Exposure to High Ultra-processed Food and Sodium Intake and its effect on Hypertension using the UK National Dietary and Nutritional Survey (NDNS) in England 2008-2019

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# Exposure to High Ultra-processed Food and Sodium Intake and its effect on Hypertension using the UK National Dietary and Nutritional Survey (NDNS) in England 2008-2019

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## Dissertation submitted in partial fulfilment of the requirements for the degree of Master of Public Health, The University of Liverpool

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## Dedication

To Julie Andrew and Sophie

for your loving patience and support

## Acknowledgments

To Zoe and Martin

To Paul

# Abstract

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 is a secondary data study the national dietary and nutrition survey (1) which looked at the risk of hypertension on exposure to high intake of UPF and Na.

Policy should aim to reduce intake of Na. The accompanying literature review discusses aspects of policy and their effectiveness.

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 |
| NAFLD | non- alcohol fatty liver disease |
| BMI | Body Mass Index |
| mmHg | Units of pressure used physiologically |
| AIC | AIC |

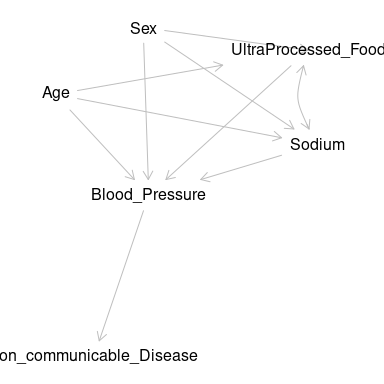
# Introduction

Cheshire and Merseyside public health collaborative (CHAMPs) have a plan to reduce BP by 2029 (2) . The strategy aims to increase awareness of individual risk and so increase individual compliance with testing and treatment of raised BP and so prevent CVD.

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.

This study looked at this association in the data set of the National Dietary and Nutrition Survey (NDNS) (1) .The study gives data from the UK from 2008 to 2019. It is representative of the population by sex, age, region and index of multiple deprivation (IMD). It recorded exposure to high UPF and high Sodium intake, and outcome BP.

This study assesses correlation between BP and exposure to these dietary factors. Age and sex remain important background factors. I have used STROBE guidance (5) in producing this report. This study explored this complex web pulling out strands within it, [diagram 1](fig:diagram 1) shows a possible arrangement of this.



The relationships explored in the analysis

## Public Health Impact

Public Health aims to reduce the burden of ill health across the population. The aim of CHAMPs in Cheshire and Merseyside is shared by public health across the world. BP is an indicator of the health of the population, it is a risk factor for a number of non-communicable diseases (NCD). Cappuccio and Capewell (4) highlight these connections.

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 approaches can 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. Marmot (6) identifies the external influences in Cheshire and Merseyside which need to be improved to permit individual action to be effective.

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 they may be on the pathway, or mechanism of action, of social and commercial determinants. Then policy to reduce exposure might deliver change at a population level.

## 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 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 (7) 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. Physicians are aware of social factors impacting health of participants as Evans and Trotter (8) discuss.

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.

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 cannot be ‘controlled for’ but instead need to be understood.

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.

## 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.

## Research Question

Using PICO I am able to frame the research question.

In adults and children across the four home nations of the UK between 2008 and 2019, was exposure to high sodium dietary intake, and or high UPF dietary intake 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 risk relationship 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?

## 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, Na and BP using regression models.

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 to promote an upstream approach to NCD prevention.

# Literature Review

## 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. 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 [table 2.1](#tab:tab2) 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.

Table of Search terms used

| Search Terms Used |
| --- |
| "ultra-processed food" OR "ultra-processed foods" OR "ultraprocessed food" OR "ultraprocessed foods" OR "ultra-processed product" OR "ultra-processed products" OR "ultra-processing" OR "food processing" OR "processed food" OR "processed foods" OR "NOVA" OR "NOVA system" OR "NOVA food classification" OR "NOVA classification system") AND (hypertension OR "high blood pressure" OR "high blood pressures" OR "blood pressure" OR "systolic pressure" OR "diastolic pressure" OR "systolic blood pressure" OR "diastolic blood pressure") AND (adult OR adults OR aged OR "middle aged" OR elderly OR "older adult" |

### 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.

## 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. 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.

### Aims of literature review

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

### Na, BP, NCD and Public Health

Non-communicable disease (NCD) is an increasing burden on public health. Cappuccio and Capewell (4) layout the charges against salt 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.

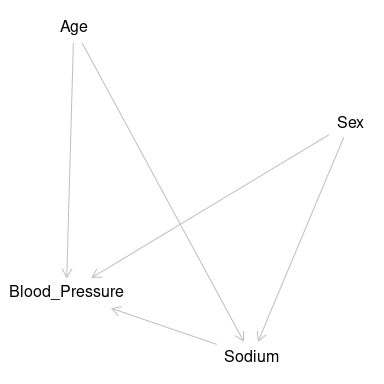


Diagram of relationships between BP and Salt

Explaining the role of the Framingham studies Kannel (9) , (10) and Mahmood (11) 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 (12) 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 (13) reported a comprehensive systematic review with 123 studies over 49 years and 613815 participants. In a more contemporary study Debon-Raque et al. (14) look at app use to improve BP monitoring. Bress (15) clearly identifies that patient trust and engagement are essential in reducing ‘race’ based inequalities. Boutain (16) identifies stress and worry as important factors for African American men and women. In North west England Roche (17) developed quality assurance approaches to BP management which highlight that there are many different approaches to assessment monitoring and control. The CHAMPS strategy follows on from this work (18).

Satisfactory explanations of the cause of BP depend on the epistemological frame used. 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 (19) , (20) , (21) .

At the level of physiology, Na is a contributor to BP. The role of Na in normal and abnormal BP control has been established through WHO and Intersalt (22) with Elliot (23) updating the findings and repeating the message. It is possible to look at these studies and identify areas where clarity is assumed.

News reports such as that of Taubes (24) and Newman (25) identify question ‘orthodox’ explanations and seek to disrupt consensus with some degree of success. Elijovich (26) carefully explains how the American Heart Association deals with the idea that there may be individuals with higher sensitivity to salt . Barris et al. (27) discuss the role of sex in salt sensitivity. Pitzer et al. (28) propose a mechanism of action.

‘Lifestyle’ causes, such as Boutain’s ( (16) ) stresses, are reported as a mix of personal ‘choice’, ‘behaviours’ and responses to other social factors. That is, they are not choices at all. Marmot’s Whitehall series (29) (30) (31) shows how ‘lifestyle’ affects BP, CVD and NCD. This identifies mechanisms for Whitehead (32) Dahlgren (33) and Diderichson’s (34) social determinants of health inequalities with their policy approaches and points of intervention.

Whilst Jones et al. (35) demonstrated that there is a cost to adopting dietary recommendations in the UK. Salisbury’s editorial (36) 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 (37) discovered that this is difficult to study with a wide range of approaches across their systematic review. Nakamura et al. (38) used NDNS to explore how alternative flavourings might reduce the use of salt.

Reducing salt intake works. Vollmer (39) reports findings that reduced salt intake can reduce BP in diverse groups in the USA. Hendriksen (40) also explored this using Dutch and other European data to support this. Laverty et al. (41) demonstrate how policy reduces salt intake, and how reversal of policy allows intake to increase again. They also show how that affects BP.

### NOVA

The NOVA classification, of Monteiro (42), looks at food beyond the nutrient level. At the level of ‘processing’. 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. Increased NOVA category four food intake, or UPF, is associated with risk of hypertension in some groups around the world.

As the NOVA concept has developed it can also be seen that ‘processsing’ incorporates how food is made available within social systems, how consumption behaviour changes in cooking and eating behaviour within social systems.

Though processing is important to the concept of UPF, Tulleken (43) describes UPF in nutritional terms quoting Rauber as calling them ‘industrially produced edible substances’.

### The ‘controversy’ of Food classification

Martinez (44) makes an attempt to develop ‘ecofoodomics’ by deconstruction. His neologism can receive a new more inclusive epistemology of food. His ‘knowledge of food’ branches into food as culture, food as biologic, and food as economic. Nutrition would sit strongly within a biologic category, but UPF intentionally carries economic aspects, and cultural aspects. this epistemology reflects the ontology, the essential nature of food is multidimensional in the same way as knowledge about it.

Meghani (45) expresses this same idea using examples actually a little way along the food chain. Identifying that there is a conceptual mismatch between the different parties in these arguments. It is essential that ‘pure’ scientists engage with the cultural and socioeconomic aspects of their science, to highlight this to direct societal and political activity.

Cifuentes (46) claims ‘foodomics’ as a descriptor of the pure science aspects of food. This shows the difficulty of defining this field.

Bearing in mind cultural and economic dimensions of food it becomes easier to understand that researchers don’t always view food in the same way as people do, or as each other. Romero et al. (47) compare Nutri-Score and NOVA. Nutri-Score concentrates on nutritional analysis and identification to ‘enable consumer choice’. Their analysis shows how foods classified nutritionally end up in all four of the NOVA categories. Asma et al. (48) as many other researchers found the concept of processing of food helpful in categorising their participants.

Bourdieu (49), (50) identified how food and food culture is associated with social position and how society is structured at a fundamental level. This includes that there is a two way process at work. Food preferences can change social position, as social position can be changed by food preferences.

Cuj et al (51) support this idea that nutrition is limited when only the chemical composition is studied. Haber et al. (52) review the role of structural arrangement of nutrients and how this alters speed of delivery of nutrients, venous glucose profile and resulting satiety. This breaks apart the idea of the nutritional content being the sole identifier of value for a food. Structure is important too.

Dickie et al. (53) , (54) tried to develop a system to describe healthy foods, but struggled to build a model which was any more effective than NOVA. Each model demonstrated the similar ‘flaws’ around different ‘bad’ foods being made ‘good’ by the classification scheme. Martinez (55) also describes trying to use different classification schemes to describe all the health related aspects of food.

Monteiro’s initial explanation uses the concept of ‘processing’ (42) , and revised after initial reviews (56). This second version is the first that knowingly separates processed and ultraprocessed food. Identifying that whilst some processing m,ight be of value, there is a threshold where risk increases. By 2013 (57) the value of the model was becoming clearer. This idea was more confidently expressed by 2016 (58). Even at this stage there is a bio-reductionist explanation around UPF. The ‘value’ of a scientific cache is too strong.

In a recent debate Monteiro (59) and Astrup (60) discuss the concept of UPF and if it is valid or useful. There is a lot agreed about the necessity and importance of processing. Contended areas include confidence in the fundamental ideas, and in the approach to improving food quality of production, supply, and consumption. The areas of contention seem to identify differing epistemological approaches. On one side there is a confidence in a positivist solution to the social questions asked. The other identifies with a multi-paradigm approach.

This conflicting conversation is evident across the scientific and lay discourse around UPF. Using Martinez’s approach we can see the confusion is brought about because of differing assumptions about the epistemological basis of the parties. In particular the value they all hold for biologic-positivist purity.

### How is UPF different?

Explanations for the differential effect of these foods have developed as quickly as new ultra-processed foods have been developed .

Aceves-Martins (61) asks is it due to nutritional content ? In 2019 Rauber et al (62) ask, is it due to effects on satiety, or changes to appetite ? Do they taste better asks BawaJeeh et al. (63) ? With Wang et al. (64) considering, Is it due to being easy to buy, and easy to eat? 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 (65) showed that household income is correlated with UPF intake in the UK identifying a social dimension. This was also shown in the French West Indies (66) describing a ‘nutrition transition’, a historic change.

Nutrition based classifications appear less socially divisive due to scientific isolation. They still contain elements of social factors. One example is 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 NOVA discuss high salt and sugar content. Webster (67) and niMurchu (68) identify the large amount of salt in ultraprocessed foods. Vargas (69) concentrates on sodium and potassium using the Mexican national health and nutrition survey.

Sugars are the focus for Rauber (62), particularly free sugar intake.

Papers describe content, discuss the effect on physiology, and pathology, but rarely develop their 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.

Byker-Shanks et al. (70) 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. It is a pragmatic response to manipulating the strange food economy described by Dimblebey (71). Armendariz (72) looks at how the retail food environment in Mexican cities has changed and how it affects BP.

### UPF and Ill Health

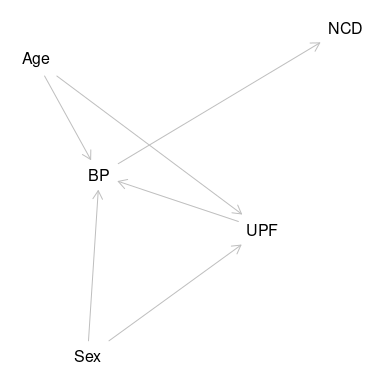


Diagram of possible relationships of UPF

Dicken and Betterham (73) provide a comprehensive review of papers considering a range of metabolic and other health endpoints.

Mertens (74), Barbosa (75), Santos (76) ,Aceves-martins (61), and Rauber (77) explore how UPF are associated with poor health. Whilst this is primarily metabolic pathology they do often mention BP. Schulze (78) comprehensively reviews UPF and metabolic health.

Oliveira et al (79) try to identify ill health in young people associated with the increasing use of UPF.

Hodge (80) dedicated an edition of ‘Public Health Nutrition’ to this question

#### obesity

The link to obesity is perhaps the most direct. Munoz (81) looked at Mexican school age children. Li (82) looked at adults in China. Rauber (77) used the NDNS study to look at obesity in the UK. Each finding links to increased UPF and increased BMI and odds of being obese, often related to increased energy intake. UPF with its nutritional, cultural, and economic parts increases obesity. Critical review of UPF findings almost always include ‘what is the mechanism?’ as an early question. We can now ask this question in three parts. How much of the mechanism is biologic, how much cultural and how much economic?

#### 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 (83) concentrates on diabetes only. Li (84) uses a national study to link UPF with diabetes in China.

de Miranda Renata Costa (85) identifies the effect on metabolic health. Martinez (55) connects the dietary share of UPF in the US population. Tavares (86) doing the same in Brazilian adolescents.

dos Santos (87) identifies this as cardiometabolic health and provides a systematic review (76) . Goodman et al (88) explore this in Venezualan adults. Vilela (89) give a ‘…prospective approach to childhood’.

Some authors look how these metabolic effects lead to other conditions. For example Weinstein (90) with dementia. Gomez-Smith (91) identify a possible pathological explanation. Ivancovsky (92) connects non- alcohol fatty liver disease (NAFLD). Lee (93) connects these to CVD.

Colombet (66) connects these changes in metabolic syndrome with changes in socioeconomic inequalities again linking the nutritional identity of diet with its social aspects.

#### cancer

Southall (94) and seperately Wang (95) have identified a risk of colorectal cancer.

#### ckd

Kityo (96) identifies the effect on the kidneys. Identifying the diverse effects of UPF and possibly also another contributory cause of BP changes.

### Increasing UPF intake

Many studies show the increasing role of UPF within the diet. Mertens (74) and ni Mhurchu (68) show how UPF are being eaten in ever greater quantities across Europe but especially across the UK.

Wang (64) identifies increasing consumption in US youths, D’Avila (97) also identify that increasingly upf are the key source of energy in adolescents. Gupta (98) explores the role of youth, identifying the peculiar age distribution of UPF intake.

Rauber (62) look instead at free sugar intake.

### UPF BP and Na

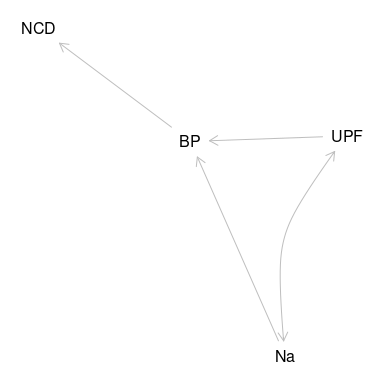


Diagram of relationship between Na and UPF and BP

Studies have started to find that hypertension is associated with increased intake of UPF in North and South America (Scaranni (99) and de Deus Mendonca (100)), Europe and in Asia Shim et al. (101) provide a Korean perspective.Du (3) gives the data for China). Wang (102) delivers a meta analysis and systematic review.

The definition of hypertension is contentious with many studies using self identification, or historical physician diagnosis. There is also a distinction between pathology, and physiology. Some papers identify hypertension as a pathological state and exclude it from analysis, others include participants on medication which alters BP value, in others ‘hypertension’ is the outcome measure irrespective of BP value.

What is the mechanism by which UPF causes BP? How much of it is nutritional? After excluding the nutritional dimension is there a further UPF effect? Most studies don’t include sodium intake in their analysis.

Before UPF, Suter (103) asked is hypertension and blood pressure nutrient based, is it mediated by Salt?

Is it other factors such as the food sales environment as explored by Goncalves (104) ?

Oliveira (79) looks at the effect in children, Rezende (105) with adolescents.

Lima (106) 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 (107) and Tzelfa (108) both look at how UPF affect the vasculature which may be part of the pathway to BP. This looks further along the causal chain within the nutritional biologic domain of food science.

### Approach to change

Understanding the best approaches to reducing salt requires approaches that also cross epsitological paradigms. As well as biologic, we need cultural and economic approaches. Indeed it may be that all the science will never make changes in behaviour and regulation in isolation, but may require addressing the cultural and economic.

The relationship between Na and socioeconomic position was demonstrated by Ji et al. (109).

Is it best to get individuals to reduce intake( (110), (111) , (39) , (112) , (113) ), or for all of the food industry to reduce salt levels Cappuccio (114) ,and He (115) .

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 (116) looks at how education may be effective in delivering change.

This can be tackled using a comprehensive integrated policy approach such as ‘healthy cities’ (117). Macregor (118) 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. It can be more effective to change laws and policies once (119) , (120) , (121) , (122) . These ‘upstream’ changes are relatively simple, and are much more effective though they can also be reversed eg Cappuccio (4) . Cost is one of the causes of change as shown by Jones (35) using NDNS to identify the cost premium of a good diet as defined by UK dietary recommendation . Opposition sometimes comes from industry.

Laverty (41) and Macgregor (118) showed that analytical models 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.

Campos-Nonato (123) identify the benefits of their strategy. They discuss the range of nation level approaches to reducing salt intake.

Dimbleby’s (71) National food strategy is an example of a high level approach to tackling biologic, cultural and economic aspects of food in order to improve all these factors and so reduce the burden of ill health and NCD across the population.

Tulleken’s (43) ultraprocessed people presents a case for stopping the use of UPF. He supports individual choice, but identifies that a whole systems approach involving governmental partners is essential. He argues largely within the biomedical paradigm.

## 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 from different epistemological viewpoints within the study of food. This study aims to look 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, which also includes cultural and economic aspects. Also understanding that Na in its nutritional paradigm similarly projects into the cultural and economic.

# Method

## Study Design and Setting

This is a secondary data analysis of data from the National Dietary and Nutritional Survey (NDNS (1)). This analysis is designed to analyse the correlation 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 cohort study in each year a new cohort of participants is enrolled. Using questionnaires, food diaries, and nurse assessments to gather data. It has been running since 2008. The latest data is available from 2019.

## Participants, Inclusion and Exclusion

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.

Participants were identified by random selection across postal units, stratified to ensure a representative sample across the four nations (England, Wales, Scotland, and Northern Ireland) and across regions in England (North West, North East, 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.

All participants in NDNS are included in this analysis.

Data was not available for some categories and years.

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.

## Exposure Variables

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.

### Salt estimation

The sodium value (Na) was calculated from intake. Food diaries were anlaysed against standard food nutrient values. Hence, this value reflects the expected Na content of standard foods. It assumes the content remains consistent.

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.

### UPF

The NOVA classification was used to estimate the intake of UPF developed by Monteiro et al. (56). 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 for this has been published more recently by Martinez-Steele et al. (124) .

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.

## 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.

## Other Variables

Additional explanatory variables are ones which can also influence BP. They include Age, Sex, and BMI. Age at completion of education (educfinh), and Index of multiple deprivation (IMD) are also used. Participants on BP medication (bpd) is used to exclude those taking medication which may lower their BP.

## Data Sources

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 food was analysed for nutritional content using a bespoke database. These reference tables are available in the available dataset.

## 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.

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 bliefs about what is percieved 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 (125) .

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

## Quantitative variables

A categorical variable (hiNa), 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).

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 (102) are low for the UK.

I have created a variable (hyp) which identifies participants with BP over 140 mmHg to enable logistic regression. This value is identified by Du et al ((3)) and others.

## Study Size

A sample size calculation for this secondary analysis is available in appendix 1 the initial proposal from OpenEpi (126) . 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 (127) .

## 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 (128). In particular the package ‘survey’ (129) was used to manage weighted data. 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.

Analysis was by regression, with univariable and multivariable linear regression as well as logistic regression used. Categorical data was analysed using chi-squared. 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.

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.

AIC was used to understand the relative importance of variables.

# Results

## Participants

NDNS identified a 9990 addresses 2008-2011 for the first 3 years of the programme. Either one adult and one child, or one child only were included. The response rate was 55% in year one for completion of a food diary. By 2019, 3466 completed food diaries of four days. Subsequent years had different response rates, but within a similar scale allowing weighting to be used to balance the samples.

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 4.1.1](tab:table3) 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.

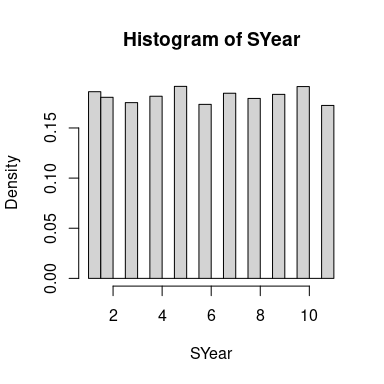
Characteristics of the sample population from National Dietary and Nutrition Study (2008-2019) N= 15,655

|  | Whole Population | Population with those on BP medication excluded | UPF >63% | Na >5000mg | hyp >140mmHg |
| --- | --- | --- | --- | --- | --- |
| **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) |
| agegad3 |  |  |  |  |  |
| (0,16] | 2,930 (19%) | 2,927 (21%) | 1,755 (37%) | 2 (2.6%) | 5 (0.6%) |
| (16,19] | 526 (3.4%) | 524 (3.7%) | 307 (6.4%) | 2 (2.8%) | 7 (0.8%) |
| (19,35] | 3,372 (22%) | 3,357 (24%) | 1,183 (25%) | 44 (61%) | 67 (7.6%) |
| (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%) |
| (D) Valid BMI | 25 (21, 29) |  |  |  |  |
| Unknown | 981 |  |  |  |  |
| 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 |  |  |  |  |  |
| 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 |
| gor |  |  |  |  |  |
| England:North East | 641 (4.1%) | 562 (4.0%) | 228 (4.8%) | 5 (6.5%) | 48 (5.4%) |
| England:North West | 1,735 (11%) | 1,564 (11%) | 554 (12%) | 17 (23%) | 96 (11%) |
| England:Yorkshire & The Humber | 1,308 (8.4%) | 1,187 (8.3%) | 449 (9.4%) | 12 (17%) | 94 (11%) |
| England:East Midlands | 1,128 (7.2%) | 1,023 (7.2%) | 365 (7.6%) | 8 (11%) | 77 (8.8%) |
| England:West Midlands | 1,384 (8.8%) | 1,243 (8.7%) | 469 (9.8%) | 6 (8.6%) | 73 (8.3%) |
| England:East of England | 1,460 (9.3%) | 1,338 (9.4%) | 444 (9.3%) | 7 (9.8%) | 76 (8.7%) |
| England:London | 2,029 (13%) | 1,863 (13%) | 428 (8.9%) | 4 (5.8%) | 51 (5.8%) |
| England:South East | 2,148 (14%) | 1,962 (14%) | 642 (13%) | 2 (2.9%) | 113 (13%) |
| England:South West | 1,321 (8.4%) | 1,201 (8.4%) | 346 (7.2%) | 0 (0.6%) | 88 (10%) |
| Wales | 753 (4.8%) | 682 (4.8%) | 247 (5.2%) | 1 (1.5%) | 62 (7.1%) |
| Scotland | 1,302 (8.3%) | 1,181 (8.3%) | 439 (9.2%) | 8 (12%) | 78 (8.9%) |
| Northern Ireland | 447 (2.9%) | 413 (2.9%) | 181 (3.8%) | 2 (2.1%) | 20 (2.3%) |
| bmival |  | 25 (21, 29) | 23 (19, 28) | 23.9 (20.6, 27.8) | 28.0 (25.2, 31.3) |
| Unknown |  | 849 | 290 | 3 | 44 |
| 1n (%); Median (IQR) | | | | | |

## Descriptive Data: Time, Place, Person

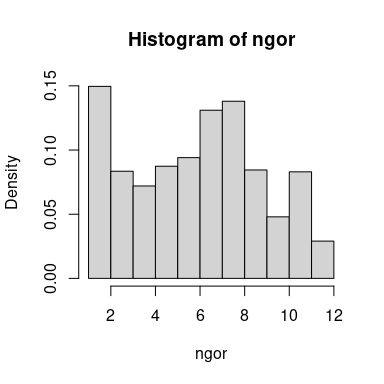
NDNS was conducted over 11 years so far, beginning in 2008 [figure 4](fig:fig-survey-year).

svyhist(~SYear , ndns\_1\_11dd )



Histogram for each annual cohort NDNS(2008-2019)

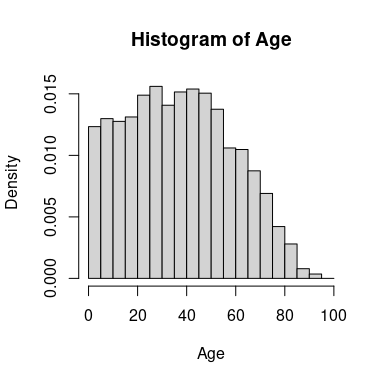
NDNS was conducted across the four nations of the UK [figure 5](fig:fig_gor).



Histogram for region NDNS(2008-2019)

## $breaks  
## [1] 1 2 3 4 5 6 7 8 9 10 11 12  
##   
## $counts  
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)[1,2]   
## 2126.3639   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(2,3]   
## 1186.5718   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(3,4]   
## 1023.4072   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(4,5]   
## 1242.5535   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(5,6]   
## 1337.5735   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(6,7]   
## 1862.7171   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(7,8]   
## 1961.7238   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(8,9]   
## 1200.6566   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(9,10]   
## 681.6304   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(10,11]   
## 1180.5106   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(11,12]   
## 412.9099   
##   
## $density  
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)[1,2]   
## 0.14956890   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(2,3]   
## 0.08346372   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(3,4]   
## 0.07198668   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(4,5]   
## 0.08740148   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(5,6]   
## 0.09408521   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(6,7]   
## 0.13102392   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(7,8]   
## 0.13798808   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(8,9]   
## 0.08445445   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(9,10]   
## 0.04794603   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(10,11]   
## 0.08303737   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(11,12]   
## 0.02904417   
##   
## $mids  
## [1] 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5  
##   
## $xname  
## [1] "variable"  
##   
## $equidist  
## [1] TRUE  
##   
## attr(,"class")  
## [1] "histogram"

NDNS included male and female participants above the age of 1.5 years [figure 6](fig:fig_Age).



Histogram for Age NDNS(2008-2019)

## $breaks  
## [1] 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90  
## [20] 95 100  
##   
## $counts  
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)[0,5]   
## 876.7417022   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(5,10]   
## 922.9389033   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(10,15]   
## 907.0774944   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(15,20]   
## 932.6684736   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(20,25]   
## 1058.6039806   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(25,30]   
## 1109.2437109   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(30,35]   
## 1000.5321202   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(35,40]   
## 1076.9537001   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(40,45]   
## 1094.0000999   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(45,50]   
## 1070.1185971   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(50,55]   
## 977.2414507   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(55,60]   
## 753.4257131   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(60,65]   
## 744.5849621   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(65,70]   
## 621.4192264   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(70,75]   
## 490.9926142   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(75,80]   
## 299.4643658   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(80,85]   
## 199.0105916   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(85,90]   
## 56.0814995   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(90,95]   
## 25.2456301   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(95,100]   
## 0.2733353   
##   
## $density  
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)[0,5]   
## 1.233404e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(5,10]   
## 1.298394e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(10,15]   
## 1.276081e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(15,20]   
## 1.312082e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(20,25]   
## 1.489249e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(25,30]   
## 1.560489e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(30,35]   
## 1.407553e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(35,40]   
## 1.515063e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(40,45]   
## 1.539044e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(45,50]   
## 1.505447e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(50,55]   
## 1.374788e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(55,60]   
## 1.059923e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(60,65]   
## 1.047485e-02   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(65,70]   
## 8.742153e-03   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(70,75]   
## 6.907305e-03   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(75,80]   
## 4.212878e-03   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(80,85]   
## 2.799690e-03   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(85,90]   
## 7.889570e-04   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(90,95]   
## 3.551566e-04   
## cut(variable, h$breaks, right = right, include.lowest = include.lowest)(95,100]   
## 3.845293e-06   
##   
## $mids  
## [1] 2.5 7.5 12.5 17.5 22.5 27.5 32.5 37.5 42.5 47.5 52.5 57.5 62.5 67.5 72.5  
## [16] 77.5 82.5 87.5 92.5 97.5  
##   
## $xname  
## [1] "variable"  
##   
## $equidist  
## [1] TRUE  
##   
## attr(,"class")  
## [1] "histogram"

In the study population The median age was 38. The largest age group was 19-35. 49% of the participants were male.

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.

[Table 4.2.2](tab:tbl-Key-Variables-by-Survey-year) shows results for continuous variables.

| **Group** | **Characteristic** | **Beta** | **95% CI**1 | **p-value** |
| --- | --- | --- | --- | --- |
| Sodium in mg | SurveyYear |  |  | <0.001 |
|  | 1 | — | — |  |
|  | 2 | -47 | -159, 65 |  |
|  | 3 | -71 | -179, 37 |  |
|  | 4 | -182 | -279, -86 |  |
|  | 5 | -250 | -345, -155 |  |
|  | 6 | -274 | -368, -180 |  |
|  | 7 | -283 | -384, -182 |  |
|  | 8 | -320 | -425, -216 |  |
|  | 9 | -344 | -450, -238 |  |
|  | 10 | -384 | -483, -286 |  |
|  | 11 | -319 | -423, -215 |  |
| Percent Energy UPF | SurveyYear |  |  | <0.001 |
|  | 1 | — | — |  |
|  | 2 | 0.98 | -0.84, 2.8 |  |
|  | 3 | 0.95 | -0.84, 2.7 |  |
|  | 4 | 0.37 | -1.3, 2.1 |  |
|  | 5 | -1.1 | -2.8, 0.61 |  |
|  | 6 | 0.67 | -1.0, 2.4 |  |
|  | 7 | -2.2 | -3.9, -0.37 |  |
|  | 8 | -4.2 | -6.0, -2.3 |  |
|  | 9 | -4.2 | -6.0, -2.4 |  |
|  | 10 | -4.1 | -6.0, -2.2 |  |
|  | 11 | -3.2 | -5.1, -1.3 |  |
| Systolic BP | SurveyYear |  |  | 0.076 |
|  | 1 | — | — |  |
|  | 2 | -0.03 | -2.7, 2.6 |  |
|  | 3 | -0.92 | -3.3, 1.4 |  |
|  | 4 | -0.51 | -3.0, 2.0 |  |
|  | 5 | -1.5 | -4.0, 1.0 |  |
|  | 6 | -3.2 | -5.9, -0.59 |  |
|  | 7 | -0.29 | -2.8, 2.2 |  |
|  | 8 | -3.1 | -5.7, -0.57 |  |
|  | 9 | -2.6 | -5.0, -0.27 |  |
|  | 10 | -1.9 | -4.2, 0.40 |  |
| Age | SurveyYear |  |  | 0.3 |
|  | 1 | — | — |  |
|  | 2 | 0.70 | -1.5, 2.9 |  |
|  | 3 | -0.21 | -2.2, 1.8 |  |
|  | 4 | 1.8 | -0.29, 4.0 |  |
|  | 5 | 2.0 | -0.16, 4.1 |  |
|  | 6 | 0.14 | -1.9, 2.2 |  |
|  | 7 | 1.6 | -0.71, 4.0 |  |
|  | 8 | 0.94 | -1.1, 3.0 |  |
|  | 9 | 1.5 | -0.68, 3.7 |  |
|  | 10 | 1.5 | -0.68, 3.7 |  |
|  | 11 | 2.0 | -0.27, 4.2 |  |
| BMI | SurveyYear |  |  | <0.001 |
|  | 1 | — | — |  |
|  | 2 | 0.06 | -0.56, 0.69 |  |
|  | 3 | -0.32 | -0.93, 0.29 |  |
|  | 4 | 0.43 | -0.18, 1.0 |  |
|  | 5 | -0.35 | -0.94, 0.24 |  |
|  | 6 | -0.41 | -1.0, 0.23 |  |
|  | 7 | -2.1 | -3.0, -1.3 |  |
|  | 8 | -2.1 | -3.0, -1.2 |  |
|  | 9 | -0.32 | -0.93, 0.30 |  |
|  | 10 | -0.18 | -0.79, 0.43 |  |
|  | 11 | -0.35 | -0.94, 0.25 |  |
| 1CI = Confidence Interval | | | | |

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.

[Table 4.2.3](tab:tbl-Categorical-variables-year) follows.

| Variable | ChiSq1 | p.value |
| --- | --- | --- |
| Sex | 0.90 | 0.53 |
| IMD | 0.86 | 0.71 |
| Age | 0.94 | 0.58 |
| Education2 |  |  |
| UPF3 | 3.22 | 0.00 |
| Hypertension3 |  |  |
| BMI | 0.78 | 0.77 |
| Region | 1.37 | 0.02 |
| Vegetarian | 1.97 | 0.02 |
| 1Chi Squared for categorical data | | |
| 2year 5 data missing | | |
| 3year 11 data missing | | |

## Exposure variables by Sex, Age and Place

The [table 4.1.1](tab:table3) shows the population exposed to UPF >63% of their calories is made up of 4793 participants. These are more commonly male, and younger than the overall population or those not on medication. 37% are 0-16 years old. There is a gradient in deprivation with more affected in the most deprived group. England’s South East has 13% of those with high UPF intake. With 11% in the North West.

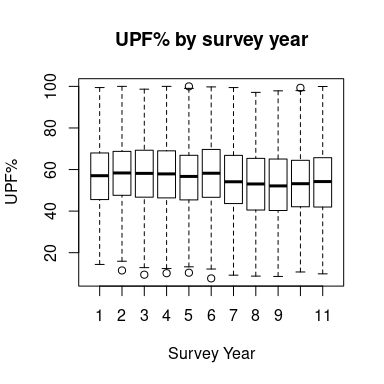
The population exposed to Na >5000mg has only 73 participants. Men are more commonly affected. They are also younger than average, 61% are 19-35. The least deprived have only 5.2% of the population compared with 39% of the population being the most deprived. The north west has 23% of those with high Na intake, much the highest.

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.

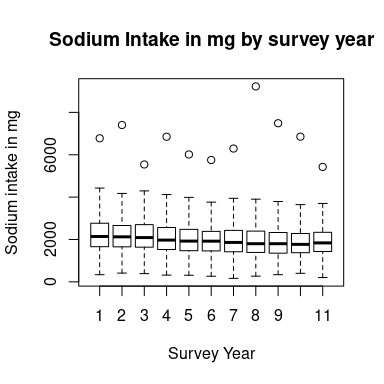
Mean UPF was highest in year 2 and year 6 at 50%. The lowest mean UPF intake was 45% in years 8,9 and 10.

The separate waves had separate participants.The data is presented in [Table 4.1.1](tab:tbl-keydata) .

Results were illustrated by plots against survey year. [figure 4](fig:fig-upf-and-survey-year) showed overlap between the waves for UPF intake. [figure 5](fig:fig-Na-and-survey-year) showed Na exposure overlap between waves.

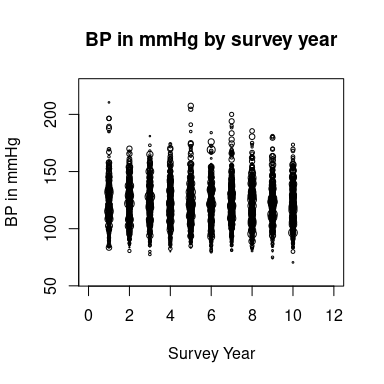


Energy from UPF% in each annual cohorts NDNS (2008-2019)



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

## Outcome variable



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

[figure 6](fig:fig-BP-and-survey-year) identified the lack of data for year 11.

The [table 4.1.1](tab:table3) shows the population with BP > 140 mmHg is 876 participants. 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! With deprivation there is a reverse gradient. The most deprived are least represented in this population. The largest proportion are in the least deprived category. The north west is second highest in raised BP after the south east.

The mean outcome variable BP was highest in year one with 125 mmHg, and the lowest 120 mmHg in year 6.

In each case the lower gradient of the relationship between the variable and Sex was statistically significant. [Table 4.3.1](tab:tbl-keydatax) shows the difference between male and female in the key variables.

| **Characteristic** | **Male**, N = 6,9921 | **Female**, N = 7,2251 | **p-value**2 |
| --- | --- | --- | --- |
| Na | 2,205 (1,676, 2,800) | 1,722 (1,351, 2,170) | <0.001 |
| zPF | 57 (45, 68) | 54 (43, 66) | <0.001 |
| zPF3 |  |  | <0.001 |
| (0,33] | 532 (7.6%) | 715 (9.9%) |  |
| (33,45] | 1,174 (17%) | 1,403 (19%) |  |
| (45,63] | 2,717 (39%) | 2,881 (40%) |  |
| (63,80] | 2,087 (30%) | 1,852 (26%) |  |
| (80,100] | 481 (6.9%) | 373 (5.2%) |  |
| Unknown | 1 | 0 |  |
| BP | 124 (115, 133) | 115 (106, 126) | <0.001 |
| Unknown | 3,431 | 3,471 |  |
| 1Median (IQR); n (%) | | | |
| 2Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction | | | |

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.

[Table 4.3.2](tab:tbl-keydataA) shows the age distribution of exposure to sodium and UPF and the resulting BP.

| **Characteristic** | **(0,16]**, N = 2,9271 | **(16,19]**, N = 5241 | **(19,35]**, N = 3,3571 | **(35,50]**, N = 3,2411 | **(50,65]**, N = 2,4751 | **(65,108]**, N = 1,6921 | **p-value**2 |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Na | 1,634 (1,254, 2,072) | 2,070 (1,615, 2,680) | 2,205 (1,624, 2,798) | 2,082 (1,601, 2,654) | 1,938 (1,518, 2,441) | 1,805 (1,427, 2,193) | <0.001 |
| zPF | 67 (57, 76) | 66 (55, 75) | 57 (45, 68) | 52 (41, 63) | 48 (38, 59) | 51 (42, 60) | <0.001 |
| zPF3 |  |  |  |  |  |  | <0.001 |
| (0,33] | 43 (1.5%) | 14 (2.7%) | 320 (9.5%) | 353 (11%) | 371 (15%) | 145 (8.6%) |  |
| (33,45] | 214 (7.3%) | 54 (10%) | 504 (15%) | 673 (21%) | 690 (28%) | 442 (26%) |  |
| (45,63] | 915 (31%) | 148 (28%) | 1,350 (40%) | 1,415 (44%) | 996 (40%) | 775 (46%) |  |
| (63,80] | 1,344 (46%) | 229 (44%) | 985 (29%) | 703 (22%) | 380 (15%) | 297 (18%) |  |
| (80,100] | 411 (14%) | 78 (15%) | 198 (5.9%) | 96 (3.0%) | 38 (1.5%) | 33 (2.0%) |  |
| Unknown | 0 | 0 | 0 | 1 | 0 | 0 |  |
| BP | 106 (99, 113) | 115 (108, 123) | 118 (110, 127) | 121 (112, 130) | 128 (118, 139) | 133 (122, 145) | <0.001 |
| Unknown | 1,635 | 246 | 1,645 | 1,448 | 1,073 | 856 |  |
| 1Median (IQR); n (%) | | | | | | | |
| 2Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction | | | | | | | |

[Table 4.3.3](tab:tbl-keydatap) shows the data.

| **Characteristic** | **England:North East**, N = 5621 | **England:North West**, N = 1,5641 | **England:Yorkshire & The Humber**, N = 1,1871 | **England:East Midlands**, N = 1,0231 | **England:West Midlands**, N = 1,2431 | **England:East of England**, N = 1,3381 | **England:London**, N = 1,8631 | **England:South East**, N = 1,9621 | **England:South West**, N = 1,2011 | **Wales**, N = 6821 | **Scotland**, N = 1,1811 | **Northern Ireland**, N = 4131 | **p-value**2 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Na | 1,908 (1,368, 2,505) | 1,954 (1,510, 2,537) | 1,915 (1,432, 2,480) | 2,002 (1,541, 2,553) | 1,949 (1,498, 2,515) | 1,959 (1,506, 2,564) | 1,813 (1,348, 2,406) | 1,909 (1,466, 2,461) | 1,962 (1,498, 2,489) | 1,896 (1,466, 2,436) | 2,005 (1,559, 2,542) | 1,968 (1,524, 2,496) | 0.003 |
| zPF | 59 (47, 70) | 56 (44, 68) | 57 (45, 70) | 56 (46, 68) | 58 (46, 69) | 55 (45, 67) | 50 (38, 62) | 55 (43, 67) | 54 (43, 65) | 57 (46, 67) | 58 (47, 68) | 61 (49, 70) | <0.001 |
| zPF3 |  |  |  |  |  |  |  |  |  |  |  |  | <0.001 |
| (0,33] | 34 (6.1%) | 128 (8.2%) | 98 (8.3%) | 75 (7.3%) | 84 (6.7%) | 101 (7.5%) | 310 (17%) | 173 (8.8%) | 92 (7.7%) | 53 (7.8%) | 81 (6.9%) | 18 (4.5%) |  |
| (33,45] | 87 (16%) | 277 (18%) | 187 (16%) | 159 (16%) | 188 (15%) | 234 (17%) | 437 (23%) | 409 (21%) | 271 (23%) | 106 (16%) | 174 (15%) | 47 (11%) |  |
| (45,63] | 213 (38%) | 605 (39%) | 452 (38%) | 424 (41%) | 502 (40%) | 558 (42%) | 687 (37%) | 738 (38%) | 491 (41%) | 275 (40%) | 486 (41%) | 167 (40%) |  |
| (63,80] | 184 (33%) | 463 (30%) | 365 (31%) | 273 (27%) | 398 (32%) | 370 (28%) | 369 (20%) | 520 (27%) | 287 (24%) | 201 (30%) | 357 (30%) | 151 (37%) |  |
| (80,100] | 44 (7.8%) | 90 (5.8%) | 85 (7.1%) | 92 (9.0%) | 70 (5.7%) | 75 (5.6%) | 59 (3.2%) | 122 (6.2%) | 59 (4.9%) | 46 (6.7%) | 83 (7.0%) | 30 (7.2%) |  |
| Unknown | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| BP | 121 (112, 133) | 120 (111, 131) | 122 (111, 134) | 122 (112, 132) | 121 (110, 131) | 120 (110, 130) | 114 (107, 124) | 119 (109, 129) | 121 (109, 132) | 121 (111, 134) | 119 (108, 131) | 121 (109, 131) | <0.001 |
| Unknown | 264 | 798 | 585 | 449 | 628 | 636 | 981 | 857 | 547 | 351 | 570 | 237 |  |
| 1Median (IQR); n (%) | | | | | | | | | | | | | |
| 2Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction | | | | | | | | | | | | | |

Chi squared table

## X-squared   
## 0.5477235

## hiNa2  
## hyp (0,5e+03] (5e+03,1e+04]  
## (0,140] 12907.70712 64.52680  
## (140,300] 1676.68780 12.07828

## X-squared   
## 1.955483e-08

## zPF2  
## hyp (0,63] (63,100]  
## (0,140] 8479.8563 4492.3776  
## (140,300] 1339.4923 349.2738

## Univariable Linear Regression

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 [Table 4.4.1](tab: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 | zPF | -0.19 | -0.22, -0.15 | <0.001 |
| UPF/Age | zPF | -0.43 | -0.46, -0.40 | <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] | — | — |  |
|  | (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 | -0.29 | -0.35, -0.23 | <0.001 |
| UPF/age | agegad3 |  |  |  |
|  | (0,16] | — | — |  |
|  | (16,19] | -1.1 | -3.0, 0.76 | 0.2 |
|  | (19,35] | -9.5 | -11, -8.4 | <0.001 |
|  | (35,50] | -13 | -14, -12 | <0.001 |
|  | (50,65] | -17 | -18, -16 | <0.001 |
|  | (65,108] | -14 | -16, -13 | <0.001 |
| UPF/ed | educfinh |  |  |  |
|  | Not yet finished | — | — |  |
|  | Never went to school | -20 | -34, -5.3 | 0.007 |
|  | 14 or under | -7.5 | -11, -4.4 | <0.001 |
|  | 15 | -5.7 | -8.3, -3.0 | <0.001 |
|  | 16 | -4.0 | -6.4, -1.5 | 0.002 |
|  | 17 | -5.9 | -8.5, -3.2 | <0.001 |
|  | 18 | -7.0 | -9.6, -4.4 | <0.001 |
|  | 19 or over | -11 | -14, -8.7 | <0.001 |
| Na/bmi | bmival | 17 | 14, 19 | <0.001 |
| Na/Agg | agegad3 |  |  |  |
|  | (0,16] | — | — |  |
|  | (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 |
| 1CI = Confidence Interval | | | | |

## Main Results

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 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 5.07 for this group.

“UPF only” shows a significant difference in odds ratio 0.61 for the group 63-80% with a p.value of 0.049.

The last model, “Sodium and UPF”, shows that when combined the effect remains. The odds ratio for 5000-6000mg of Na remains statistically significant. The odds ratio for UPF also remains.

[Table 4.5.1](tab:tbl-multivariable-outputs-bp) follows below.

## [1] 3586.331

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** |
| hiNa |  |  |  |  |  |  |  |  |  |
| (0,1.5e+03] | — | — |  |  |  |  | — | — |  |
| (1.5e+03,3e+03] | 0.99 | 0.68, 1.43 | >0.9 |  |  |  | 1.04 | 0.72, 1.51 | 0.8 |
| (3e+03,5e+03] | 1.24 | 0.74, 2.07 | 0.4 |  |  |  | 1.37 | 0.81, 2.29 | 0.2 |
| (5e+03,6e+03] | 5.07 | 1.37, 18.8 | 0.015 |  |  |  | 5.43 | 1.44, 20.4 | 0.012 |
| (6e+03,1e+04] | 0.00 | 0.00, 0.00 | <0.001 |  |  |  | 0.00 | 0.00, 0.00 | <0.001 |
| zPF3 |  |  |  |  |  |  |  |  |  |
| (0,33] |  |  |  | — | — |  | — | — |  |
| (33,45] |  |  |  | 0.86 | 0.54, 1.36 | 0.5 | 0.83 | 0.52, 1.33 | 0.4 |
| (45,63] |  |  |  | 0.73 | 0.48, 1.12 | 0.2 | 0.71 | 0.46, 1.09 | 0.12 |
| (63,80] |  |  |  | 0.61 | 0.37, 1.00 | 0.049 | 0.57 | 0.35, 0.95 | 0.032 |
| (80,100] |  |  |  | 0.74 | 0.26, 2.06 | 0.6 | 0.69 | 0.24, 1.95 | 0.5 |
| 1OR = Odds Ratio, CI = Confidence Interval | | | | | | | | | |
| All models include Sex,Age, BMI, Education, IMD and Survey Year | | | | | | | | | |

Using the AIC statistic for each model gives another way of understanding the comparative effects. The subsequent [Table 4.5.2](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] 195.2547

| Model | AIC |
| --- | --- |
| No Na or UPF | 3,586.331 |
| Na only | 3,580.840 |
| UPF only | 3,584.397 |
| Na and UPF | 3,577.452 |

# Discussion

## Key Results

The chi squared test shows a statistically significant correlation between UPF and hypertension.

The multivariable logistic regression shows a statistically significant correlation between high Na intake and hypertension, and between high UPF and hypertension.

There is change in intake of Na and UPF over time.

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.

## Limitations

### The study

This study was organised by the government departments connected with food and farming alongside the Department of Health. This means it was intended to monitor outcomes relevant to these departments. My analysis is a secondary analysis using the data for different purposes. It is unrealistic to expect the data to be ideal for my analysis.

There may also be unintentional bias in the structure of the study because of the funding and commissioning processes. This might also affect participant engagement and expectation. In particular there might be an unconscious desire to be portrayed in a way that ‘the government’ would prefer to hear.

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.

### The data

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 would be an explanation.

If the diet and recording stay the same, an alternative cause is a uniform change in the nutrient content of the food. By changing the nutritional definitions the derived results would be affected uniformly.

These changes would not affect the outcome variable. 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. However the algorithm used 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. 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.

### The analysis

## Interpretation

The results suggest that those with high Na are more likely to have hypertension. This could be that raised BP stimulates ingestion of Na, or that Na ingestion increases hypertension.

The results around high UPF intake also do no more than imply correlation. Causation might be the high BP reduces intake of UPF..?

could be; 1 real 2 sample error 3 increasing social desirability of low Na, low UPF.

### Ideas for further research

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

#### 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.

#### 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

#### 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.

## Generalisability

This study used national data. This was standardised across the four home nations. It was standardised for IMD, and sex also. 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

There are a complex interaction between fixed factors and societal factors at work. Na is correlated with hypertension. UPF is also correlated with hypertension, with a negative gradient.

NOVA and UPF are a conceptual model. As a model they are useful in bridging the chasm between ‘scientific’ (or more specifically ‘positivist’) nutrition and more social science paradigms.

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

# Bibliography

::: {#refs} :::

# Appendix

# Appendix 1 Approved Proposal

The approved proposal

# Appendix 2 Ethics Certificate

The ethics cert.

# Appendix 3 Software used

The software used

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