Trends in the association between Ultra-processed foods, salt intake and Blood Pressure using the National Dietary and Nutritional Survey (NDNS) in England 2008-2019

Contents

Trends in the association between Ultra-processed foods, salt intake and Blood Pressure using the National Dietary and Nutritional Survey (NDNS) in England 2008-2019

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Dedication

To Julie Andrew and Sophie

Acknowledgments

To Zoe and Martn

To Paul

Abstract

This study shows that the odds ratio between high Na intake and high BP is 7.71(CI 2.12,28.0).It also shows that UPF has no statistically significant correlation with high BP within a multivariable logistic regression model.

In univariable regression UPF shows a negative gradient with BP, and a stronger negative gradient with age balancing the relationship between age and BP. This suggests interaction between UPF, Na and Age.

Reduction of sodium intake may be effective at reducing the overall risk.

This is a secondary data study the national dietary and nutrition survey (1) which looked at BP and the effects of UPF and Na. BP is in important clinical and public health measurement, and is a proxy measure for CVD.

Policy should aim to reduce intake of Na and UPF and increase percentage intake of unprocessed foods. The accompanying literature review discusses aspects of policy and their effectiveness.

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1 Introduction

There is evidence of an association between blood pressure (BP) and intake of Ultra-processed Foods (UPF) (2) and BP and Salt intake (3) from studies of different types in multiple countries. This study looked at this association in the data set of the National dietary and nutrition survey ((1)).The study gives data from the UK from 2008 to 2019. There have been changes in the intake of UPF, of salt and BP over that time.This study described those changes. As part of this description, I identify how BP is affected by these key dietary factors. I identify the role salt intake plays in the effect of ultraprocessed food on BP.

It seems that there are relationships between UPF, Na and BP and an onward relationship to non-communicable disease. There is an underlying importance of age and sex. This study explored this complex web pulling out strands within it, (**fig-diag1?**) shows a possible arrangement of this.
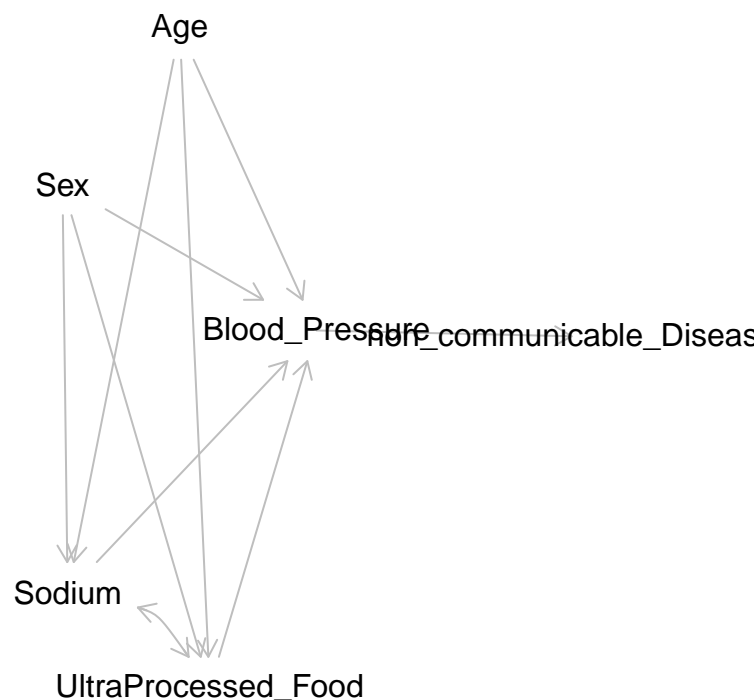
Figure 1: The relationships explored in the analysis

1.1 Public Health Impact

Public Health aims to reduce the burden of ill health across the population. BP is an indicator of the health of the population, in that it is a risk factor for a number of non-communicable diseases (NCD) (3) .

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.

Dietary approaches can also be used by individuals. This approach risks the development of a culture of blame of individuals. The commercial and social determinants of health play out a significant role in research, and delivery of public health improvements around food (4) .

1.2   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 an incomplete description of the whole of reality. I am aware that the paradigm encourages experimental isolation. This attempts to isolate the study from the world through control of explanatory variables.

Real world application to dietary change requires understanding interaction with social and economic factors. 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 the reality of dietary effects on BP and on the availability of UPF and on their nutritional constituents.

1.3   Positionality

In a positivist paradigm the observer is external to the experiment. Acknowledging that there are constructivist aspects to this study allows that the observer is closer to the model. My positionality is therefore of interest to interpretation of the model, and also to understand reasons for decisions about the approach to the data. I share with Jafar (5) an intention to lead in describing my positionality in this quantitative study.

From a biomedical background, I bring an attachment to positivist ideals. However, as a practising physician I am aware of the interaction of any number of social factors on the health of participants as Evans and Trotter (6) discuss. These impact on food 'choices', which might be determined by social expectations as much as by income, or geography. They also impact on 'hard' clinical measurements such as BP. This can also be affected by 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.

In relying on NDNS I am aware that the reasons for ongoing funding for this study relate to its being established by the government department responsible for food policy in collaboration with that for health. These influences affect the development of the study and therefore the data collected and available.

Positivist 'grand isolation' may reduce the influence of these 'external' factors, but they remain as influences.

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.

1.4   University Research Governance and Ethical Review

The ethics process for the University of Liverpool was followed and a certificate of compliance is attached at appendix 2.

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

1.5   Research Question

What proportion of the association between blood pressure (SBP) and UPF intake can be explained by the changes in salt intake in England between 2008 and 2019?

The question can be split into parts,

What was intake of UPF between 2008 and 2019? What was intake of salt between 2008 and 2019? What was BP between 2008 and 2019?

Did each of these change over that time and how? Did the changes in any one affect any other? What are the sizes of the changes? Which element was most important in these changes?

All of these questions look for numbers as answers.

Answering the question starts with collecting a sample of participants. Measurements are taken, and then collated. The collected numbers are then compared in different ways to answer each part of the question.

1.6 Key Objectives

1 Literature Review of UPF and BP, with Na

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

3 Analysis for correlation between UPF and BP using regression models incorporating Na in different ways.

4 Discussion of implications of results in relation to limitations of study and data as well as suggestions for further research

5 Publication of findings in peer reviewed journal/ direct delivery to policy makers.

2 Literature Review

2.1 Search Strategy

The search strategy has a core systematic approach augmented with additional items from a range of sources. The search identified a wide variety of articles, which outlined and augmented the review.

The search identified many related articles. The terms used are in (**tbl-search-terms?**). Starting with a broad search strategy, the results were narrowed. Those of particular relevance were identified by reading abstracts and cross referencing with other papers. Colleagues identified further relevant literature.

Additional papers were identified from the bibliographies of relevant papers. Reviews and meta-analyses presented search strategies and identified highly relevant studies.

The search was limited to to high blood pressure, however, many papers consider broader clinical endpoints. These included metabolic syndrome, diabetes and cerebrovascular and cardiovascular disease.

My search terms are included in (**tbl-search-terms?**) below. They were searched through a university meta database which includes Medline, and Ovid and Scopus. This meta database includes an ongoing search sends notification of articles as they are published.

2.1.1 Search results

The search produced 1328 results. The search allowed medical, public health, nursing articles to be prioritised. Engineering, chemical, and technology articles were deprioritised.

No time limits, language limits or availability limits were included in the initial search. Reading titles and abstracts identified relevant articles.

Papers were excluded which related to technology including food technology. They were also excluded if the primary purpose of the paper was unrelated to dietary or nutritional causes of clinical outcomes.

2.2 Overview of literature

The literature has developed over some time. The results arrange themselves into several groups. The oldest are those which describe the development of the argument that Na relates to BP and to NCD. UPF is a recent concept developed within the Nova framework which was described in 2009. Hence articles around UPF and its relation to BP and NCD are more recent. This later group do build on earlier work. Importantly they analyse the way that UPF is correlated with BP. They don't go into how Na might be involved in this relationship.

Papers are also categorised as primary research, systematic reviews with meta analysis, model analysis, and papers which use the other categories to consider public health policy approaches.

2.2.1 Aims of literature review

- 1 describe literature
- 2 synthesise literature
- 3 critique literature
- 4 explain role of study within context

2.2.2 Na, BP, NCD and Public Health

Non-communicable disease is an increasing burden on public health. (3) layout the charges against salt most clearly. They identify comprehensively the connection between changes in salt intake and changes in blood pressure and changes in cardiovascular (CVD) and cerebrovascular diseases. They link the nutritional effect of salt but they also identify the way this is affected by social and commercial determinants of health. These are branches from different epistemological backgrounds, nutrition from positivism, and the social determinants from a more constructivist approach.
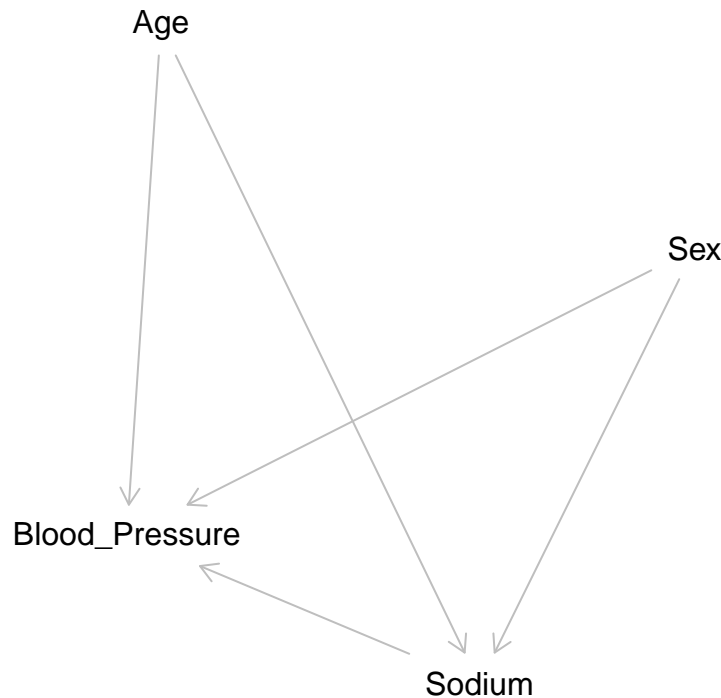
Figure 2: Diagram of relationships between BP and Salt

Explaining the role of the Framingham studies Kannel ((7) , (8)) and Mahmood (9) describe how risk factor medicine came about. They describe raised blood pressure as a 'prominent member' of a group of risks in cardiovascular disease. A disease which is the outcome of 'multiple forces'. Their description sees Framingham as part of the march of progress in understanding cardiovascular disease in particular, but also non-communicable disease. Kannel identifies that cardiologists alone cannot conquer cardiovascular disease. Pringle (10) shows how stroke risk relates to BP.

Since then BP has come to feature more and more in NCD, following studies showing that reducing BP reduced the risk of CVD. This placed detection, management, and control of BP at the centre of reducing CVD. Ettehad (11) reported a comprehensive systematic review with 123 studies over 49 years and 613815 participants. More contemporary studies look at app use to improve BP monitoring (12). Bress (13) clearly identifies that patient trust and engagement are essential in reducing 'race' based inequalities. Boutain (14) identifies stress and worry as important factors for African American men and women. In North west England Roche (15) developed quality assurance approaches to BP management which highlight that there are many different approaches to assessment monitoring and control.

Causes come from different epistological paradigms. Medically, the causes of BP, as Kannel explains, are divided into secondary BP where there is an identified pathological cause and 'essential' or idiopathic BP where no cause is identifiable. Contributors to and partial causes of this essential BP have been sought, at

individual and societal levels, using medical and epidemiological approaches ((16) , (17) , (18)).

At the level of physiology, salt (Na) is a contributor to BP. The role of salt in normal and abnormal BP control has been established through WHO and Intersalt (19) with Elliot (20) updating the findings and repeating the message. However news reports such as that of Newman (21) identify contentious aspects. Elijovich (22) carefully explains how the American Heart Association deals with the idea that there may be individuals with higher sensitivity to salt .

'Lifestyle' causes, such as Boutain's ((14)) stresses, are reported as a mix of personal 'choice', 'behaviours' and responses to other social factors. That is, they are not choices at all. Whilst Jones et al. (23) demonstrated that there is a cost to adopting dietary recommendations in the UK. Salisbury's editorial (24) discusses how commerce also has a role to play in a causation model which embraces an understanding of causation on a population scale.

Personal choice may be affected by taste sensation and satiety. Tan (25) discovered that this is difficult to study with a wide range of approaches across their systematic review. Nakamura et al. (26) used NDNS to explore how alternative flavourings might reduce the use of salt.

Reducing salt intake works. Vollmer (27) reports findings that reduced salt intake can reduce BP in diverse groups in the USA. Hendriksen (28) also explored this using Dutch and other European data to support this. Laverty et al. (29) demonstrates how policy reduces salt intake, and how reversal of policy allows intake to increase again.

2.2.3 Food classification

has traditionally concentrated on nutritional analysis eg Nutriscore ((30) , (31), (32) , (33)).

The social aspect of food has been studied famously by Bourdieu ((34), (35)).

The effect of the social and commercial nature of food is partly accounted for in Monteiro's Nova classification. Dickie et al((36) , (31)) tried to develop a system which took this idea further, but struggled to build a model which was any more effective.

Monteiro's initial explanation uses the concept of 'processing' ((37) , (38) , (39) , (40)). In a recent debate (41) and (42) discuss the concept of UPF and if it is valid or useful.

Explanations for the differential effect of these foods have developed as quickly as new ultra-processed foods have been developed . Is it due to nutritional content((43))? They are high in salt and sugar on average. Is it due to effects on satiety, or changes to appetite((44))? Do they taste better (45) ? Is it due to being easy to buy, and easy to eat((46))? Is it because they don't require time and effort in the home to process? Is it because these processes are industrial? Is it because these foods contain 'chemicals' or new ingredients? These explanations move from nutritional through into social and commercial.

Colombet (47) showed that household income is correlated with UPF intake in the UK as well as exploring the relationship in the French West Indies (48).

All these critiques are possible because of the social element to the classification. Colombet (47) identify that the intake of UPF has an inequality dimension and then (49) use modeling to describe a 'nutrition transition'.

Nutrition based classifications appear less socially divisive due to scientific isolation. They still contain elements of social factors. In particular, the way that foods are analysed can change their reported nutritional content. Eg a 'standard' food may be compared to a 'traditionally prepared' food. The first is prepared in a factory with control of its nutrition, the second by a home cook with limited access to nutrition modification technology.

Statements about the scheme often discuss the high salt and sugar content. Papers discussing the effect on physiology, and pathology in particular highlight these, but they do not back their statements with analysis. They do not show that the sodium, and UPF together increase the risk of CVD, or BP rise. This dissertation intends to address this gap

(50) show an approach between individual action and changing laws. This approach would target those most at risk due to negative social determinants. It does move into the realm of coercion of those 'making the wrong choices' into making better choices.

2.2.4 UPF

NOVA classification (37) looks at food beyond the nutrient level. It primarily incorporates ideas relating to 'processing of food'. As the Nova concept has developed it can also be seen that 'processsing' incorporates how food is made available within social systems. Nova also involves 'processing' affects consumption behaviours through changes in cooking and eating behaviour within social systems.

Group one are foods which are in a natural state, as plucked from the tree. Group two is foods which are used in processes to modify group one foods. Group three initially was all other foods, but was soon separated into minimally processed foods, and group four the ultra-processed foods.Increasing Nova category four food, or UPF, is associated with increasing BP. There are other approaches to food classification which try to address more than the nutritional content.
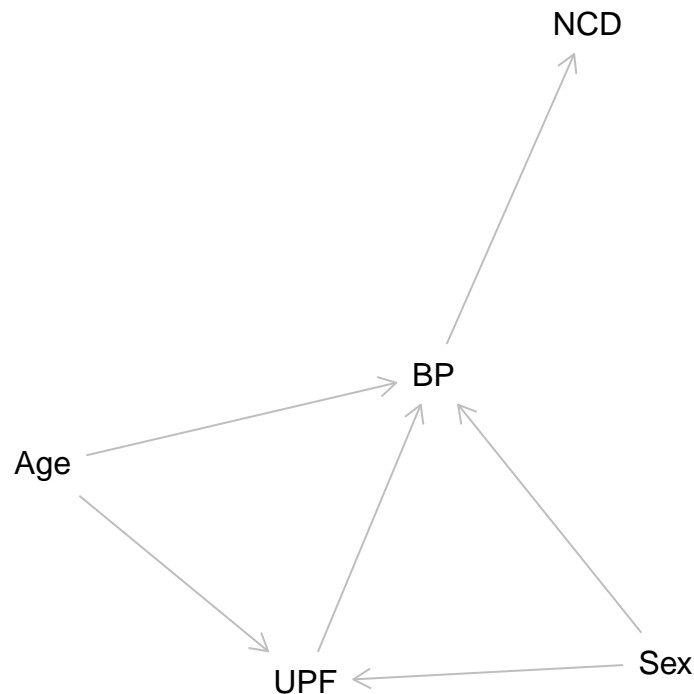
Figure 3: DAG of relationships of UPF

2.2.5 Can UPF be described in nutritional terms?

Webster (51) and niMurchu (52) identify the amount of salt in ultraprocessed foods. Vargas (53) concentrates on sodium and potassium using the Mexican national health and nutrition survey.

Sugars are the focus for Rauber (44), particularly free sugar intake.

Armendariz (54) look at how the retail food evironment in Mexican cities has changed and how it affects BP.

2.2.6

2.2.7 UPF and Ill Health

Mertens (**mertens?**), Barbosa (55), Santos (56) ,Aceves-martins (43), and Rauber (57) explore how UPF are associated with poor health. Whilst this is primarily metabolic pathology they do often mention BP. Schulze (58) comprehensively reviews UPF and metabolic health. Dicken and Betterham (59) provide a comprehensive review of papers considering a range of metabolic and other health endpoints.

(60) try to identify ill health in young people associated with the increasing use of UPF.

Hodge (61) dedicated an edition of 'Public Health Nutrition' to this question

(20)

2.2.7.1 obesity The link to obesity is perhaps more direct. Munoz (62) looked at Mexican school age children. Li (63) looked at adults in China. Rauber (57) used the NDNS study to look at obesity in the UK.

2.2.7.2 diabetes and cardiometabolic syndromes Given the effects on obesity and the increase of energy intake the connection to diabetes and cardiometabolic syndromes has been the subject of more papers.

Aguiar (64) concentrates on diabetes only. Li (65) uses a national study to link UPF with diabetes in China.

de Miranda Renata Costa (66) identifies the effect on metabolic health. Martinez (67) connects the dietary share of UPF in the US population. Tavares (68) doing the same in Brazilian adolescents.

dos Santos (69) identifies this as cardiometabolic health and provides a systematic review (56) . Goodman et al (70) explore this in Venezualan adults. Vilela (71) give a '...prospective approach to childhood'.

Some authors look how these metabolic effects lead to other conditions. For example Weinstein (72) with dementia. Gomez-Smith (73) identify a possible pathological explanation. Ivancovsky (74) connects NAFLD. Lee (75) connects these to CVD.

Colombet (48) connects these changes in metabolic syndrome with changes in socioeconomic inequalities again linking the nutritional identity of diet with its social aspects.

2.2.7.3 cancer (76) and seperately (77) have identified a risk of colorectal cancer.

2.2.7.4 ckd Kityo (78) identifies the effect on the kidneys. Identifying the diverse effects of UPF and possibly also another contributory cause of BP changes.

2.2.8 Increasing UPF intake

Many studies show the increasing role of UPF within the diet. Mertens (79) and ni Mhurchu (52) show how UPF are being eaten in ever greater quantities across Europe but especially across the UK.

Wang (46) identifies increasing consumption in US youths, D'Avila (80) also identify that increasingly upf are the key source of energy in adolescents. Gupta (81) explores the role of youth, identifying the peculiar age distribution of UPF intake.

Rauber (44) look instead at free sugar intake.
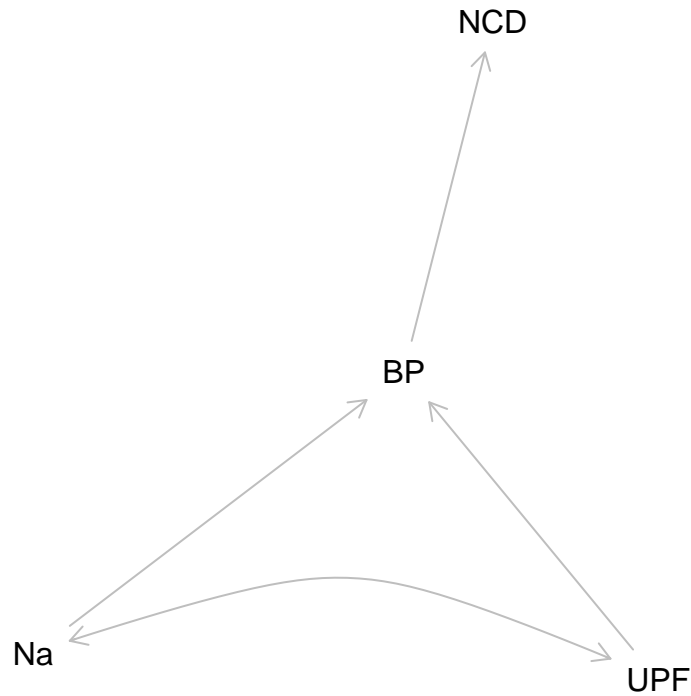
Figure 4: DAG of relationships explored by analysis

2.2.9 UPF BP and Salt

What is not known is how UPF cause BP. Suter (82) asked Is it nutrient based? In which case is this mediated by Salt? Is it other factors such as the food sales environment as explored by Goncalves (83) ? This study looks only at if Na is part of the causal pathway The thesis is that UPF is more of a risk than the salt it contains

Many studies use quite carefully constructed categories to achieve significant results.

The role of UPF in BP is described in a number of papers. Wang (84) delivers a meta analysis and systematic review. This identifies the best primary research and gives an odds ratio. Scaranni (85) and de Deus Mendonca (86) deliver key primary studies in specific populations with Shim (87) providing a Korean perspective.Du (2) gives the data for China. Oliveira (60) looks at the effect in children, Rezende (88) with adolescents.

Lima (89) reviewed already hypertensive individuals.

These papers answer to a connection between UPF and Hypertension. They leave the next obvious question to brief speculation and future research. Their offer is that UPF are high in Salt and sugars. The question is dropped, the focus elsewhere.

smiljenac (90) and tzelfa (91) both look at how UPF affect the vasculature which may be part of the pathway to BP.

2.2.10 Approach to change

Understanding the best approaches to reducing salt requires approaches that also cross epsitological paradigms.

The relationship between Na and socioeconomic position was demonstrated by Ji et al. (92).

Is it best to get individuals to reduce intake((93), (94) , (27) , (95) , (96)), or for all of the food industry to reduce salt levels((97) , (98)).

Lifestyle factors are contented. Whilst individual choice is involved. The range of choices available to individuals is limited by the nature of their society. A misapplication of lifestyle results in blaming individuals for the poor choices determined by their social and commercial environment. Iso (99) looks at how education may be effective in delivering change.

This can be tackled using a comprehensive integrated policy approach such as 'healthy cities' (100). Macregor (101) explores how political change affects both the process and outcome of population level approaches to improving health.

Instead of trying to change activity of millions of people can be more effective to change laws and policies once ((102) , (29) , (103) , (104) , (105)). These 'upstream' changes are relatively simple, and are much more effective though they can also be reversed ((3)). Cost is one of the causes of change as shown by Jones (23) using NDNS to identify the cost premium of a good diet as defined by UK dietary recommendation . Opposition sometimes comes from industry.

(29) and (101) showed that an analytical model can effectively demonstrate the effects of different policies on population health. They identify that reducing the effectiveness of a policy on salt in food leads to changes in BP and so on to NCD.

(106) identify the benefits of their strategy. They discuss the range of nation level approaches to reducing salt intake.

Dinbleby's (107) National food strategy

(108) ultraprocessed people

2.3   Literature review Conclusion

The literature review identified and analysed a range of literature across the field. Key points being that CVD is a significant NCD, and has links with Na and UPF. These links are often described in different paradigms. This study aims to cross link these paradigms looking at how Na and UPF interact and looking to understand from a positivist approach what effects UPF have within the positivist paradigm. At the same time knowing and accepting that effects of UPF in this paradigm are a subset of the total effect. Whilst also understanding that Na in its nutritional paradigm similarly projects into the other paradigm.

3 Method

3.1 Study Design and Setting

National Dietary and Nutritional Survey (NDNS (1))

This survey is a collaboration between government departments responsible for health and for food production. They have engaged academic partners to deliver reports on diet and nutrition across the United Kingdom. The study is designed to be representative across the four home nations, across age with balanced representation for children. NDNS data are available via the UK national Data service for research purposes.

NDNS is a rolling cohort study in each year a new cohort of participants is selected. 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 design is random selection across postal units (psu), stratified to ensure a representative sample across the four nations (England, Wales, Scotland, and Northern Ireland) and across regions within those nations (North West, North East, Scotland, Northern Ireland, Wales, Yorkshire and Humberside, East Midlands,West Midlands, London, The South East, The South West). The sample is also representative for age and sex and IMD.

3.2 Participants, Inclusion and Exclusion

All participants in NDNS are included. The data from the NDNS study contains information about each individual, and their household. This was collected through questionnaires. Then weight, height, and blood pressure were measured by a nurse. Finally, dietary information was collected through a 4-day food diary.

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 were excluded for analysis.

3.3 Variables

The key variables are systolic BP (BP), the outcome dependant variable, and the explanatory exposure variables, UPF intake (UPF) and Sodium intake (Na).

Additional explanatory variables are ones which can also influence BP. They include Age, Sex, and BMI. Age at completion of education (educfinh), and IMD are also used. BP medication (bpd) identifies which participants have medication.

Categorical variables have been made from UPF,Na and BP, to enable analysis.

3.3.1 Systolic BP (BP)

The mean systolic blood pressure (BP) is a validated measurement with significant quality assessment within the dataset.

The variable BP is a quality assured mean value which is reliable across the dataset. In particular it was assessed for the effects of exercise, temperature and ill health and 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 (hyp) a variable which identifies participants with BP over 140 mmHg to enable logistic regression. This value is identified by Du et al ((2)) and others.

3.3.2 Dietary data

The participants recorded their food intake prospectively over 4 days recording food and portion size as well as where food was eaten. Adults recorded this for the child participants.

Based on the food and drink intake reported and with a composition data table, the NDNS team have estimated the overall intake of a large range of nutrients.

3.3.3 Salt estimation

The sodium value (Na, hiNa) was calculated from intake based on food diaries and standard food nutrient values. This reflects the expected Na content of standard foods.It assumes the content remains consistent. A categorical variable hiNa, has been produced to use in logistic regression. The cut off was 3000mg which is the WHO recommended amount and to match those used in Du et al (2). 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.

3.3.4 UPF

The NOVA classification was used to estimate the intake of UPF developed by Monteiro et al. ((39)). There is no record of NOVA classification in NDNS. Data from Rauber et al ((44)) was used as a key for NDNS food groups.

Each participant food diary entries are assessed against the Nova food classification. 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 (84) are low for the UK.

A second variable UPF2 was derived from this. This identifies those more than one standard deviation above the mean.

3.4 Analysis of the data

3.4.1 Description of sample

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 ((109)). In particular the package 'survey' (110) was used to manage weighted data. Once the data labels were made consistent across the batches, weighting recalculation was done. Generated weighting values account for differences in population balance across the annual cohorts. These result from differences in compliance and uptake within and across the years and maintains IMD, Sex, Age, IMD and regional representation in the resultant populations

A table showing representative statistics for the population was developed. Mean values for the data are displayed with a comparison for weighted values. The exposure variables are sodium intake (Na), and ultra processed food intake (UPF). The outcome variable, the mean systolic blood pressure (BP).

3.4.2 Analysis of Change over Survey Wave Sex Age and Place

Change over the survey waves was demonstrated. These were not the same participants so matched analysis, and time series analysis was not applicable.

Other variables in the data were also compared to show that waves were comparable across controlled variables.

The main variables were analysed against sex, age, and UK government region. This showed the distribution of the sample across these categories.

Statistical significance of changes in the data were shown by p.values with continuous data, and categorical data analysed using chi squared tables. In all analysis a value of $p < 0.05$ was taken as the threshold of statistical significance.

3.5 Univariable Regression

Analysis of the association between BP and sodium intake, and then BP and UPF intake was done using univariable linear regression.

Analysis with age,sex, region and between each of the variables identified their relationships.

P.values and confidence intervals were calculated.

3.6 Multivariable Regression on BP

Multivariable regression models were developed. These demonstrate the interactions between variables and identify mathematical models of the relationships. The optimal model is one which best explains the pattern of data, but which also makes practical sense for the wider understanding of relationships.

A set of four models was developed. The baseline model had the outcome variable and explanatory variables. Each exposure variable was added separately for the next two models. The final model contained all three of the key variables.

AIC was used to understand the relative importance of variables.

4 Results

4.1 Participants and Descriptive Data

The whole NDNS population was 15,655. The mean age was 40. Categorising age shows that 22% of the population was between 19 and 35. There were 49% male participants. Mean BP was 123 mmHg. On outcome, 7256 participants had a BP below 140 mmHg, but there were 7196 participants unknown. There was no BP recorded for year 11. The mean exposure to Na was 2037 mg daily. The mean UPF exposure was 48%.

The population with those on medication included 14217 participants. The mean age was 38. The biggest age group again was 19-35. There were again 49% male participants. Mean outcome, BP was 121 mmHg. The exposure, Na was 2043 mg and UPF was still 48%.

There appeared little difference in bmi, educational level, IMD, or region of origin. This first table (**tbl-table1?**) shows all variables.

Continuous variables are represented by the mean and standard deviation in brackets. Categorical variables give the number of participants and the percentage of the sample in brackets.

Characteristic	N = 15,655
Age	40 (22, 58)
agegad3	
(0,16]	2,930 (19%)
(16,19]	526 (3.4%)
(19,35]	3,372 (22%)
(35,50]	3,355 (21%)
(50,65]	2,912 (19%)
(65,108]	2,561 (16%)
Sex	
Male	7,699 (49%)
Female	7,956 (51%)
(D) Omron valid mean systolic BP	122 (110, 133)
Unknown	7,196
hyp	
(0,140]	7,256 (86%)
(140,300]	1,202 (14%)
Unknown	7,196
(D) Valid BMI	25 (21, 29)
Unknown	981
Sodium (mg) diet only	1,927 (1,480, 2,478)
hiNa	
(0,1.5e+03]	4,045 (26%)
(1.5e+03,3e+03]	9,852 (63%)
(3e+03,5e+03]	1,685 (11%)
(5e+03,6e+03]	54 (0.3%)
(6e+03,1e+04]	19 (0.1%)
UPF	47 (37, 58)
UPF3	
(0,33]	2,678 (17%)
(33,45]	4,184 (27%)
(45,63]	6,240 (40%)
(63,80]	2,292 (15%)
(80,100]	261 (1.7%)

Characteristic	N = 15,655
educfinh	
Not yet finished	375 (2.9%)
Never went to school	41 (0.3%)
14 or under	504 (3.9%)
15	1,773 (14%)
16	3,483 (27%)
17	1,074 (8.3%)
18	1,588 (12%)
19 or over	4,172 (32%)
Unknown	2,645
IMD	
1	2,977 (19%)
2	3,128 (20%)
3	2,905 (19%)
4	3,269 (21%)
5	3,372 (22%)
Unknown	5
gor	
England:North East	641 (4.1%)
England:North West	1,735 (11%)
England:Yorkshire & The Humber	1,308 (8.4%)
England:East Midlands	1,128 (7.2%)
England:West Midlands	1,384 (8.8%)
England:East of England	1,460 (9.3%)
England:London	2,029 (13%)
England:South East	2,148 (14%)
England:South West	1,321 (8.4%)
Wales	753 (4.8%)
Scotland	1,302 (8.3%)
Northern Ireland	447 (2.9%)
bpd	
not taking drug	14,217 (91%)
Taking drug	1,438 (9.2%)

```
## [1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/dat
```

4.1.1 Population by Survey Wave

The variables were compared across annual waves. The numbers seemed smaller towards the end of the series, for Na, UPF and for BP. Each cohort was adjusted to be comparable using weighting values given by the study coordinators. The highest mean value for Na was 2257 (standard deviation is 878) in year one. The lowest mean value for Na was 1892 (724) in year ten.

Mean UPF was highest in year 2 and year 6 at 50%. The lowest mean UPF intake was 45% in years 8,9 and 10. The mean outcome variable BP was highest in year one with 125 mmHg, and the lowest 120 mmHg in year 6.

The separate waves had separate participants.The data is presented in (**tbl-keydata?**).

Results were illustrated by plots against survey year. (**fig-upf-and-survey-year?**) showed overlap between the waves for UPF intake. (**fig-Na-and-survey-year?**) showed Na exposure overlap between waves. (**fig-BP-and-survey-year?**) identified the lack of data for year 11.

UPF% by survey year
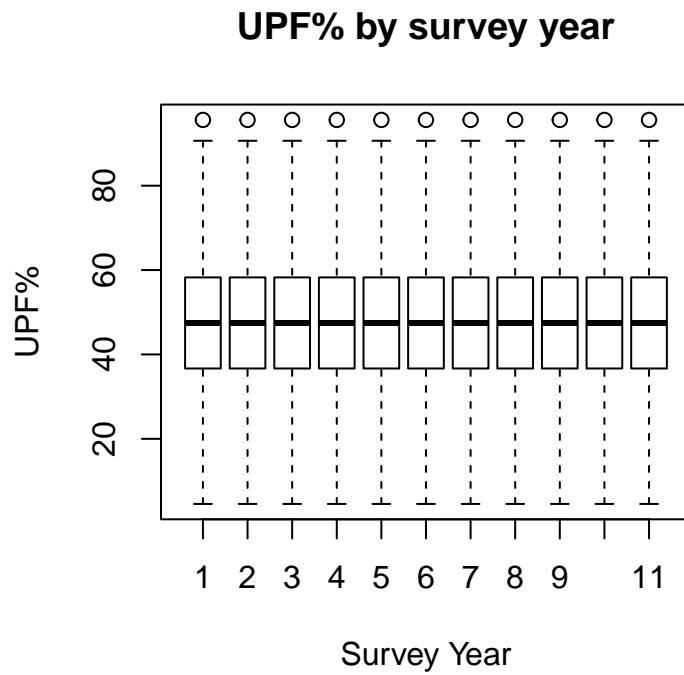
Figure 5: Energy from UPF% in each annual cohorts NDNS (2008-2019)

Sodium Intake in mg by survey year
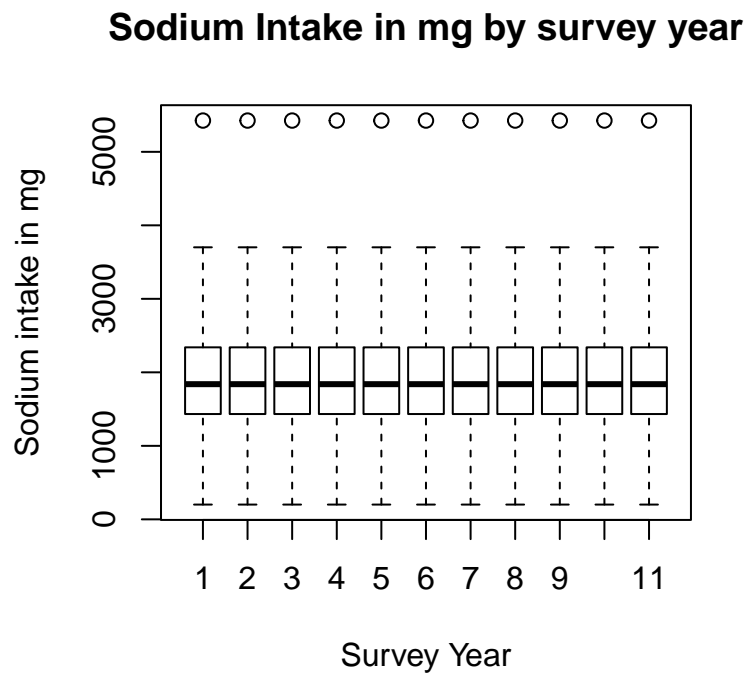
Figure 6: Na in mg in each annual cohort NDNS(2008-2019)

BP in mmHg by survey year
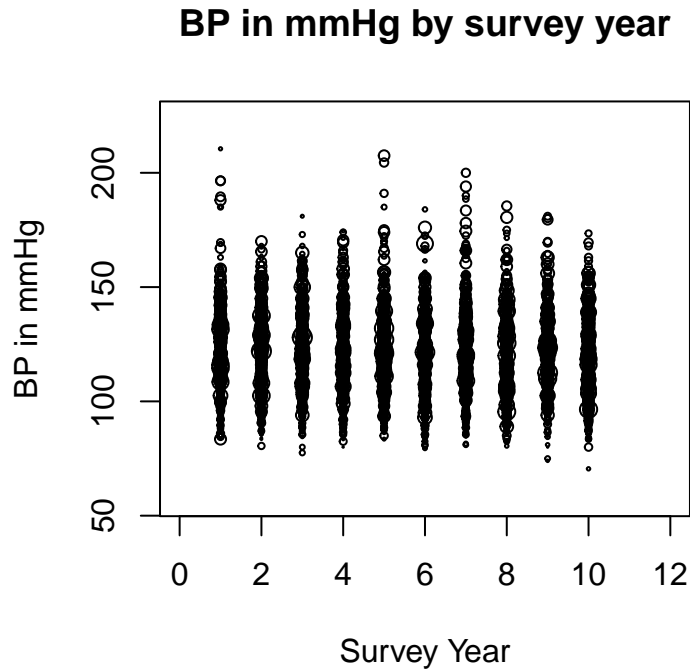
Figure 7: Plot of the BP in mmHg by year from NDNS (2008-2018)

General linear regression modelling was used, with wave 1 as a comparator for analysis of the other waves.

This showed that for Na there was a negative beta value with p.value <0.001 in wave 4-11. For UPF the beta value was negative in wave 7,8,9 and 10 with p.value <0.05. The BP had a negative beta value in all waves, with p.value <0.05 in waves 5,6,8,9 and 10.

Age was a variable which the whole sample was weighted to be maintained across the waves. There were no p.values below 0.12.

BMI had a negative p.value in most years but the p.value was <0.05 only in wave 7 and 8.

(**tbl-Key-Variables-by-Survey-year?**) shows results for continuous variables.

```
## [1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/dat
```

The categorical data also 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.

Vegetarian, categorised UPF intake, and hypertension had a p.value of <0.05.

BMI had a p.value of 0.77.

Data for year 5 was absent for education. Data for year 11 was absent for hypertension.

(**tbl-Categorical-variables-year?**) follows.

Variable	ChiSq[1]	p.value
Sex	0.90	0.53
IMD	0.86	0.71
Age	0.94	0.58
Education[2]		
UPF3	2.48	0.00
Hypertension[3]		
BMI	0.78	0.77
Region	1.37	0.02
Vegetarian	1.97	0.02

[1]Chi Squared for categorical data

[2]year 5 data missing

[3]year 11 data missing

```
## [1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/dat
```

4.2 Exposure and outcome variables by Sex, Age and Place

In each case the lower gradient of the relationship between the variable and Sex was statistically significant. (**tbl-keydatax?**) shows the difference between male and female in the key variables.

Characteristic	Male, N = 6,992[1]	Female, N = 7,225[1]	p-value[2]
Na	2,205 (1,676, 2,800)	1,722 (1,351, 2,170)	<0.001
UPF	49 (39, 60)	47 (36, 57)	<0.001
UPF3			<0.001
(0,33]	1,036 (15%)	1,336 (18%)	
(33,45]	1,747 (25%)	1,942 (27%)	
(45,63]	2,875 (41%)	2,851 (39%)	
(63,80]	1,199 (17%)	978 (14%)	
(80,100]	135 (1.9%)	118 (1.6%)	
BP	124 (114, 133)	114 (106, 126)	<0.001
Unknown	3,431	3,471	

[1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/data

Peak mean Na was 2302mg in the 19-35 age group. The mean peak UPF exposure was 58% in the 16-18 age group, but was almost matched by 56% the 0-16 group. BP rose through life to a mean of 134 mm Hg in the over 65 age category.

(**tbl-tbl-keydataA?**) shows the age distribution of exposure to sodium and UPF and the resulting BP.

Characteristic	(0,16], N = 2,927[1]	(16,19], N = 524[1]	(19,35], N = 3,357[1]	(35,
Na	1,634 (1,254, 2,072)	2,070 (1,615, 2,680)	2,205 (1,624, 2,798)	2,08
UPF	57 (47, 66)	57 (48, 69)	50 (39, 60)	
UPF3				
(0,33]	157 (5.4%)	27 (5.2%)	502 (15%)	
(33,45]	435 (15%)	66 (13%)	782 (23%)	
(45,63]	1,399 (48%)	244 (47%)	1,420 (42%)	
(63,80]	834 (28%)	155 (30%)	572 (17%)	
(80,100]	101 (3.5%)	31 (5.9%)	81 (2.4%)	
BP	106 (99, 113)	114 (108, 123)	118 (110, 126)	1
Unknown	1,635	246	1,645	

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

[2]Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-

[1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/data

UPF exposure was highest in Northern Ireland and lowest in London. The sodium exposure was highest in Scotland and lowest in London. Outcome BP was also lowest in London, with the highest in the North East. (**tbl-keydatap?**) shows the data.

Characteristic	England:North East, N = 562[1]	England:North West, N = 1,564[1]	Eng
Na	1,908 (1,368, 2,505)	1,954 (1,510, 2,537)	
UPF	50 (40, 60)	48 (37, 60)	
UPF3			
(0,33]	74 (13%)	270 (17%)	

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

[2]Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-

Characteristic	England:North East, N = 562[1]	England:North West, N = 1,564[1]	Eng
(33,45]	123 (22%)	385 (25%)	
(45,63]	264 (47%)	609 (39%)	
(63,80]	92 (16%)	280 (18%)	
(80,100]	10 (1.8%)	20 (1.3%)	
BP	121 (112, 133)	120 (110, 131)	
Unknown	264	798	

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

[2]Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-

```
## [1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/data
```

4.3 Paired Regression of variables on each other

Simple linear regression equations look for the relationship between the outcome BP, and the independent exposure variable.

The regression model for Sodium against BP shows that there is no linear relationship between Sodium and BP in this table (**tbl-univariable-regressions?**). UPF compared to Na also shows a zero beta value indicating no linear relationship.

UPF does show a negative relationship with age, which is statistically significant. There is also a negative relationship with Age, again statistically significant.

Age has a relationship with BP with a statistically significant positive gradient. There is also a positive relationship with Na, which is also statistically significant to the 95% level.

In conclusion the linear regression models show that there are correlations between the systolic BP and energy intake only. The next section will examine how this situation changes as variables interact in more complex models.

Group	Characteristic	Beta	95% CI[1]	p-value
BP/Na	Na	0.00	0.00, 0.00	<0.001
UPF/Na	Na	0.00	0.00, 0.00	<0.001
UPF/bp	UPF	-0.20	-0.23, -0.16	<0.001
UPF/Age	UPF	-0.45	-0.48, -0.42	<0.001
Age/BP	Age	0.43	0.41, 0.45	<0.001
Age/Na	Age	1.5	0.77, 2.3	<0.001
BP/bmi	bmival	1.0	0.92, 1.1	<0.001
BP/Agg1	agegad3			
	(0,16]	—	—	

[1]CI = Confidence Interval

Group	Characteristic	Beta	95% CI[1]	p-value
	(16,19]	9.7	7.9, 11	<0.001
	(19,35]	12	11, 13	<0.001
	(35,50]	15	14, 17	<0.001
	(50,65]	23	21, 24	<0.001
	(65,108]	28	26, 30	<0.001
BP/ed	educfinh			
	Not yet finished	—	—	
	Never went to school	7.6	3.6, 12	<0.001
	14 or under	19	14, 24	<0.001
	15	15	12, 18	<0.001
	16	7.2	4.8, 9.6	<0.001
	17	8.2	5.4, 11	<0.001
	18	6.4	3.8, 9.0	<0.001
	19 or over	5.5	3.3, 7.7	<0.001
UPF/bmi	bmival	-0.27	-0.32, -0.21	<0.001
UPF/age	agegad3			
	(0,16]	—	—	
	(16,19]	1.4	-0.25, 3.1	0.10
	(19,35]	-6.7	-7.7, -5.7	<0.001
	(35,50]	-11	-12, -10	<0.001
	(50,65]	-15	-16, -14	<0.001
	(65,108]	-13	-14, -12	<0.001
UPF/ed	educfinh			
	Not yet finished	—	—	
	Never went to school	-18	-28, -6.9	0.001
	14 or under	-8.9	-12, -5.8	<0.001
	15	-6.8	-9.5, -4.0	<0.001
	16	-4.9	-7.5, -2.3	<0.001
	17	-6.2	-9.0, -3.4	<0.001
	18	-7.4	-10, -4.7	<0.001
	19 or over	-11	-13, -8.0	<0.001
Na/bmi	bmival	17	14, 19	<0.001
Na/Agg	agegad3			
	(0,16]	—	—	

[1]CI = Confidence Interval

Group	Characteristic	Beta	95% CI[1]	p-value
	(16,19]	477	384, 569	<0.001
	(19,35]	586	529, 643	<0.001
	(35,50]	454	408, 499	<0.001
	(50,65]	295	250, 341	<0.001
	(65,108]	137	91, 183	<0.001
Na/ed	educfinh			
	Not yet finished	—	—	
	Never went to school	-759	-1,354, -164	0.012
	14 or under	-362	-517, -206	<0.001
	15	-223	-361, -85	0.002
	16	-121	-255, 14	0.078
	17	-174	-321, -26	0.021
	18	-126	-268, 17	0.083
	19 or over	-136	-270, -0.85	0.049

[1]CI = Confidence Interval

```
## [1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/data
```

4.4 Multi variable logistic regression

This set of models looked at when the data was regressed against hyp a variable identifying hypertension as 140mmHg in patients who are not on BP reducing medication.

The first model, labelled "No sodium or UPF" of this set looks at the relationships between BP and some of the background variables (Age and Sex, education and IMD) all of which may have an effect on BP. The result shows that the odds ratio for females is 0.6 and this is statistically significant. That is the odds of a female participant having a BP above 140 are almost half those for a male participant. BMI odds ratios are not statistically significant across the categories. That is a BMI over 30 is not associated with a BP above 140mmHg in this data set. All age groups have statistically significant differences in odds of hypertension compared to the under 16 age group. That of the oldest age group being a 372 times greater risk. The IMD groups are not statistically different from the least deprived.

The second model, "Sodium Only", adds 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 7.5 for this group. It also shows minimal effects on other variables in the model.

"UPF only" is the third model. Here there is no significant difference in odds ratio for any group. Again there are minimal effects on the other variables.

The last model, "Sodium and UPF", shows that when combined there is still little effect identified statistically, on each other or on the other variables. The difference in odds ratio for 5000-6000mg of Na remains, and remains statistically significant. (**tbl-multivariable-outputs-bp?**) follows below.

Characteristic	No Na or UPF			Na only		
	OR[1]	95% CI[1]	p-value	OR[1]	95% CI[1]	p-value
Sex						
Male	—	—		—	—	
Female	0.59	0.45, 0.77	<0.001	0.62	0.47, 0.83	0.001
BMI						
(0,18]	—	—		—	—	
(18,24]	1.68	0.25, 11.3	0.6	1.67	0.25, 11.4	0.6
(24,30]	2.63	0.39, 17.7	0.3	2.63	0.39, 17.9	0.3
(30,50]	4.26	0.63, 28.9	0.14	4.24	0.62, 29.0	0.14
agegad3						
(0,16]	—	—		—	—	
(16,19]	19.7	3.73, 104	<0.001	18.9	3.56, 99.8	<0.001
(19,35]	17.0	3.68, 78.5	<0.001	15.4	3.31, 72.0	<0.001
(35,50]	43.5	9.85, 192	<0.001	41.1	9.31, 181	<0.001
(50,65]	98.4	22.7, 427	<0.001	96.1	22.2, 416	<0.001
(65,108]	221	49.4, 988	<0.001	220	49.4, 979	<0.001
educfinh						
Not yet finished	—	—		—	—	
Never went to school	0.00	0.00, 0.00	<0.001	0.00	0.00, 0.00	<0.001
14 or under	8.96	1.70, 47.3	0.010	8.68	1.65, 45.6	0.011
15	5.18	1.07, 25.0	0.041	5.07	1.04, 24.6	0.044
16	3.48	0.76, 15.9	0.11	3.38	0.74, 15.6	0.12
17	3.81	0.78, 18.6	0.10	3.74	0.76, 18.4	0.10
18	4.42	0.92, 21.3	0.064	4.33	0.89, 21.0	0.069
19 or over	4.21	0.89, 19.9	0.069	4.13	0.87, 19.6	0.075
IMD						
1	—	—		—	—	
2	1.06	0.67, 1.68	0.8	1.07	0.67, 1.70	0.8
3	0.75	0.47, 1.19	0.2	0.74	0.47, 1.19	0.2
4	1.11	0.72, 1.71	0.6	1.13	0.73, 1.76	0.6
5	1.04	0.65, 1.65	0.9	1.06	0.67, 1.68	0.8
hiNa						
(0,1.5e+03]				—	—	
(1.5e+03,3e+03]				1.02	0.71, 1.47	>0.9

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

	No Na or UPF			Na only			
Characteristic	**OR**[1]	**95% CI**[1]	**p-value**	**OR**[1]	**95% CI**[1]	**p-value**	
(3e+03,5e+03]				1.33	0.80, 2.20	0.3	
(5e+03,6e+03]				6.56	1.87, 23.0	0.003	
(6e+03,1e+04]				0.00	0.00, 0.00	<0.001	
UPF3							
(0,33]							
(33,45]							
(45,63]							
(63,80]							
(80,100]							

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

[1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/data

Using the AIC statistic for each model gives another way of understanding the comparative effects. The subsequent (**tbl-AIC-comparison?**) shows the size of the effect relating to sodium. 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 80/20 is due to UPF

There is a significant sensitivity of the data set to improved modelling. Though the set of models around the same values includes the four regressed against BP, and two of those against UPF which include BP.

[1] 100

[1] 70.65783

Model	AIC
No Na or UPF	3,586.917
Na only	3,577.975
UPF only	3,591.290
Na and UPF	3,581.882

[1] "/media/david/Elements1/contents/DOHmed/MPH/MPHModules/dissertation/alternativequant/upfnabp/data

5 Discussion

5.1 Data

NDNS data is well collected and comprehensive. There have been several changes over the course of the study. These changes have meant that collating the data was more than just bringing all the numbers together.

In addition the differing take up rates between different groups in each of the cohorts meant that the numbers from each cohort are not comparable. This is overcome by using weighting factors to balance the datasets. This needs adjusting every time there is a new group added to the collected data set.

5.2 Discussion of change across cohorts

The analysis using these weighted datasets is performed using "survey" which is a software package used in r studio.

The change in intake of sodium and UPF over time could be; 1 real 2 sample error 3 increasing social desirability of low sodium, low UPF

5.2.0.1 of other variables compared across cohorts Age seems to be related to UPF having a similar effect on BP. This would mean that the relationship of different aged participants and their UPF habit is affecting the comparisons within the multivariable models.

5.3 Discussion of Key variables by Sex,Age and Place

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. When this is on BP there is a change between cohort sex balance. This is possibly as a result of changing/ increasing acceptance of BP results of all people whereas in earlier cohorts there were less women with raised BP levels.

This effect is perhaps greater when medication exclusions are made. Treatment of women and younger men has increased over the 10 years of the study.

Comparison of pairs of variables identifies the degree of correlation between them. The key comparisons are between UPF and BP, and Na and BP. These highlight that there is an effect of UPF on BP, though there is no effect of Na.

The third side of this triangle is the relationship between Na and UPF which confirms that UPF is high in Sodium.

The results here show that there is regional variation in key variables with consistently better values in London.

5.4 Discussion Paired Regression of key variables on each other

5.5 Multi variable logistic regression for BP

The multivariable regression is made of four models. These show the change from excluding Na and UPf to adding each individually and then together.

This means that the all have effects on the systolic blood pressure, but the effect of UPF and that of Age is closely intertwined.

5.6 Limitations of Study

5.6.1 The study

5.6.2 The data

5.6.3 The analysis

5.7 Ideas for further research

I will divide these suggestions into quantitative and qualitative. Within the quantitative there are biomedical

5.7.1 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.

5.7.2 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.

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.

Modelling research has allowed projections to be made using

5.8 Ideas for policy

Policy is an 'upstream' approach.

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.

6 Conclusion

In conclusion there is a complex interaction between fixed factors and societal factors at work.

NOVA and UPF are a conceptual model they are not reality. As a model they are useful in bridging the chasm between 'scientific' (or more specifically 'positivist') nutrition and more social science paradigms. They are a Rosetta stone, or key which has elements from each side.

This study looked at how this crossover applied to a clinical (or biomedical) characteristic. The result implied this characteristic is best explained within the positivist paradigm when examined using this positivist methodolgy.

7 Bibliography

::: {#refs} :::

Appendix

8 Appendix 1 Approved Proposal

The approved proposal

9 Appendix 2 Ethics Certificate

The ethics cert.

10 Appendix 3 Software used

The software used

```
##  [1] "base"          "dagitty"       "datatable"     "flextable"
##  [5] "gtsummary"     "knitr2023"     "knitr2015"     "knitr2014"
##  [9] "labelled"      "officer"       "rmarkdown2023" "rmarkdown2018"
## [13] "rmarkdown2020" "sensemakr"     "srvyr"         "stargazer"
## [17] "survey2020"    "survey2004"    "survey2010"    "tidyverse"
```

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