.8, 18.0] to each female dietary micronutrient recommendation per 100g. MPFs would contribute on average 11.7% [IQR: 7.2, 22.5], PFs 12.0% [IQR: 6.3, 12.7]; UPFs 11.2% [IQR: 6.9, 16.4], and PCIs 3.9% [IQR: 0.1, 9.8]. The distributions of MPF and UPF contributions significantly differed ($p<0.001$), but PF did not significantly differ from MPF and UPF contributions. The distributions of MPF, PF and UPF contributions did not significantly differ when including Na and Cl into average percentage contributions. Average absolute micronutrient content per 100g is reported in Supplementary Table 4, including micronutrients without governmental recommendations. Findings were similar for percentage contributions to daily dietary micronutrient recommendations for males aged 19-64 years per 100g (Supplementary Table 5).

Figure 1:

Average percentage contribution to meeting UK government micronutrient recommendations from food and drink items in the UK National Diet and Nutrition Survey for females aged 19-64 years across each Nova group, (a) all items per 100g, (b) all items per 100kcal.

Table 1 reports the average percentage contribution to daily recommendations of each key micronutrient per 100kcal of the 2955 food and drink items for females aged 19-64 years, and across each Nova group. Table 3 also reports percent contributions per 100kcal of reported energy intake from food diaries of females, aged 19-64 from the NDNS Year 9-11 survey. The average absolute micronutrient content per 100kcal is reported in Supplementary Table 6, including micronutrients without governmental recommendations. Food and drink items on average would contribute 7.8% [IQR: 4.1, 14.4] to each female dietary micronutrient

recommendation per 100kcal. MPFs would contribute on average 14.4% [IQR: 8.2, 28.1], PFs 7.7% [IQR: 4.6, 10.9]; UPFs 5.8% [IQR: 3.1, 9.7], and PCIs 0.9% [IQR: 0.0, 5.0]. MPF, PCI, PF and UPF contributions all significantly differed. Including Na and Cl into average percentage contributions did not alter findings. Findings were similar for percentage contributions to daily dietary micronutrient recommendations for males aged 19-64 years per 100kcal (Supplementary Table 7, including percent contributions per 100kcal of reported energy intake from food diaries of males, aged 19-64 from the NDNS Year 9-11 survey). Supplementary Figure 1 shows the percentage contributions to UK government micronutrient recommendations for females aged 19-64 years for each micronutrient by Nova group, per 100g (1a), and per 100kcal (1b).

Table 1:

Average percentage contribution per 100kcal to UK government micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years, and across each Nova group.

The proportions of Nova groups across quartiles of average percentage contributions to daily dietary recommendations of food and drink items significantly differed per 100g and per 100kcal (both $p < 0.001$) (Supplementary Table 8). In the highest quartile of average percentage contribution to daily micronutrient recommendations per 100g, 330 were MPF, 5 were PCI, 91 were PF and 322 were UPF. In total, 33.5% of MPF were in the highest quartile, compared with 19.3% of UPF, and 32.2% of PF. In the highest quartile of average percentage contribution to daily micronutrient recommendations per 100kcal, 489 were MPF, 7 were PCI, 43 were PF and 199 were UPF. Fifty percent of MPF were in the highest quartile, compared with 12.2% of UPF and 15.2% of PF, while 6.1% of MPF were in the lowest quartile, compared with 35.2% of UPF and 21.6% of PF. The proportion of healthy and unhealthy items based on FOPL significantly differed across quartiles of average percentage contributions to daily micronutrient recommendations per 100g and per 100kcal (both $p < 0.001$) (Supplementary Table 8). Per 100g, the lowest vs. highest quartile of average percentage contribution to daily micronutrient recommendations contained a greater proportion of items with one or more red FOPLs (unhealthy items; 30.4% vs 50.5%). Per 100kcal, the lowest vs. highest quartile of average percentage contribution to daily micronutrient recommendations contained a greater proportion

of items with no red FOPLs (healthy items; 27.9% vs. 83.5%). Per 100kcal, only 16.5% of the highest quartile were unhealthy items.

Contributions of food and drink to recommended micronutrient intakes by Nova group and FOPL MTL

Average percentage contributions to daily recommendations of key micronutrients per 100g of the 1849 healthy food and drink items for females aged 19-64 years across each Nova group are reported in Figure 2 and Supplementary Table 9. Healthy food and drink items on average would contribute 10.3% [IQR:6.3, 16.4] to each female dietary micronutrient recommendation per 100g. MPFs would contribute on average 10.4% [IQR: 6.7, 18.6], PFs 8.6% [IQR: 3.3, 14.3]; UPFs 10.5% [IQR: 6.3, 15.3], and PCIs 3.9% [IQR: 0.3, 39.7] per 100g. The distribution of MPF was similar to UPF, but PF was significantly different to MPF. Healthy UPF would provide significantly lower average micronutrient content per 100g than healthy MPF for three micronutrients, and higher average content for 10 micronutrients (including sodium and chloride). Compared with healthy PF, UPF would provide significantly lower average micronutrient content for two micronutrients (vitamins A and C), and significantly greater average micronutrient content for nine micronutrients.

Figure 2.
Average *percentage contribution to UK government micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years across Nova groups, (a) healthy items per 100g, (b) healthy items per 100kcal, (c) unhealthy items per 100g, (d) unhealthy items per 100kcal.*

Table 2 reports the average percentage contribution to daily recommendations of key micronutrients per 100kcal of the 1825 healthy food and drink items for females aged 19-64 years, and across each Nova group. Healthy food and drink items on average would contribute 9.9% [IQR:6.1, 18.8] to each female micronutrient recommendation per 100kcal. MPFs would contribute on average 15.7% [IQR: 9.0, 31.7], PFs 7.9% [IQR: 5.5, 12.4]; UPFs 7.2% [IQR: 5.1, 11.5], and PCIs 132.7% [IQR: 0.3, 386.2] per 100kcal. The distribution of MPF was significantly

higher than PF and UPF, but PF and UPF were similar. Healthy UPF would provide significantly lower average micronutrient content per 100kcal than healthy MPF for 17 micronutrients. Compared with healthy PF, UPF would provide significantly lower average micronutrient content for four micronutrients (vitamin A and C, potassium and iodine), and would provide significantly greater average micronutrient content for three micronutrients (thiamine, sodium and chloride). Absolute content of healthy items per 100g and per 100kcal are reported in Supplementary Tables 10 and 11.

Table 2:

Average percentage contribution of healthy items per 100kcal to UK government micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years, and across each Nova group.

The average percentage contribution to daily recommendations of key micronutrients of unhealthy items for females aged 19-64 years are reported in Figure 2 and Supplementary Tables 12 (per 100g) and 13 (per 100kcal). P-values comparing healthy and unhealthy items are in Supplementary Table 14. Compared with healthy items per 100g, unhealthy items would provide higher average contributions to female micronutrient recommendations (unhealthy: 13.1% [IQR: 8.0, 22.7]; healthy: 10.3% [IQR:6.3, 16.4], $p < 0.001$). Within MPF, PF and UPF, unhealthy items would also provide higher average micronutrient content than healthy items in the same Nova group. Unhealthy MPFs would provide significantly greater average micronutrient contributions per 100g (25.7% [IQR: 13.0, 45.1] compared with UPF (12.0% [IQR: 7.5, 17.8], but not PF (18.8% [IQR: 11.1, 30.7]).

Compared with healthy items per 100kcal, unhealthy items would provide lower average contributions to female micronutrient recommendations (unhealthy: 4.4% [IQR: 2.2, 8.6]; healthy: 9.9% [IQR: 6.1, 18.8], $p < 0.001$). Within MPF, PF and UPF, unhealthy items would provide lower average micronutrient contributions per 100kcal than healthy items in the same Nova group. Unhealthy MPF would contribute significantly greater average micronutrient content per 100kcal (9.8% [IQR: 6.0, 15.2]) than unhealthy UPF (3.5% [IQR: 2.0, 7.0]), or unhealthy PF (6.8% [IQR: 3.5, 9.3]). Healthy UPF and MPF would provide significantly greater

contributions to sodium recommendations per 100kcal than unhealthy UPF (healthy: 8.6% [IQR: 3.8, 13.0] vs unhealthy: 4.5% [IQR: 1.9, 11.3]) and MPF (healthy: 2.1% [IQR: 0.4, 6.1] vs. unhealthy: 1.4% [IQR: 0.2, 4.1]), respectively (both p<0.001).

Average percentage contributions to daily recommendations of key micronutrients of healthy items for males aged 19-64 years are reported in Supplementary Table 15 (per 100g) and 16 (per 100kcal), and unhealthy items in Supplementary Table 17 (per 100g) and 18 (per 100kcal). Findings for percentage contributions to daily micronutrient recommendations within and between healthy and unhealthy items were similar for males aged 19-64 years, both per 100g and per 100kcal.

Contributions of food and drink to recommended micronutrient intakes, independent of MTL FOPL

Table 3 reports the binary regression models between Nova groups, FOPL score and micronutrient contributions per 100g and per 100kcal for females and males aged 19-64 years. After accounting for a healthy/unhealthy FOPL, compared with MPF, UPF had lower odds of an above median micronutrient contribution (i.e. content) per 100g (odds ratio (OR): 0.76 (95% confidence interval (95%CI): 0.64, 0.90), p < 0.001), as did PCI (OR: 0.16 (95%CI: 0.09, 0.31), p < 0.001). Compared with MPF, PF had similar odds of an above median micronutrient contribution (i.e. content) per 100g (OR: 0.95 (95%CI: 0.72, 1.24), p < 0.689). Per 100 kcal, MPF had higher odds of an above median micronutrient contribution per 100kcal than UPF (OR: 5.9 (95%CI: 4.9, 7.2)), and PF (OR 3.2 (95%CI: 2.4, 4.2)). Results were similar for overall micronutrient contributions for males aged 19-64 years. Per 100g, unhealthy items had higher odds of an above median micronutrient contribution than healthy items (OR: 1.9 (95%CI: 1.6, 2.2), p < 0.001). Per 100kcal, healthy items had higher odds of an above median micronutrient contribution than unhealthy items (OR: 2.6 (95%CI: 2.2, 3.0), p < 0.001). Per 100kcal, healthy items also had higher odds of an above median sodium contribution than unhealthy items (OR: 2.0 (95%CI: 1.7, 2.4), p < 0.001).

Table 3:

Binary regression models between Nova groups, multiple traffic light front of package label score and micronutrient contributions per 100g and per 100kcal for females and males aged 19-64 years.

Micronutrient-dense food and drink items

UPF in the top 25% of all items contributing to micronutrient recommendations per 100kcal included ready-to-drink lower calorie fruit juices/squash, drinkable/fortified/fruit yoghurts, reduced fat and yeast extract spreads, baby formula (made up), meal replacement drinks/bars liver-based products (pate, sausage), beef-based ready meals/dishes, mocha, fish in breadcrumbs, lean/low-fat processed meats, breakfast cereals, plant-based meat alternatives and fortified plant-based milk alternatives. Of which items with an unhealthy FOPL spanned reduced fat and yeast extract spreads, baby formula, meal replacement bars, liver-based products, mocha, breakfast cereals, lean/low-fat processed meats. PF in the top 25% of all items contributing to micronutrient recommendations per 100kcal included tinned fish, canned soup, sauerkraut, and gherkins. The top 10% of all items contributing to micronutrient recommendations per 100kcal included several UPF, such as ready-to-drink lower calorie fruit juices/squash, drinkable yoghurts, yeast extract spreads, liver-based products (pate, sausage), plant-based meat burger and fortified soya milks.

Discussion

This analysis indicates variation across UK food and drink in meeting government micronutrient recommendations, based on degree of processing and FOPL. Per 100g, MPF, PF and UPF provided similar average contributions to recommended intakes. However, per 100kcal, MPF provided on average nearly double the micronutrient content of PF, and nearly two and a half times more than UPF. While PF per 100kcal also provided nearly a third more micronutrient content than UPF. Micronutrient contributions also differed between healthy and unhealthy items based on the presence of one or more red FOPL. Per 100g, unhealthy items provided on average 27% greater contributions to micronutrient recommendations than healthy items. However, per 100kcal, contributions to micronutrient recommendations of healthy items were on average over

double that of unhealthy items. Furthermore, the significant differences in average micronutrient contributions per 100kcal between MPF, PF and UPF were still observed within healthy items. Per 100kcal, healthy MPFs provided significantly higher contributions than both healthy PF or UPF, where healthy PF and UPF were not significantly different from each other and provided around half the micronutrient contribution of MPFs. This data therefore suggests that the degree of processing may impact on the micronutrient content of an individual's diet.

Previous work on the UK NDNS demonstrated partial overlap between FOPL and the degree of processing in the UK food and drink (14). In general, UPF had a poorer nutrient profile than MPF, but generally similar to PF. This was unchanged after considering only items with healthy FOPLs (14). This analysis builds upon these findings by showing that the micronutrient content and respective contributions to government micronutrient recommendations of food and drink in the UK also differs by degree of processing, and the differences are still observed within healthy items. UPF tended to be in the lower quartiles of average micronutrient contributions, and items with zero content for a given micronutrient content were generally over-represented by UPF. As in the previous analysis, some UPF had a nutritional profile comparable to MPF when looking at fat, saturated fat, salt and sugar (14), and would be considered healthy. This analysis of micronutrient content shows similar findings; around 25% of items in the highest quartile of average micronutrient contributions per 100kcal were UPF. These items spanned a range of UPF sub-groups, including fruit juices/squash, yoghurts, ready meals, fish products, breakfast cereals, and plant-based meat and milk alternatives. Our data questions the suggestions made by some authors that UPF are relatively deficient in micronutrients (28), and should all be avoided in favour of MPF.

Previous studies across several nations have shown that high-UPF diets tend to contain a lower micronutrient content (13). However, to date few studies have examined the micronutrient content of food and drink across a nationally representative database based on the degree of processing, and none in the UK. In the US, an analysis of the approximately 370 food and drink items captured in a food frequency questionnaire demonstrated that UPF tended to have a poorer nutrient density compared with MPF, based on Nutrient Rich Food ($NRF_{9.3}$) score (including vitamins A, C, E, calcium, magnesium and potassium, but also saturated fat, added sugar, and

sodium content per 100kcal) (29,30). However, similar to this study, some UPF scored well. Our results expand upon these findings by demonstrating similar findings across a UK database of nearly 3,000 food and drink items, with greater detail to classify items into the Nova classification as previously described (12).

Arguments for reducing UPF intake have included their displacement of 'real food', and their 'intrinsically unhealthy' properties (4). The results here indicate that after adjusting for energy content and FOPL score, UPF had a poorer micronutrient profile than MPFs. Our analysis of Year 9-11 NDNS data indicates that for a number of micronutrients, large proportions of adults do not meet the recommended RNI, particularly for several minerals, including potassium. When considering micronutrient contributions per 100kcal reported here as a 2000kcal diet, as recommended for females aged 19-64 years (11), only five out of 20 micronutrient RNI recommendations would be met with a diet composed solely of UPF (two of which being Na and Cl), compared with 12 for a diet solely of MPF (which does not include Na or Cl). Diets solely of UPF or MPF would also provide at least 80% of RNI recommendations for a further two micronutrients. When considering micronutrient contributions from healthy UPF per 100kcal for a 2000kcal diet, only six micronutrient recommendations would still be met (two of which being Na and Cl). However, a diet solely from healthy UPF would provide at least 80% of RNI recommendations for a further six micronutrients. This may imply that a healthy UPF diet (i.e. avoiding items with a red FOPL) would be less micronutrient dense and less likely to meet micronutrient recommendations than an energy matched, healthy MPF diet. On average in the UK, UPF contributes to over 50% of daily energy intake, with nearly one third of energy intake provided by MPF, and only around 10% by PF (31). Given the large contributions of UPF to daily energy intake, the lower micronutrient content of UPF compared with MPF has potentially important implications for meeting micronutrient recommendations within the UK population. In contrast, a US modelling study suggested that UPFs are necessary to achieve a nutritionally adequate diet, with UPFs making considerable contributions to vitamin E, thiamin, niacin, folate and calcium intake (32). Furthermore, modelling studies indicate the potential for nutritional deficiency with avoidance of some fortified UPF (33). In this study, the micronutrient content of healthy PF per 100kcal was also significantly lower than MPF, and similar to UPF. This might imply that a healthy PF diet would also be less likely to meet micronutrient recommendations

than an energy-matched, healthy MPF diet, but not more likely than an energy-matched, healthy UPF diet. However, in contrast to the wide range of micronutrient-dense UPF, the range of micronutrient-dense PF in the highest quartile of micronutrient contributions was limited (e.g., tinned fish, soup, sauerkraut and gherkins), potentially limiting the ability to construct a diet solely from healthy PF.

These findings have potential implications for how consumers interpret FOPLs and the healthiness of foods and drinks. It is unclear whether FOPL, Nova, or both, are most valuable for identifying micronutrient dense products, and thus the value of the degree of processing in addition to current UK governmental guidance. SACN reported insufficient evidence to justify incorporating ultra-processing into the EWG (7), due to limitations in the largely observational evidence, and that the adverse associations may possible be covered in current UK dietary guidance. Reformulated products, such as UPF lower in fat, saturated fat, salt, sugar or higher in fibre, can include FOPL nutrition claims. Importantly, nutrition claims influence consumer choice, including purchase intentions, consumption guilt, expected tastiness and consumption (34). The implications of this messaging across UPF varying in overall nutritional content requires further investigation and may further confuse the consumer in the retail environment. For example, in this analysis, healthy UPF contained more sodium per 100kcal than unhealthy UPF, given the higher energy density of unhealthy UPF. An ongoing trial assessing healthy MPF vs. UPF diets meeting the UK EWG will provide valuable insights into the health impacts of nutritionally improved UPFs with nutrition claims (35). The UPF diet includes sub-groups in the highest quartile of average micronutrient contributions per 100kcal in this study (including squash, yoghurts, ready meals, breakfast cereals, and plant-based alternatives) (35).

Discussion on UPF must consider that lower income in the UK is associated with poorer dietary quality (36), and lower social classes with higher UPF intakes (37). With UPF tending to be cheaper than MPF (29,38), many individuals are forced to choose the food which they can afford. Therefore, any policy or legislative action must therefore consider the potential wider social consequences of people reducing their UPF intake.

Strengths and limitations

Strengths of this study include the nationally representative database of food and drink items for the UK, with a matching nutrient database containing average nutrient compositions. The micronutrient content of items was compared by weight (per 100g) and energy (per 100kcal), as well as after considering existing governmental dietary guidance provided through FOPL MTL. Limitations include the lack of analysis based on actual portion size or food consumed. Whilst analyses were conducted per 100g and 100kcal allowing for uniform comparability between food and drink items, they may not reflect the micronutrient intakes of actual portion sizes or foods eaten by consumers. However, as the UK government recommends a 2000kcal per day for females, and 2500kcal per day for males, the analysis per 100kcal provides important insights into micronutrient contributions for a recommended diet according to degree of processing. However, this assumes items within each grouping are consumed in equivalent amounts, which may not represent actual intakes in a real-world setting and should be taken into account when interpreting the data. The actual average UK adult micronutrient intakes in the total diet, and per 100kcal were therefore also included for comparison. Across food processing classifications, Nova has been most used. However, Nova has been criticised for difficulties in its application (39), with reports of coding inconsistencies (40). Despite this, several studies with multiple coders report that most items are consistently coded using Nova, with misclassified or ambiguous items tending to be only 5-10% of all items (41–43). Furthermore, the SACN report on food processing also highlighted that Nova was the only food processing classification that met their five criteria, including its applicability to individuals in the UK (51). In this analysis, there was author agreement on classifying items.

Conclusions

Across a nationally representative food and drink database, MPF, PF and UPF per 100g provide similar average contributions to UK government micronutrient recommendations. However, contributions significantly differed when compared per 100 kcal. MPF provided the greatest average contributions per 100kcal, followed by PF and then UPF. Healthy items with no red FOPL provided higher average contributions to micronutrient recommendations per 100kcal than unhealthy items. Observed differences in average contributions between Nova groups persisted after accounting for healthy/unhealthy FOPLs. Within healthy items per 100kcal, MPF provided

the greatest average contributions to micronutrient recommendations, followed by PF and UPF, which were similar. These findings suggest healthy UPF or PF diets would be less likely to meet UK government micronutrient recommendations than an energy matched healthy MPF diet. The results are important for understanding the healthiness of the UK food and drink supply based on FOPL and degree of processing and implications for future potential policy and legislation regarding UPF.

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Patient and Public Involvement

Patients and the public were not involved in the design, conduct, reporting or dissemination of the analysis.

Author Contributions

S.J.D., conceptualisation, data collection and processing, design, data analysis, writing—first draft; R.L.B., writing—editing and reviewing, supervision; A.B. conceptualisation, data processing, writing—editing and reviewing, supervision. All authors have read and agreed to the final manuscript version.

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Conflicts of interest

All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/disclosure-of-interest/ and declare: S.J.D receives royalties from Amazon for a self-published book that mentions ultra-processed food, and payments from Red Pen Reviews. R.L.B reports honoraria from Novo Nordisk, Eli Lilly, Medscape, ViiV Healthcare Ltd and International Medical P and advisory board and consultancy work for Novo Nordisk, Eli Lilly, Pfizer, Gila Therapeutics Ltd, Epitomee Medical Ltd and ViiV Healthcare Ltd. R.L.B is an employee and shareholder of Eli Lilly. A.B. reports honoraria from Novo Nordisk, Office of Health Improvement and Disparity, Johnson and Johnson and Obesity UK outside the submitted work and is on the Medical Advisory Board and shareholder of Reset Health Clinics Ltd.

Data availability

Data can be made available upon request to the authors. For access to Intake24 datasets, please contact the Intake24 team directly: support@intake24.co.uk; https://intake24.co.uk.

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Table 1: Average percentage contribution per 100kcal to UK government dietary micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years, and across each Nova group, and percentage of government dietary micronutrient recommendations consumed per 100 kcal of reported energy intake for females, aged 19-64 from the National Diet and Nutrition Survey Year 9-11 survey.

Micronutrient	**Total (n = 2955)**		**MPF (n = 978)**		**PCI (n = 57)**		**PF (n = 283)**		**UPF (n = 1637)**		**Number of items with 0 content of micronutrient per 100kcal**	**Percentage of RNI consumed per 100 kcal of reported energy intake from NDNS Years 9-11**	
	Median	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**		**Median (%)**	**IQR**
Vitamins													
Vitamin A (retinol equivalents) (%)	1.4	0, 8.30	2.4 (a)	0.0, 15.9	0.0 (b)	0.0, 20.8	4.5 (a)	0.5, 10.7	0.9 (b)	0.0, 5.3	949	7.1	4.6, 11.1
Vitamin D (%)	0.0	0, 1.242	0.0 (a)	0.0, 0.9	0.0 (a)	0.0, 0.5	0.7 (b)	0.0, 2.5	0.0 (c)	0.0, 1.2	1733	1.4	0.8, 2.2

Thiamin (%)	7.1	2.9, 15.4	12.1 (a)	6.6, 25.0	0.0 (b)	0.0, 0.7	4.1 (c)	1.6, 8.0	5.6 (d)	2.0, 12.5	331	10.3	8.5, 12.5
Riboflavin (%)	5.2	2.0, 10.8	8.1 (a)	3.8, 16.1	0.0 (b)	0.0, 7.1	5.9 (c)	2.7, 10.0	4.0 (d)	1.4, 8.2	287	7.6	6.1, 9.7
Niacin equivalent (%)	11.6	4.6, 22.4	17.3 (a)	9.5, 33.3	0.0 (b)	0.0, 0.8	11.6 (c)	5.6, 19.9	8.8 (d)	3.5, 17.4	173	14.7	12.1, 18.0
Vitamin C (%)	0.0	0.0, 11.2	7.3 (a)	0.0, 64.5	0.0 (b)	0.0, 0.0	0.1 (c)	0.0, 6.0	0.0 (d)	0.0, 2.5	1481	11.6	7.1, 17.0
Vitamin E (%)	11.2	3.3, 31.0	17.3 (a)	4.6, 47.6	6.5 (b)	0.0, 18.9	10.7 (b)	4.0, 27.1	10.5 (b)	2.8, 24.7	459		
Vitamin B6 (%)	5.7	0.0, 13.0	11.9 (a)	6.2, 24.9	0.0 (b)	0.0, 0.0	4.6 (c)	2.0, 9.5	3.4 (d)	0.0, 8.2	805	7.4	6.1, 9.3
Vitamin B12 (%)	0.0	0.0, 22.5	0.0 (a)	0.0, 38.2	0.0 (b)	0.0, 1.9	10.3 (c)	0.0, 35.8	1.6 (a)	0.0, 18.3	1583	16.9	12.5, 23.2
Folate (%)	3.6	1.3, 8.9	6.8 (a)	2.9, 23.2	0.0 (b)	0.0, 0.8	3.4 (c)	1.5, 7.2	2.6 (d)	1.0, 5.9	279	6.4	5.1, 7.9

				1									
Minerals													
Potassium (%)	3.6	1.8, 8.0	9.1 (a)	5.1, 15.0	0.1 (b)	0.0, 1.5	3.2 (c)	1.6, 5.4	2.5 (d)	1.5, 4.2	36	4.5	3.8, 5.3
Calcium (%)	3.8	1.6, 9.3	4.2 (a)	1.6, 14.3	0.3 (b)	0.0, 6.5	4.3 (a)	2.1, 10.8	3.6 (c)	1.6, 7.5	31	6.5	5.3, 7.6
Magnesium (%)	4.8	2.9, 9.3	9.0 (a)	5.2, 15.4	0.1 (b)	0.0, 1.9	3.9 (c)	2.6, 6.7	3.8 (c)	2.2, 6.3	59	5.5	4.6, 6.5
Phosphorus (%)	11.7	6.0, 19.7	18.2 (a)	9.9, 29.9	0.2 (b)	0.0, 7.3	12.4 (c)	5.8, 20.1	9.5 (d)	5.0, 14.8	61	12.4	10.9, 14.5
Iron (%)	3.4	1.8, 7.3	6.6 (a)	3.0, 13.5	0.1 (b)	0.0, 0.9	2.7 (c)	1.4, 5.3	2.8 (c)	1.6, 5.2	210	4.3	3.5, 6.0
Copper (%)	4.4	2.2, 8.3	7.4 (a)	3.5, 15.5	0.1 (b)	0.0, 1.3	3.5 (c)	1.7, 7.6	3.8 (c)	1.9, 6.3	376	5.5	4.7, 6.6
Zinc (%)	5.7	2.7, 11.9	10.9 (a)	5.1, 19.9	0.4 (b)	0.0, 2.4	6.2 (c)	2.8, 11.1	4.1 (d)	2.1, 8.0	266	6.6	5.6, 7.9

		9	(a)	0				6					
		1.2,						2.1,		2.6,			
		10.	2.0	0.3,	0.2	0.0,	6.0	11.	6.8	12.			
Sodium (%)	4.5	4	(a)	5.8	(b)	1.4	(c)	7	(c)	6	85	6.9	5.8, 8.2
		1.6,						2.7,		2.0,			
		10.	3.5	1.3,	0.1	0.0,	6.1	11.	6.1	12.			
Chloride (%)	5.0	9	(a)	8.2	(b)	1.4	(c)	0	(c)	5	115	7.4	6.3, 8.4
		0.8,	3.1	1.3,	0.0	0.0,	4.4	1.7,	2.0	0.6,			
Iodine (%)	2.5	6.0	(a)	7.9	(b)	1.6	(c)	8.4	(c)	4.6	493	5.6	4.3, 7.4
				0.7,									
		0.,	4.4	10.	0.0	0.0,	2.4	0.0,	2.2	0.7,			
Selenium (%)	2.6	6.5	(a)	5	(b)	0.0	(c)	5.9	(c)	5.0	668	4.3	3.4, 5.7
Overall (%) /18, Exc		4.1,	14.	8.2,				4.6,					
VitE, NA, CL) (n =		14.	4	28.	0.9	0.0,	7.7	10.	5.8	3.1,			
2953)	7.8	4	(a)	1	(b)	5.0	(c)	9	(d)	9.7	14	8.0	6.9, 9.4
Overall (%) /20, Inc		4.3,	13.	7.8,				4.8,		3.2,			
NA, CL, Exc VItE) (n		13.	3	26.	0.8	0.0,	7.5	11.	6.3	10.			
= 2953)	7.9	8	(a)	4	(b)	4.7	(c)	0	(d)	4	11	7.9	7.0, 9.1

Overall (%) (/18) includes all micronutrients except Sodium, Chloride and Vitamin E. Overall (%) (/20) includes all micronutrients except Vitamin E. Unlike letters indicate significantly different P < 0.05. Pairwise comparisons conducted using Kruskal–Wallis ANOVA with Bonferroni correction for multiple comparisons. Selenium: total = 2953 (UPF, n = 1635). IQR: inter-quartile range; MPF: minimally processed food; PCI: processed culinary ingredients; PF: processed food; UPF: ultra-processed food; mg, milligram; µg, microgram; NA, sodium; CL, chloride; Exc., excluded; Inc, included; %, percentage; n, number; RNI, reference nutrient intake; NDNS, National Diet and Nutrition Survey.

Table 2: Average percentage contribution of healthy items per 100kcal to UK government dietary micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years, and across each Nova group.

Micronutrient	**Total (n = 1825)**		**MPF (n = 812)**		**PCI (n = 9)**		**PF (n = 162)**		**UPF (n = 842)**		**Number of items with 0 content of micronutrient per 100kcal**
	Median	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	
Vitamins											
Vitamin A (retinol equivalents) (%)	1.7	0.0, 9.1	2.9 (a)	0.0, 18.2	0.0 (b)	0.0, 0.0	2.6 (a)	0.4, 8.3	0.8 (c)	0.0, 5.7	572
Vitamin D (%)	0.0	0.0, 1.1	0.0 (a)	0.0, 0.8	0.0 (a)	0.0, 0.0	0.1 (b)	0.0, 2.2	0.0 (b)	0.0, 1.1	1118
Thiamin (%)	10.3	5.2, 19.2	13.4 (a)	7.3, 27.4	125.0 (abc)	0.0, 146.2	5.2 (b)	2.4, 9.5	9.4 (c)	4.3, 15.5	174
Riboflavin (%)	6.1	2.7, 12.4	8.3 (a)	4.0, 17.6	215.2 (ab)	0.0, 545.5	5.4 (b)	2.7, 10.0	4.5 (b)	1.9, 9.1	161
Niacin equivalent (%)	14.8	8.0, 26.8	18.3 (a)	10.3, 36.7	0.0 (b)	0.0, 35.3	10.8 (b)	5.5, 21.6	13.3 (b)	6.6, 21.2	66
Vitamin C (%)	2.2	0.0, 31.1	13.3 (a)	0.0, 80.6	0.0 (b)	0.0, 0.0	2.2 (c)	0.0, 20.9	0.1 (b)	0.0, 8.1	733

Vitamin E (%)	12.4	3.1, 33.9	17.5 (a)	4.5, 50.5	0.0 (b)	0.0, 0.0	12.9 (c)	3.9, 29.6	10.9 (c)	2.8, 27.8	306
Vitamin B6 (%)	7.6	2.3, 18.3	13.9 (a)	6.3, 27.8	0.0 (b)	0.0, 47.2	6.9 (b)	0.0, 13.4	4.8 (b)	0.0, 10.4	438
Vitamin B12 (%)	0.0	0.0, 27.9	0.0 (a)	0.0, 36.7	0.0 (a)	0.0, 0.0	5.5 (b)	0.0, 29.4	0.0 (ab)	0.0, 24.5	1061
Folate (%)	5.1	2.6, 13.7	8.2 (a)	3.3, 30.2	50.0 (ab)	0.0, 614.6	3.4 (b)	1.8, 8.6	4.4 (b)	2.3, 8.0	107
Minerals											
Potassium (%)	5.4	2.9, 10.8	10.0 (a)	5.8, 17.3	20.0 (ab)	0.1, 28.6	4.7 (b)	2.9, 6.9	3.3 (c)	2.1, 5.4	13
Calcium (%)	4.6	2.2, 11.1	4.4 (a)	1.8, 14.8	6.8 (a)	0.2, 100.0	4.1 (a)	2.2, 9.5	4.7 (a)	2.5, 9.6	11
Magnesium (%)	6.4	4.0, 11.3	9.3 (a)	5.8, 16.5	37.0 (ab)	0.0, 39.1	4.7 (bc)	3.4, 8.0	4.8 (c)	3.3, 7.8	18
Phosphorus (%)	14.2	8.7, 23.8	19.9 (a)	10.7, 32.7	36.4 (ab)	0.0, 89.6	11.6 (b)	5.7, 17.6	12 (b)	7.8, 16.4	28
Iron (%)	4.6	2.5, 9.1	6.9 (a)	3.0, 14.5	63.7 (ab)	0.0, 1824.3	3.5 (b)	2.3, 7.3	3.7 (b)	2.2, 5.9	129
Copper (%)	5.4	2.8, 9.7	7.4 (a)	3.8, 15.8	246.5 (ab)	0.0, 3500.0	4.3 (b)	2.2, 7.6	4.4 (b)	2.4, 6.9	223

Zinc (%)	7.3	3.7, 13.9	11.4 (a)	5.3, 20.4	67.6 (ab)	0.0, 714.3	5.8 (b)	2.5, 9.5	5.6 (b)	3.2, 9.1	170
Sodium (%)	5.2	1.2, 10.3	2.1 (a)	0.4, 6.1	1.9 (abc)	0.3, 1250.0	5.9 (b)	1.3, 11.0	8.6 (c)	3.8, 13.0	57
Chloride (%)	5.9	2.0, 11.3	4.0 (a)	1.6, 8.5	0.0 (a)	0.0, 8.2	5.9 (a)	1.5, 10.5	8.3 (b)	3.5, 12.9	74
Iodine (%)	2.8	1.0, 6.8	3.4 (a)	1.4, 7.9	0.0 (b)	0.0, 1.5	5.4 (a)	1.8, 8.6	2.2 (b)	0.6, 5.2	315
Selenium (%)	3.9	0.8, 7.9	4.9 (a)	0.8, 11.3	0.0 (ab)	0.0, 24.4	2.3 (b)	0.0, 7.9	3.5 (b)	1.3, 6.5	443
Overall (/18, Exc VitE, NA, CL) (n = 1824)	9.9	6.1, 18.8	15.7 (a)	9.0, 31.7	132.7 (ab)	0.3, 386.2	7.9 (b)	5.5, 12.4	7.2 (b)	5.1, 11.5	9
Overall (/20, Inc NA, CL, Exc VItE)	9.8	6.3, 17.6	14.7 (a)	8.7, 29.6	120.3 (ab)	0.3, 410.1	7.6 (b)	5.4, 12.1	7.6 (b)	5.4, 11.8	7

Overall (%) (/18) includes all micronutrients except Sodium, Chloride and Vitamin E. Overall (%) (/20) includes all micronutrients except Vitamin E. Unlike letters indicate significantly different P < 0.05. Pairwise comparisons conducted using Kruskal–Wallis ANOVA with Bonferroni correction for multiple comparisons. Items were classified into 'healthy' or 'unhealthy' based on the presence or absence of a red FOPL traffic light for fat, saturated fat, total sugar or salt. This is based on research that when identifying healthier products, UK consumers are more cautious to avoid items with red traffic lights, than to select items with green traffic lights (26,27) and has been previously used in published research (14). Selenium: total = 1824 (UPF, n = 841). MPF: minimally processed food; MTL: multiple traffic light; PCI: processed culinary ingredients; PF: processed food; UPF: ultra-processed food; mg, milligram; µg, microgram; NA, sodium; CL, chloride; Exc., excluded; Inc, included; %, percentage; n, number; RNI, reference nutrient intake; NDNS, National Diet and Nutrition Survey..

Table 3: Binary regression models between Nova groups, multiple traffic light front of package label score and percentage micronutrient contributions per 100g and per 100kcal, for females aged 19-64 years.

Micronutrient	**% Contribution per 100g**				**% Contribution per 100kcal**			
	Exp(Beta)	**95% Confidence Interval**		**p-value**	**Exp(Beta)**	**95% Confidence Interval**		**p-value**
		Lower	**Upper**			**Lower**	**Upper**	
Vitamin A (retinol equivalents) (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.330	0.186	0.588	<.001	0.398	0.222	0.712	0.002
PF	1.563	1.187	2.057	0.001	1.568	1.187	2.072	0.002
UPF	0.831	0.704	0.982	0.030	0.67	0.567	0.792	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.683	0.583	0.800	<.001	1.096	0.935	1.284	0.259
Vitamin D (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.707	0.384	1.299	0.263	0.777	0.42	1.437	0.421
PF	3.571	2.704	4.715	<.001	3.548	2.687	4.685	<.001
UPF	1.876	1.575	2.235	<.001	1.893	1.588	2.256	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.867	0.739	1.018	0.082	0.885	0.754	1.039	0.137
Thiamin (%)								
Nova								

MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.062	0.019	0.201	<.001	0.098	0.041	0.235	<.001
PF	0.578	0.436	0.767	<.001	0.197	0.145	0.267	<.001
UPF	1.236	1.047	1.459	0.012	0.396	0.331	0.475	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.936	0.799	1.097	0.415	3.802	3.205	4.51	<.001
Riboflavin (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.266	0.146	0.485	<.001	0.209	0.113	0.387	<.001
PF	1.308	0.995	1.72	0.054	0.629	0.479	0.828	<.001
UPF	1.104	0.932	1.307	0.252	0.334	0.281	0.397	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.425	0.362	0.499	<.001	1.397	1.188	1.642	<.001
Niacin equivalent (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.057	0.018	0.184	<.001	0.05	0.015	0.163	<.001
PF	1.606	1.226	2.103	<.001	0.593	0.449	0.784	<.001
UPF	1.356	1.149	1.601	<.001	0.46	0.387	0.548	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.799	0.683	0.936	0.006	2.915	2.471	3.438	<.001
Vitamin C (%)								

Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.201	0.099	0.405	<.001	0.215	0.106	0.436	<.001
PF	0.829	0.629	1.091	0.181	0.818	0.620	1.078	0.153
UPF	0.55	0.464	0.652	<.001	0.552	0.466	0.656	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	2.373	2.019	2.790	<.001	2.435	2.070	2.864	<.001
Vitamin E (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.692	0.405	1.183	0.179	0.358	0.198	0.647	<.001
PF	1.059	0.806	1.391	0.683	0.756	0.578	0.988	0.041
UPF	1.256	1.061	1.486	0.008	0.708	0.599	0.836	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.457	0.389	0.536	<.001	1.155	0.987	1.352	0.073
Vitamin B6 (%)	2 outliers							
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.039	0.009	0.161	<.001	0.027	0.008	0.088	<.001
PF	0.513	0.382	0.688	<.001	0.27	0.203	0.359	<.001
UPF	0.616	0.518	0.733	<.001	0.22	0.183	0.265	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.714	0.604	0.843	<.001	2.188	1.851	2.588	<.001

Vitamin B12 (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.577	0.321	1.036	0.066	0.637	0.352	1.153	0.136
PF	2.803	2.126	3.695	<.001	2.781	2.109	3.666	<.001
UPF	1.796	1.515	2.130	<.001	1.807	1.523	2.144	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.695	0.593	0.814		0.707	0.603	0.829	<.001
Folate (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.072	0.026	0.201	<.001	0.114	0.047	0.274	<.001
PF	0.941	0.719	1.231	0.657	0.569	0.428	0.756	<.001
UPF	0.824	0.698	0.974	0.023	0.442	0.370	0.527	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	1.447	1.235	1.694	<.001	3.702	3.129	4.381	<.001
Potassium (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.069	0.032	0.149	<.001	0.063	0.029	0.139	<.001
PF	0.309	0.234	0.408	<.001	0.201	0.148	0.272	<.001
UPF	0.418	0.352	0.496	<.001	0.107	0.087	0.132	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference

Healthy (no red MTL)	0.735	0.626	0.864	<.001	4.072	3.390	4.891	<.001
Calcium (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.544	0.305	0.971	0.04	0.638	0.351	1.159	0.14
PF	2.128	1.618	2.8	<.001	1.312	0.998	1.726	0.052
UPF	2.458	2.070	2.918	<.001	1.059	0.895	1.254	0.503
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.529	0.45	0.622	<.001	2.228	1.897	2.616	<.001
Magnesium (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.094	0.042	0.210	<.001	0.117	0.057	0.242	<.001
PF	0.598	0.454	0.786	<.001	0.186	0.138	0.25	<.001
UPF	0.914	0.774	1.079	0.287	0.197	0.163	0.239	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.610	0.520	0.715	<.001	3.705	3.111	4.412	<.001
Phosphorus (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.078	0.031	0.199	<.001	0.118	0.054	0.255	<.001
PF	1.68	1.277	2.210	<.001	0.553	0.418	0.73	<.001
UPF	1.541	1.302	1.823	<.001	0.337	0.282	0.402	<.001
FOPL								
Unhealthy (one or more red	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference

MTLs)								
Healthy (no red MTL)	0.468	0.398	0.550	<.001	2.446	2.074	2.884	<.001
Iron (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.157	0.078	0.317	<.001	0.107	0.047	0.242	<.001
PF	0.603	0.456	0.797	<.001	0.329	0.247	0.437	<.001
UPF	1.139	0.964	1.346	0.127	0.383	0.321	0.457	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.53	0.452	0.622	<.001	2.717	2.303	3.205	<.001
Copper (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.207	0.107	0.40	<.001	0.122	0.057	0.263	<.001
PF	0.815	0.618	1.076	0.149	0.436	0.331	0.574	<.001
UPF	1.525	1.288	1.804	<.001	0.46	0.388	0.547	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.457	0.389	0.537	<.001	1.796	1.529	2.109	<.001
Zinc (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.123	0.057	0.265	<.001	0.105	0.049	0.227	<.001
PF	1.223	0.933	1.604	0.144	0.508	0.385	0.671	<.001
UPF	1.091	0.923	1.289	0.31	0.302	0.253	0.360	<.001
FOPL								

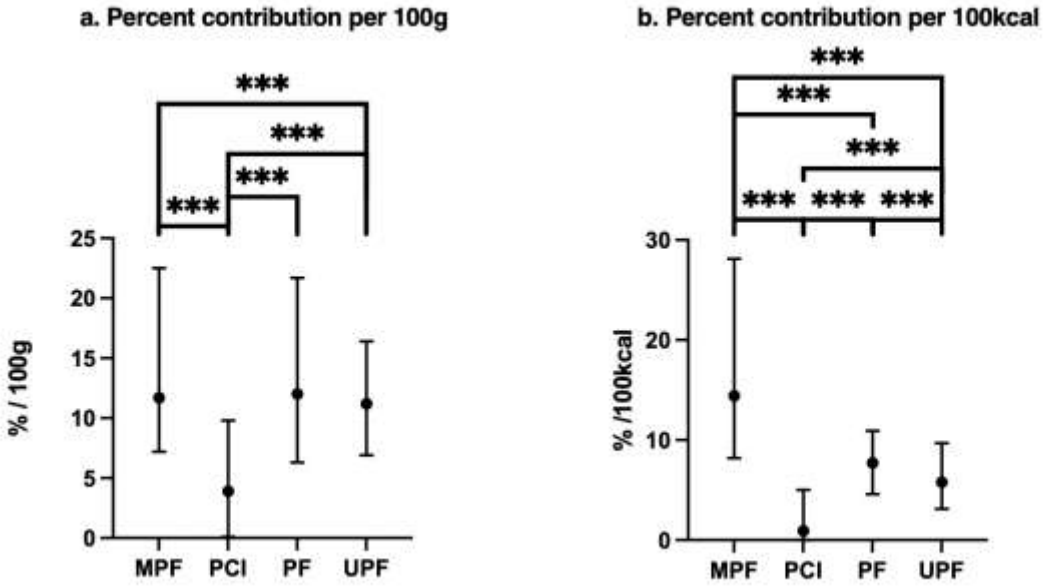
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.540	0.460	0.633	<.001	2.149	1.823	2.534	<.001
Sodium (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.790	0.407	1.532	<.001	0.488	0.216	1.100	0.084
PF	7.412	5.515	9.962	<.001	4.191	3.157	5.563	<.001
UPF	8.049	6.618	9.790	<.001	4.336	3.616	5.201	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.630	0.530	0.748	<.001	2.022	1.709	2.394	<.001
Chloride (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.562	0.269	1.172	0.124	0.306	0.129	0.728	0.007
PF	7.874	5.849	10.601	<.001	2.913	2.200	3.857	<.001
UPF	7.814	6.427	9.500	<.001	2.523	2.119	3.005	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.643	0.541	0.764	<.001	2.344	1.987	2.766	<.001
Iodine (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.370	0.205	0.668	<.001	0.269	0.142	0.510	<.001
PF	3.229	2.418	4.311	<.001	1.464	1.108	1.933	0.007
UPF	1.577	1.330	1.871	<.001	0.644	0.545	0.762	<.001

FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.426	0.362	0.501	<.001	1.333	1.137	1.563	<.001
Selenium (%)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.131	0.051	0.331	<.001	0.105	0.041	0.270	<.001
PF	1.572	1.201	2.057	<.001	0.643	0.488	0.847	0.002
UPF	1.23	1.039	1.457	0.016	0.656	0.553	0.779	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.86	0.734	1.008	0.062	2.639	2.242	3.106	<.001
Female Overall (%) (/18, Exc VitE, NA, CL)								
Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.163	0.086	0.309	<.001	0.086	0.041	0.181	<.001
PF	0.946	0.722	1.241	0.689	0.316	0.237	0.422	<.001
UPF	0.758	0.641	0.896	0.001	0.169	0.139	0.204	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.532	0.453	0.624	<.001	2.562	2.159	3.042	<.001
Male Overall (%) (/18, Exc VitE, NA, CL)								

Nova								
MPF	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
PCI	0.138	0.072	0.267	<.001	0.092	0.044	0.194	<.001
PF	0.874	0.666	1.146	0.330	0.333	0.249	0.444	<.001
UPF	0.727	0.614	0.860	<.001	0.176	0.145	0.212	<.001
FOPL								
Unhealthy (one or more red MTLs)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Healthy (no red MTL)	0.502	0.427	0.589	<.001	2.820	2.374	3.349	<.001

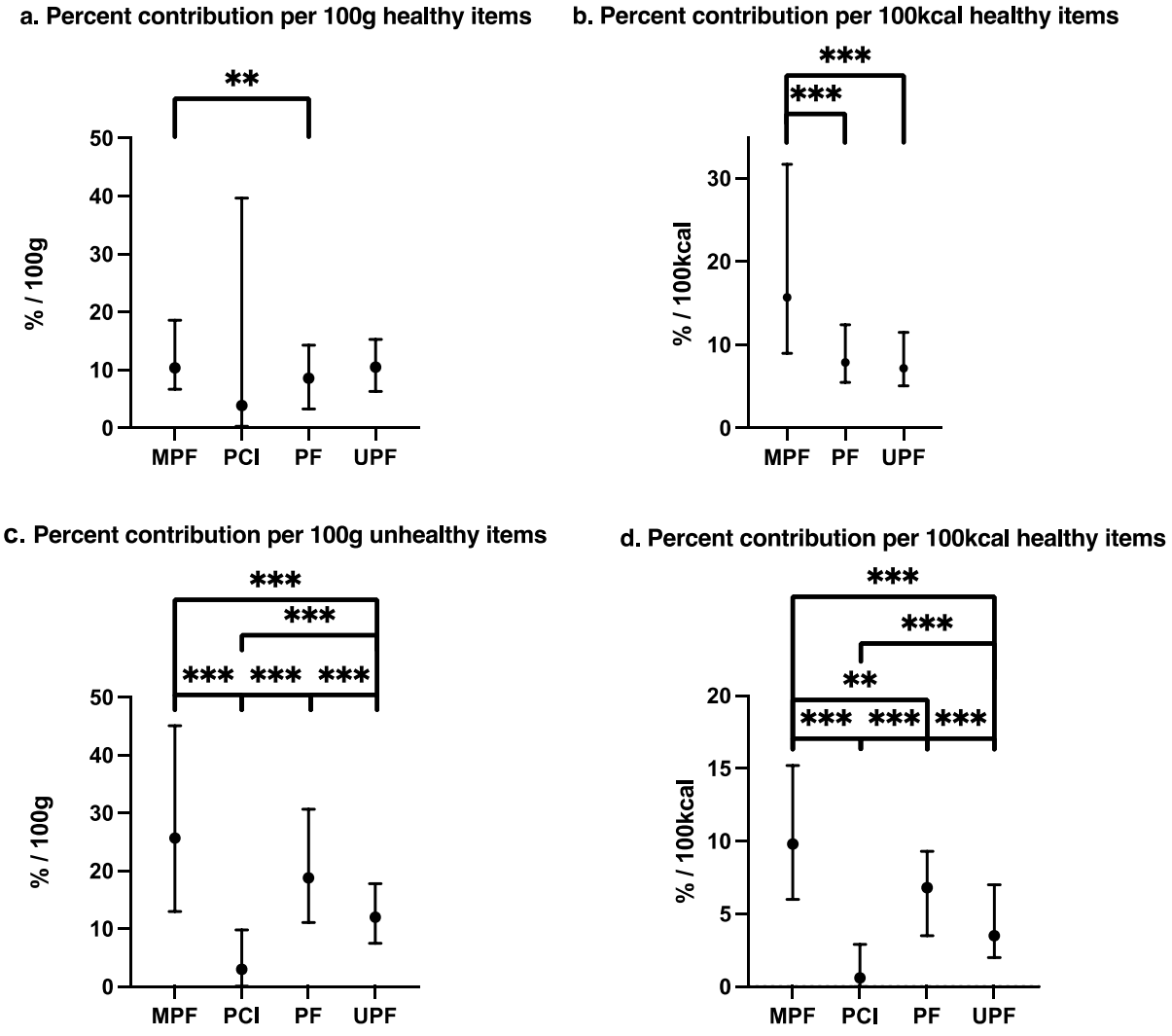
Overall (%) (/18) includes all micronutrients except Sodium, Chloride and Vitamin E. Items were classified into 'healthy' or 'unhealthy' based on the presence or absence of a red FOPL traffic light for fat, saturated fat, total sugar or salt. This is based on research that when identifying healthier products, UK consumers are more cautious to avoid items with red traffic lights, than to select items with green traffic lights (26,27). FOPL: front of package label; IQR: inter-quartile range; MPF: minimally processed food; MTL: multiple traffic light; PCI: processed culinary ingredients; PF: processed food; UPF: ultra-processed food; %, percentage; NA sodium; CL, chloride.

Figure 1. Average *percentage contribution to UK government dietary micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years across Nova groups, (a) all items per 100g, (b) all items per 100kcal.*



****denotes significance at P < 0·001, ** denotes significance P < 0.01 conducted from Kruskal–Wallis ANOVA with Bonferroni correction for multiple comparisons. Abbreviations: MPF, minimally processed food; PCI: processed culinary ingredient; PF, processed food; UPF, ultra-processed food; kcal, calories; %, percentage; g, grams.*

Figure 2. Average *percentage contribution to UK government dietary micronutrient recommendations from the UK National Diet and Nutrition Survey for females aged 19-64 years across Nova groups, (a) healthy items per 100g, (b) healthy items per 100kcal, (c) unhealthy items per 100g, (d) unhealthy items per 100kcal.*



****denotes significance at P < 0·001, ** denotes significance P < 0.01 conducted from Kruskal–Wallis ANOVA with Bonferroni correction for multiple comparisons. 1.d PCI omitted from the graph for clarity. Items were classified into 'healthy' or 'unhealthy' based on the presence or absence of a red FOPL traffic light for fat, saturated fat, total sugar or salt. This is based on research that when identifying healthier products, UK consumers are more cautious to avoid items with red traffic lights, than to select items with green traffic lights (26,27). Abbreviations: MPF, minimally processed food; PCI: processed culinary ingredient; PF, processed food; UPF, ultra-processed food; kcal, calories; %, percentage; g, grams.*