Exposure to High Ultra-processed Food and Sodium Intake and its effect on Hypertension from a Cross-sectional study UK National Dietary and Nutritional Survey (NDNS) in England 2008-2019

David O'Hagan

200299857

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Dedication

To Julie Andrew and Sophie

for your loving patience and support

Acknowledgments

Thanks to Zoe and Martin

Thanks to Paul for the project which didn't quite come together

Abstract

Hypertension is associated with exposure to high intake of UPF and high Sodium intake. This research examines assumptions about salt and UPF. What contributes to 'unhealthiness'? Will 'reformulation' generate 'healthy UPF'? Can this help reduce BP in one part of the the UK?

Method

This research uses cross-sectional data with a stratified sample representative of the UK population. It is secondary data analysis of the National Dietary and Nutrition Survey (NDNS 2008-2019).

Using multivariable logistic regression analysis of high sodium intake and high UPF intake against hypertension, secondary end points included regression of Sodium intake against UPF intake, age against BP, sodium intake and UPF intake.

Results

There was an increased odds ratio of hypertension with higher sodium intake (OR=5.57(1.47,21.2)).

There was a lower odds ratio of hypertension with high upf intake (OR=0.57(0.34,0.94)).

There was no correlation between UPF intake and sodium intake (beta=0).

There is a strong correlation between age and BP (beta =0.43 (CI 0.41,0.45)), as well as age and Sodium intake.

There is a strong age gradient of UPF intake (beta= -0.25 (CI -0.26,-0.23)).

Conclusion

This study shows that high Na intake is associated with hypertension. Reduction of sodium intake may be effective at reducing the overall risk.

UPF intake is also associated with hypertension. This may show reverse causation in this cross-sectional study.

Policy should aim to reduce intake of sodium, longitudinal studies may be more effective at identifying the causal relationship between UPF and BP.

The lack of association between UPF and sodium intake is odd. Most UPF contains more sodium. Some UPF contains less sodium. This result suggests that the mix of UPF consumed by this population has no net increase in sodium content. If this is true, reformulation for low salt would not eliminate the association identified in the main results. Public health policy will need to reduce UPF, not simply reformulate.

Keywords

UPF, Sodium, hypertension, reformulation, Nutrition

Abstract 306 words

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Table of Contents

Table of Figures

Index of Tables

Table of Abbreviations used

Abbreviation	Term
NDNS	National Dietary and Nutrition Survey
BP	Blood Pressure
Na	Sodium intake in mg
UPF	Ultra Processed Foods
NCD	Non communicable Disease
CVD	Cardiovascular Disease
CHAMPs	Cheshire and Merseyside public health collaborative
NOVA	NOVA is a classification system, it is not an acronym
IMD	Index of Multiple Deprivation
BMI	Body Mass Index
AIC	Akaike Information Criterion

Introduction

417482 people, 15.4% of the population, have hypertension in Cheshire and Merseyside (1). Cheshire and Merseyside public health collaborative (CHAMPs) have a plan to reduce blood pressure (BP) by 2029 (2) . The strategy aims to increase 'awareness'. This is intended to increase individual compliance with testing and treatment of raised BP. This study intends to offer additional opportunities for improving outcomes.

UPF makes up up to 60% diet in UK especially in the North West of England. There is evidence of an association between hypertension and intake of Ultra-processed Foods (UPF) (3) and hypertension and Salt intake (4) from studies of different types in multiple countries. Moreira et al (5) model a scenario where "halving intake of (NOVA) group 3 foods could result in approximately 22,055 fewer deaths" across the UK in 2030. Local food policies around UPF might be a way of reducing hypertension at a population level. There is potential for significant public health impact.

Marmot (6) identifies the external influences in Cheshire and Merseyside which need to be improved to permit individual action to be effective. Using a better understanding of the role of UPF, and the interaction with sodium, might give a mechanism of action of some of Marmot's categories of influence.

This study assessed prevalence of exposure to sodium and UPF, and hypertension in the data set of the National Dietary and Nutrition Survey (NDNS) (7) .The study gives data from the UK from 2008 to 2019. It is stratified to be representative of the population of the UK by sex, age, region and index of multiple deprivation (IMD). BP, UPF and Sodium intake

were recorded. Age and sex remain important background factors. This leads to the research question below.

I have used STROBE guidance (8) in producing this report. This study explored this complex web pulling out strands within it, diagram 1 shows a possible arrangement of this.

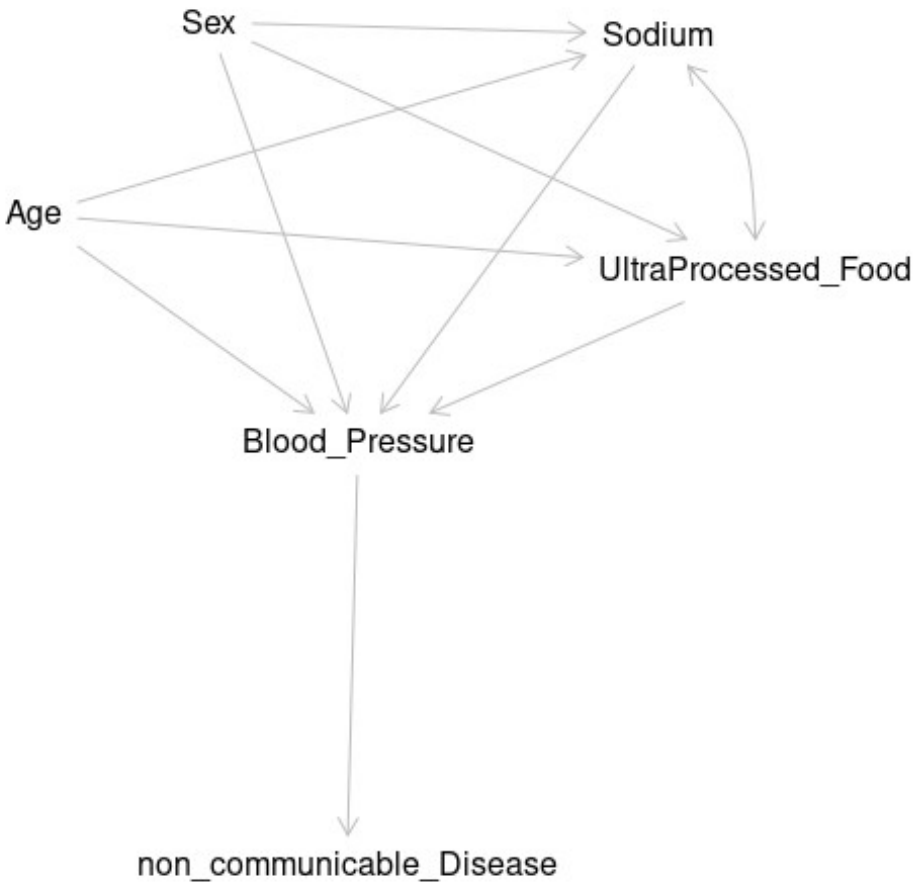

Figure 1: The relationships explored in the analysis

Epistemology

The epistemological approach of this study is positivist. I use a quantitative approach in a mechanistic and deterministic model. However, I am aware that this model is incomplete.

Positivism encourages experimental isolation. The study is isolated from the world through control of the experimental environment.

Real world dietary change requires understanding interaction with social and economic factors, not isolation. Critical realist and social constructionist studies are needed to complement the information from this study. The commercial and social determinants of health are models which have a great deal of impact on exposure to UPF and Na and on dietary effects on BP.

Positionality

In a positivist paradigm the observer is external to the experiment. Acknowledging the constructivist aspects to this study allows that the observer is closer to the model making my positionality of interest. Jafar (9) argues that understanding the position of the investigator be of interest to understanding this quantitative study.

I bring an attachment to positivist ideals from my biomedical background. As an older physician I am aware of social factors impacting health of participants as Evans and Trotter (10) discuss. I also understand that my perception of the world is from a position of significant privilege. To proceed, I need to be aware of the limitations of the positivist approach. I need to make pragmatic selections to bring some degree of validity to the resulting dataset.

These constructed ideas, social expectations, income, or geography affect food and health ‘choices’. They also impact on ‘hard’ clinical measurements such as BP, through physical

position and room temperature as well as by the relationship between the observer and the participant.

This work is primarily to complete requirements for an MPH degree which means that it is influenced by factors around health equity and classic epidemiology as taught on the course. It is produced in collaboration with a research group with a long established reputation in food research in public health, which may steer the results in a conservative direction.

Literature Review

Rationale

- 1 develop search
- 2 review search and confirm inclusion
- 3 describe literature
- 4 synthesise literature
- 5 critique literature
- 6 explain role of study within context

This literature review was intended as a systematic search, to identify papers with information about UPF, sodium and blood pressure informed by PRISMA (11).

The rationale for this review is to contribute background and to answering the research question;

What is the evidence that in adults and children across the four home nations of the UK between 2008 and 2019, would exposure to high sodium dietary intake, and or high UPF dietary intake, compared to lower exposure, increase the odds of having a mean systolic blood pressure of over 140mmHg?

Method

Eligible studies were cross-sectional studies, and systematic reviews considering the relationship between the exposure, and outcome in comparable general populations.

Papers were excluded where the population was specifically of one type, or had a specified health condition. Another exclusion criterion was where specific foods were considered.

Scopus (12) , Pubmed , Web of Science and Medline(ovid) (13) were searched.

The search strategy is included in table 1 below. The search concentrated on systematic reviews, these identified high quality primary research. Other sources were identified by cross referencing bibliographies particularly from the systematic reviews. Colleagues identified further relevant literature.

My search terms

Table 1: Description of Search

search terms (("ultraprocessed food*" OR "ultra-processed food*" OR "ultra processed food*" OR "NOVA food*")OR (salt OR sodium OR "sodium intake")) AND ("blood pressure" OR hypertension OR "cardiovascular disease" OR "cardiovascular risk")AND(cohort OR cross-section* OR prospective OR meta-analysis OR "systematic review")					
Inclusion prospective and observational studies and systematic reviews specifically on hypertension with relevant exposures					
Exclusions ("renal cell cancer" OR "gastric cancer" OR "multiple sclerosis" OR dialysis OR DHA OR auto-immunity OR autoimmunity OR diarrhoea OR telomere OR crp OR "c-reactive" OR CKD OR "chronic kidney disease" OR autosomal OR geneti* OR "Inflammatory bowel disease" OR diabetes OR atherosclerosis OR osteoporosis OR angiotensin* OR aldosteron* OR covid-19 OR gestation* OR stroke OR "birth weight" OR hypertensive OR "immune mechanisms" OR "heart failure"OR taste OR "cognitive decline" OR dementia OR mortality OR validation)					
Name	Scopus search	Medline (Ovid)Search	Pubmed search	Web of Science Search	Total

Date of Search	18/6/23	18/6/23	18/6/23	18/6/23	18/6/23
Number of results	240	202	103	48	593

Selection strategy

Inclusions and exclusions are identified in the table. No time limits, language limits or availability limits were included in the search.

The papers were reviewed by the author only.

The data sought were odds ratios for the effect of UPF or sodium on blood pressure.

There is risk of bias due to the single reviewer approach.

There is little homogeneity of approach to reporting exposure or outcome making it difficult to compare items directly.

Search results

The search identified 593 papers, 348 after removing duplicates. Chart 1 shows how these were assessed.

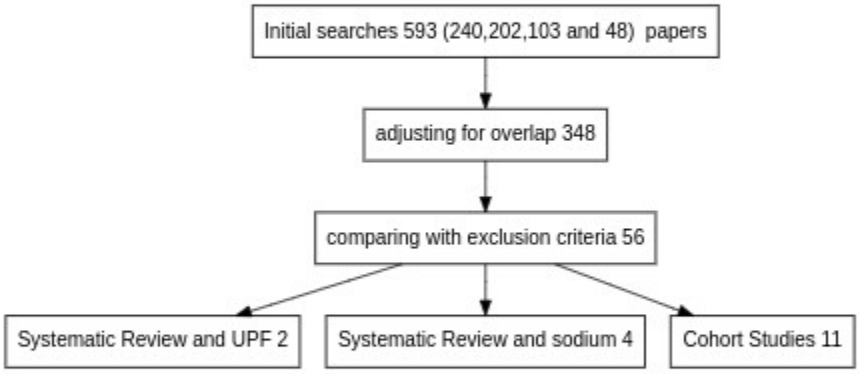

Figure 1:

These were then reviewed by comparing the titles against the inclusion and exclusion criteria leaving 56. 6 systematic reviews were identified, one which considered both UPF and sodium intake. Some of these calculated odds ratios using meta-analysis.

Discussion of literature

Table 2: Systematic reviews and Meta-analyses

First Author	Type of Study	Subject of Study	Results
Barbosa (14)	systematic review Papers from Americas	UPF and Sodium and Hypertension	5 cross-sectional and 4 cohort studies +ve association found
Wang (15)	systematic review and meta analysis	UPF and hypertension	5 cross-sectional and 4 cohort studies (odds ratio: 1.23; 95% CI: 1.11, 1.37; P=0.034)
Mambrini (16)	systematic review few studies one women only study	UPF and BP	4/17 UPF and BP +ve association found
D'Elia (17)	meta-analysis	Salt and CVD	*a 2.84% (95% CI 0.51–5.08) reduction in PWV*
Leyvraz (18)	meta-analysis	children sodium blood pressure	13/18 studies every additional gram of sodium intake per day, systolic blood pressure increased by 0.8 mmHg (95% CI: 0.4, 1.3)
Frias (19)	systematic review of cohorts	children and BP	2 studies BP no association systolic BP
	nb BP is Blood Pressure	nb CI is confidence interval	nb CVD is cardiovascular disease UPF is Ultraprocessed food

UPF and BP

Three systematic reviews, those of Mambrini et al,Barbosa et al, and Wang et al highlight the risk of hypertension with high UPF. They also identify that the effect is not always evident. Wang's meta-analysis was used to calculate the sample size for this study.

Mambrini et al identify that few papers attempt to link UPF with hypertension. Their systematic review identifies Monge, Scaranni, and Mendonca. These three cohort studies of middle aged adults were followed up for between 2.2 and 9.1 years.

Scaranni used Brazil's ELSA study, in middle aged civil servants, finding that higher UPF had a marginally greater risk of developing hypertension (OR = 1.17; 95% CI: 1.00, 1.37) compared with lower intake %.

Monge found no association between categories of UPF, from ≤20% to >45% energy/d and incident hypertension. This study used mexican female teachers, this group may have a different exposure and outcome profile to a more general population.

Mendonca in Spain found an affect on hypertension (HR = 1.21, 95% CI: 1.06, 1.37, Ptrend = 0.004). This sample had a strong effect on Wang's meta analysis with a weighting of 16.72 from 9 studies.

Wang's meta analysis included six more studies;

Ivancovsky-Wajcman OR = 1.53, (1.07- 2.19)

Levigne- OR =0·99 (0·59, 1·68)

Martinez-Steele OR =1.19 (1.03,1.38)

Nardocci OR = 1.60, (1.26–2.03)

Nasreddine OR =3.10, (0.84,16.66)

Rezende-Alves OR =1.35 (1.01,1.81).

Of these studies the study by Nasreddine was a very small localised study in Lebanon, as shown by the wide confidence interval. Monge and Levigne- also had equivocal results. Levigne- 's sample was a specific population in Canada.

Barbosa identified a different group of studies. No meta-analysis was done. The studies included a wider range of outcomes. This made it hared to compare results as accurately.

Shim demonstrated the effect on hypertension in Korea, despite the highest tertile percentage UPF being only >28.55%.

Table 3: Table of papers on UPF and BP

First Author	Study Type	Subject	Results
Shim (20)	Korean Cross-sectional	UPF and Hypertension	OR= 1.25,CI: 1.11 and 1.40
Scaranni (21)	Brazil ELSA cohort	UPF and Hypertension	OR = 1.17; 95% CI: 1.00, 1.37
Rezendez-Alves (22)	Brazil cohort	UPF and Hypertension	RR: 1.35; 95% CI: 1.01, 1.82).
Martinez-Peres (23)	Spain Transverse	UPF and BP	no significant effect
Monge (24)	Mexico women only Cohort	UPF and BP	no effect
da Conceicao (25)	Cross-sectional	UPF and BP	no effect
Nardocci (26)	Canada Cross-sectional	UPF and hypertension	OR = 1.60, 95% CI: 1.26–2.03)
Nasreddine (27)	Lebanese Cross-sectional	UPF and BP	OR 3.10 (0.58,16.66)
Lavigne-Robichaud (28)	Canada Cree People Cross-	UPF and BP	0.99 (0.59,1.68)

First Author	Study Type	Subject	Results
	sectional		
Martinez-Steele (29)	USA Cross-sectional	UPF and Mets	1.19(1.03,1.38)
Smiljanec (30)	USA Cross-sectional	UPF and BP	Positive association between UPFs and general SBP (B = 0.25, 95% CI: 0.03, 0.46, p = 0.029)
Ivancovsky-Wajcman (31)	USA Cross-sectional	UPF and BP	OR = 1.53, 1.07- 2.19, P = .026
de Deus Mendonca (32)	Spain SUN cohort middle aged uni grads	UPF and (self -reported) hypertension	HR, 1.21; 95% CI, 1.06, 1.37; P for trend = 0.004
	nb BP is Blood Pressure	nb CI is confidence interval	nb CVD is cardiovascular disease nb UPF is Ultraprocessed food

Salt and CVD

Table 4: Review papers Sodium and BP

First Author	Study Type	Subject	Results
He (33)	meta-analysis	Salt and hypertension	11 trials in 'normotensive' A reduction of 100 mmol/day (6 g of salt) in salt intake predicted a fall in systolic blood pressure of ... 3.57 mmHg in normotensive individuals (systolic: Po0.001)
Strazzullo (34)	meta-analysis	Salt and CVD	13 studies risk of stroke (pooled relative risk higher salt intake 1.23, 95% confidence interval 1.06 to 1.43; P=0.007) and cardiovascular disease (1.14, 0.99 to 1.32; P=0.07)
Graudal (35)	meta-analysis	Salt and CVD	*ACM: HR = 1.16, 95% CI = 1.03-1.30; CVDEs: HR = 1.12, 95% CI = 1.02-1.24*
Ma (36)	meta-analysis	urinary sodium and CVD	Each daily increment of 1000 mg in sodium excretion was associated with an 18% increase in cardiovascular risk (hazard ratio, 1.18; 95% CI, 1.08 to 1.29),
	nb BP is	nb CI is confide	nb CVD is cardiovascular disease

First Author	Study Type	Subject	Results
	Blood Pressure	nce interval	nb UPF is Ultraprocessed food

The systematic reviews identified in the search include Barbosa, and D'Elia. Leyvraz and Frias concentrate on effects in children.

He, Graudal and Strazzullo were not identified in this search but were referenced in the other papers.

He identifies reduction in BP with reduction in sodium intake. Graudal reports that sodium reduction can go too far, identifying a 'j'-shaped curve. He Identifies the inclusion of papers with big effect sizes, and short follow up in Graudal as contributing to this effect of very low sodium intakes.

D'Elia et al look at arterial stiffness pressure wave velocity 'PWV' and show that this increases with salt intake. This arterial stiffness is potentially more sensitive to sodium intake than BP. They included 11 studies, of 14 cohorts and 431 participants studied over 1-6 weeks. Reducing sodium intake by 89.3mmol/day was associated with 2.84% (CI0.51-5.08) reduction in PWV.

D'Elia's results show that BP is less accurately predicted than arterial stiffness. This may be a cause of the equivocal results found by studies looking at BP.

Graudal et al. Studied cohort studies as there were no RCTs of increased sodium intake. They found data from 23 cohort studies (n=274,683). They showed acute cardiac events

(ACM) and cerebrovascular events CVDE were increased in high sodium intake compared with usual sodium intake *(ACM: HR = 1.16, 95% CI = 1.03-1.30; CVDEs: HR = 1.12, 95% CI = 1.02-1.24)*.

Their findings identify that there might be 'too much' salt reduction possible. They provide an explanation as to how low sodium levels may causes issues.

Straluzzo et al identifies He et al (33) as a source for hypertension and salt.

Literature review Conclusion

Of the identified papers the majority describe 2/3 elements, UPF or salt intake or BP/ CVD .

They show an odds ratio for cvd with raised sodium intake and hypertension with high UPF intake. They suggests BP is an uncertain outcome measurement. Papers often look to CVD outcomes as stronger endpoints.

Where UPF exposure has been studied with hypertension as an endpoint the cross-sectional studies have identified a link in adults, but sometimes there is an inverse gradient. The cohort studies are consistent in showing a small but measurable positive effect. This is also identified in the meta-analyses.

This study aims to identify these two effects within a large representative cross-sectional population. The relationship between these two effects can be shown by studying both in the same population. This study also gives the opportunity to consider if there are associated factors.

Research Question

Using PICO (37) approach,

In adults and children across the four home nations of the UK between 2008 and 2019, did exposure to high sodium dietary intake, and or high UPF dietary intake, compared to lower exposure, increase the odds of having a mean systolic blood pressure of over 140mmHg?

This primary question can be split into parts,

For a representative population across the UK What was dietary intake of UPF between 2008 and 2019? What was dietary intake of salt between 2008 and 2019? What was BP between 2008 and 2019? What was the correlation between these?

In addition it may be possible to consider, How did each of these change over that time? Is there evidence of interaction between these? Was UPF or Na most important in these changes?

Objectives

1 Literature Review of UPF and BP, and Sodium and BP

2 Descriptive analysis of participants from NDNS with amalgamation of data across the rolling programme.

3 Analysis of exposure to UPF and sodium, and prevalence of BP >140mmHg using regression models with associated data analysis.

4 Discussion of implications of results in answer to the research question, Public health implications and actions. Also in relation to limitations of cross- sectional studies, and available data, as well as suggestions for further research

Method

Study Setting and Design

This is a secondary data analysis of data from the National Dietary and Nutritional Survey (NDNS (7)). This analysis intends to analyse the association between sodium intake, UPF intake and BP.

The NDNS was commissioned in collaboration between government departments responsible for health and for food production. Academic partners delivered reports on diet and nutrition across the United Kingdom. The study is designed to be representative across the four home nations, and across age with balanced representation for children. NDNS data are available via the UK national Data service for research purposes.

NDNS is a rolling cross-sectional study, in each year a new cross section of participants is enrolled from the wider population. Questionnaires, food diaries, and nurse assessments are used to gather data. It has been running since 2008. The most recent data is available from 2019.

University Research Governance and Ethical Review

The ethics process for the University of Liverpool was followed and confirmation of compliance is attached at Appendix 2 Ethics Certificate

The storage of the data is in keeping with the research governance agreements of the University and the Data set owners.

Participants, Inclusion and Exclusion

Participants were identified by random selection across postal units. The sample is stratified to ensure a representative sample across the four nations (England, Wales, Scotland, and Northern Ireland) and across regions in England (North, Central/Midlands, South(including London)). The sample is also stratified for age and sex and Index of multiple deprivation (IMD).

For NDNS the intended sample is 1000 per year with 50% adults. Each year the sample is slightly different due to differential uptake. Oversampling is used to control this.

The relationship between salt and systolic blood pressure may be different in individuals with pathologically high BP. Those taking BP controlling medications may have a different relationship to sodium and UPF and so were excluded for analysis.

Exposure Variables

The participants recorded their food intake as a food diary. Four days of the diary including a weekend day are used for each participant. They record food and portion size as well as where food was eaten.

Based on the food and drink intake reported and with a composition data table, the NDNS team have estimated the daily intake of food by group, and large range of nutrients including sodium.

Sodium estimation

This analysis used the daily sodium intake in mg from NDNS. This value reflects the expected content of standard foods.

Serum sodium values are available for the early dataset, but not the later one. 24 urinary sodium is a better indicator of dietary sodium but values are not available across the whole time period.

A categorical variable, has been produced with a cut off values at 3000mg, 5000mg and 6000mg. These values are the WHO recommended amount and match values used in Du et al (3).

UPF

The NOVA classification, developed by Monteiro et al. (38), was used to estimate the intake of UPF. There is no record of NOVA classification in NDNS. The dataset provided by Dr Colombet (personal communication) was used to identify food by NOVA group. This was developed by comparing every food level entry in NDNS against NOVA. A standard methodology describing the approach used has been published by Martinez-Steele et al. (39) .

Next the energy content of the day's food was calculated by NOVA group. This was added to the intake for the other 3 days and the total intake by NOVA group established. The percentage of the total intake of energy was then calculated for each of the 4 Nova categories. Nova group 4 or UPF intake (UPF) is used for this study.

A variable (UPF3) was developed from the mean UPF intake. The central category is the mean with one standard deviation above and below. This effectively identifies 67% in the centre of the distribution. Categories used in other papers eg (40) are low for the UK.

Outcome Variable

BP is a quality assured mean systolic BP which is reliable across the dataset. It was measured in mmHg using a calibrated automatic sphygmomanometer by a study nurse under specified conditions. These conditions controlled for the effects of exercise, temperature and ill health. The data on all these is in the dataset. Raw BP values are also present in the dataset to allow quality review.

I have created a categorical variable which identifies participants with BP over 140 mmHg to enable logistic regression. This value is identified by Du et al ((3)) and others, though some use lower values such as 120mmHg ((41))

Other Variables

Additional explanatory variables are ones which can also influence BP. They include Age, Sex, and BMI. Age at completion of education , and IMD are also used. These may have effects such as confounding, mediation, and obstruction within the analysis.

Stratification is used in the design and sampling stage to modify for these. Including them in multivariable regression attempts to prevent them confounding the analysis.

Age is used as continuous and as categorised data for the analysis. It has a complex role in cross-sectional analysis. It acts as an explanatory variable, but also as mediator and

obstructor. It is complicated further by stratification to ensure a large enough sample of 50/50 children and adults.

The sex of participants is identified. and is an important explanatory variable.

BMI is identified as a potential explanatory variable. There is also a known association with BP.

IMD is included to identify socio-economic patterns in the data. This UK- nation based data is used consistently in UK studies, but has no analogue across the world. Instead age at completion of education, or income are often used internationally.

Study Size

A sample size calculation for this secondary analysis is available in appendix 1 the initial proposal from OpenEpi (42) . This calculated the sample size of 3526, with a ratio of 0.75 unexposed to exposed. An intended power of 80%, at a level of statistical significance of 95% was used. An odds ratio of 1.2 was used based on a meta-analysis by Wang et al (43) .

Statistical Methods

Four data batches of data (2008-2012, 2013-2014, 2015-2016, 2017-2019) were combined. The data was read using ‘r-studio’ with the processing being carried out using packages (see appendix 3) available from CRAN (44). In particular the package ‘survey’ (45) was used to manage weighted data. Generated weighting values account for differences uptake and drop out across the annual cohorts. ‘Survey’ also accounts for sample stratification.

Analysis Plan

Descriptive data was tabulated to enumerate the outline structure.

The sensitivity of the data to changes in the annual cohorts was assessed.

Then the data was analysed for correlation by regression. AIC statistics were used to assess 'goodness of fit'.

In all analysis P.values and confidence intervals were calculated and a value of $p < 0.05$ was taken as the threshold of statistical significance.

Multivariable regression models were constructed to manage variables which might have confounding effects on the outcome of the analysis. Sample stratification was also used to reduce potential confounding. Tables of results were produced to best demonstrate the data. For the main results a set of multivariable logistic regression models was developed. Each exposure variable was modelled separately, the final model included both of the exposure variables.

Results

Participants

Considering participants who opted in and completed questionnaires, the whole NDNS population was 15,655. The median age was 40. Categorising age shows that 22% of the population was between 19 and 35. There were 49% male participants.

After excluding those on medication, the population was 14217 participants.

This table table 31 shows the participants.

Continuous variables are represented by the median and interquartile range in brackets. Categorical variables give the number of participants and the percentage of the sample in brackets.

Table 5: Characteristics of the Sample Population (National Dietary and Nutrition Study 2008-2019)

	Whole Population	Population not on BP medication	UPF >63%	Na >5000 mg	hyp >140mm Hg
Characteristic	**N = 15,655**[1]	**N = 14,217**[1]	**N = 4,793**[1]	**N = 73**[1]	**N = 876**[1]
Sex					
Male	7,699 (49%)	6,992 (49%)	2,568 (54%)	58 (80%)	505 (58%)
Female	7,956 (51%)	7,225 (51%)	2,225 (46%)	15 (20%)	371 (42%)
Age	40 (22, 58)	37 (20, 54)	23 (12, 42)	31 (22, 39)	60 (48, 70)

	Whole Population	Population not on BP medication	UPF >63%	Na >5000 mg	hyp >140mm Hg
Characteristic	**N = 15,655**[1]	**N = 14,217**[1]	**N = 4,793**[1]	**N = 73**[1]	**N = 876**[1]
agegad3					
(0,18]	3,284 (21%)	3,278 (23%)	1,970 (41%)	4 (5.5%)	12 (1.3%)
(18,35]	3,544 (23%)	3,529 (25%)	1,275 (27%)	44 (61%)	67 (7.7%)
(35,50]	3,355 (21%)	3,241 (23%)	799 (17%)	21 (28%)	177 (20%)
(50,65]	2,912 (19%)	2,475 (17%)	418 (8.7%)	1 (1.8%)	314 (36%)
(65,108]	2,561 (16%)	1,692 (12%)	330 (6.9%)	3 (4.0%)	307 (35%)
educfinh					
Not yet finished	375 (2.9%)	375 (3.2%)	185 (5.1%)	2 (2.4%)	1 (0.2%)
Never went to school	41 (0.3%)	29 (0.2%)	0 (<0.1 %)	0 (0%)	0 (0%)
14 or under	504 (3.9%)	345 (2.9%)	89 (2.5%)	2 (2.4%)	57 (7.2%)
15	1,773 (14%)	1,426 (12%)	472 (13%)	5 (8.3%)	186 (24%)
16	3,483 (27%)	3,160 (27%)	1,180 (33%)	24 (36%)	188 (24%)
17	1,074 (8.3%)	974 (8.3%)	332 (9.2%)	2 (2.5%)	60 (7.6%)
18	1,588 (12%)	1,484 (13%)	482 (13%)	7 (11%)	78 (9.9%)
19 or over	4,172 (32%)	3,922 (33%)	878 (24%)	25 (38%)	218 (28%)
Unknown	2,645	2,502	1,174	8	89
IMD					

	Whole Population	Population not on BP medication	UPF >63%	Na >5000 mg	hyp >140mm Hg
Characteristic	**N = 15,655**[1]	**N = 14,217**[1]	**N = 4,793**[1]	**N = 73**[1]	**N = 876**[1]
Most deprived	2,977 (19%)	2,748 (19%)	1,139 (24%)	28 (39%)	112 (13%)
2	3,128 (20%)	2,870 (20%)	1,086 (23%)	21 (28%)	169 (19%)
3	2,905 (19%)	2,609 (18%)	850 (18%)	15 (20%)	136 (16%)
4	3,269 (21%)	2,953 (21%)	914 (19%)	5 (7.2%)	210 (24%)
least deprived	3,372 (22%)	3,031 (21%)	804 (17%)	4 (5.2%)	247 (28%)
Unknown	5	5	0		2
region					
England: North	3,684 (24%)	3,313 (23%)	1,231 (26%)	34 (46%)	238 (27%)
England: Central/Midlands	2,512 (16%)	2,266 (16%)	834 (17%)	14 (20%)	150 (17%)
England: South(including London)	6,958 (44%)	6,363 (45%)	1,861 (39%)	14 (19%)	329 (37%)
Scotland	1,302 (8.3%)	1,181 (8.3%)	439 (9.2%)	8 (12%)	78 (8.9%)
Wales	753 (4.8%)	682 (4.8%)	247 (5.2%)	1 (1.5%)	62 (7.1%)
Northern Ireland	447 (2.9%)	413 (2.9%)	181 (3.8%)	2 (2.1%)	20 (2.3%)
SurveyYear					
1	1,459 (9.3%)	1,323 (9.3%)	481 (10%)	12 (16%)	100 (11%)
2	1,429 (9.1%)	1,284 (9.0%)	496 (10%)	7 (10%)	83 (9.5%)
3	1,372	1,246 (8.8%)	472	13	92 (10%)

	Whole Population	Population not on BP medication	UPF >63%	Na >5000 mg	hyp >140mm Hg
Characteristic	**N = 15,655**[1]	**N = 14,217**[1]	**N = 4,793**[1]	**N = 73**[1]	**N = 876**[1]
	(8.8%)		(9.9%)	(18%)	
4	1,432 (9.1%)	1,291 (9.1%)	495 (10%)	6 (8.4%)	94 (11%)
5	1,485 (9.5%)	1,361 (9.6%)	461 (9.6%)	6 (8.5%)	86 (9.8%)
6	1,362 (8.7%)	1,234 (8.7%)	473 (9.9%)	1 (1.7%)	75 (8.6%)
7	1,442 (9.2%)	1,312 (9.2%)	421 (8.8%)	10 (14%)	92 (11%)
8	1,405 (9.0%)	1,276 (9.0%)	378 (7.9%)	5 (6.6%)	75 (8.5%)
9	1,444 (9.2%)	1,305 (9.2%)	362 (7.6%)	5 (6.8%)	81 (9.3%)
10	1,481 (9.5%)	1,360 (9.6%)	375 (7.8%)	1 (1.6%)	98 (11%)
11	1,345 (8.6%)	1,226 (8.6%)	379 (7.9%)	6 (8.1%)	0 (0%)

[1]n (%); Median (IQR)

Descriptive Data

The study population the median age was 38. The largest age group was 18-35. 49% of the participants were male.

The table 4.1.1 shows the population exposed to UPF >63% of their calories is made up of 4793 from a total of 14217 participants. This compares with 9424 participants with lower exposure. That is an exposure prevalence of 34%.

High UPF is more common in younger males than in the overall population or those not on medication. 37% are 0-16 years old. There is a gradient in deprivation with more exposure

in the most deprived group. England's South East has 13% of those with high UPF intake. With 11% in the North West.

The population exposed to Na >5000mg has only 73 out of 14217 participants. An exposure frequency of 0.5%. 61% are 18-35, and 80% male . The least deprived makes up 5.2% of the participants compared with 39% of the most deprived. The north has 46% of those with high Na intake, much the highest.

Sensitivity to Survey Year

Internal consistency was examined by comparing background data across survey years. This might also be called sensitivity analysis by survey year. Wave 1 was a comparator for analysis of the other waves.

The data had p.values >0.05 for the controlled variables (age, sex, IMD) against annual wave. UK region is part of the weighting, but this sample showed variation with p.value <0.05.

Table 4.2.3 follows.

Table 6: Sensitivity of categorical variables to survey year (NDNS 2008-2019)

Variable	p.value
Sex	0.53
IMD	0.71
Age	0.66
BMI	0.77

Variable	p.value
Region	0.00

The exposure variables were compared across annual waves. Most people have sodium exposure less than 3000mg. In year one this was 81%, with only 0.9% exposed to more than 5000mg. By year eleven 92% are reporting less than 3000mg, and 0.5% over 500mg.

UPF exposure was steady with 37%-40% of the participants exposed to 45%-63% throughout the survey. Up to 38.2% of the participants were exposed to levels of more than 63%, the peak being in year 6.

Results were illustrated by plots against survey year. figure 4 showed overlap between the waves for UPF intake. figure 5 showed sodium exposure overlap between waves.

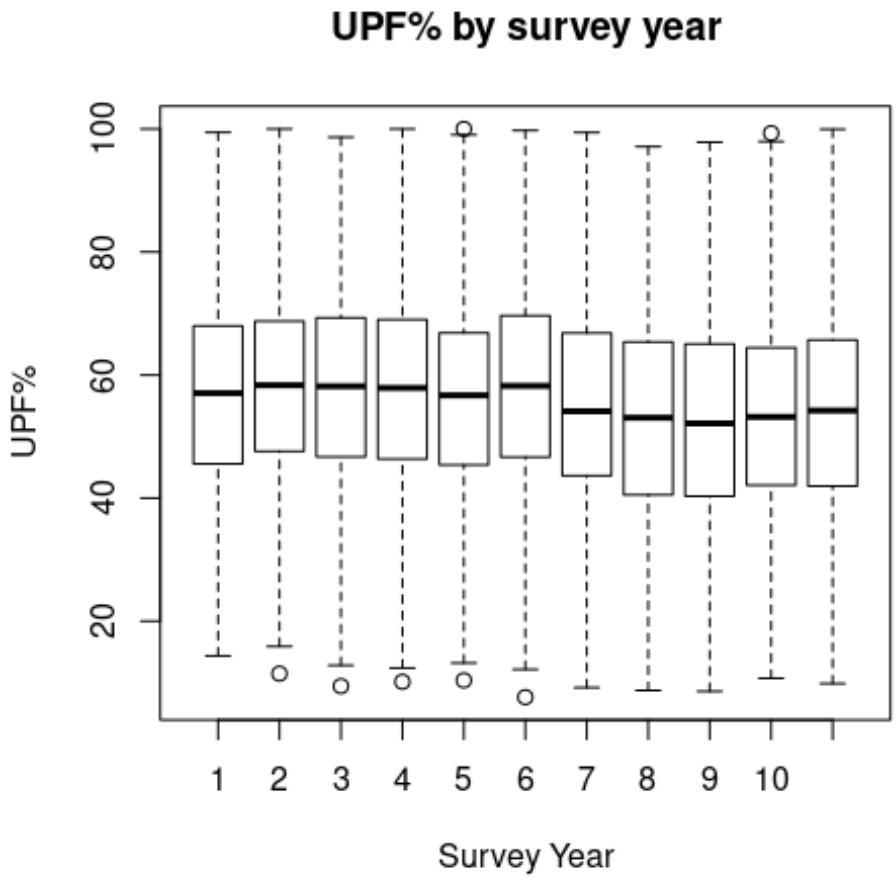

Figure 1: Energy from UPF% in each annual cohorts NDNS (2008-2019)

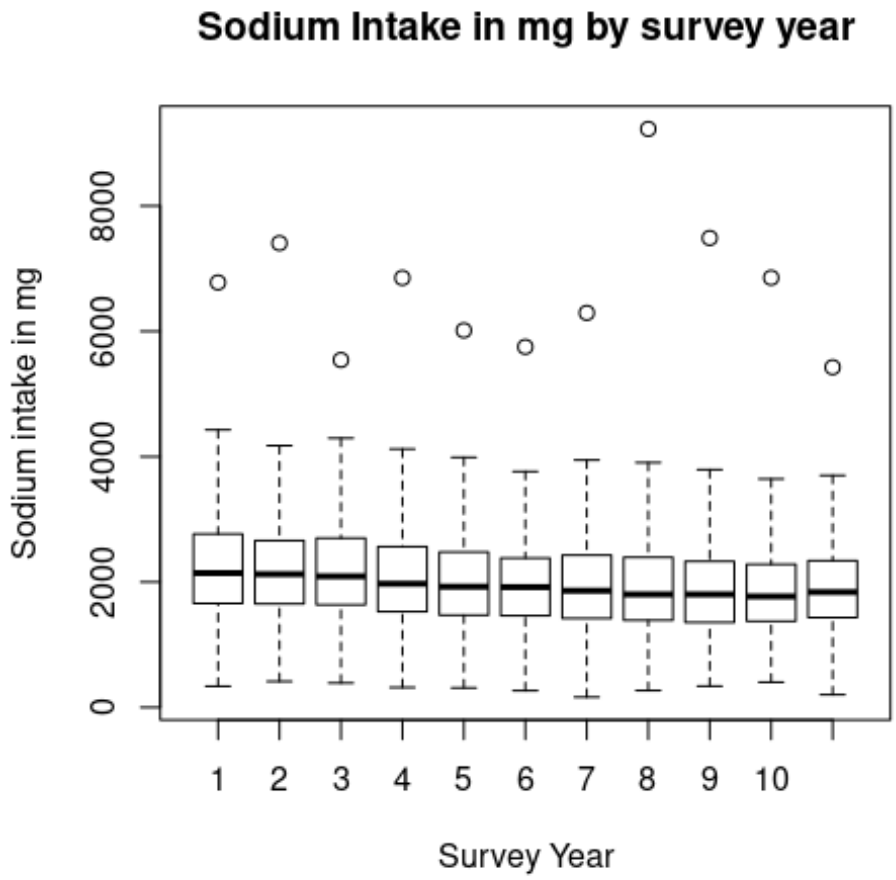

Figure 2: Na in mg in each annual cohort NDNS(2008-2019)

Outcome variable

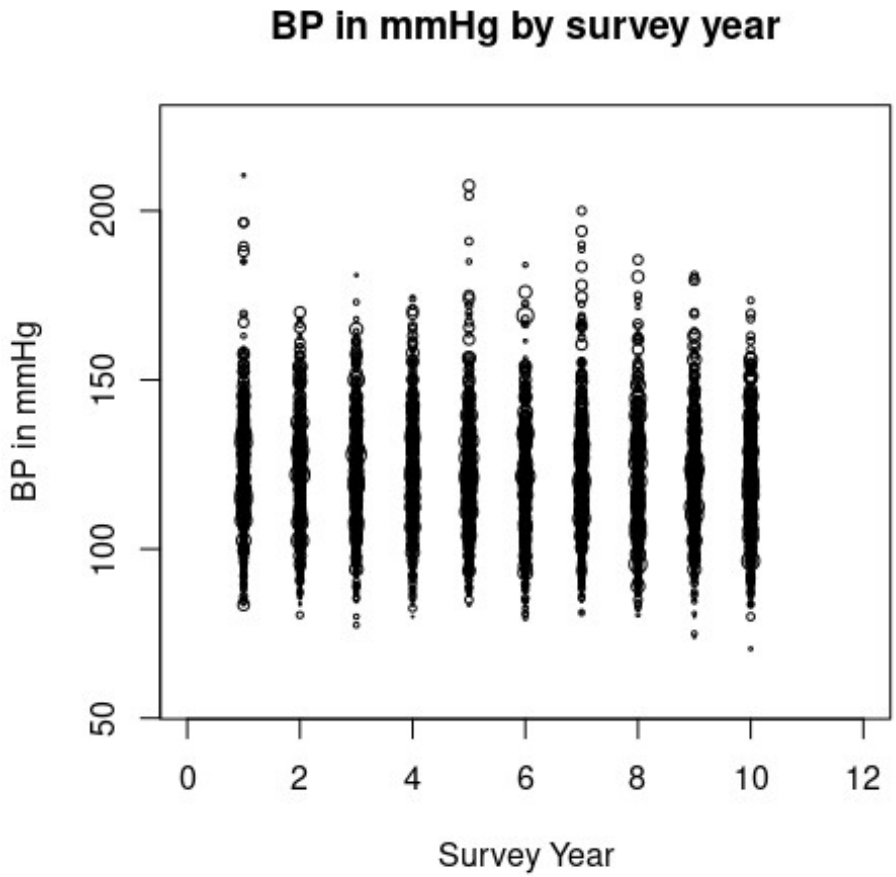

Figure 3: Plot of the BP in mmHg by year from NDNS (2008-2018)

figure 6 shows that the mean BP is consistent across the waves.

The table 3 shows the population with BP > 140 mmHg is 876 participants. This gives a prevalence of 6%.Men are once again overrepresented. These participants are older than the population median, 44% of theses participants are over 65. This group are statistically significantly different from the populations with high Na, or high UPF! There is a reverse gradient with IMD in this population. The most deprived are least represented in this population. The largest proportion are in the least deprived category. The north is second highest in raised BP after the south east. The BP was highest in year one with 125 mmHg,

and the lowest 120 mmHg in year 6. BP rose through life to a mean of 134 mm Hg in the over 65 age category.

Main Results

The main results are the correlation between the exposure and the outcome variables. Univariable regression demonstrates the interaction with other explanatory variables. Then multivariable regression is used. Mathematical models containing explanatory variables are constructed and compared using 'goodness of fit' statistics.

By calculation using a Chi squared 2*2 table, the odds ratio for hypertension in participants exposed to UPF >63% is 0.5. The odds ratio for hypertension in participants exposed to Na >5000mg is 1.45. This results takes no account of weighting, or confounding.

Univariable regression is adjusted for weighted survey samples. It is used to identify important relationships within the data. Confounding plays a part in these results.

The result for Sodium against UPF shows that there is no linear relationship between Sodium and UPF, in this table Table 4.4.1. UPF compared to Na also shows a zero beta value indicating no linear relationship.

UPF does show a negative relationship with BP, which is statistically significant, beta = -0.19 (CI -0.22,-0.15).

There is also a negative relationship for UPF with Age, again statistically significant beta = -0.25 (CI -0.26,-0.23).

Age has a relationship with BP with a statistically significant positive gradient beta= 0.43 (CI 0.41,0.45).

There is also a positive relationship with Na, which is also statistically significant 1.5 (CI 0.77,2.3).

Table 7: Univariable Regression (NDNS data 2008-2019)

	BP			UPF			Sodium		
Characteristic	**Beta**	**95% CI**[1]	**p-value**	**Beta**	**95% CI**[1]	**p-value**	**Beta**	**95% CI**[1]	**p-value**
zPF	-0.19	-0.22, -0.15	<0.001						
Na	0.00	0.00, 0.00	<0.001	0.00	0.00, 0.00	<0.001			
Age	0.43	0.41, 0.45	<0.001	-0.25	-0.26, -0.23	<0.001	1.5	0.77, 2.3	<0.001
agegad3									
(0,18]	—	—		—	—		—	—	
(18,35]	11	9.6, 12	<0.001	-9.1	-10, -8.0	<0.001	540	485, 595	<0.001
(35,50]	14	13, 15	<0.001	-13	-14, -12	<0.001	408	363, 454	<0.001
(50,65]	22	20, 23	<0.001	-17	-18, -16	<0.001	250	204, 295	<0.001
(65,108]	27	25, 29	<0.001	-14	-15, -13	<0.001	91	45, 138	<0.001
bmival	1.0	0.92, 1.1	<0.001	-0.29	-0.35, -0.23	<0.001	17	14, 19	<0.001
IMD									
Most	—	—		—	—		—	—	

	BP			UPF			Sodium		
Characteristic	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**	**Beta**	**95% CI[1]**	**p-value**
deprived									
2	2.2	0.49, 4.0	0.012	-1.6	-3.0, -0.18	0.027	47	-31, 126	0.2
3	2.3	0.69, 4.0	0.005	-3.5	-4.8, -2.1	<0.001	77	2.0, 151	0.044
4	3.1	1.5, 4.8	<0.001	-4.2	-5.6, -2.9	<0.001	86	13, 159	0.021
least deprived	3.3	1.5, 5.0	<0.001	-5.3	-6.6, -4.0	<0.001	4.6	-60, 69	0.9

[1]CI = Confidence Interval

Multivariable regression models were constructed. They are regressed against hypertension in patients who are not on BP reducing medication.

The model, “Sodium Only”, includes sodium as the exposure variable. The odds ratio for the group taking between 5000mg and 6000mg per day is statistically significantly different from those taking less than 3000mg per day. There is an odds ratio of 5.20 (CI 1.39,19.5) for this group.

“UPF only” shows a significant difference in odds ratio 0.60(CI 0.36,0.99) for the group 63-80%.

The last model, “Sodium and UPF”, shows that when combined the effect remains. The odds ratio for 5000-6000mg of Na remains statistically significant 5.57(1.47,21.2). The odds ratio for UPF also remains 0.57(0.34,0.94). These are both changed from the separate models. The Akaike Inclusion coefficient (AIC), a measure of ‘goodness of fit’, is lower for this combined model, 3590.81, indicating it is a better fit for the data also.

Table 4.5.1 follows below.

Table 8: Table of multivariable regression against BP to identify the effects relating to Na and UPF NDNS data 2008-2019

	Na only			UPF only			Na and UPF		
Characteristic	**OR**[1]	**95% CI**[1]	**p-value**	**OR**[1]	**95% CI**[1]	**p-value**	**OR**[1]	**95% CI**[1]	**p-value**
Sodium Intake mg									
(0,1.5e+03]	—	—					—	—	
(1.5e+03,3e+03]	0.99	0.69, 1.44	>0.9				1.05	0.72, 1.52	0.8
(3e+03,5e+03]	1.25	0.75, 2.09	0.4				1.38	0.82, 2.33	0.2
(5e+03,6e+03]	5.20	1.39, 19.5	0.015				5.57	1.47, 21.2	0.012
(6e+03,1e+04]	0.00	0.00, 0.00	<0.001				0.00	0.00, 0.00	<0.001
Ultraprocessed Food %									
(0,33]				—	—		—	—	
(33,45]				0.86	0.54, 1.36	0.5	0.83	0.52, 1.32	0.4
(45,63]				0.73	0.48, 1.12	0.15	0.70	0.46, 1.08	0.11
(63,80]				0.60	0.36, 0.99	0.046	0.57	0.34, 0.94	0.029
(80,100]				0.74	0.27, 2.05	0.6	0.69	0.24, 1.94	0.5
AIC	3594.65			3598.17			3590.81		

[1]OR = Odds Ratio, CI = Confidence Interval

All models include additional variables Sex,Age, BMI, Education, IMD and Survey Year

Relative Effect SIze calculation

Using the AIC statistic assessing goodness of fit for each model gives another way of understanding the comparative effects between variables. The lowest scored model is the optimal model. The ‘best’ of these models is that with only sodium included “Na only”. The UPF models both being further away from the lowest value.

Of the difference between the lowest scoring model and the highest 70/30 is due to the sodium. the additional effect of UPF is in proportion to this.

Discussion

Key Results

This analysis shows a statistically significant correlation between high Na intake and hypertension , and between high UPF and hypertension. This is present with each variable independently and with a combined model. Multivariable logistic regression controls a number of additional variables. Sex and age probably contribute the largest effects.

Univariable regression of UPF with sodium identifies no correlation. There are strong correlations between age and BP, hypertension, sodium intake and UPF intake.

There is a reduction in reported sodium intake over time. There is a slight reduction in UPF % over time, this might be reporting, or assessment as there were some changes to understanding and analysis.

Limitations

The study

This is a cross-sectional study, and so has the limitations of this design. In particular the study measures exposure and outcome at the same time. Causal relationships cannot be understood from this data.

Time and age have particular effects in cross sectional studies. Researchers in aging, and learning have identified this clearly, separating the effects of experiential learning, from

cohort effects and duration effects. Prospective studies such as Cohort or RCT studies have less of this affect sometimes inverting relationships between variables as a result.

This study was organised by government departments connected with food and farming alongside the Department of Health. The sample was designed to monitor relevant outputs. Funding and commissioning processes affect design structure and might also affect participant engagement and expectation. The study was not powered sufficiently for in-depth subgroup analysis.

The data

In particular this might affect social desirability bias. Social desirability and other participant reporting bias may well be significant within dietary diaries. Double labelled water studies on the first wave showed some significant differences between measured energy intake, and reported energy intake with differences between different age groups.

Bias

Selection bias was approached by using random selection of participants using a carefully constructed stratification model. Addresses were selected by postal units to ensure geographic spread of participants. This ensured that whilst random the sample remained representative.

Take up and Drop out bias was approached by ensuring that sample sizing included scope for this to enable comparable sample sizes across annual waves.

Social desirability bias acknowledges that participants remember and record intake framed by their beliefs about the needs of the study, and their beliefs about what is perceived as being healthy. To examine this, in the first wave a double labelled water study was incorporated. This compared reported energy intake with measured values (46) .

Finally bias at the analysis stage used weighting to standardise the sample for several variables. Those selected were Age, Sex, region and IMD. Weights are available for different levels of analysis as participants who did not complete the initial interview were not selected for subsequent blood analysis.

Sensitivity analysis looked to see how the variables changed over the survey years after weighting. This is intended to assess changes in sampling over the course of the study.

The result depends on participants recording foods in the same way as time goes on. Exposure of the whole population to a stimulus to change their diet or the recording of their diet may result in systematic changes in results.

A uniform change in the nutrient content of the food or changing the nutritional definitions would affect results. Years 9-11 used a slightly different methodology for identifying foods for analysis as researchers have started to become aware of the need to understand ‘processing’. This may account for the apparent lower exposure in the last three years.

These changes would affect the outcome variable less. However BP measurement technology has changed over ten years. BP machines derive their results from the changes in pressure detected in the arm of the participant, the algorithm used by the sphygmomanometer may have changed.

Weighting maintains age, sex, IMD, and government region across the waves. BMI is no different, and educational attainment is also unaffected. There are more vegetarians as time goes on.

The populations do change over time as some of the added variables do show statistical significant changes. In particular the number of vegetarians increases, which perhaps is one indicator of social desirability affecting the study.

In populations with exclusions the careful sample selection and weighting are overcome by the biasing effect of different selections. Selecting for BP, UPF or sodium changes the cohort sex balance, age range and IMD pattern making theses samples less representative.

The analysis

Interpretation

Participants with high Na >5000mg are more likely to have hypertension. Causation from other studies is likely to be that this high Na intake is contributing to high BP. However from this study causation cannot be identified. Other possibilities are that raised BP stimulates ingestion of Na, that Na ingestion increases hypertension, or that people with hypertension share another characteristic that increases their Na intake.

The results around high UPF intake also do no more than imply correlation. Causation might be the high BP reduces intake of UPF, or that participants with high BP are more aware of dietary UPF content. This can affect the detected directionality of the correlation.

The UK remains one of the highest % and so the reduction might be behaviour of a saturated market the USA or Canada might behave similarly. Other European countries are still fighting to retain a different food culture. Countries in the rest of the world are at differing levels of transition. This might be influenced by the degree of 'westernisation'/'internationalization'/ or 'capitalist colonialisation' into local culture.

There is a clear association with high sodium intake and hypertension. This remains an issue with UPF. There appear to be additional interactions as the multivariable regression shows a further effect when high UPF is added to the model.

UPF has a negative association with BP. This would fit with Zhang's finding in 'CVH'. It might also explain the curious absence of reporting in the many cross-sectional studies of BP and UPF. Rauber has published 3-4 papers on NDNS without mentioning salt or BP!

Is the explanation of the finding in cross section due to the nature of the data. Cross-section is a snapshot of exposure and outcome at the same time point. This lends itself to 'reverse causality'. This is where the outcome has lead to a a change in activity reducing the exposure. In this case those who are concerned about their BP being more likely to take great care of their diet.

One of the odd findings is that there is no relationship between % UPF and sodium intake. If UPF is 'high in salt' then high UPF should = high sodium, the finding suggests that the nature of the UPF varies. Despite this there is still an affect! so it may not be the salt in the UPF which is responsible for this effect, if so reformulation will not be effective!

The effect of sodium is augmented by that of UPF. The two together is greater than either individually

Age

Age is a particular feature in this outcome. BP is very strongly affected by age. In cross sectional studies Age has several dimensions. Age identifies cohorts of people with particular experiences, it identifies duration of experience, it represents physiologically different states, and it also identifies access to resources financial, material, and experiential. In psychology studies of ageing these separate aspects are understood and some can be controlled for, but not all. Prospective, longitudinal studies, and case matching can help reduce some of the effects. However longitudinal studies have reported similarly equivocal results, indentifying a potentially more complex interaction.

Ideas for further research

I will divide these suggestions into quantitative and qualitative.

Quantitative

There is scope for more research based on this data set. Within this same biomedical paradigm there are whole range of variables which can be compared against the clinical and biochemical outcomes. These include measured variables such as BMI, biochemical indicators such as Hba1c and medical diagnostic categories such as Diabetes.

Modelling research has allowed projections to be made using the data from studies such as this as a base for projected models. This can evaluate policy effects.

Mixed and Qualitative

The richness of the quantitative data in this survey calls for its use within an approach allowing more detailed description and in depth assessment with participants. In the study data there are data allowing research around cooking activities, hobbies, and eating activities.

It could also be used as a template for studies smaller in geographical scope, but more in depth as cross over studies collecting both quantitative and qualitative data.

Ideas for policy

Policy is an 'upstream' approach. It can be used to reduce exposure indirectly or directly. Ideas include legislation to reduce UPF use, this might be by pricing, or other approaches. Health promotion policy needs to match policy activity. People who know that UPF is bad, are more likely to accept policy limiting availability.

Reformulation is a policy suggestion, where UPF is further processed to remove the salt. This is frequently discussed. By demonstrating that UPF is not just high in salt this study supports the argument of avoiding further formulation as a policy for reducing BP.

Dietary approaches to improving public health are able to deliver proportionate and universal interventions to populations to reduce the incidence of NCD. When delivered up stream at the policy level they are effective and efficient and minimise cost. These approaches offer significant benefits over actions targeted at individuals.

Dietary and 'awareness' approaches can be used by individuals. These approaches risk the development of a culture of blame of individuals and of sub-groups in society. The

commercial and social determinants of health play out a significant role in research, and delivery of public health improvements around food.

This study aims to inform local policy to reduce BP and so Non-Communicable Disease. If UPF and sodium intake increase the risk of hypertension then policy to reduce exposure might deliver change at a population level.

Generalisability

This study used national data. This was stratified across the four home nations. It was stratified for IMD, and sex and to cover adults and children. The study can therefore be generalised to the UK population. The results are comparable with those in Korea, Brazil and USA. These include countries with lower UPF intake, but also similar levels.

Conclusion

In summary,

In adults and children across the four home nations of the UK between 2008 and 2019, did exposure to high sodium dietary intake, and or high UPF dietary intake, compared to lower exposure, increase the odds of having a mean systolic blood pressure of over 140mmHg?

In answer, the odds ratio for hypertension is increased and statistically significant for high Na compared to lower exposure to Na. The odds ratio for hypertension is statistically significant for high UPF, being lower compared to lower exposure to UPF. The OR of each is altered by combining the two exposure variables in the same regression model indicating some degree of interaction. The AIC also reduces by combining the two variables into the same model.

The first finding matches the findings of other researchers in other countries and in past studies in the UK. The second finding seems to be contrary to other studies. Further research will be needed to understand this result.

Other objectives were also met with a literature review examining the research around Na and UPF and BP, and discussion of the interpretation and generalisability of the study. I will present the findings to support policy development.

Bibliography

::: {#refs} :::

Appendix

Appendix 1 Approved Proposal

The approved proposal

Appendix 2 Ethics Certificate

The ethics cert.

Appendix 3 Software used

The software used

CRAN

GT Summary (47)

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