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PhD in Epidemiology, Environment and Public Healthcare

Dietary inequality and chronic disease outcomes

The mediating effect of income and education using the UK National and Dietary Survey (NDNS) Data

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THE THESIS IS BASED ON THE FOLLOWING PUBLISHED PAPERS

1. Patel, L. Alicandro, G, La Vecchia, C (2018). Low-Calorie Beverage Consumption, Diet Quality and Cardiometabolic Risk Factors in British Adults. *Nutrients*, *10*

2. Patel L, Alicandro G, La Vecchia C (2020) Dietary approach to stop hypertension (DASH) diet and associated socioeconomic inequalities in the United Kingdom. *Br J Nutr*, 1-24. – **AWARDED UK NUTRITION SOCIETY PAPER OF THE MONTH JUNE 2020.**

3. Patel L, Bertuccio P, Alicandro G, La Vecchia C (2020). Educational inequality in the dietary approach to stop hypertension (DASH) diet in the UK: evaluating the mediating role of income. Br J Nutr, 1-20

The mediating effect of income and education using the UK National and Dietary Survey (NDNS) Data

ABSTRACT

Diet substantially contributes to socioeconomic inequalities in cardiovascular morbidity and mortality. High adherence to the dietary approach to stop hypertension (DASH) has been proved effective in lowering blood pressure in patients with cardiovascular disease (CVD) as well as to prevent CVD risk factors in the general population. Little is known about time trends in diet quality and associated inequalities in the United Kingdom (UK). In addition, the causal pathway between education and dietary choices has not been fully explained and the role of income in preventing a healthy diet has not been clarified. This doctorate firstly, aimed to quantify the differences in adherence to the DASH in relation to socioeconomic position (SEP) in the UK and to evaluate recent trends. Secondly, it aimed to quantify the mediating effect of income on the relationship between education and the DASH score in the UK population.

Data used for analysis was obtained from three waves of the National Diet and Nutrition Survey Rolling Programme (NDNS) 2008-2012, 2013-2014 and 2015-2016). The DASH score was calculated based on Fung et al methodology and was calculated using sex-specific quintiles of DASH items. For the first part of the analysis (Paper 2) data analysis included 6435 subjects aged 18 and older who participated in the NDNS. Multiple linear regressions were used to evaluate the relationship between the socioeconomic variables and the DASH score. Quantile regression analysis was used to model the median intake of each component as a function of the socioeconomic variable and the survey year. In the second analysis (Paper 3), analysis was done on 4864 subjects aged 18 and older. Counterfactual-based mediation analysis was carried out to decompose the total effect of

education on DASH score into average direct effect (ADE) and average causal mediation effect (ACME) mediated by income.

A gradient relationship between the DASH score and all socioeconomic variables emerged with increasing values of the score at higher socioeconomic positions (SEP effect p value: <0.0001 for education, occupation, and income) in the initial analysis. The interaction term between survey year and the socioeconomic variables was not significant showing that the trend was not different across socioeconomic groups (p >0.05). The estimated difference between people with no qualification and those having the highest level of education was -3.59 points (95% CI: -3.91; -3.20). The difference between people engaged in routine occupations and those engaged in high managerial and professional occupations was -3.40 points (95% CI: -3.87; -2.92), and the difference between subjects in the first fifth and last fifth of the household income distribution was -2.73 points (95% CI: -3.16; -2.29). The widest socioeconomic differences emerged for consumption of fruit, vegetables, whole grains, nuts, seeds and legumes. Mediation analysis indicated that the overall mediating effect of income on the relationship between education and the DASH score was only partial, with an estimated proportion mediated ranging between 6 to 9%. The mediating effect was higher among women (11.6%) and younger people (17.9%).

Findings from this doctorate add an important contribution to the existing literature and more importantly, provide an updated picture of socio-economic inequalities in diet amongst UK adults in context of the whole diet. The results show that overall, the DASH score increased over time, yet the overall score remains low. Moreover, persistent disparities between individuals with higher versus lower SEP were observed. Additional analysis indicates that low income plays a modest role in explaining educational differences in the UK population.

Further research is needed to investigate which other factors may explain differences in diet quality.

In conclusion, findings in this doctorate have substantial implications for public nutrition policy. An immediate implication is the need for public nutrition policies that are individualised to SEP. Targeted interventions for those within the lower SEP need a multi-factorial approach not just focusing on the cost of food but on other factors such as nutrition literacy, attitudes towards healthy eating as well as access to healthy food. Further research is needed to fully investigate which other factors may explain the socioeconomic inequality in the adoption of the DASH diet in UK.

INTRODUCTION TO THE THESIS

Socioeconomic differences in morbidity and mortality are widening even in Europe (1, 2) . Taking the United Kingdom as an example, the difference in life expectancy of people living in more affluent areas than people living in the most deprived areas is almost a decade for both men and women (3). Differences like these imply adverse health consequences at an individual level and ultimately at a societal level (2, 3).

Chronic diseases such as cancer and cardiovascular diseases are some of the illnesses that contribute the most to social and health inequalities in Europe (1, 4, 5). The UK is among the countries with the highest incidence of CVD in western Europe (3). One in four premature deaths in the UK is due to CVD. Those in the most deprived of the population are almost twice as likely to die as a result of CVD as those in the least deprived of the population(6) . Moreover, people of a lower socioeconomic position (SEP) are reported to suffer from a higher prevalence of chronic diseases such as CVD (1, 7-9).

Health behaviours such as smoking, inactivity, excessive consumption of alcohol are well established modifiable risk factors for common chronic diseases included cardiovascular disease(2, 5, 9, 10) . In addition, diet substantially contributes to socioeconomic inequalities in cardiovascular morbidity and mortality (10-13). As such, improving the diet of people of low SEP is of utmost importance to reduce the burden of chronic diseases such as CVD (10, 12, 14).

Compliance to the dietary approach to stop hypertension (DASH) has been proved effective in lowering blood pressure in patients with CVD as well as to prevent risk factors for CVD in the general population (12-15). The DASH diet is high in fruits and vegetables, moderate in low-fat dairy products and low in animal protein but with a substantial amount of plant protein from legumes and nuts (14, 15). However, the higher cost of healthy food (such foods within DASH diet) may represent a barrier to adopting healthy eating patterns (16-21). In addition to this for individuals with a lower SEP, the perceived cost of healthy foods in combination with a limited individual diet food budget may indeed be a constraint with a lower SEP in consuming a high quality diet (17-21).

Dietary inequalities can be characterized at various levels from the level of nutrients and moving upwards to consider specific foods, food groups, eating occasions and dietary patterns (15). Whilst inequalities in diet have been documented cross-sectionally over time, little is known about the evolution of dietary inequalities today. Existing reviews of socioeconomic differences in dietary intakes across Europe have also only focused on intakes of one food nutrient at a time (19, 22-25).

In the United Kingdom, most research has focused on socioeconomic inequalities and a small number of food groups or a limited number of UK dietary recommendations. A 2014 UK based study reporting data from the National Dietary Surveillance Data (NDNS) used the three separate indicators of SES to examine whether socio-economic gradients existed for selected food groups (fruit and vegetables, red processed meat and oily fish and nutrients (saturated fat and non-milk extrinsic sugars) (26). Another recent study examined the time trends in adherence to the same dietary recommendations for fruit and vegetables, salt, oily fish, and red and processed meat among sociodemographic subgroups from 1986 to 2012(25). A recent study focusing on adolescents found that frequent consumption of takeaways meals may have a negative impact on adolescents' diet quality (27).

However, to date no research has explored the impact of SES indicators on the whole diet or in the context of diet quality in the UK. Another major limitation of studies to date is the relatively short-term effects that have been explored in most studies (19, 23-25). Therefore, there is need for research to focus on a broader scope of dietary factors, nutrition quality and dietary habits over time. In depth insight into dietary behaviours (substitution between food groups) is also required as well as deeper understanding of the mediating factors involved in dietary choices. The income-diet relationship for example is mediated by dietary cost and access to food (17, 19, 20, 28-31). However, the role of income in dietary choices has not been clarified and the causal pathway between education and dietary choices has not been fully explained.

OVERALL AIM OF THE THESIS

The overall aim of the thesis was to assess diet quality trends in the UK and then to investigate mediating factors that contribute to the diet inequality in terms of cardiovascular disease. Using the UK National Nutrition and Dietary survey (NDNS) the thesis was organised around the following research questions.

1. What are the recent dietary inequality trends in the UK?
2. What is the role of income in mediating dietary choices?

The initial aspect of this doctorate was to analyse a number of different hypotheses on new dietary trends using the NDNS data and from there on be able to explore the mediating factors associated with making healthy food choices. Objective 1 was to assess recent trends in the intake of diet quality in relation to low calorie beverage consumption. More specifically, to verify the association between low calorie beverage consumption, diet quality and cardiometabolic risk factors in British adults. As shown in Publication 1, the proposed hypothesis was proved wrong. This outcome, in addition to missing key variables in the dataset and the need for a more granular data to continue analysis meant that new research questions needed to be investigated. The following new objectives were therefore identified:

2. To evaluate recent trends in the adherence to the DASH diet in relation to socioeconomic position in the UK and to quantify the differences
3. To quantify the mediating effect of income on the relationship between education and the DASH score in the UK population.

Objectives 2 and 3 (Year 2 and 3) are therefore the focal points of this dissertation however details of objective 1 (Year 1) are also included.

BACKGROUND

Cardiovascular disease (CVD) is one of the leading contributors to the global disease burden (1, 2, 5). The UK is among the countries with the highest incidence of CVD in western Europe accounting for one in four premature deaths. One in four premature deaths in the UK is due to CVD. Those in the most deprived of the population are almost twice as likely to diet as a result of CVD as those in the least deprived of the population(1, 3, 6). The role of socioeconomic position (SEP) on CVD (and other health outcomes) has been recognized for a long time (1, 7-9, 17) . Recent trends in the UK show that despite the overall decreasing CVD mortality rates, more favourable trends amongst the highest socioeconomic groups have widened relative inequality (3, 6) .

Diet is a key modifiable risk factor for CVD (2, 8, 10, 32-34). An unhealthy diet is likely a major contributor and also a main determinant of the socioeconomic disparities in CVD that have been observed in the UK (8, 24, 26, 35). Diet substantially contributes to socioeconomic inequalities in cardiovascular morbidity and mortality (5, 10, 13, 14).

Diet is a key modifiable risk factor for CVD and is among the contributing factors to socioeconomic inequalities in CVD morbidity and mortality(5, 10, 13, 14). Higher quality diets are associated with greater affluence and a poorer diet has long been reported in low SEP individuals and thus, improving the diet of people of low SEP is of utmost importance to reduce their burden of disease (17, 19, 20, 22, 33, 36).

Compliance to the dietary approach to stop hypertension (DASH) has been proved effective in lowering blood pressure in patients with CVD as well as to prevent risk factors for CVD in the general population (12-15). The DASH diet is high in fruits and vegetables, moderate in low-fat dairy products and low in animal protein but with a substantial amount of plant protein from legumes and nuts (12, 37). However, the higher cost of healthy food (such foods within DASH diet) may represent a barrier to adopting healthy eating patterns (19, 23, 29, 31, 36, 38, 39).

Infact, it is well established that in most industrialised countries, that lower quality diets (high in refined carbohydrates, added sugars and saturated fats) are generally less expensive on a per-calorie basis (23, 24, 35, 36, 38). Vegetables and fruit, which are recognized as the core components of a healthy diet have also been shown to account for a large part of diet cost (20, 36). Consequently, people of low SEP are clearly at a disadvantage when it comes to the adoption of healthier eating habits. They are likely to consume less fruit, vegetables, fish and consequently less fibre and more unhealthful fats, salt and processed food than individuals of high SES (23, 26, 31, 33) .

Dietary inequalities can be characterized at various levels from the level of nutrients and moving upwards to consider specific foods, food groups, eating occasions and dietary patterns (15, 26). Whilst inequalities in diet have been documented cross-sectionally over time, little is known about the evolution of dietary inequalities today. Studies conducted in the USA and the Netherlands found persisting or widening inequalities in diet quality by education, income, ethnicity, age and sex (16, 22, 40, 41). Existing reviews of socioeconomic differences in dietary intakes across Europe have also only focused on intakes of one food nutrient at a time(22).

In the United Kingdom, most research has focused on socioeconomic inequalities and a small number of food groups or a limited number of UK dietary recommendations. A 2014 UK based study reporting data from the National Dietary Surveillance Data (NDNS) used the three separate indicators of SES to examine whether socio-economic gradients existed for selected food groups (fruit and vegetables, red processed meat and oily fish and nutrients (saturated fat and non-milk extrinsic sugars) (26). Another recent study examined the time trends in adherence to the same dietary recommendations for fruit and vegetables, salt, oily fish, and red and processed meat among sociodemographic subgroups from 1986 to 2012 (25). A recent study focusing on adolescents found that frequent consumption of takeaways meals may have a negative impact on adolescents' diet quality (27).

However, to date no research has explored the impact of SES indicators on the whole diet or in the context of diet quality in the UK. The DASH diet represents an overall dietary pattern because it aims to encompass the whole diet making it a useful indicator of overall diet quality (37, 42). Another major limitation of studies to date is the relatively short-term effects that have been explored in most studies (19, 24-26) . Therefore, there is need for research to focus on a broader scope of dietary factors, nutrition quality and dietary habits over time. In depth insight into dietary behaviours (substitution between food groups) is also required. In addition, the causal pathway between education and dietary choices has not been fully explained, and the role of low income in dietary choices has not been clarified.

AIM

The aim was:

- To evaluate recent trends in dietary quality in the UK adult population
- To evaluate and quantify the differences in adherence to the DASH in relation to socioeconomic position in the UK
- To quantify the mediating effect of income on the relationship between education and the DASH score

METHODS AND MATERIALS

Data Source

Analysis was done on three grouped waves (2008-2012, 2013-2014, 2015-2016) of the UK National Diet and Nutrition Survey (NDNS) data. The NDNS is an annual rolling cross-sectional survey carried out on behalf of Public Health England and the Food Standards Agency. It is designed to assess the diet, nutrient intake and nutritional status of a representative sample of UK adults and children. Households were randomly sampled from the U.K. Postcode Address File, with one adult and one child (18 months or older) or one child selected for inclusion. All subjects aged 18 years and older at the time of interview with available data on dietary records, education and income were included. Energy intakes below 500 kcal or above 5000 kcal per day were excluded as implausible total daily intakes (43, 44). Sociodemographic data, lifestyle behaviours, dietary habits, use of medications and dietary supplements were collected during a computer-assisted personal interview. Written informed consent was obtained from participants or their parents/guardians. The survey was conducted according to the Declaration of Helsinki guidelines. Ethical approval for the NDNS was obtained from the Oxfordshire A Research Ethics Committee and the Cambridge South NRES Committee (Ref. No. 13/EE/0016) (43, 44).

Interview

Within the NDNS sociodemographic data, lifestyle behaviours, dietary habits, use of medications and dietary supplements were collected during a computer-assisted personal interview.

Dietary Records

Respondents were asked to complete a dietary record for four chosen consecutive days (including weekends and weekdays), giving a detailed description of each item consumed, the time of consumption, and amount, using household measures and photographs. Participants recorded brand names for foods wherever possible and were asked to collect the food label information/wrappers for any unusual foods and ready meals consumed to help coders identify or clarify items. For homemade dishes participants were asked to record on a separate page in the diary the individual ingredients and quantities for the whole dish along with a brief description of the cooking method and how much of the dish the participant had consumed. Information on missing food items was collected on repeat visits by interviewers. Trained diet coders then entered the food intake data from completed recordings using an in-house dietary assessment system DINO (Diet In Nutrients Out). The food composition data used was the Department of Health's NDNS Nutrient Databank. Coders attempted to match each food or drink item with a food code and a portion code from DINO. Where the coder could not resolve the food or portion consumed, the entry was flagged as a query for action by an editor who had greater nutrition knowledge and experience. For a random 10% of all diaries the editors also undertook a further 100% check of all food and portion code entries (43, 44).

Measurement of dietary quality

The primary outcome of the study was the DASH score, while average daily intakes of fruit and vegetables were considered as secondary outcomes. The DASH score was computed according to the method described in Fung et al., where points (from 1 to 5) were assigned based on sex-specific quintiles of intake in order of most consumption for fruit; vegetables (excluding potatoes); whole grains; low-fat dairy products; nuts, seeds and legumes (13). Quintiles for red and processed meats, free sugar and sodium were assigned 1-5 points in order of least consumption. According to this algorithm the overall DASH score ranged between 8 (lowest compliance) and 40 points (highest compliance) (13). To compute the DASH score, we retrieved variables from the NDNS food and nutrient database, which included nutrient and granular food level information for each subject. Using disaggregated foods from the database, we derived the intakes of whole grains, low fat dairy products, nuts, seeds and legumes as well red and processed meats. Collectively, this information was then used to compute the DASH score.

Variables of socioeconomic position (SEP)

We used three main classifications to define the SEP of the individuals:

Income

Total household income over the previous 12 months was equalised to adjust for the presence of other adults and children in the household. The median values of each household income over each year was then used to categorise the income into quartiles in Paper 2.

For the mediation analysis in paper 3, income was equivalised to allow comparison across households of different size and composition. Total disposable household income includes income contributions from earnings, state support, pensions and investment income over the previous 12 months and is net of tax. Each household member was given a standard weight (0.67 for the first adult, 0.33 for other adults, 0.20 for each additional child aged less than 14 years and 0.33 for each additional child aged 14 and over). Then household income was divided by the sum of the standard weights. Low equivalised household income as defined by income below £ 304 per week over the previous 12 months (i.e. 15,850 £ per year) was considered as a mediator of the relationship between education and adherence to the DASH diet. Income was equivalised to adjust for the presence of other adults and children in the household(45).

Education

For Paper 2 analysis the eight original categories for the highest educational qualification were merged into the following four categories:

a. Degree or equivalent
b. Higher educational, below degree level
c. GCSE
d. No qualification

Those in categories “Still in full-time education” or “Foreign education” were included as ‘Other’.

For the mediation analysis in paper 3, highest level of attained education was the exposure of this study. We reclassified the eight original categories for the highest educational qualification into the following four categories: Degree or equivalent [1], Higher educational, below degree level [2], General Certificate of Secondary Education (GCSE) [3-5] and No qualification [7]. The original categories 3 to 5 were merged in the same category (GCSE) since these categories correspond to academic school-leaving qualifications typically completed between 16-18 years or vocational courses of equivalent level. We excluded: “foreign or other qualifications” [6] since this category included individuals with different levels of education, full-time students [8] (i.e. they had not completed their education program), and individuals with missing values.

Occupational social class.

The occupational social class of the survey household reference person was reported in paper 2 and 3 were according to the NS-SEC8 categorisation (routine; semi-routine; lower supervisory and technical, small employers and own account holders; intermediate; lower managerial and professional; higher managerial and professional). Those in the eighth category ‘never worked’ and ‘long-term unemployed’ were excluded.

Data Analysis

In Paper 2 multiple linear regression models were used to evaluate the association between socioeconomic variables and the DASH score. The models included terms for sex, age (as linear and quadratic term to account for nonlinear relationship between age and the DASH score), socioeconomic variable, survey year and an interaction term between the socioeconomic variable and the survey year. The likelihood ratio test was used to test the statistical significance of each term. All statistical tests were two-sided with α=0.05.

Since the distribution of each component of the DASH score was highly skewed, quantile regression analysis was performed to model the median intake of each component as a function of the socioeconomic variable and the survey year. These models included the same set of terms used in the main analysis for Paper 2.

All analyses for Paper 2 were performed using R (version 3.5.0) and quantile regression models were fitted using the package “quantreg”.

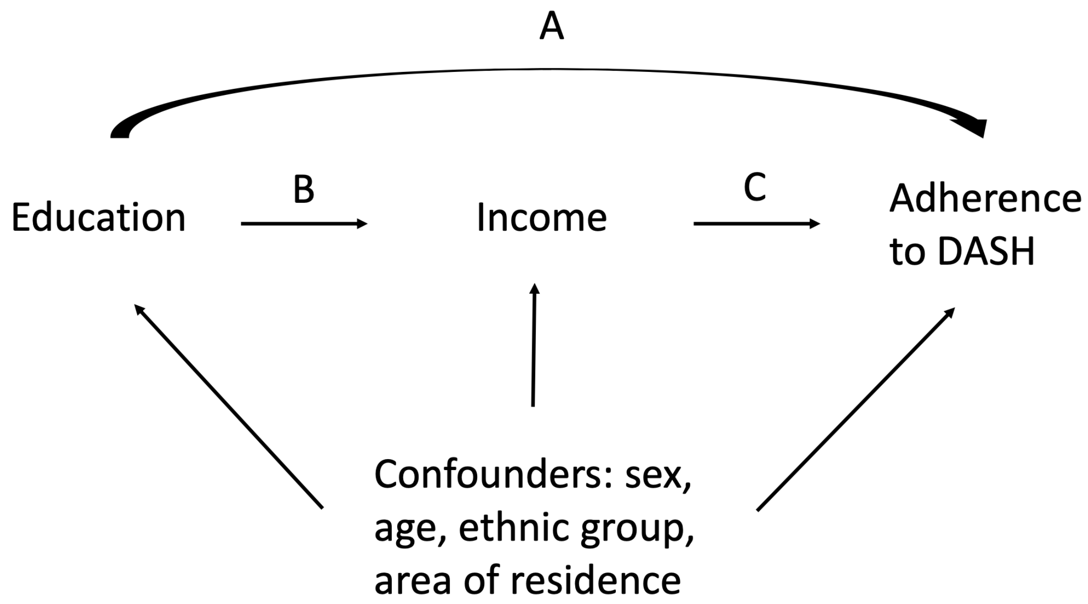
Statistical Analysis for mediation

Mediator

In Paper 3, total disposable household income includes income contributions from earnings, state support, pensions and investment income over the previous 12 months and is net of tax. It was equivalised to adjust for the presence of other adults and children in the household, in order to allow comparisons across households of different size and composition (23). Each household member was given a standard weight (0.67 for the first adult, 0.33 for other adults, 0.20 for each additional child aged less than 14 years and 0.33 for each additional child aged 14 and over (23). Then, household income was divided by the sum of the standard weights. Equivalised household income as defined by income below or above £ 304 per week over the previous 12 months (i.e. 15,850 £ per year) was considered as a mediator of the relationship between education and adherence to the DASH diet.

Sociodemographic characteristics and outcome measures across educational levels were compared using χ^2 test for categorical variables or Wilcoxon rank sum test for continuous variables. When the overall tests gave significant results, the highest level of education was compared with each other level applying the Bonferroni correction for multiple comparisons (i.e. the differences between groups were considered significant at α = 0.017, 0.05/3 comparisons). A counterfactual-based mediation analysis to decompose the total effect of education on DASH score into average direct effect (ADE) and average causal mediation effect (ACME) mediated by income was carried out (46).

Figure 1 shows the causal relationship hypothesized in the mediation analysis. We performed the mediation analysis also on the secondary outcomes (i.e., fruit and vegetables intake). It is a directed acyclic graph showing the relationship between education and adherence to the dietary approach to stop hypertension (DASH). Arrow A displays the average direct effect (ADE) of education on adherence to DASH, while path B + C displays the average causal mediation effect (ACME) mediated by low income. The sum of ADE and ACME gives the total effect. The last three arrows display the confounding variables.



The ADE represents the expected difference in the potential value of DASH score when the level of education is changed but income is held constant at the value that would take if education equals the exposed category. The ACME represents the expected difference in the potential value of DASH score when income takes the value that would take under the exposed education category as opposed to the reference category, while education is held constant. The two quantities add up to the estimated total effect of education on DASH score. The proportion of total effect mediated by income was also computed as the ratio between ACME and total effect. Confidence intervals (CI) at 95% level were obtained by bootstrap with 1000 replications.

The estimate of these quantities requires a system of equations with two different regression models: a model for the outcome and a model for the mediator. For the primary outcome, we used a linear regression, while for the secondary outcomes we modelled the median values using quantile regression models to account for the skewed distribution of fruit and vegetable intakes. For the mediator, we fitted a binomial regression model with probit link function. The model for the mediator included terms for education, sex, age (as linear and quadratic term to account for nonlinear relationship between age and income or DASH score), ethnic group (white or others) and area of residence as dependent variables, while the model for the outcome included the same set of predictors plus income.

We also tested the interaction between income and education, and since it did not yield statistically significant results, we did not include it in the models. In addition, we tested if the magnitude of ACME differed among sexes, age-groups (individuals aged less than 65 years *vs* 65 and over) and areas of residence by performing a moderated mediation analysis. To perform the moderated mediation analysis, we fit the mediator and the outcome models including the moderator and its interaction terms with respect to education and income. To run the mediation analysis, we used the R package “mediation”, and to test the difference between the mediation effects among moderator strata, we used the “test.modmed” function. All tests were two-sided with a threshold for significance set at 0.05 (47).

RESULTS

Dietary approach to stop hypertension (DASH) diet and associated socioeconomic inequalities in the United Kingdom (Paper 2).

Paper 2 cohort included 6435 adults (3757 women and 2678 men). **Table 1** gives their demographic and socioeconomic characteristics by survey year. More women were enrolled in each wave of the survey and the proportion of men and women did not change over the period. More than 90% of subjects were whites, although the proportion of non-whites increased over the period. Mean age was 48 years (range: 18-96 years) with no significant differences across survey years. One fourth of subjects were obese and almost one third overweight, and these figures remained constant over the period. The proportion of less educated individuals significantly decreased, while there was no difference in the proportion of individuals engaged in routine occupations. Household income also tended to increase over the period.

Table 1. Demographic and socioeconomic characteristics of the study population by survey year.

	2008	2009	2010	2011	2012	2013	2014	2015	p for trend
Sex									
Males	355 (42.4)	370 (43.5)	365 (43.9)	430 (39.6)	264 (40.2)	265 (38.6)	336 (45.4)	293 (39.2)	0.211
Females	482 (57.6)	480 (56.5)	466 (56.1)	655 (60.4)	393 (59.8)	422 (61.4)	404 (54.6)	455 (60.8)	
Age									
Mean (SD)	48.1 (18.3)	48.2 (18.4)	47.3 (18.5)	48.9 (17.6)	48.7 (18.3)	48.7 (18.6)	48.9 (19.2)	48.6 (18.2)	0.205
Race									
White	787 (94.0)	802 (94.4)	772 (92.9)	1021 (94.1)	599 (91.2)	638 (92.9)	681 (92.0)	672 (89.8)	0.001
Other	50 (6.0)	48 (5.6)	59 (7.1)	64 (5.9)	58 (7.8)	49 (7.1)	59 (8.0)	69 (10.2)	
BMI category									
<18.5	11 (1.3)	15 (1.8)	13 (1.6)	15 (1.4)	15 (2.3)	9 (1.3)	14 (1.9)	10 (1.3)	0.946
18.5-24.9	279 (33.3)	272 (32.0)	270 (32.5)	322 (29.7)	231 (35.2)	229 (33.3)	228 (30.8)	236 (31.6)	
25.0-30.0	292 (34.9)	290 (34.1)	274 (33.0)	353 (32.5)	222 (33.8)	236 (34.4)	252 (34.1)	248 (33.2)	
>=30	210 (25.1)	229 (26.9)	212 (25.5)	318 (29.3)	151 (23.0)	188 (27.4)	189 (25.5)	191 (25.5)	
Not available	45 (5.4)	44 (5.2)	62 (7.5)	77 (7.1)	38 (5.8)	25 (3.6)	57 (7.7)	63 (8.4)	
Education									0.006
Degree or equivalent	168 (20.1)	169 (19.9)	187 (22.5)	227 (20.9)	172 (26.2)	151 (22.0)	179 (24.2)	208 (27.8)	
Higher education, below degree level	218 (26.0)	190 (22.4)	211 (25.4)	298 (27.5)	148 (22.5)	143 (20.8)	153 (20.7)	152 (20.3)	
GCSE	168 (20.1)	181 (21.3)	168 (20.2)	225 (20.7)	112 (17.0)	162 (23.6)	153 (20.7)	154 (20.6)	
No qualification	212 (25.3)	225 (26.5)	173 (20.8)	256 (23.6)	148 (22.5)	134 (19.5)	155 (20.9)	157 (21.0)	
Other	71 (8.5)	85 (10.0)	92 (11.1)	79 (7.3)	77 (11.7)	97 (14.1)	100 (13.5)	77 (10.3)	
Occupation									0.858
Higher managerial and professional occupations	109 (13.0)	110 (12.9)	119 (14.3)	141 (13.0)	128 (19.5)	106 (15.4)	115 (15.5)	109 (14.6)	
Lower managerial and professional occupations	207 (24.7)	229 (26.9)	210 (25.3)	255 (23.5)	151 (23.0)	158 (23.0)	173 (23.4)	175 (23.4)	
Intermediate occupations	79 (9.4)	65 (7.6)	89 (10.7)	113 (10.4)	64 (9.7)	83 (12.1)	65 (8.8)	65 (8.7)	
Small employers and own account workers	88 (10.5)	85 (10.0)	95 (11.4)	118 (10.9)	71 (10.8)	68 (9.9)	88 (11.9)	90 (12.0)	
Lower supervisory and technical occupations	97 (11.6)	98 (11.5)	84 (10.1)	86 (7.9)	58 (8.8)	51 (7.4)	67 (9.1)	63 (8.4)	
Semi-routine occupations	111 (13.3)	123 (14.5)	106 (12.8)	170 (15.7)	80 (12.2)	105 (15.3)	98 (13.2)	124 (16.6)	
Routine occupations	104 (12.4)	101 (11.9)	93 (11.2)	157 (14.5)	65 (9.9)	76 (11.1)	101 (13.6)	92 (12.3)	
Never worked	20 (2.4)	21 (2.5)	29 (3.5)	20 (1.8)	21 (3.2)	26 (3.8)	28 (3.8)	19 (2.5)	
Other	22 (2.6)	18 (2.1)	6 (0.7)	18 (1.7)	19 (2.9)	11 (1.6)	3 (0.4)	6 (0.8)	
Not available	0 (0.0)	0 (0.0)	0 (0.0)	7 (0.6)	0 (0.0)	3 (0.4)	2 (0.3)	5 (0.7)	
Income (thousands)									
Median (Q1-Q4)	25.6 (12.3-44.1)	26.9 (12.8-45.1)	27.5 (13.1-42.5)	23.9 (12.3-45.1)	24.7 (12.9-47.5)	26.2 (12.5-45.1)	27.5 (12.9-45.0)	27.8 (12.5-49.2)	0.059
Not available	112 (13.4)	105 (12.4)	124 (14.9)	188 (17.3)	82 (12.5)	97 (14.1)	108 (14.6)	111 (14.8)	

Q: Quantile, SD: Standard Deviation

Table 2 shows the mean values of the DASH score across socioeconomic groups. Less educated individuals, those engaged in routine occupations and subjects with lower incomes had lower values of the score compared to the individuals with higher socioeconomic positions.

Table 2. DASH score according to socioeconomic groups and survey years.

SEP variable	2008	2009	2010	2011	2012	2013	2014	2015	SEP effect (p value) [a]	Survey year effect (p value) [a]	SEP x Survey year effect (p value) [a]
Education											
Degree or equivalent	25.5 (5.4)	25.8 (4.9)	25.4 (5.3)	24.9 (5.3)	26.4 (5.1)	26.5 (5.3)	26.4 (5.0)	26.1 (5.2)	<0.0001	<0.0001	0.192
Higher education, below degree level	22.9 (5.5)	23.8 (5.2)	23.4 (5.4)	23.8 (5.3)	24.3 (4.9)	24.1 (5.5)	23.4 (5.4)	24.4 (5.1)			
GCSE	22.0 (5.5)	22.1 (5.9)	21.8 (5.6)	22.3 (5.5)	23.6 (6.2)	23.5 (5.4)	23.9 (5.8)	24.0 (6.2)			
No qualification	22.5 (5.2)	22.5 (5.2)	23.3 (5.3)	24.2 (5.1)	23.6 (4.9)	23.2 (5.2)	23.5 (4.6)	24.4 (5.0)			
Occupation											
Higher managerial and professional occ.	24.9 (4.9)	25.2 (4.9)	25.9 (5.0)	25.5 (5.4)	26.3 (5.2)	25.4 (5.4)	25.3 (5.1)	26.3 (5.2)	<0.0001	<0.0001	0.120
Lower managerial and professional occ.	23.7 (5.6)	24.3 (5.5)	24.0 (5.3)	24.7 (5.2)	24.1 (5.5)	25.4 (5.4)	25.4 (5.2)	25.6 (5.5)			
Intermediate occupations	22.5 (5.3)	23.2 (5.1)	23.3 (5.4)	23.9 (5.6)	24.2 (5.6)	23.9 (5.4)	24.3 (5.6)	24.4 (5.1)			
Small employers and own account workers	24.0 (5.6)	23.9 (5.8)	23.0 (5.0)	24.0 (5.2)	24.9 (4.6)	24.0 (5.0)	24.9 (5.3)	23.7 (5.4)			
Lower supervisory and technical occ.	22.6 (5.1)	23.0 (5.5)	23.0 (5.9)	23.3 (5.4)	24.2 (5.6)	22.3 (5.9)	23.0 (5.6)	25.0 (5.0)			
Semi-routine occ.	22.3 (5.4)	22.4 (5.5)	21.9 (5.3)	22.4 (5.3)	24.1 (5.4)	23.2 (5.0)	23.4 (5.1)	24.2 (5.7)			
Routine occ.	21.0 (6.0)	20.9 (5.3)	21.3 (5.5)	22.8 (5.4)	22.5 (5.3)	23.2 (5.5)	22.6 (5.2)	23.1 (5.1)			
Hoisehold income											
<Q1	21.5 (5.2)	21.3 (5.4)	22.6 (5.6)	22.5 (5.4)	23.0 (5.2)	22.5 (5.1)	22.7 (5.9)	23.6 (5.9)	<0.0001	<0.0001	0.942
Q1-Q2	22.7 (5.9)	23.0 (5.8)	22.1 (5.3)	23.5 (6.0)	24.2 (5.4)	23.3 (5.3)	23.8 (5.8)	24.6 (5.7)			
Q2-Q3	23.6 (5.5)	23.7 (5.5)	23.4 (5.5)	23.8 (5.1)	24.0 (5.9)	24.8 (5.5)	24.2 (5.0)	24.7 (5.3)			
Q3-Q4	23.4 (5.7)	24.4 (5.6)	23.8 (5.5)	24.5 (5.2)	24.5 (5.6)	24.3 (5.5)	25.5 (4.9)	25.0 (5.5)			
>=Q4	23.9 (5.2)	24.7 (5.0)	25.2 (4.9)	24.5 (5.1)	26.3 (5.0)	25.8 (5.3)	25.1 (5.2)	25.9 (5.3)			

Data are mean (Standard deviations)
Q: Quintile, SEP: Socieconomic position
[a] *p* values were obtained from likelihood ratio test comparing multiple linear regression models with and without the term. The models included also sex, age (centered at mean), age^2 and ethnic group (whites and non-whites) as covariates.

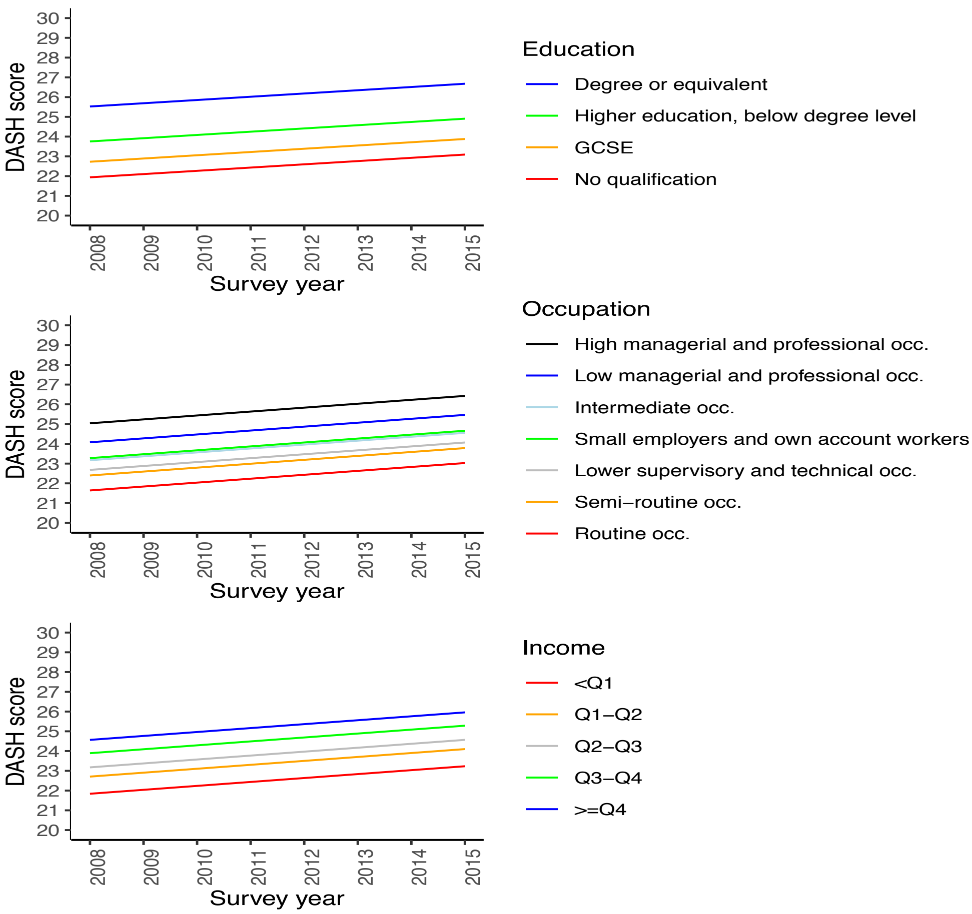
The regression models in **Table 3** showed a positive and significant effect of the survey year, indicating that the DASH score increased over the period, while the interaction term between the survey year and the socioeconomic variables was not significant showing that the trend was not different across socioeconomic groups. In model 1 the estimated difference between people with no qualification and those having the highest level of education was -3.59 points (95% CI: -3.91; -3.20). Similarly, in model 2 the difference between people engaged in routine occupations and those engaged in high managerial and professional occupations was -3.40 points (95% CI: -3.87; -2.92), and in model 3 the difference between subjects in the first fifth and last fifth of the household income distribution was -2.73 points (95% CI: -3.16; -2.29). A gradient relationship between DASH score and all socioeconomic variables emerged, with increasing values of the score at higher socioeconomic positions (**Figure 2**).

Table 3. Results of the multiple linear regression models used to evaluate the relationship between socioeconomic variables and the DASH score

	Model #1	Model #2	Model #3
Parameter	β (95% CI)	β (95% CI)	β (95% CI)
Intercept	25.12 (22.31; 23.93)	22.05 (21.27; 22.83)	21.18 (20.37; 21.98)
Female sex	0.42 (0.16; 0.68)	0.55 (0.29; 0.80)	0.52 (0.25; 0.80)
Non-white	1.82 (1.28; 2.35)	2.24 (1.74; 2.75)	2.67 (2.13; 3.20)
Age (centered to the mean)	0.121 (0.113; 0.129)	0.100 (0.093; 0.107)	0.102 (0.095; 0.110)
Age^2	-0.0019 (-0.0023; -0.0015)	-0.0018 (-0.0022; -0.0015)	-0.0014 (-0.0018; -0.0010)
Education			
Degree or equivalent	1	.	.
Higher education below degree level	-1.77 (-2.13; -1.41)	.	.
GCSE	-2.80 (-3.17; -2.42)	.	.
No qualification	-3.59 (-3.91; -3.20)	.	.
Occupation			
High managerial and professional	.	1	
Low managerial and professional	.	-0.96 (-1.37; -0.55)	.
Intermediate	.	-1.87 (-2.38; -1.36)	.
Small employers and own account workers	.	-1.76 (-2.25; -1.27)	.
Lower supervisory and technical	.	-2.38 (-2.87; -1.84)	.
Semi routine	.	-2.64 (-3.10; -2.18)	
Routine	.	-3.40 (-3.87; -2.92)	.
Household income			
>=Q4	.	.	1
Q3-Q4	.	.	-0.67 (-1.11; -0.24)
Q2-Q3	.	.	-1.39 (-1.82; -0.96)
Q1-Q2	.	.	-1.86 (-2.29; -1.43)
<Q1	.	.	-2.73 (-3.16; -2.29)
Survey year	0.16 (0.11; 0.22)	0.20 (0.14; 0.25)	0.20 (0.14; 0.26)

CI: Confidence intervals, Q: Quintile

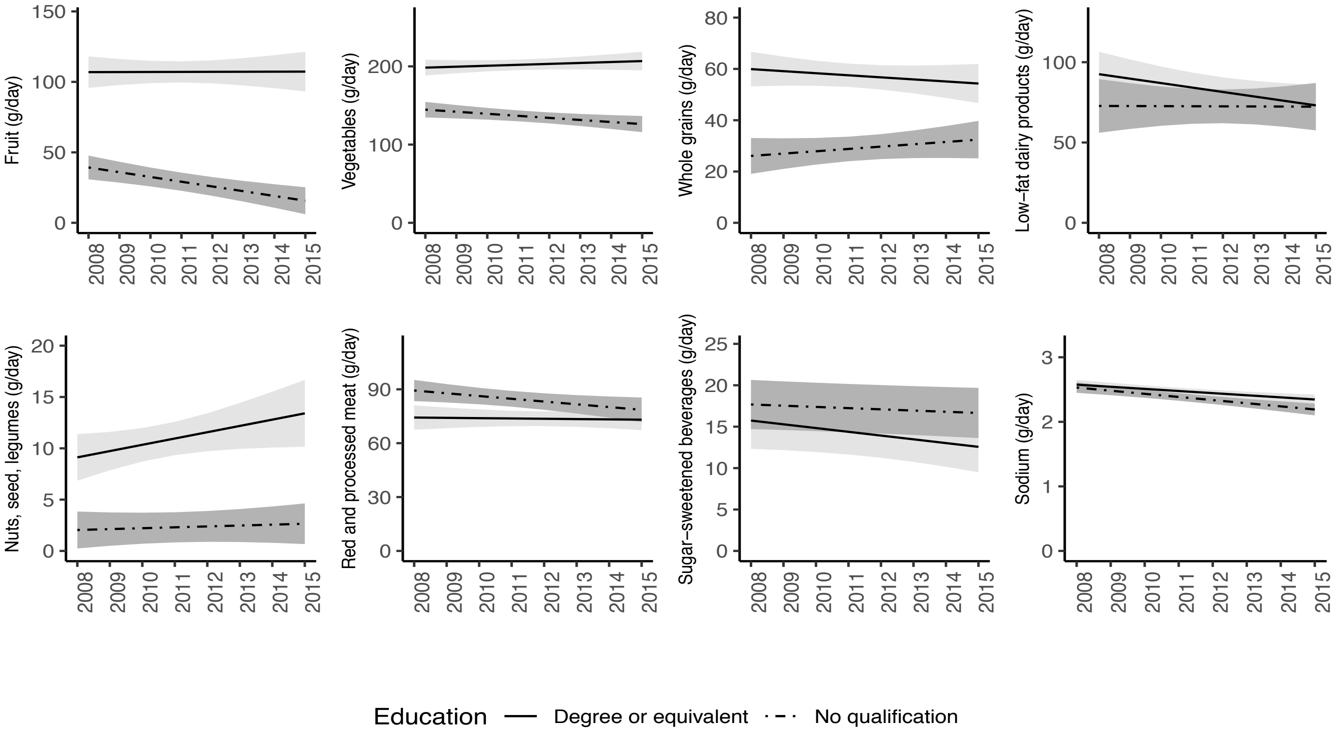
Figure 2. Estimated trends of DASH score by socioeconomic groups.



The figure shows the model predicted values for white male individuals of age equal to the population mean.

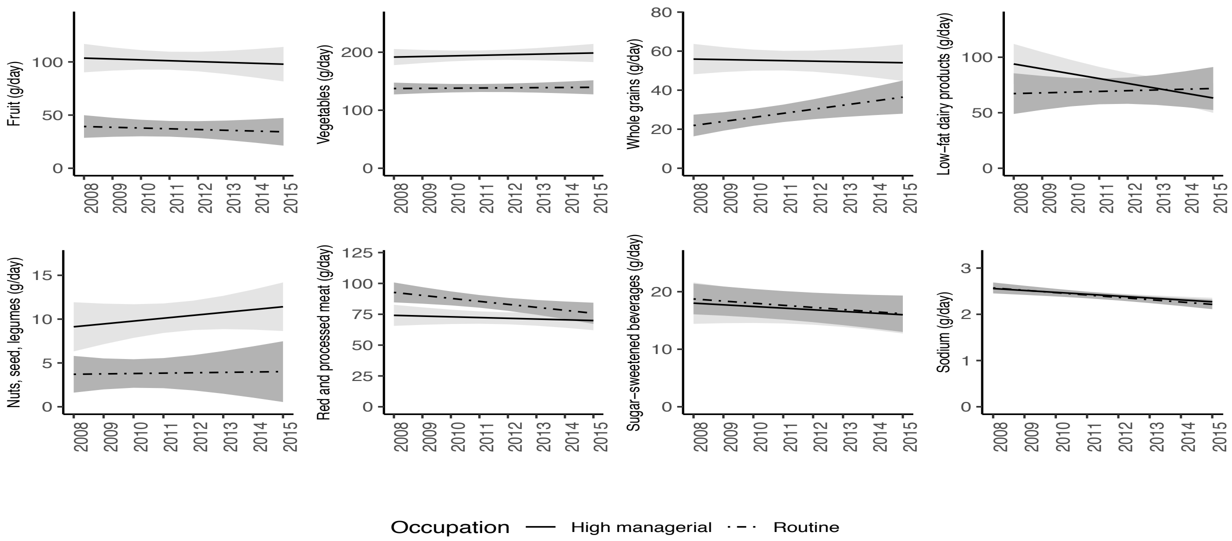
Figures S1-S3 in show the trend in median intake of each component of the DASH score estimated for the extreme categories of education, occupation and household income, respectively. The widest socioeconomic differences emerged for consumption of fruit, vegetables, whole grains, nuts, seeds and legumes. Over the period, consumption of fruit and vegetables decreased in less educated individuals; consumption of whole grains increased among those engaged in routine occupations and those with the highest income; consumption of nuts, seeds and legumes increased in all the highest socioeconomic groups; consumption of red and processed meat decreased among all the lowest socioeconomic groups; consumption of sugar sweetened beverages decreased among individuals with the highest income; sodium intake decreased in all groups.

Figure S1. Estimated trends of median intake of each DASH score component according to educational level.



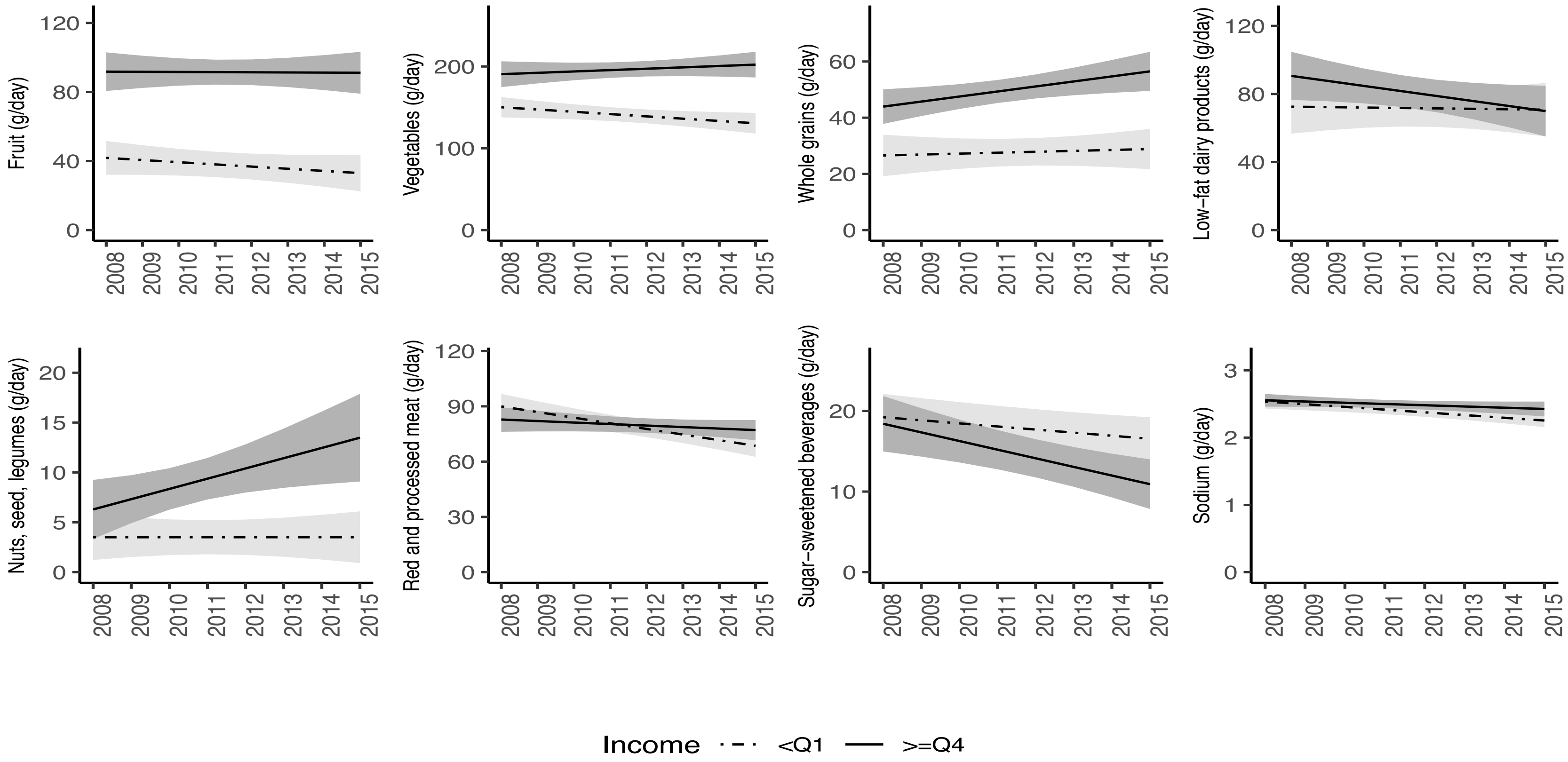
The figure shows the quantile regression predicted values for white men and the corresponding 95% confidence interval (shaded bands) of age equal to the population mean.

Figure S2. Estimated trends of median intake of each DASH score component according to the National Statistics Socioeconomic Classification.



The figure shows the quantile regression predicted values for white men of age equal to the population mean.

Figure S3. Estimated trends of median intake of each DASH score component according to quintiles of household income.



The figure shows the quantile regression predicted values for white men of age equal to the population mean.

Educational inequality in the dietary approach to stop hypertension (DASH) diet in the UK: evaluating the mediating role of low income (Paper 3).

Table 4 shows the distribution of sociodemographic characteristics of the study population by educational level. We included 4864 subjects (2055 males and 2809 females). Graduated compared to not qualified individuals were younger (median age: 43 vs 63 years), more likely non-whites (12.7% *vs* 3.2%) and had a higher household income (median income: 41.100 *vs* 17.500 £ per year).

Table 4. Sociodemographic characteristics of the study population by educational level.

	Degree or equivalent N = 1295	Higher education, below degree level N = 1334	GCSE N = 1094	No qualification N = 1141	All levels N = 4864	*P* value [a]
Sex						0.78
Males	536 (41.4)	566 (42.4)	458 (41.9)	495 (43.4)	2055 (42.2)	
Females	759 (58.6)	768 (57.6)	636 (58.1)	646 (56.6)	2809 (57.8)	
Age						
Median (IQR)	43 (34-55)	45 (34-56)	46 (36-58)	63 (49-73)	48 (36-62)	<0.001[c,d]
Ethnic group						<0.001[b,c,d]
White	1129 (87.3)	1265 (95.0)	1047 (95.9)	1105 (96.8)	4546 (93.5)	
Other	164 (12.7)	67 (5.0)	45 (4.1)	36 (3.2)	312 (6.4)	
Area of residence						
England: North	213 (16.4)	221 (16.6)	212 (19.4)	185 (16.2)	831 (17.1)	<0.001[b,c,d]
England: Central/Midlands	170 (13.1)	165 (12.4)	130 (11.9)	129 (11.3)	594 (12.2)	
England: South (incl. London)	444 (34.3)	375 (28.1)	311 (28.4)	230 (20.2)	1360 (28.0)	
Scotland	188 (14.5)	237 (17.8)	147 (13.4)	195 (17.1)	767 (15.8)	
Wales	137 (10.6)	177 (13.3)	161 (14.7)	194 (17.0)	669 (13.8)	
Northern Ireland	143 (11.0)	159 (11.9)	133 (12.2)	208 (18.2)	643 (13.2)	
Income (£ per year, thousands)						
Median (IQR)	41.1 (27.5-61.6)	28.7 (17.5-40.6)	22.2 (12.9-32.5)	17.5 (12.3-28.7)	27.5 (16.4-42.5)	<0.001[b,c,d]
Low (< 15.85)	109 (8.4)	254 (19.0)	337 (30.8)	443 (38.8)	1143 (23.5)	
High (≥ 15.85)	1186 (91.6)	1080 (81.0)	757 (69.2)	698 (61.2)	3721 (76.5)	

[a] Chi-squared test for categorical variables; Wilcoxon rank sum test for continuous variables.
[b,c,d] denote the significant results of the comparisons across levels of education after applying the Bonferroni correction for multiple comparisons: b) “Higher education, below degree level” significantly differs from “Degree or equivalent” c) GCSE significantly differs from “Degree or equivalent”, d) “No qualification” significantly differs from “Degree or equivalent”.
GCSE: General Certificate of Secondary Education; IQR: Interquartile Range.

Table 5 shows the mean values of DASH score and the median values of fruit and vegetable consumption across the educational levels. The mean values of DASH score were 25.6 in the group of graduated individuals, 23.6 in those with a high education below the degree, and around 23 in the lower education levels. Fruit and vegetables consumption increased with the increasing of education levels.

Table 5. DASH score, fruit and vegetable consumption according to educational level.

	Degree or equivalent	Higher education, below degree level	GCSE	No qualification	*P* value [a]
DASH score, mean (SD)	25.6 (5.2)	23.6 (5.4)	22.8 (5.8)	23.2 (5.2)	<0.001[b,c,d]
Fruit (g), median (IQR)	110 (45-184)	75 (20-148)	54 (5-134)	50 (4-120)	<0.001[b,c,d]
Vegetables (g), median (IQR)	197 (138-269)	161 (106-229)	147 (94-214)	134 (85-195)	<0.001[b,c,d]

[a] Wilcoxon rank sum test for continuous variables.
[b,c,d] denote the significant results of the comparisons across levels of education after applying the Bonferroni correction for multiple comparisons: b) "Higher education, below degree level" significantly differs from "Degree or equivalent" c) GCSE significantly differs from "Degree or equivalent", d) "No qualification" significantly differs from "Degree or equivalent".
DASH: Dietary approach to stop hypertension; GCSE: General Certificate of Secondary Education; IQR: Interquartile Range; SD: Standard Deviation.

Table 6 gives the results of the mediation analysis. Being in the "higher education below degree level", GCSE level and "no qualification" categories showed average differences in DASH score (i.e., total effect) of -1.81 (95% CI: -2.21 to -1.45), -2.81 (95% CI: -3.20 to -2.34) and -3.58 (95% CI: -4.03 to -3.16), respectively, as compared to "degree or equivalent". The proportion of these differences mediated by income were 6.1%, 8.3% and 8.8%, respectively. Similar patterns, though with greater proportion mediated, emerged for total fruit and vegetables intake. The proportion mediated on total fruit intake was 6.5% for "higher education below degree level", 9.6% for GCSE level, and 9.2% for "no qualification". Corresponding figures for total vegetable intake were 7.4% for "higher education below degree level", 10.8% for GCSE level, and 10.5% for "no qualification".

Table 6. Decomposition of the total effect of education on adherence to DASH diet, fruit and vegetable consumption into direct and indirect effect mediated through low income and corresponding 95% confidence intervals. Reference category: degree or equivalent.

	Higher education, below degree level	GCSE	No qualification
DASH score			
ACME	-0.11 (-0.16; -0.07)	-0.23 (-0.32; -0.14)	-0.31 (-0.45; -0.21)
ADE	-1.70 (-2.10; -1.33)	-2.58 (-2.98; -2.09)	-3.27 (-3.72; -2.83)
Total effect	-1.81 (-2.21; -1.45)	-2.81 (-3.20; -2.34)	-3.58 (-4.03; -3.16)
Proportion mediated	6.1 (3.6; 9.0)	8.3 (5.0; 12.0)	8.8 (5.6; 13.0)
Total fruit			
ACME	-2.2 (-3.4; -1.5)	-4.9 (-6.7; -3.6)	-6.9 (-9.7; -5.1)
ADE	-31.1 (-38.9; -20.8)	-46.6 (-54.3; -35.2)	-68.0 (-75.8; -56.0)
Total effect	-33.3 (-41.4; -23.2)	-51.6 (-59.3; -40.2)	-74.9 (-82.3; -64.1)
Proportion mediated	6.5 (4.5; 12.0)	9.6 (6.8; 14.0)	9.2 (6.7; 14.0)
Total vegetables			
ACME	-2.5 (-3.8; -1.4)	-5.0 (-6.7; -3.3)	-6.8 (-9.3; -4.6)
ADE	-31.0 (-39.2; -22.3)	-40.8 (-50.1; -32.8)	-57.8 (-67.2; -48.7)
Total effect	-33.5 (-41.5; -24.7)	-45.8 (-55.1; -37.5)	-64.6 (-74.6; -55.2)
Proportion mediated	7.4 (4.1; 11.0)	10.8 (6.9; 15.0)	10.5 (7.1; 15.0)

ACME: Average causal mediation effect; ADE: Average direct effect; DASH: Dietary approach to stop hypertension; GCSE: General Certificate of Secondary Education.

The regression models used for the mediation analysis are reported in the **Supplements**, **Table S1**. Education was directly related to income and it was also directly related to DASH score, fruit and vegetables intakes, after controlling for income. Income, in turn, was also directly associated with higher values of the DASH score, fruit and vegetable intakes.

Supplemental Table S1. Results of the regression models for the mediator and for the outcomes.

	Model for the mediator[a]	Models for the outcome[b]		
	Dependent variable: Income	Dependent variable: DASH score	Dependent variable: Fruit intake	Dependent variable: Vegetable intake
Predictors	ß (SE)	ß (SE)	ß (SE)	ß (SE)
Intercept	1.483 (0.221) ***	12.997 (0.779) ***	-40.377 (15.144) ***	38.290 (15.409) ***
Education				
Degree or equivalent	Ref.	Ref.	Ref.	Ref.
Higher education, below degree level	0.548 (0.058) ***	-1.703 (0.199) ***	-31.138 (4.577) ***	-30.987 (4.425) ***
GCSE	0.042 (0.062) ***	-2.576 (0.213) ***	-46.649 (4.565) ***	-40.841 (4.495) ***
No qualification	1.201 (0.069) ***	-3.266 (0.228) ***	-67.951 (4.680) ***	-57.797 (4.909) ***
Income				
High	-	Ref.	Ref.	Ref.
Low	-	-0.996 (0.179) ***	-20.964 (3.288) ***	-20.729 (3.581) ***
Sex				
Male	Ref.	Ref.	Ref.	Ref.
Female	0.192 (0.043)***	0.452 (0.147) **	15.236 (3.107) ***	-0.926 (3.143)
Ethnic group				
White	Ref.	Ref.	Ref.	Ref.
Non-white	0.600 (0.084) ***	2.111 (0.305) ***	16.704 (7.971) *	43.248 (6.396) ***
Area of residence				
England: North	Ref.	Ref.	Ref.	
England: Central/Midlands	0.083 (0.078)	-0.077 (0.271)	6.177 (5.614)	4.254 (5.778)
England: South (incl. London)	-0.170 (0.065) **	0.607 (0.222) **	19.355 (4.847) ***	9.238 (5.029)
Scotland	0.071 (0.072)	-0.409 (0.252)	9.472 (5.199)	-13.003 (5.214) *
Wales	-0.029 (0.074)	0.319 (0.262)	10.007 (5.165)	-1.088 (5.890)
Northern Ireland	0.191 (0.0735) **	-0.068 (0.267)	10.344 (5.133) *	-16.045 (4.686) ***
Age	-0.031 (0.007) ***	0.299 (0.025) ***	2.983 (0.436) ***	4.410 (0.475) ***
Age^2	0.0025 (0.00006) ***	-0.0018 (0.0002) ***	-0.015 (0.004) ***	-0.037 (0.005) ***

DASH: Dietary approach to stop hypertension; GCSE: General Certificate of Secondary Education; SE: standard error.

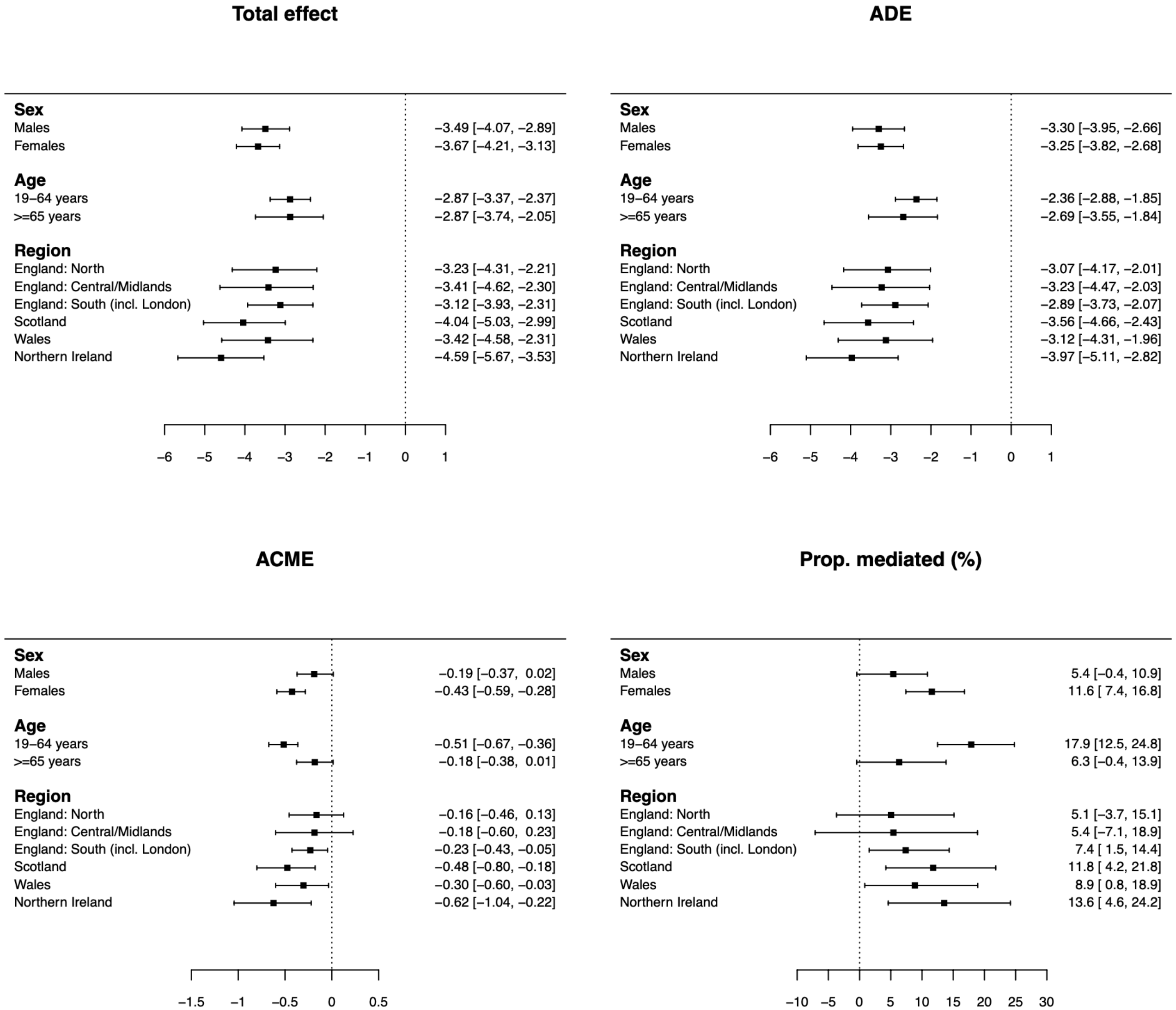
[a] A binomial regression model with probit link function was used to estimate the mediator. Income was categorized as low (<15,850 £ per year) and high (≥15,850 £ per year).

[b] A linear regression model was used to estimate the DASH score, while quantile regression models were used to estimate fruit and vegetables intake.

* <0.05 **<0.01 ***<0.001

Figure 3 shows the results of the moderation analysis of the mediated effect of income on the relationship between education and adherence on DASH score, according to sex, age and area of residence. The mediating effect were significantly different among strata of sex and age group (*P*= 0.042 and *P*= 0.018, respectively). The proportions mediated were greater for females (11.6%) compared to males (5.4%), and for individuals aged below 65 years (17.9%) compared to older ones (6.3%). A greater mediating effect was observed in Scotland and Northern Ireland as compared to England, however the differences were not significant (*P*= 0.42 and *P*= 0.11, respectively).

Figure 3. Moderation analysis of the mediated effect of low income on the relationship between education and adherence on DASH score



DISCUSSION

Discussion of main findings

The main findings of Paper 2 indicate that overall the DASH score increased over time within the UK adult population however the analysis indicates that persistent disparities between individuals with higher versus lower SEP exist. Less educated individuals, those engaged in routine occupations and subjects with lower incomes had lower values of the score compared to the individuals with higher SEP's indicating a persisting socioeconomic dietary gap. To put the magnitude of the disparity in perspective, the median DASH score observed in 2015/2016 for individuals with lower education or income or being engaged in routine occupations was still lower than the median DASH score for those with the highest level of education, a higher income or being engaged in high managerial and professional occupations almost a decade earlier (2008/2009). Evidence shows that long-term adherence to a DASH-type diet is associated with favorable CVD risk profile (12-14).

Similarly persisting or widening sociodemographic inequalities in diet and modest improvements in overall population diet quality were observed in the United States and Netherlands (16, 22, 40, 41) . Findings from assessing the dietary intake in Dutch adults over a period of 10 years also found that dietary intake changed over time and these changes were found in all socioeconomic classes. However, the dietary intake among subjects in higher SEP groups tended to be closer to the national recommendations and this was reported to be relatively stable over time. In nutrients terms, across time a higher SEP was associated with higher intake of vegetable protein, dietary fibre and most micronutrients (40). Wang et al showed from 1999 to 2010 the quality of the American diet improved modestly overall although the dietary quality remained poor. The improvement seen in the USA was greater among people with higher SEP and the disparities that existed in 1999 increased over the decade (41). Our study is also consistent with other existing UK studies, which reported that overall, population adherence to four key UK recommendations (fruit and vegetable intake, oily fish intake, salt intake and red and processed meat intake) was low to moderate, but improved over time (19, 23, 25, 48).

The results show that a lower intake of fruit and vegetables separates individuals of lower SEP form those of a higher SEP. Moreover, over the period, consumption of fruit and vegetables decreased in less educated individuals. In line with the analysis, a systematic review of socio-economic differences in food habits in Europe also showed that a higher SES is associated with a greater consumption of both fruit and vegetables (22). Also in agreement with the findings, another study looking at the NDNS data that reported that those from the highest socio-economic groups consumed up to 128g/day more fruit and vegetables (26). Another study by Pechy et al in the UK reported that low income groups not only consumed less vegetables and fruit but also consumed greater quantities of processed meat and sweet snacks or processed potato products (chips, crisps) (23). In this study, higher SES groups purchased more grams of fibre per 1000 kcal than lower SES groups, as well as a greater percentage of their energy from total sugars and protein as well as 3% less sodium per 1000 kcal. While the SES differences were mainly small in absolute terms, at the population-level and over time, these differences are likely to have cumulative effects on health risks such as obesity and CVD (23). Interestingly over the time, the results showed a lower consumption of sugar sweetened beverages amongst individuals with the highest income and a decrease in sodium in all groups. The gradual decrease in sodium consumption across all socio-economic groups is an encouraging reflection of the UK Salt Reduction Programme(49) .

Another interesting observation from the results in paper 2 are differences found in the higher consumption of wholegrains, nuts and legumes by the higher SEP groups.

Wholegrains and legumes are high in fibre. Epidemiological evidence suggests an inverse association between wholegrain and fibre consumption and the risk of non-communicable diseases such as CVD (50). Inclusion of more wholegrains and legumes in particular in the diet has been shown to be a cost-effective way of improving diet quality and yet these results show that the low intake suggests the contrary(24, 35) . One recent UK study using optimisation modelling reported that changing the current UK diet to meet the recommendations does not increase the cost (48). Whilst the adoption of healthier eating habits seems theoretically achievable the dietary discrepancies shown in this study are a reminder and an addition to the existing research suggesting that current public nutrition strategies in the UK are not sufficiently addressing the dietary inequalities (49).

Intertwined pathways

A range of mechanisms are at work in determining food intake across all socioeconomic groups and the results in both Paper 2 and Paper 3 support this notion (28, 30, 39, 51-54). Accessibility, availability, cost as well as one's food preferences, nutritional knowledge and sociocultural norms all influence the intake of healthy diet (21, 53, 55). Based on the results in Paper 2 the estimated difference between people with no qualification and those having the highest level of education was the greatest (- 3 59 points 95% CI: -3.91; -3.20). Similarly, the difference between people engaged in routine occupations and those engaged in high managerial and professional occupations was strong (-3.40 points (95% CI; -3.87; -2.92). Paper 2 analysis indicates that the difference between subjects in the first fifth and last fifth of the household income distribution was least (-2.73 points (95% CI: -3.16; -2.29). The results support the existing perspective that diet selection may be influenced by education and occupation independently. Alternatively, the influence of education and occupation on diet costs could be indirect, through links with income (28, 51) . Income may reflect the economic resources available to individuals, whilst education maybe a proxy for a range of factors such as knowledge or ability to use nutritional information and occupation group could represent social networks amongst other factors (51, 53, 56, 57).

High dietary cost is more likely to be a barrier against adopting a healthy diet among people of lower socio economic status(9, 17, 21, 28, 52) . Differentials in the price of 'healthy' and 'less healthy' foods and diets can contribute to obesity, non-communicable diseases (NCDs) such as CVD and their inequalities (31). Some literature suggests that income–diet cost–diet pathway is stronger in lower-educated individuals than in higher-educated individuals(17, 28, 51, 52) . In support of this, a recent study in Australia found that those households with the lowest incomes are more vulnerable to increasing food prices, as they spend less per person on food, but a greater proportion (28% and 40%) of their total expenditure on food compared with 20% for families on the average income (39). Studies that have estimated dietary costs in the UK have shown that people who score more favourably on healthy diet indicators, as well as those who consume more fruit and vegetables in particular tend to spend more on food or consume higher value diets(35) . This could be the case for the findings of this doctorate showing a decrease in consumption of fruit and vegetables in lowest income quartile. An increase in the price of whole fruit may drive consumers in the direction of fruit juices where as higher socioeconomic status groups consume more fruit (33, 48).

Paper 3 however found that the mediating effect of income on the relationship between education and the DASH score was small, with an estimated proportion mediated ranging between 6 to 9%. This result is in line with a recently published study that used a large cohort of Dutch adults to investigate to what extent dietary costs explain educational differences in diet quality. This study found that dietary cost explained between 2- 7% of the association between educational level and diet quality measures (49). These results suggests that the limited explanatory power of dietary cost warrants further discussion about other potential factors that explain SEP inequalities in diet quality.

Socio-economic inequalities are traditionally explained through tree mechanisms; the material explanation, the behaviour explanation and the psychosocial explanation. While several studies have explored explanatory mechanisms separately it would be of great interest to study the relative contributions of dietary costs compared to other explanatory factors. Other explanatory factors include access to healthy food as well as psychosocial resources such as social support, knowledge of healthy eating, cooking skills as well as one's ability to use dietary knowledge and attitudes to achieve better diet quality within a given food budget(8, 24) . There is supporting literature indicating that high SEP is associated with nutrition and health literacy and other psychosocial resources which may explain the low mediating effect we found in our study (8, 24, 34) . The education-diet relationship is mediated by knowledge about food and attitudes towards healthy eating which in turn affect behaviour and make the individual more receptive to health education measures (34, 55) . Interestingly, people of low SEP are less able to make decisions that favour long-term health benefits (8). People living in lower socio-economic groups already have difficult trade-offs to make about household expenditure which in turn, makes healthy food choices more difficult (52). Moreover, in the UK as well as in other high-income countries, the amount of money spent by people on food as a proportion of their overall income is relatively low, though it is higher among poorer households.

Previous studies investigating the extent of mediating factors such as availability and accessibility have found substantively different results across various contexts (i.e. 4-76%). In addition, none of these evaluations have accommodated the possibility that the mediated effect of affordability, availability and accessibility may require the joint operation of exposure and mediator (30). Acceptability of foods for example, may also explain the observed sex differences seen in dietary quality in these results as well as in previous research (58). In this study, women had a higher DASH score and the mediated effect of low income was greater in women than in men. This is likely the consequence of the different attitude of women towards healthy food choices. In fact, women tend to express greater health concerns, are more motivated to control their weight, spend more on healthier food and more likely to be responsible for meal preparation (51, 59) . For example, a study among European adults showed that while price was amongst the top four important factors influencing food choices for females this was not the case in men (60). In addition, a man's diet may reflect his spouse's/partners food choices more than his own preferences (53). However, this difference could also reflect a more accurate completion of dietary reports among women who are more likely involved in the preparation of meals.

When looking at age differences, the results in Paper 3 show that the mediating effect of low income was higher amongst young people in comparison to older people. Previous studies have shown that healthy eating and also knowledge on nutrient recommendations increases with age (10, 38, 60). For younger people identity is inextricably linked with health behaviours and additional knowledge may not necessarily have an impact on dietary choices made (38). Other factors that may contribute to the higher mediating effect within younger adults include a lack of motivation and apathy to eat healthily (particularly in males), the preference for unhealthy food, emotional responses to eating, a lack of the skills to plan for, shop, prepare and cook healthy foods (61). Some researchers have also suggested that young people may not possess the cognitive maturity or development to rationally attribute their current dietary choices/behaviour (60-62). In addition, other studies suggest that SEP indicators such as income and education may have different interactions and impact across the life course. For example, education is achieved during early adulthood, whereas income and occupational position describe SES during later adulthood (34). For younger adults, the association with education may also be related to the parents' nutrition education or perhaps to their knowledge of health and chronic diseases (38, 60, 62).

A recent population-based study in the UK demonstrated that the likelihood of consuming a DASH-style diet was dependent on economic factors and geographical location (21). Within the UK, geographical differences have been shown to affect differing foods changes. These results also suggest that in Scotland and Northern Ireland low income has a greater mediating effect than in England. Although the precision of estimates is low and no firm conclusions can be made, these findings, like previous literature, suggest that race, tradition and perceived acceptability of energy-dense foods celebrated and marketed as part of culture heritage also influence food choice (10, 61).

Methodological considerations

This research and subsequent papers published from it have important strengths. Firstly, analysis was based on the NDNS data, a high quality, representative, up-to-date U.K data source. Results are thus generalizable on a population level and can be compared to other recent studies. Second, food and nutrient data were gathered from a self-reported four-day diary, which provides better representation of usual consumption than FFQs or 24-h dietary recalls, commonly used in epidemiological studies (63). However, it is known that food diaries are self-reported and so are subject to both random error and systematic error or bias. Infact, underreporting may especially be the case for participants with a lower education (64). However what effect this may have on the results in the published papers are unknown and beyond the scope of the current research. Another strength is the use of the DASH score which is a diet quality indicator that was relevant to the study population and widely used in international literature (12-15). The use of multiple socio-economic indicators is another strength as it allows the consideration of different dimensions of socio-economic position rather than considering it as a single phenomenon (57).

However, there are methodological considerations to consider. Given the cross-sectional nature of the NDNS survey any causal inference between socio-economic position and diet is limited. For example, it is possible that higher educational level leads to more dietary knowledge, in turn leading to a healthier diet and that this healthier diet leads to higher dietary costs and vice versa (44). In addition, there are unmeasured confounders such as early life socioeconomic conditions which may have affected income and eating behaviours independently from individual education (64). Children born in low socioeconomic conditions are likely to have fewer opportunities both within their education and within their career (42, 60). In addition, they are more likely to emulate the unhealthy eating behaviours which they may have been exposed to in their homes and communities. As in most nationwide population surveys, the most deprived groups may be under-represented (i.e. homeless, unemployed or migrants not speaking English) as they are less likely to participate in the survey (64). However, measures were taken by the NDNS team to reduce the effect of potential non-response bias (43, 44) . Finally, food diaries are self-reported and are then subject to recall bias and misreporting (63).

In addition, the DASH score was measured at a unique point of time (i.e. at the time of survey), however in reality, it is likely that health behaviours may influence chronic disease outcomes in accumulative fashion over the life-course (5, 7, 10).

CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH AND PUBLIC HEALTH POLICY

In order to ascertain potential targets of public strategies aiming to reduce the burden of the diseases attributable to unhealthy diet in the UK population, it is necessary to have valid data on recent trends of socioeconomic inequality in dietary habits, food intake and dietary quality. Findings from this doctorate (Paper 2) add an important contribution to the existing literature and more importantly provide an updated picture of socio-economic inequalities in diet among the UK adults in context of the whole diet and suggest the need for additional actions to improve dietary quality, especially for those with low SEP. The results show that although the DASH dietary score improved overtime in the UK population dietary quality remains poor and moreover has persisted over time.

Public health policies aiming to reduce cardiovascular inequalities need to be take into consideration behavioural mediating factors to be effective. For example, although affordability could be a limiting factor to consuming a healthy diet, the finding from this doctorate indicate that income is a minor mediating factor. Thus, before developing new interventions, future studies should focus on providing insights into the most relevant causes and mechanism that underlie socioeconomic differences in diet quality. When these are clearly known, only then can interventions be adequately designed and tailored to the needs and capacities of the target population. For example, some interventions to date have increased diet quality without increasing socioeconomic inequalities include subsides on healthy foods and sugar sweetened beverage taxes (70).

The findings in this doctorate have substantial implications for public nutrition policy. An immediate implication is the need for public nutrition policies that are individualised to SEP. Targeted interventions for those within the lower SEP need to multifactorial focusing not just on cost but on nutrition literacy, an increased ability of dietary knowledge, should address attitudes towards healthy eating as well as access to healthy foods. Further research is needed to investigate which other factors may explain the socioeconomic inequality in the adoption of healthy diet such as the DASH diet. Addressing cardiovascular inequalities without its socioeconomic determinants that influence eating behaviours would mean leaving people in poverty without the strategies to cope with it.

Low Calorie Beverage Consumption, Diet Quality and Cardiometabolic Risk Factors in British Adults

ABSTRACT

Nearly two thirds of adults in the UK are either overweight or obese. Free or added sugars have been acknowledged as a readily available source of energy, which accounts for a large percentage of daily energy intake leading to excess calories, weight gain and obesity. Data from the National Diet and Nutrition Survey in the UK show that one of the main sources of added sugars in the diet are sugar sweetened beverages (SSB's). Low calorie beverages (LCBs) are promoted as (healthy) alternatives to sugar sweetened beverages (SSBs), however their effects on diet quality and cardiometabolic profile are debated. The aim of this research was therefore to verify the association between LCB consumption, diet quality and cardiometabolic risk factors in British adults.

Data analysis from 5521 subjects aged 16 and older who participated in two waves of the National Diet and Nutrition Survey Rolling Programme (2008-2012 and 2013-2014) was carried out. Multiple linear regressions were used to estimate differences in nutrient intake and cardiometabolic measures across groups. Multiple logistic regression models estimated the odds ratio of being compliant with the UK dietary recommendations.

Compared with SSB consumption, LCB consumption was associated with lower energy [mean difference: -173 kcal (95% confidence interval, CI: -134; -112)] and free sugar intake [-5.6 % of energy intake (95% CI: -6.1; -5.1)], while intake of other nutrients was not significantly different across groups. The % difference was more

pronounced among the young (16 – 24 years) [-7.3 of energy intake (95% CI: -7.8; -6.8)]. The odds of not exceeding the UK recommendation for free sugar intake were remarkably higher in the LCB as compared to the SSB group (OR: 9.4, 95% CI: 6.5-13.6). No significant differences were observed for plasma glucose, total cholesterol, LDL, HDL and triglycerides.

Findings thus far suggest that low calorie beverages are associated with lower free sugar intake without affecting the intake of other macronutrients or negatively impacting cardiometabolic risk factors. Further research should consider providing information of type and dosage of low calorie sweeteners in the whole diet, in addition to investigating the long-term effects of low calorie sweeteners on specific populations having multiple comorbidities, including diabetes and metabolic syndrome.

BACKGROUND

Nearly two thirds of adults in the UK are either overweight or obese (65). Men are more likely to be overweight or obese (65.7% vs. 57.1%). Regardless of the measure used, for women in the UK, obesity prevalence increases with increasing levels of deprivation. For men, only occupation- based and qualification-based measures show differences in obesity rates by levels of deprivation. Those in professional occupations have lower obesity prevalence than any other group. This overall pattern is similar for women where the prevalence of obesity has been shown in unskilled occupations to be almost twice that of those in professional occupations. In addition, obesity rates are highest for children from low-income background. Children aged 5 and from the poorest income groups are twice as likely to be obese compared to their most well-off counterparts and by the age of 11 they are three times more likely (65, 66) .

Obesity is an independent risk factor for many health problems including cardiovascular disease, type 2 diabetes and certain cancers. Obese adults are seven times more likely to become type 2 diabetic than adults of a healthy weight for example (67).

Obesity is a complex problem with many drivers, however at its root obesity is caused from an energy imbalance (66). Free or added sugars have been acknowledged as a readily available source of energy, which accounts for a large percentage of daily energy intake leading to excess calories, weight gain and obesity (68). Worldwide, intake of added sugars has increased dramatically during the past few decades (66-68).

In response, the World Health Organisation (WHO) in 2015 issued sugar guidelines, recommending that adults and children restrict their added sugar intake to less than 10% of total energy intake per day and suggests a further reduction to below 5% (68). In the United Kingdom (UK) the Scientific Advisory Committee on Nutrition (SACN) recommend that added sugars should account for no more than 5% daily energy intake (67).

Data from the National Diet and Nutrition Survey in the UK show that sugar makes up 12% of total daily calorie intake in adults, and one of the main sources of added sugars in the diet are sugar sweetened beverages (SSB's) (69). In order to achieve a reduction in sugar intake, public health policies promoting SSB reduction are on the increase. Consequently, the food industry is responding in multiple ways, including investing in the formulation of artificially sweetened food products, promoting them as healthier alternatives (70). For example, as a first step towards tackling sugar intake in August 2016, the Uk government challenged the food industry to remove sugar in the nine categories of food that make the largest contributions to children's sugar intakes; breakfast cereals, yogurts, biscuits, cakes, confectionery, pastries, puddings, ice-cream and sweet spreads through product reformulation. Hopes are to reduce the sugar in these products by 5% in year 1 and at least by 20% by 2020(70-72) .

Current guidelines developed for public health authorities and consumers consistently recommend a reduction in sugar consumption and recommend artificial sweeteners within foods as a healthy alternative (67). As a substitute for SSB, LCB's offer the potential satisfy both thirst and an innate desire for sweetness with minimal caloric load (69, 70)however their effects on diet quality, weight control and cardio-metabolic biomarkers continue to be debated. In addition, evidence of the long-term impact of

NNS on diet quality, weight management and related health outcomes on a macro level is limited (73-77).

A limited number of studies have examined the associations of SSB/LCB consumption with diet quality and cardiometabolic indicators (73, 74, 77-79). There have been no previous examinations in an adult population.

AIM

This study therefore aims to verify the association between low calorie beverage consumption, diet quality and cardiometabolic risk factors in British adults

Primary Objectives

1. To assess the impact of LCB intake on total energy consumption, macronutrient intake (carbohydrates (specifically/including sugars), fat (saturated fat), and protein) in relation to SSB consumption and no consumption

2. To assess the percentages of subjects meeting the UK recommendations for free sugar intake, saturated fatty acids and fibre according to beverage consumption groups

3. To assess the impact of beverage consumption groups on plasma glucose and lipid profile

Secondary Objectives

1. On obtaining outcomes in primary objectives 1,2,3, it initially proposed that a microsimulation model will be used evaluate the population impact of changes in dietary patterns, macronutrient intake and BMI on the risk of non-communicable diseases in 10 or 20 years.

METHODS AND MATERIALS

Study Design

We carried out data analysis on a cross-sectional study based on two waves (2008-2012 and 2013-2014) of the UK National Diet and Nutrition Survey (NDNS). The NDNS is an annual rolling cross-sectional survey carried out on behalf of Public Health England and the Food Standards Agency. It is designed to assess the diet, nutrient intake and nutritional status of a representative sample of UK adults and children. Households were randomly sampled from the UK Postcode Address File, with one adult and one child (18 months or older) or one child selected for inclusion. We included all subjects aged 16 and older at the time of interview.

Interview

Socio-demographic data, lifestyle behaviours, dietary habits, use of medications and dietary supplements were collected during a computer assisted personal interview.

Dietary Records

Respondents were asked to complete a dietary record for 4 consecutive days (including weekends and weekdays), giving a detailed description of each item consumed, time of consumption, and amount, using household measures and photographs. Information on missing food items were collected on repeat visits by interviewers. Trained diet coders then entered the food intake data from completed recordings using an in-house dietary assessment system (Data In, Nutrients Out – DINO).

From the NDNS archives we retrieved average daily energy intake, proteins, total carbohydrates, total sugars, intrinsic sugars, free sugars, total fats, monounsaturated, n-6 and n-3 polyunsaturated, saturated and trans-fatty acids, fibre, sodium and alcohol intake.

Sugar refers to free or added sugars as defined in the NDNS archives as non-milk extrinsic sugars, comprised either sugars added or naturally present to foods, excluding extrinsic sugars in milk and milk products.

Anthropometric Measurements

Weight, height and waist circumference were taken by trained nurses for those participants who completed 90% of the diet record. BMI was calculated in kg/m^2 from weight and height measurements.

Blood Samples

Fasting blood was collected for all participants during the nurse second visit. The following variables were considered in this study: plasma glucose, total cholesterol, low density lipoproteins (LDL), high density lipoproteins (HDL) and triglycerides.

Classification of Participants

Subjects were classified into four groups according to beverage consumption:

1) LCB group - subjects who consumed LCB (average LCB intake > 0 g/day and average SSB = 0 g/day);
2) SSB group - subjects who consumed only sugar-sweetened beverage (average LCB intake = 0 g/day and average SSB > 0 g/day);

3) BB group - subject consuming both types of beverages (average LCB intake > 0 g/day and average SSB > 0 g/day);
4) NC group - subjects who did not consume either LCB and SSB (average LCB intake = 0 g/day and average SSB = 0 g/day).

LCB being defined as low or no calorie drinks without added sugar or sugar free, including carbonated, ready-to-drink and concentrated soft drinks and squashes, excluding water. SSB being defined as drinks not low calorie, with a range of sugar contents, carbonated and still, ready to drink and diluted, excluding water. Tea, coffee, fruit and vegetable juices, milk and alcoholic beverages were not considered.

Data Analysis

The response variables considered in this study were: nutrient intake expressed as percentage of total energy intake, UK recommendations for free sugar, saturated fatty acid and fibre intake (80), plasma glucose and lipid profile. Basic characteristics of the population were presented as counts and percentages and compared between LCB and SSB groups by Chi-squared test. To estimate differences in nutrient intake or plasma glucose and lipid profile across beverage consumption groups, we fitted multiple linear regression models. To determine if the differences across groups were statistically significant we used the Chi-squared test between two nested models (including or not the group variable in the model). We estimated the odds ratio (OR) of being compliant with the UK recommendation for free sugar, saturated fatty acids and fibre intake by using multiple logistic regression models. All models were adjusted for sex, age groups, socio-economic status and BMI.

We carried out also stratified analyses for free sugar consumption across strata of sex, age group, socio-economic status and BMI category. To test the heterogeneity of the group effect in each stratifying variable we used the Chi-squared test comparing two nested models, one including the interaction between the beverage consumption group and the stratifying variable and the other not including the interaction term. All statistical tests were two-sided and *p* values <0.05 were considered statistically significant. The analysis was performed using R version 3.5.0.

RESULTS

Study Population

We included 5521 subjects who completed the 4-day dietary record, of whom 17.0% were classified in the LCB group, 29% in the SSB group, 19.8% in the BB group and 34.2% in the NC group. The median (interquartile range) intake of LCB was 207 mL/day (100-426) in the LCB group, 198 mL/day (83-398) in the BB group and zero mL/day in the other two groups (SSB and NC). The median (interquartile range) intake of SSB was 169 mL/day (83-373) in the SSB group, 163 mL/day (83-330) in the BB group and zero mL/day in the remaining two groups (LCB and NC).

Table 1 gives their socio-demographic characteristics, BMI and smoking status according to group of beverage consumption. Compared with the SSB and NC group, subjects consuming LCB were more likely to be women, in the age category 25-49 years, white and obese, while there were no significant differences in terms of socioeconomic status.

Table 1. *Characteristics of the population according to type of beverage consumption*

	Number of subjects (N= 5521)				% of the population				
	BB	LCB	NC	SSB	BB	LCB	NC	SSB	*p* value[a]
Number of subjects	1095	936	1887	1603	100	100	100	100	
Sex									<0.0001
Men	449	326	819	739	41.0	34.8	43.4	46.1	
Women	646	610	1068	864	59.0	65.2	56.6	53.9	
Age category (years)									<0.0001
16-24	399	137	146	441	36.4	14.6	7.7	27.5	
24-49	482	454	579	634	44.0	48.5	30.7	39.6	
49-64	131	208	556	278	12.0	22.2	29.5	17.3	
64-96	83	137	606	250	7.6	14.6	32.1	15.6	
Race									<0.0001
White	1035	894	1752	1454	94.5	95.5	92.8	90.7	
Mixed ethnic group	17	10	11	20	1.6	1.1	0.6	1.2	
Black or Black British	13	10	39	47	1.2	1.1	2.1	2.9	
Asian or Asian British	22	13	51	55	2.0	1.4	2.7	3.4	
Any other group	8	9	34	27	0.7	1.0	1.8	1.7	
SES									0.08
Higher managerial and professional occupations	133	162	269	229	12.1	17.3	14.3	14.3	
Lower managerial and professional occupations	299	236	433	399	27.3	25.2	22.9	24.9	
Intermediate occupations	113	98	171	166	10.3	10.5	9.1	10.4	
Small employers and own account workers	121	98	211	155	11.1	10.5	11.2	9.7	
Lower supervisory and technical occupations	112	95	181	154	10.2	10.1	9.6	9.6	
Semi-routine occupations	145	118	275	224	13.2	12.6	14.6	14.0	
Routine occupations	126	96	245	187	11.5	10.3	13.0	11.7	
Never worked	23	18	62	44	2.1	1.9	3.3	2.7	
Other	23	12	34	42	2.1	1.3	1.8	2.6	
Not answer	0	1	2	1	0.0	0.1	0.1	0.1	
Not available	0	2	4	2	0.0	0.2	0.2	0.1	
BMI category									<0.0001
Normal weight	430	273	605	679	39.3	29.2	32.1	42.4	
Overweight	305	319	633	459	27.9	34.1	33.5	28.6	
Obesity	283	270	478	323	25.8	28.8	25.3	20.1	
Missing	77	74	171	142	7.0	7.9	9.1	8.9	

4. [a] χ^2 *test*

Nutrients Intake

Table 2 shows the average nutrient intake computed over a 4-day dietary records across beverage consumption groups. Compared to the SSB group, subjects in the LCB group had a lower energy intake, as well as a lower intake of total carbohydrates, sugars, intrinsic sugars, free sugars and alcohol, while protein and fibre intakes were slightly higher. Compared to NC group, the LCB had a slight increased sodium intake. Conversely, intakes of other nutrients were not substantially different across groups.

Table 2. *Energy and nutrients intake according to type of beverage consumption*

	BB	LCB	NC	SSB	Across group difference *p* value [a]	Estimated adjusted difference between LCB and SSB (95% CI) [b]	Estimated adjusted difference between LCB and NC (95% CI) [b]
Energy (Kcal)	1903 (564)	1651 (514)	1673 (514)	1872 (593)	<0.0001	-173 (-212; -133)	+2 (-37; 42)
Carbohydrates (% of energy)	50.7 (7.3)	48.7 (7.8)	48.3 (8.2)	50.7 (7.7)	<0.0001	-1.7 (-2.3; -1.1)	0 (-0.6; 0.6)
Sugars (% of energy)	22.1 (6.6)	18.7 (6.5)	19.7 (6.8)	23.3 (7.2)	<0.0001	-4.4 (-5.0; -3.9)	-0.8 (-1.3; -0.2)
Intrinsic sugars (% of energy)	7.2 (3.7)	9.2 (4.4)	9.7 (4.7)	7.6 (3.9)	<0.0001	-1.1 (0.8; 1.4)	-0.2 (-0.5; 0.1)
Free sugars (% of energy)	14.9 (6.5)	9.5 (5.1)	10.1 (5.7)	15.6 (7)	<0.0001	-5.6 (-6.1; -5.1)	-0.6 (-1.1; -0.1)
Proteins (% of energy)	15.6 (3.4)	17.5 (4.2)	17 (4)	15.5 (3.3)	<0.0001	+1.70 (1.4; 2.0)	+0.4 (0.1; 0.7)
Fats (% of energy)	33 (5.7)	33.1 (6.6)	33.6 (6.6)	33.2 (6)	0.25	0 (-0.5; 0.6)	-0.3 (-0.8; 0.2)
Monounsaturated fatty acids (% of energy)	12.3 (2.5)	11.9 (2.8)	11.9 (2.8)	12.1 (2.7)	0.74	-0.1 (-0.3; 0.1)	-0.1 (-0.3; 0.1)
Polyunsaturated n-6 fatty acids (% of energy)	4.7 (1.3)	4.7 (1.4)	4.7 (1.6)	4.7 (1.5)	0.049	+0.1 (-0.1; 0.2)	-0.1 (-0.2; 0.1)
Polyunsaturated n-3 fatty acids (% of energy)	0.9 (0.4)	1.0 (0.4)	1.0 (0.5)	0.9 (0.4)	0.0003	+0.03 (0; 0.07)	-0.02 (-0.05; 0.01)
Saturated fatty acids (% of energy)	12.1 (3)	12.3 (3.4)	12.7 (3.6)	12.4 (3.2)	0.66	0 (-0.2; 0.3)	-0.1 (-0.3; 0.2)
Trans-fatty acids (% of energy)	0.6 (0.3)	0.6 (0.3)	0.6 (0.3)	0.6 (0.3)	0.76	-0.01 (-0.03; 0.01)	0 (-0.03; 0.02)
Fibers (g)	13.1 (4.6)	13.3 (4.9)	13.6 (5.2)	12.9 (4.9)	0.003	+0.4 (0; 0.8)	0 (-0.4; 0.3)
Sodium (mg)	2.4 (0.8)	2.1 (0.8)	2.0 (0.8)	2.2 (0.8)	<0.0001	-66 (-126; -6)	+109 (49; 168)
Alcohol (g)	11.4 (19.9)	9.6 (18.5)	11.2 (21.1)	11.2 (21.7)	0.003	-1.6 (-3.2; 0)	-0.7 (-2.3; 0.9)

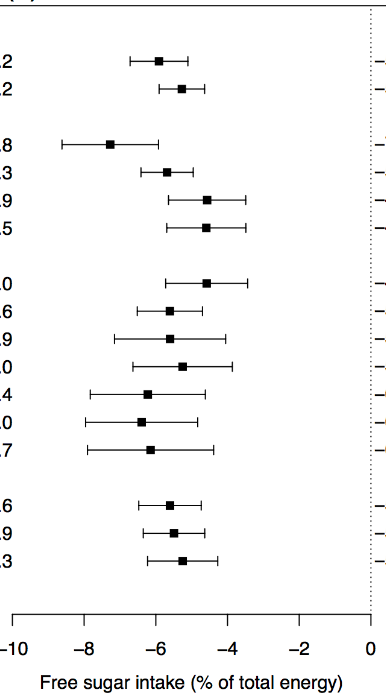
[a] *group differences were tested using analysis of covariance*

[b] *between group differences were estimated by multiple linear regression models adjusted for sex, 5-year age category, socioeconomic status and BMI category*

The difference in free sugar intake between the LCB and SSB group was similar across strata of sex (P for the interaction= 0.300), socio-economic status (P for the interaction= 0.140) and BMI category (P for the interaction= 0.630), whereas it was more pronounced in the young as compared to older individuals (P for the interaction= 0.006) (Figure 1 below).

Figure 1: the differences in free sugar intake between the low calorie and sugar sweetened beverage group and corresponding 95% confidence intervals (CIs) according to strata of sex, age, socio-economic status and body mass index (BMI).

Stratum	LCB – mean free sugar intake (%)	SSB – mean free sugar intake (%)	Estimated mean difference [95% CI] (LCB vs. SSB)*
Sex			
Men	9.8	16.2	−5.9 [−6.7; −5.1]
Women	9.4	15.2	−5.3 [−5.9; −4.6]
Age group (years)			
16–24	10.6	17.8	−7.3 [−8.6; −5.9]
25–49	9.3	15.3	−5.7 [−6.4; −5.0]
50–64	9.2	13.9	−4.6 [−5.6; −3.5]
65+	9.6	14.5	−4.6 [−5.7; −3.5]
Socio–economic status			
High managers/professionals	10.1	15.0	−4.6 [−5.7; −3.4]
Lower managers/professionals	9.5	15.6	−5.6 [−6.5; −4.7]
Intermediate occupations	9.0	14.9	−5.6 [−7.2; −4.1]
Small employers/own account workers	9.7	15.0	−5.3 [−6.6; −3.9]
Lower supervisor technicians	9.5	16.4	−6.2 [−7.8; −4.6]
Semi–routine occupations	9.1	16.0	−6.4 [−8.0; −4.8]
Routine occupations	9.9	16.7	−6.1 [−7.9; −4.4]
BMI category			
Normal weight	10.5	16.6	−5.6 [−6.5; −4.7]
Overweight	9.4	14.9	−5.5 [−6.4; −4.6]
Obesity	8.6	14.3	−5.3 [−6.2; −4.3]



* The estimates for strata of sex were obtained by multiple linear regression models adjusted for age, socio-economic status and BMI; the estimates for strata of age were obtained by multiple linear regression models adjusted for sex, socio-economic status and BMI; the estimates for strata of socio-economic status were obtained by multiple linear regression models adjusted for sex, age, and BMI; the estimates for strata of BMI were obtained by multiple linear regression models adjusted for sex, age, and socio-economic status.

UK Recommendation for Free Sugar Intake, Saturated Fatty Acids and Fibre

Table 3 gives the percentages of subjects meeting the UK recommendation for free sugar intake, saturated fatty acids and fibre. The percentage of people meeting the UK recommendation for free sugar was very low in all groups, although the odds of meeting the UK recommendation were remarkably higher in the LCB as compared to the SSB group (adjusted OR: 9.4, 95% CI: 6.5-13.6). Percentage of subjects within the UK recommendation for saturated fatty acid intake were similar across groups. Only a few people were within the UK recommendation for fibre intake, with no differences across groups. There were no significant differences between LCB and NC group in the percentage people meeting the UK recommendation for free sugars, saturated fatty acids and fibre.

Table 3. *UK recommendation on free sugars, saturated fatty acids and fiber intake according to type of beverage consumption*

		BB	LCB	NC	SSB	Adjusted OR (95% CI) (LCB vs. SSB) [a]	Adjusted OR (95% CI) (LCB vs. SSB) [a]
Free sugar	Within the UK recommendation	27 (2.5)	180 (19.2)	359 (19.0)	36 (2.2)	9.39 (6.47-13.63)	0.94 (0.76-1.16)
	Over the UK recommendation	1068 (97.5)	756 (80.8)	1528 (81.0)	1567 (97.8)		
SFA	Within the UK recommendation	270 (24.7)	235 (25.1)	431 (22.8)	363 (22.6)	1.10 (0.90-1.33)	1.01 (0.83-1.21)
	Over the UK recommendation	825 (75.3)	701 (74.9)	1456 (77.2)	1240 (77.4)		
Fibre	Within the UK recommendation	2 (0.2)	6 (0.6)	8 (0.4)	12 (0.7)	0.90 (0.33-2.48)	1.76 (0.59-5.27)
	Below the UK recommendation	1093 (99.8)	930 (99.4)	1879 (99.6)	1591 (99.3)		

1. *[a] ORs were estimated by multiple linear regression models adjusted for sex, 5-year age category, socioeconomic status and BMI category*

Plasma Glucose and Lipid Profile

Table 4 shows fasting plasma glucose and lipid profile according to beverage consumption groups. The were no significant differences in plasma glucose, total cholesterol, LDL, HDL and triglycerides among groups.

Table 4. *Plasma glucose and lipid profile according to type of beverages consumption*

	BB	LCB	NC	SSB	Across group difference *p* value [a]	Estimated adjusted difference between LCB and SSB (95% CI) [b]	Estimated adjusted difference between LCB and NC (95% CI) [b]
Plasma glucose (mmol/L)	5.07 (0.73)	5.34 (1.22)	5.36 (1.28)	5.16 (1.08)	0.30	0.20 (-0.05; 0.46)	0.16 (-0.10; 0.41)
Total cholesterol (mmol/L)	4.84 (1.06)	5.04 (1.11)	5.14 (1.17)	5 (1.13)	0.62	0.07 (-0.17; 0.32)	0.10 (-0.15; 0.34)
LDL (mmol/L)	2.91 (0.9)	3.03 (0.93)	3.11 (1.03)	3 (0.97)	0.64	0.06 (-0.11; 0.22)	0.06 (-0.10; 0.23)
HDL (mmol/L)	1.42 (0.40)	1.43 (0.42)	1.49 (0.46)	1.47 (0.42)	0.76	0.03 (-0.07; 0.13)	0.02 (-0.08; 0.12)
Triglicerides (mmol/L)	1.22 (0.84)	1.35 (0.93)	1.27 (0.82)	1.25 (0.83)	0.17	0.07 (-0.03; 0.171)	0.10 (0; 0.20)

[a] *group differences were tested using analysis of covariance*

[b] *between group differences were estimated by multiple linear regression models adjusted for sex, 5-year age category, socioeconomic status and BMI category*

DISCUSSION

This study examined the association between low calorie beverage consumption, diet quality and cardiometabolic risk factors in British adults. It found that compared to the SSB group, subjects in the LCB group had a lower energy intake as well as a diet lower in total sugar and free sugars, with an increased odds of meeting current UK dietary guidelines on free sugar intake. Moreover, there were no differences in blood glucose, triglycerides, total cholesterol, LDL, or HDL between LCB and SSB or NC group.

A limited number of studies have examined the associations of SSB/LCB consumption with diet quality and cardiometabolic indicators (73, 74, 77). Our findings are in line with studies supporting the hypothesis that replacing SSB with LCB leads to a reduced energy intake and an improved dietary quality in adults. Evidence from the Choose Healthy Options Consciously Everyday (CHOICE) randomised control trial indicated that those who replaced SSBs with either LCB or water also reduced their consumption of added sugar and desserts with the LCB group sustaining a larger reduction in desserts than the water group. (75) Data from the National Health and Nutrition Examination Survey (1999 – 2008 NHANES, n = 22,231) showed that LCB consumers had better Healthy Eating Index subscores for vegetables, whole grains and low-fat dairy, whereas they had a higher intake of saturated fatty acids and sodium (81). Conversely, we did not find that LCB consumers had a higher intake of saturated fat and sodium. A recent study using the UK's National Dietary and Nutrition Survey (2008 – 2011) also showed that in all main respects (energy, macronutrient and micronutrient intakes) the diets of the LCB group were similar to those who consumed no soft drinks at all (NC). It also showed that LCB consumers did not compensate for the sugar and energy deficit (69).

Our findings are also similar to those from a recent systematic review and meta-analysis (76), based on 129 short-term randomized controlled trials in children and adults, reported that the consumption of low calorie sweetners (LCS) in place of sugar reduces energy intake and body weight. The meta-analysis reported that the consumption of low energy sweetners versus sugar-sweetened food before an *ad libitum* meal reduced energy intake by 94 kcal (95% CI -122 to -66), with no difference versus water (-2 kcal, 95% CI -30 to 26). The meta-analysis of nine sustained intervention randomized controlled trials (4 weeks to 40 months) showed that consumption of low energy sweetners versus sugar led to a reduction in body weight (-1.35 kg, 95% CI -2.28 to -0.42) that was comparable to that observed when sugar was replaced with water (-1.24 kg, 95% CI -2.22 to -0.26).

On the other hand, other studies have reported a positive association between LCB consumption and BMI and weight gain over time questioning the benefit of LCB for weight management in the long term (74, 79, 82). It is also postulated there may be differences in cognitive behaviour between subjects in a randomised trial and free-living subjects as to how they use LCB in the context of their diet. (73, 83, 84). Further evidence also suggests that consumption of low calorie sweeteners may result in complete caloric compensation from other sources (73, 84). In addition, findings from a recent study reported that for morbidly obese subjects the use of low calorie sweeteners was associated with an unhealthy lifestyle and unfavourable eating habits (increased energy intake including sugar and reduced intake of some vitamins) (85). However, our findings indicate that consumption of LCS did not result in poor dietary quality.

There is limited and inconsistent research examining the health impact (in particular related to cardiometabolic indicators) of LCS. In addition, many of them have focused on children or adolescents and not adults (74). Positive associations between the use of artificial sweeteners and glucose tolerance (86, 87) and hypertension (88) have been identified from observational studies and clinical trials (46, 89, 90). A recent children focused study using NDNS data (2008 – 2012) had contrasting findings to our study. It reported that SSB intake is associated with higher sugar intake. However, in that study both SSB and LCB intake were linked with less healthy cardiometabolic profiles (87).

In contrast, a recent review (91) including 372 studies (15 systematic reviews, 155 randomised controlled trials, 23 non-randomised controlled trials, 57 cohort studies, 52 case-control studies, 28 cross sectional studies, 42 case series/case reports) found that in healthy subjects, there was no conclusive evidence for the harmful effects of low calorie sweetners risk on cardio-metabolic indicators. In subjects with diabetes and hypertension, the evidence regarding health outcomes of low calorie sweeteners use was also found to be inconsistent. This review also highlighted the large heterogeneity in studies that could be related to different studied populations, age related differences in dietary patterns, frequency of low calorie sweetener use, the need to examine cardio-metabolic effects in the contest of boarder health behaviours as well as publication bias (74).

Strengths and Limitations

The study has important strengths. First, analyses were based on the NDNS data, a high quality nationally representative UK data source. Results are thus generalisable on a population level and can be compared to other recent studies. Second, food and nutrient data were gathered from a self-reported 4-day diary which provides better representation of usual consumption than FFQs or 24-h dietary recalls, commonly used in epidemiological studies. However, it is known that food diary may also be somewhat inaccurate in estimating food and nutrient consumption, including sugars. In addition, the increasing use of a mixture of sugars and low-calorie sweeteners within many beverages may have added complexity to the analysis. For example, fruit juices, which were not considered in our analysis, could be an important source of added sugars and increasingly, low calorie sweeteners.

Given the cross-sectional nature of the NDNS survey, we cannot rule out reverse causality for some of the study outcomes, such as obesity and other cardiometabolic indices (74, 91) . However, randomised trials within this area are also limited by the short or medium-term evaluation of interventions (92).

Finally, we did not consider the contribution of physical activity and genetic predisposition that may also have affected cardiometabolic risk factors, in particular plasma glucose and triglycerides levels.

CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH AND PUBLIC HEALTH POLICY

This study adds to the body of evidence that LCB can have a positive impact on diet quality. Future studies need to be rigorous in design, including well-defined interventions (i.e. providing information of type and dosage of low calorie sweeteners in the whole diet) and controls. Research should also investigate the long-term effects of using low calorie sweeteners on specific population groups having multiple comorbidities, including diabetes and metabolic syndrome.

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DATA SOURCE

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CONFLICTS OF INTEREST

None

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