

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 an 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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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 Monitoring Programme
NOVA	NOVA is a classification system, it categorises foods into four groups based on the degree of processing
NAFLD	non- alcohol fatty liver disease
BMI	Body Mass Index

# 1 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 blood pressure (BP) and intake of Ultra-processed Foods (UPF) (3) and BP 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 ((1) ).The study gives data from the UK from 2008 to 2019 and captured changes in intake of UPF and Na, as well as changes in BP over that time.

This study assess correlation between BP and these dietary factors and the association between salt intake and the effect of ultraprocessed food on BP within the data from this study.

Age and sex remain important background factors. This study explored this complex web pulling out strands within it, @ref(fig:figdiag1) shows a possible arrangement of this.

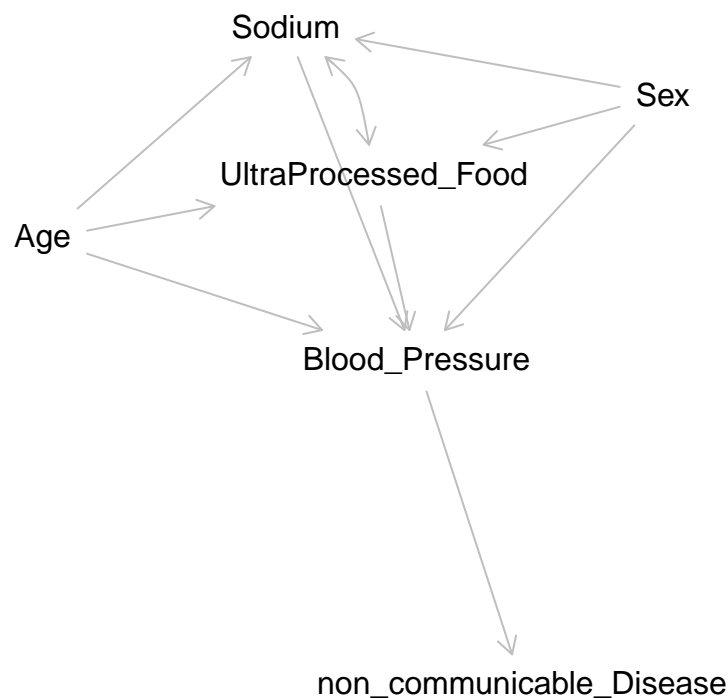


Figure 1: The relationships explored in the analysis

## 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). 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 (5) 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, by understanding the pathway or mechanism of action of social and commercial determinants. This may then be manipulated to deliver change at a population level.

## **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 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 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 the constructivist aspects to this study allows that the observer is closer to the model making my positionality of interest. Jafar (6) 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 (7) 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.

## **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?

## 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 to promote an upstream approach to NCD prevention.



## 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. 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 @ref(tab: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.

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#### Search Terms Used

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"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")

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#### 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. 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 (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.

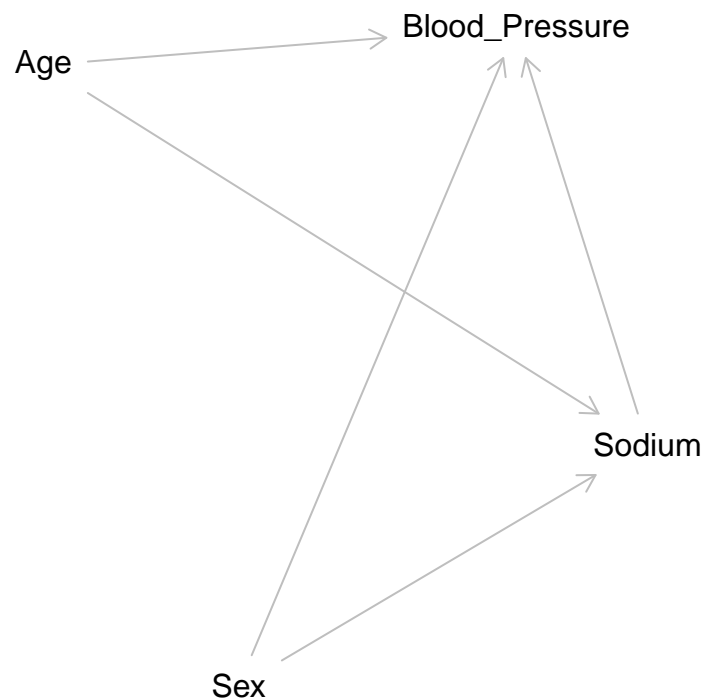


Figure 2: Diagram of relationships between BP and Salt

Explaining the role of the Framingham studies Kannel (8) , (9) and Mahmood (10) 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 (11) 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 (12) reported a comprehensive systematic review with 123 studies over 49 years and 613815 participants. In a more contemporary study Debon-Raque et al. (13) look at app use to improve BP

monitoring. Bress (14) clearly identifies that patient trust and engagement are essential in reducing ‘race’ based inequalities. Boutain (15) identifies stress and worry as important factors for African American men and women. In North west England Roche (16) 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 (17).

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 (18) , (19) , (20) .

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 (21) with Elliot (22) 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 (23) and Newman (24) identify question ‘orthodox’ explanations and seek to disrupt consensus with some degree of success. Eljovich (25) carefully explains how the American Heart Association deals with the idea that there may be individuals with higher sensitivity to salt . Barris et al. (26) discuss the role of sex in salt sensitivity. Pitzer et al. (27) propose a mechanism of action.

‘Lifestyle’ causes, such as Boutain’s ( (15) ) 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 (28) (29) (30) shows how ‘lifestyle’ affects BP, CVD and NCD. This identifies mechanisms for Whitehead (31) Dahlgren (32) and Diderichson’s (33) social determinants of health inequalities with their policy approaches and points of intervention.

Whilst Jones et al. (34) demonstrated that there is a cost to adopting dietary recommendations in the UK. Salisbury’s editorial (35) 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 (36) discovered that this is difficult to study with a wide range of approaches across their systematic review. Nakamura et al. (37) used NDNS to explore how alternative flavourings might reduce the use of salt.

Reducing salt intake works. Vollmer (38) reports findings that reduced salt intake can reduce BP in diverse groups in the USA. Hendriksen (39) also explored this using Dutch and other European data to support this. Lavery et al. (40) demonstrate how policy reduces salt intake, and how reversal of policy allows intake to increase again. They also show how that affects BP.

### 2.2.3 NOVA

The NOVA classification, of Monteiro (41), 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 (42) describes UPF in nutritional terms quoting Rauber as calling them ‘industrially produced edible substances’.

### 2.2.4 The ‘controversy’ of Food classification

Martinez (43) 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 (44) 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 (45) 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. (46) 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. (47) as many other researchers found the concept of processing of food helpful in categorising their participants.

Bourdieu (48), (49) 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 (50) support this idea that nutrition is limited when only the chemical composition is studied. Haber et al. (51) 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. (52) , (53) 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 (54) 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’ (41) , and revised after initial reviews (55). This second version is the first that knowingly separates processed and ultraprocessed food. Identifying that whilst some processing might be of value, there is a threshold where risk increases. By 2013 (56) the value of the model was becoming clearer. This idea was more confidently expressed by 2016 (57). 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 (58) and Astrup (59) 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.

### 2.2.5 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 (60) asks is it due to nutritional content ? In 2019 Rauber et al (61) ask, is it due to effects on satiety, or changes to appetite ? Do they taste better asks BawaJeeh et al. (62) ? With Wang et al. (63) 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 (64) 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 (65) 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 (66) and niMurchu (67) identify the large amount of salt in ultraprocessed foods. Vargas (68) concentrates on sodium and potassium using the Mexican national health and nutrition survey.

Sugars are the focus for Rauber (61), 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. (69) 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 (70). Armendariz (71) looks at how the retail food environment in Mexican cities has changed and how it affects BP.

## **2.2.6 UPF and Ill Health**

Dicken and Betterham (72) provide a comprehensive review of papers considering a range of metabolic and other health endpoints.

Mertens (73), Barbosa (74), Santos (75), Aceves-Martins (60), and Rauber (76) explore how UPF are associated with poor health. Whilst this is primarily metabolic pathology they do often mention BP. Schulze (77) comprehensively reviews UPF and metabolic health.

Oliveira et al (78) try to identify ill health in young people associated with the increasing use of UPF.

Hodge (79) dedicated an edition of 'Public Health Nutrition' to this question

**2.2.6.1 obesity** The link to obesity is perhaps the most direct. Munoz (80) looked at Mexican school age children. Li (81) looked at adults in China. Rauber (76) 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?

**2.2.6.2 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.

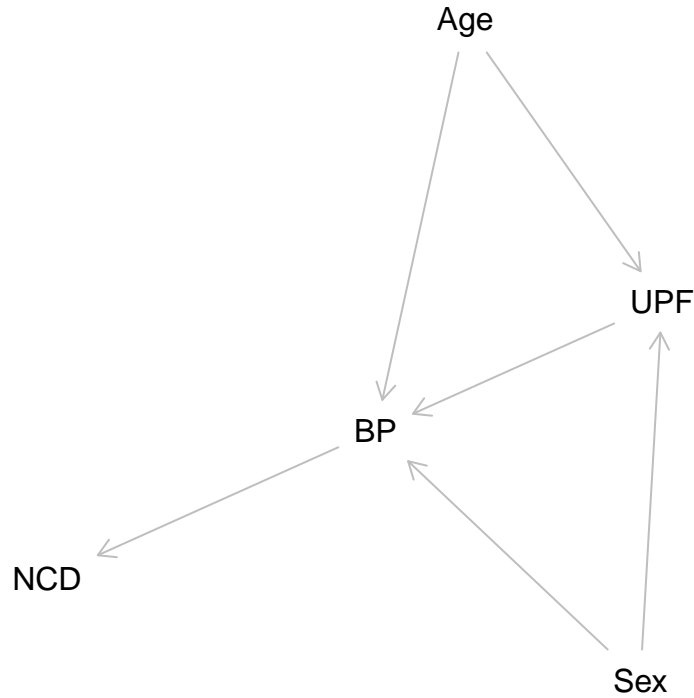


Figure 3: Diagram of possible relationships of UPF

Aguiar (82) concentrates on diabetes only. Li (83) uses a national study to link UPF with diabetes in China. de Miranda Renata Costa (84) identifies the effect on metabolic health. Martinez (54) connects the dietary share of UPF in the US population. Tavares (85) doing the same in Brazilian adolescents.

dos Santos (86) identifies this as cardiometabolic health and provides a systematic review (75) . Goodman et al (87) explore this in Venezuelan adults. Vilela (88) give a ‘...prospective approach to childhood’.

Some authors look how these metabolic effects lead to other conditions. For example Weinstein (89) with dementia. Gomez-Smith (90) identify a possible pathological explanation. Ivancovsky (91) connects non-alcohol fatty liver disease (NAFLD). Lee (92) connects these to CVD.

Colombet (65) connects these changes in metabolic syndrome with changes in socioeconomic inequalities again linking the nutritional identity of diet with its social aspects.

**2.2.6.3 cancer** Southall (93) and separately Wang (94) have identified a risk of colorectal cancer.

**2.2.6.4 ckd** Kityo (95) identifies the effect on the kidneys. Identifying the diverse effects of UPF and possibly also another contributory cause of BP changes.

### 2.2.7 Increasing UPF intake

Many studies show the increasing role of UPF within the diet. Mertens (73) and ni Mhurchu (67) show how UPF are being eaten in ever greater quantities across Europe but especially across the UK.

Wang (63) identifies increasing consumption in US youths, D’Avila (96) also identify that increasingly upf are the key source of energy in adolescents. Gupta (97) explores the role of youth, identifying the peculiar age distribution of UPF intake.

Rauber (61) look instead at free sugar intake.

### 2.2.8 UPF BP and Na

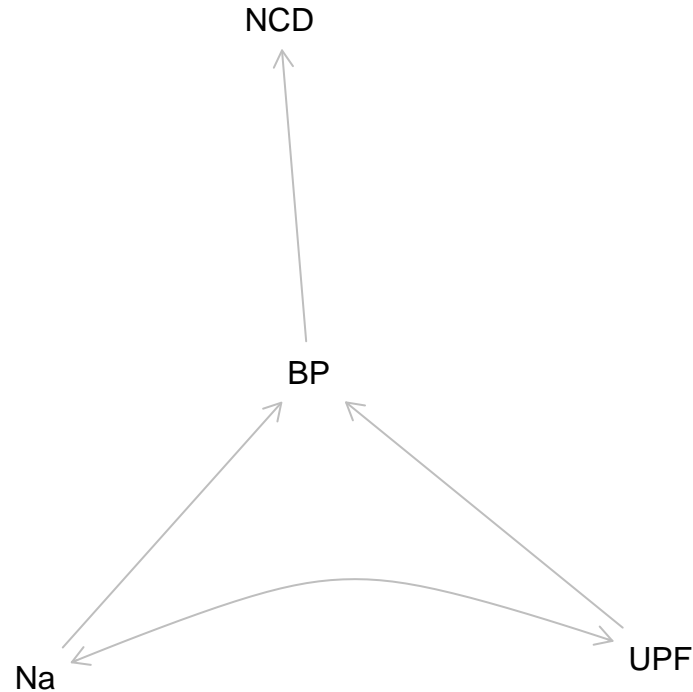


Figure 4: Diagram of relationship between Na and UPF and BP

Studies have started to find that hypertension is associated with increased intake of UPF in North and South America (Scaranni (98) and de Deus Mendonca (99)), Europe and in Asia Shim et al. (100) provide a Korean perspective. Du (3) gives the data for China). Wang (101) 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 (102) 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 (103) ?

Oliveira (78) looks at the effect in children, Rezende (104) with adolescents.

Lima (105) 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 (106) and Tzefa (107) 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.

### 2.2.9 Approach to change

Understanding the best approaches to reducing salt requires approaches that also cross epistological 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. (108).

Is it best to get individuals to reduce intake( (109), (110) , (38) , (111) , (112) ), or for all of the food industry to reduce salt levels Cappuccio (113) ,and He (114) .

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

This can be tackled using a comprehensive integrated policy approach such as ‘healthy cities’ (116). Macgregor (117) 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 (118) , (119) , (120) , (121) . 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 (34) using NDNS to identify the cost premium of a good diet as defined by UK dietary recommendation . Opposition sometimes comes from industry.

Laverty (40) and Macgregor (117) 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 (122) identify the benefits of their strategy. They discuss the range of nation level approaches to reducing salt intake.

Dimbleby’s (70) 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 (42) 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.

## 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 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.



## 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.

In the first wave a double labelled water study was performed to compare reported energy intake, with measured values (123) . 24 hour urinary sodium was measured for some of the waves but not all. Separate 24 hour urinary sodium results were reported by NDNS.

### 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 ((3)) 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 (3).

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. ((55)). There is no record of NOVA classification in NDNS. Data from Rauber et al ((61)) was used as a key to translate NDNS food groups to NOVA.

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 (101) 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 ((124)). In particular the package 'survey' (125) 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 P.values and confidence intervals were calculated and a value of  $p < 0.05$  was taken as the threshold of statistical significance.

### **3.5 Univariable Regression**

Univariable linear regression analysis of the association between BP and sodium intake, and then BP and UPF intake was done.

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

### **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%.

The population exposed to UPF >63% of their calories is made up of 5121 participants. These are more commonly male, and younger than the overall population or those not on medication. 34% are 0-16 years old. There is a gradient in deprivation with more affected in the most deprived group. The north west has 13% of those with high UPF intake along with the south east.

The population exposed to Na >5000mg has only 73 participants. Men are more commonly affected. They are also younger than average. 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 population with BP > 140 mmHg is 1244 participants. Men are once again overrepresented. These participants are older than the population mean, 44% of these participants are over 65. 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.

This table @ref(tab: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	Whole Population N = 15,655 <sup>1</sup>	Population with those on BP medica N = 14,217 <sup>1</sup>
Sex		
Male	7,699 (49%)	6,992 (49%)
Female	7,956 (51%)	7,225 (51%)
Age	40 (22, 58)	37 (20, 54)
agead3		
(0,16]	2,930 (19%)	2,927 (21%)
(16,19]	526 (3.4%)	524 (3.7%)
(19,35]	3,372 (22%)	3,357 (24%)
(35,50]	3,355 (21%)	3,241 (23%)
(50,65]	2,912 (19%)	2,475 (17%)
(65,108]	2,561 (16%)	1,692 (12%)
(D) Valid BMI	25 (21, 29)	
<sup>1</sup> n (%); Median (IQR)		

	Whole Population	Population with those on BP medica
<b>Characteristic</b>	<b>N = 15,655<sup>1</sup></b>	<b>N = 14,217<sup>1</sup></b>
Unknown	981	
educfinh		
Not yet finished	375 (2.9%)	375 (3.2%)
Never went to school	41 (0.3%)	29 (0.2%)
14 or under	504 (3.9%)	345 (2.9%)
15	1,773 (14%)	1,426 (12%)
16	3,483 (27%)	3,160 (27%)
17	1,074 (8.3%)	974 (8.3%)
18	1,588 (12%)	1,484 (13%)
19 or over	4,172 (32%)	3,922 (33%)
Unknown	2,645	2,502
IMD		
Most deprived	2,977 (19%)	2,748 (19%)
2	3,128 (20%)	2,870 (20%)
3	2,905 (19%)	2,609 (18%)
4	3,269 (21%)	2,953 (21%)
least deprived	3,372 (22%)	3,031 (21%)
Unknown	5	5
gor		
England:North East	641 (4.1%)	562 (4.0%)
England:North West	1,735 (11%)	1,564 (11%)
England:Yorkshire & The Humber	1,308 (8.4%)	1,187 (8.3%)
England:East Midlands	1,128 (7.2%)	1,023 (7.2%)
England:West Midlands	1,384 (8.8%)	1,243 (8.7%)
England:East of England	1,460 (9.3%)	1,338 (9.4%)
England:London	2,029 (13%)	1,863 (13%)
England:South East	2,148 (14%)	1,962 (14%)
England:South West	1,321 (8.4%)	1,201 (8.4%)
Wales	753 (4.8%)	682 (4.8%)
Scotland	1,302 (8.3%)	1,181 (8.3%)
Northern Ireland	447 (2.9%)	413 (2.9%)
bmival		25 (21, 29)
Unknown		849

1n (%); Median (IQR)

## 4.2 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 @ref(tab:tbl-keydata) tbl-keydata.

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

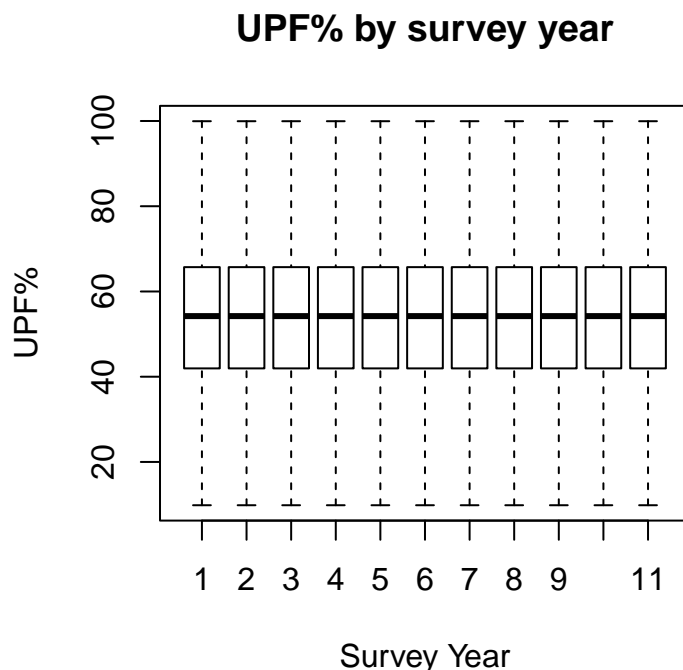


Figure 5: Energy from UPF% in each annual cohorts NDNS (2008-2019)

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.

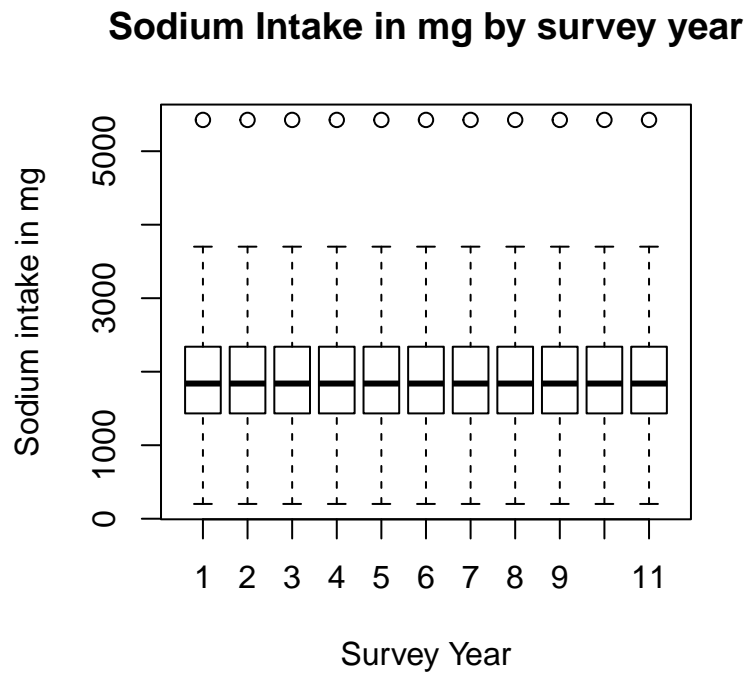


Figure 6: Na in mg in each annual cohort NDNS(2008-2019)

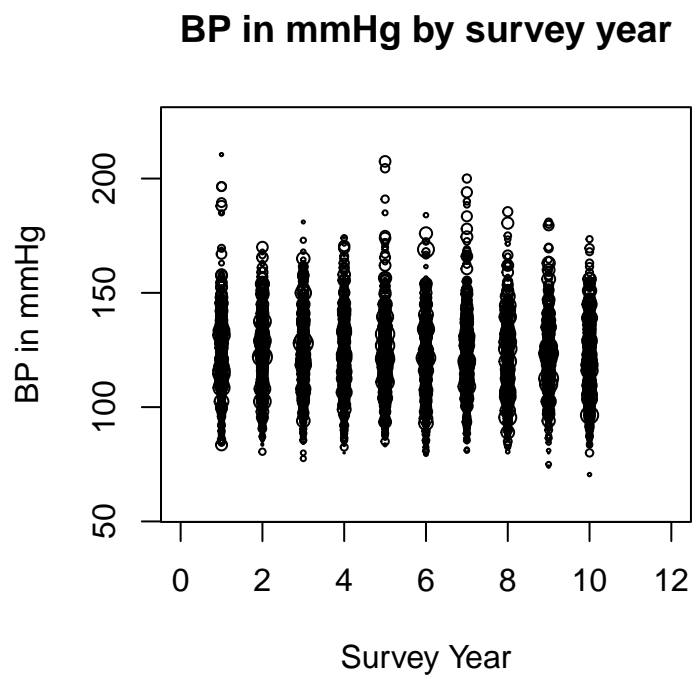


Figure 7: Plot of the BP in mmHg by year from NDNS (2008-2018)

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

<b>Group</b>	<b>Characteristic</b>	<b>Beta</b>	<b>95% CI<sup>1</sup></b>	<b>p-value</b>
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	

<sup>1</sup>CI = Confidence Interval



Group	Characteristic	Beta	95% CI <sup>1</sup>	p-value
Age	9	-2.6	-5.0, -0.27	0.3
	10	-1.9	-4.2, 0.40	
	SurveyYear			
	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	

<sup>1</sup>CI = Confidence Interval

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

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.

(ref?)(tab:tbl-Categorical-variables-year) follows.

Variable	ChiSq <sup>1</sup>	p.value
Sex	0.90	0.53
IMD	0.86	0.71
Age	0.94	0.58
Education <sup>2</sup>		
UPF3	3.22	0.00
Hypertension <sup>3</sup>		
BMI	0.78	0.77
Region	1.37	0.02
Vegetarian	1.97	0.02

<sup>1</sup>Chi Squared for categorical data

<sup>2</sup>year 5 data missing

<sup>3</sup>year 11 data missing

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

### 4.3 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. (ref?)(tab:tbl-keydatax) shows the difference between male and female in the key variables.

Characteristic	Male, N = 6,992 <sup>1</sup>	Female, N = 7,225 <sup>1</sup>	p-value <sup>2</sup>
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 (114, 133)	114 (106, 126)	<0.001
Unknown	3,431	3,471	

<sup>1</sup>Median (IQR); n (%)

<sup>2</sup>Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction

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

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.

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

Characteristic	(0,16], N = 2,927 <sup>1</sup>	(16,19], N = 524 <sup>1</sup>	(19,35], N = 3,357 <sup>1</sup>	(35,65], N = 1,000 <sup>1</sup>
Na	1,634 (1,254, 2,072)	2,070 (1,615, 2,680)	2,205 (1,624, 2,798)	2,080 (1,510, 2,650)
zPF	67 (57, 76)	66 (55, 75)	57 (45, 68)	56 (45, 67)
zPF3				
(0,33]	43 (1.5%)	14 (2.7%)	320 (9.5%)	290 (29%)
(33,45]	214 (7.3%)	54 (10%)	504 (15%)	450 (45%)
(45,63]	915 (31%)	148 (28%)	1,350 (40%)	1,200 (12%)
(63,80]	1,344 (46%)	229 (44%)	985 (29%)	850 (85%)
(80,100]	411 (14%)	78 (15%)	198 (5.9%)	170 (17%)
Unknown	0	0	0	0
BP	106 (99, 113)	114 (108, 123)	118 (110, 126)	118 (110, 126)
Unknown	1,635	246	1,645	1,645

<sup>1</sup>Median (IQR); n (%)

<sup>2</sup>Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction

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

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. (ref?)(tab:tbl-keydatap) shows the data.

Characteristic	England:North East, N = 562 <sup>1</sup>	England:North West, N = 1,564 <sup>1</sup>	England:South East, N = 1,564 <sup>1</sup>
Na	1,908 (1,368, 2,505)	1,954 (1,510, 2,537)	1,954 (1,510, 2,537)
zPF	59 (47, 70)	56 (44, 68)	56 (44, 68)
zPF3			

<sup>1</sup>Median (IQR); n (%)

<sup>2</sup>Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction

<b>Characteristic</b>	<b>England:North East, N = 562<sup>1</sup></b>	<b>England:North West, N = 1,564<sup>1</sup></b>	<b>England:South East, N = 1,564<sup>1</sup></b>
(0,33]	34 (6.1%)	128 (8.2%)	128 (8.2%)
(33,45]	87 (16%)	277 (18%)	277 (18%)
(45,63]	213 (38%)	605 (39%)	605 (39%)
(63,80]	184 (33%)	463 (30%)	463 (30%)
(80,100]	44 (7.8%)	90 (5.8%)	90 (5.8%)
Unknown	0	0	0
BP	121 (112, 133)	120 (110, 131)	120 (110, 131)
Unknown	264	798	798

<sup>1</sup>Median (IQR); n (%)

<sup>2</sup>Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction

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

## 4.4 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 (ref?)(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.

<b>Group</b>	<b>Characteristic</b>	<b>Beta</b>	<b>95% CI<sup>1</sup></b>	<b>p-value</b>
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

<sup>1</sup>CI = Confidence Interval

<b>Group</b>	<b>Characteristic</b>	<b>Beta</b>	<b>95% CI<sup>1</sup></b>	<b>p-value</b>
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

<sup>1</sup>CI = Confidence Interval