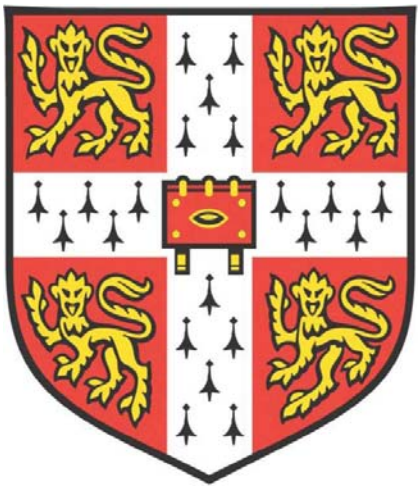
Local food availability, diet and obesity: Development and empirical testing of a complex theory



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Summary

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Individuals with poor quality diets face an increased risk of developing a range of chronic diseases. Aspects of the local food environment, including food availability, have been linked with less healthy diets and increased body weight in adults. However there is limited theory development to guide the synthesis of empirical studies, or the design and evaluation of intervention strategies. Therefore, this dissertation sought to 1) develop a theory of change for unpacking the association between local food availability, diet quality and weight status through identifying hypothesized pathways of influence; and 2) test identified mechanisms using nationally representative data for adults across the United Kingdom and England.

Firstly, a systematic review and realist synthesis was used to generate a novel theory of change for food availability, diet and obesity. This involved integration of tacit knowledge from an expert panel with evidence from a range of published food availability interventions. The resulting theory suggested that the influence of food availability on diet and weight status involves a complex set of pathways. These included the importance of understanding the link between the adoption of, and exposure to, different types of food outlets and the alignment of these factors with the needs of people with different socio-economic position (SEP).

Thus, use of different away-from-home food outlets (i.e. fast food, restaurant and café) were examined in adults from the National Diet and Nutrition Survey showing that only use of fast food outlets (but not restaurants or cafés) was associated with poor diet quality and obesity, after accounting for SEP. Next, given the potential importance of exposure to density of food outlets in their use, the same types of away-from-home food outlets were examined in a cross-

sectional spatial study of adults from the first wave of the UK Household Longitudinal Study (UKHLS). This analysis showed that, again regardless of individual SEP, density of fast food outlets around the home was positively associated with away-from-home food spending and obesity, while density of restaurants was negatively associated with obesity, and no link to density of cafés.

Lastly, preliminary longitudinal analysis using adults from five waves of the UKHLS explored the utility of residential relocation as a means of examining the effect of change in exposure to away-from-home food outlet density on diet and obesity. Results suggest that relocation can lead to substantial change in food outlet exposures; however relocation is also accompanied by changes in a variety of demographic and socio-economic circumstances.

Collectively, this work demonstrates that theory development and empirical testing can provide a solid conceptual foundation to improve our understanding of how food availability influences unhealthy diet and obesity, for different groups of people and across a range of circumstances. The application of this systematic approach could lead to a more nuanced view of mechanisms of action and thereby more effectively address complex public health problems.

Declaration

This dissertation is the result of my own work under the supervision of Dr Pablo Monsivais and advice of Dr Thomas Burgoine. I have not submitted this work, in whole or part, for any other degree at the University or elsewhere. This dissertation does not include work done in collaboration except where specifically indicated in the text below.

My theoretical development study included the participation of a panel made up of subject matter experts within my department including my supervisor Dr Monsivais and other senior and junior scientists including Drs Helen E Brown (HEB), Eva Maguire (EM), Thomas Burgoine,. Jean Adams and Prof. Martin White. My empirical studies used data collected by the National Diet and Nutrition Survey team at the MRC Human Nutrition Research and the UK Household Longitudinal Survey at the University of Essex. I contributed to 70% of the systematic review presented in chapter 2 which was done in collaboration with the expert panel, and second screening done by HEB and EM where indicated in the chapter. The remaining chapters are based upon papers in development (Appendix 1) conducted in collaboration, together contributing to approximately 10% of the work of my dissertation. For each study in chapters 3-5, I solely performed all statistical analyses with advice from my supervisor and co-authors. I also conceived each study's objectives, interpreted the findings and led the writing of all manuscripts; thus contributing approximately 90% to the work of co-authored papers.

In accordance with the Degree Committee of the Faculty of Clinical Medicine and Veterinary Medicine guidelines, this thesis is does not exceed 60,000 words.

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‘If you don’t ask, you don’t know, and if you don’t know, you can’t act.’

– Nancy Krieger, 1992 in 'The making of public health data: paradigms, politics and policy.'

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I am most grateful to my best friend and partner Shane Hinchey, without whom I would not have had the courage to seize this opportunity to study and live abroad. I would also like to give a heartfelt thank you to my family by marriage, particularly Anne and Sweeney Hinchey who have supported me as one a member of their family; I would not have had the opportunity to have such an adventure without your years of love and support.

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List of Abbreviations

BMI	Body Mass Index
CI	Confidence Interval
DASH	Dietary Approaches to Stop Hypertension
GPS	Global Positioning System
MRC	Medical Research Council
NDNS	National Diet and Nutrition Survey
OR	Odds Ratio
RAMESES	Realist And Meta-narrative evidence Syntheses
UKHLS	United Kingdom Household Longitudinal Study

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1 Background

Individuals with poor quality diets face an increased risk of developing a range of chronic diseases. Aspects of the local food environment, including food availability, have the potential to support healthy eating behaviour across the population and are linked with diet and weight status in adults. However inconsistencies within observational and intervention evidence have called into question the causal nature of these associations. To this end, there is a need for theory development to deepen our understanding, ground evidence synthesis, and guide the implementation and evaluation of intervention strategies. Therefore, this dissertation sought to 1) develop a complex theory of change for unpacking the potential causal association between local food availability, diet quality and weight status through identifying hypothesized pathways of influence; and 2) test identified mechanisms using nationally representative data for adults across the United Kingdom and England. This chapter provides the foundations for meeting these aims.

1.1 The prevention of chronic disease and dietary public health

Chronic diseases are a global burden, attributable in 2015 to nearly 60% of the over fifty million deaths world-wide.[1] Dietary risk factors account for the highest amount of disease burden, with poor diet quality associated with an increased risk of cardiovascular disease[2–4], diabetes[5], certain types of cancer[6] and conditions such as overweight and obesity.[7–9] Obeisty (a body mass index >= 30kg/m^2) in particular is considered a global epidemic with a doubling of prevelance worldlide since 1980, reaching approximately 600 million adults as of 2014.[10] In the United Kingdom, approximately 26% of men and

23.8% of women are living with obeisty in England.[11] Dietary patterns that pose a risk for obesity and chronic disease include diets low in fruits and vegetables, whole grains, low fat milk, fibre, nuts and seeds, and high in red and processed meat, sugar and sodium.[9] In the UK adult population, the average consumption of recommended fruit and vegetable intake is too low; and consumption of red meat, sugar and sodium is too high.[12]

1.1.1 Diet quality, the distribution of risk and shifting the curve

Although there is considerable evidence that a diet of good quality contributes to a reduction in the risk of obesity and other chronic diseases; translating this evidence into improved food choice, reported diet quality and reduced obesity at the population level has yet to be achieved.[13] Food choice, and the resulting diet quality of those choices, is a modifiable risk factor that is incredibly challenging to change and sustain.[14–16] This is not wholly surprising given the wide range of determinants of diet quality, including individual factors such as taste, motivation, food skills, knowledge and attitudes[17,18]; social factors such as social support or isolation[19]; economic factors such as food costs or material resources[20]; and physical environmental factors such as availability of foods or point of purchase information.[21] Coupled with the challenge of multiple determinants, the prevention of poor diet quality has traditionally involved targeting 'high-risk' groups and exploring determinants that independently contribute to diet quality in these populations, leading to tailored individual-level interventions that provide limited population level impact.[22]

As an alternative to the individually focused 'high-risk' approach, Geoffrey Rose put forward an approach that seeks to 'shift the curve' of the distribution of risk for everyone, rather than reducing risk for a specific group.[23] Reflecting this approach to reduce population level risk, policy makers are seeking actionable evidence to improve diet quality and reduce obesity for whole populations. Therefore, there is a need to move away from individual level determinants toward those factors, interventions, policies or programs that shift the distribution of health risk by addressing the underlying social, economic and environmental conditions.[24–29] Toward this end, the work in this thesis is focused on the recent surge in research related to improving the local food environment to reduce diet related risk for chronic disease, including obesity.[30,31]

1.1.2 The local food environment

In the broadest sense, local food environments consist of any factor beyond the individual that has the potential to shape food choice and diet quality.[32] While no consistent definition of the local food environment exists, common conceptualisations and frameworks have emerged. Specifically, social-ecological (i.e. wide ranging multi-levelled) models of health behaviour are intended to elucidate how people operate within their environments, by positing a complex set of factors that influence health at the intrapersonal, interpersonal, institutional, community and public policy levels.[33] The primary purpose of this multi-levelled perspective is to move our understanding beyond individual level determinants of behaviour and health. This view suggests structural factors shape individual level determinants, meaning that providing individuals with knowledge and confidence to change behaviour may not be effective if environments and policies make it difficult, or impossible, for individuals to engage in these behaviours.[34,35] For example, a popular descriptive framework has been proposed by Glanz et. al., 2005 who developed a model of Community Nutrition Environments (**Figure 1.1**) depicting the directional influence of policy variables (i.e. government and industry policies) influencing environmental variables (i.e. community and consumer nutrition environments across settings) and informational variables (i.e. media and advertising), which then impact upon individual-level factors and behaviours. However, some aspects of the framework remain vague, for example types of policies and their direct or indirect effects are not clearly articulated and specific influences across different organizational environments (i.e. settings) are also absent, as are specific individual level factors and their specific determinants.[36–38]

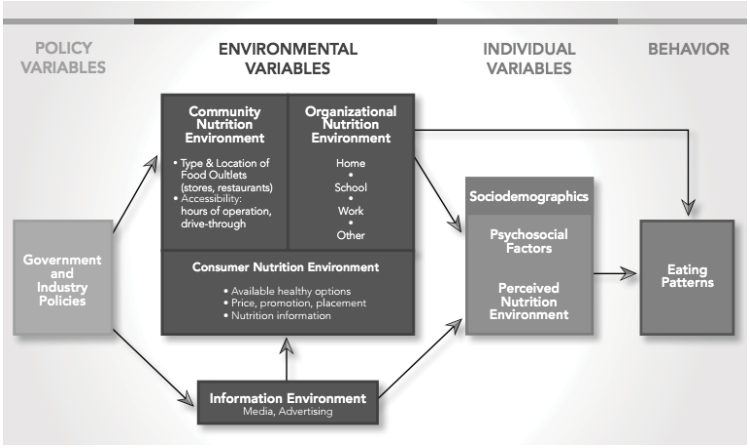


Figure 1.1 An ecological model of community nutrition environments by Glanz et. al., 2005

In addition to social-ecologically inspired frameworks, other typologies for the local food environment have been proposed which focus more specifically on characterising processes by which the food environment might influence diet. Specifically, in a recent review of the food environment five dimensions were used to organise the review including food availability (i.e. adequacy of the food supply), accessibility (i.e. ease of getting to food locations), affordability (i.e. worth relevant to cost of food), acceptability (i.e. people attitudes of their environment) and accommodation (i.e. how well local food sources adapt to needs).[39] Even within these example frameworks and typologies, the multidimensional nature of the food environment as a single area of research and intervention becomes clear.

1.1.2.1 A focus on the built environment and food availability

To improve specificity, and improve our understanding of one aspect of the local food environment, this thesis will focus on local food availability at the community and consumer level (i.e. retail environment). Broadly, food availability at the community and consumer level can be thought of as *what* is sold within the retail setting (i.e. the location and type of outlets and food within those outlets), rather than *how* it is sold (i.e. cost, placement, promotions, labelling within the outlet). Therefore, availability could be considered the *necessary condition* for improving food choice among individuals and populations; if the outlet and food are not physically available, they cannot be chosen.[40] This is in stark contrast to those aspects of the local food environment that may be characterized as *sufficient conditions* for improving food choice. That is, if the price is too great, placement not prominent or promotion of products not applied, or food not acceptable, improving food choice may also be negatively affected.[41]

1.2 Local food availability: definitions, measurement and evidence

As discussed above, research into influences of the local food environment and diet was conceptualised to include a range of environments and contexts that could influence diet behaviour. Depending on the underlying approach, the definitions and typologies vary greatly, which also means that much of the research in the field combines different measures, settings, exposures and outcomes. It is also important to note that many of these characteristics are combined for evidence synthesis, resulting in the combining of factors that do not necessarily address the necessary conditions for food choice, or diet

quality. Therefore, for the purpose of this thesis, local food availability was selected as a fundamental aspect of the broader food environment, presenting the necessary conditions for food choice, separate from the other aspects of the food environment.

1.2.1 Definitions and measurement

Local food availability has been defined as the adequacy of the food supply, particularly the presence, amount and/or density of food sources for an individual. At the community level this often includes the location and type of retail food sources (i.e. food outlets); at the consumer level it includes food provision within a food outlet. Local food availability specified for this work has specific characteristics that are important to clarify related to its classification, potential data sources and measurement.

1.2.1.1 Classification

One of the challenges in food environment research broadly, and food availability research specifically, is the classification of different kinds of food sources. This is particularly relevant for the classification of different types of retail food outlets.

Food outlet classification tends to take one of two valences, type of food outlet (i.e. a market driven classification) and healthfulness of the food outlet (i.e. a research or intervention driven classification). Food outlet types most often include:[42,43]

- Chain supermarkets (large or small): defined as chain self-service grocery stores
- Specialised markets: defined as stores that sell only specific food items including fresh produce or seafood
- Bakeries: defined as stores that primarily sell bread, rolls and muffins
- Convenience stores: defined as self-service grocery stores offering limited line of high convenience items, usually opened for longer hours
- Fast food outlets: defined as nationally recognised chains that sell inexpensive, quickly served foods
- Restaurants: defined as providing sit down food and drink service
- Cafés: defined as coffee and/or sandwich shops

Some research has also used food outlet type to estimate the healthfulness of foods available or purchased at these locations, particularly with supermarkets and markets

representing healthy food outlets; and convenience stores, fast food and restaurants as representing unhealthy food outlets.[44] However, while some tools for examining the healthfulness of supermarkets, grocery stores and convenience stores has been tested with some success[45], similar tools for other food outlets have yet to be used routinely.[46]

Therefore, outlet classification for this thesis will not assume *a priori* healthy and unhealthy valences, but will be based on the similarities of types of food outlets based on their market classification (i.e. fast food, sit down restaurants, etc.).

1.2.1.2 Data sources

Data for the location and type of food outlets and food within outlets is challenging to collect. It is often time consuming and sources of community level data often include local councils who collect details on food providers within their jurisdictions, the yellow pages, or large marketing databases which collect and pool data from several sources, although this can be of questionable quality. However, research conducted in the UK has found these mass administrative food outlet sources (e.g. Ordnance Survey Points of Interest Data) to be reasonably comparable to local council data.[47] In addition, collecting data on within store food availability is similarly challenging and time consuming, requiring trained store auditors to visit each store to evaluate food availability using specific measurement tools, online websites to examine food items, or collecting menu options from the outlet itself or outlet website.[48]

1.2.1.3 Measurement

Current estimates of community level food environment exposure are based on a range of person (e.g. distance, density, mix; focus on home, work, wider activity spaces; and use of global positioning system (GPS) data)[49] and place (e.g. administrative or community boundaries) based metrics. Even though the technology exists to determine the most accurate estimates of food outlet exposure based on where people travel and how much time they spend in particular locations (i.e. GPS units), the participant and financial burden are often too great for widespread use. Therefore, a 'gold standard' of food exposure has not yet been developed for benchmarking and comparative testing against other common metrics that can be applied more broadly. In the UK, usually a density of food outlets within 1 mile of the residents home is considered a meaningful exposure[50], although other distances and boundaries have been used (**Figure 1.2**).

Figure 1.2 An illustration of possible network and buffer based person-centric geographies for community food availability.

Food availability within food outlets is typically measured based upon a basket or audit of shelf-space dedicated to particular foods. For example, the linear shelf space of fruits and vegetables, check lists of different types of food items or full market baskets to capture all food available.[48]

1.2.2 Evidence for food availability, diet and weight status

Observational studies examining local food availability, diet and weight status include a range of exposure and outcome measurements, and study designs. As discussed above, the work for this thesis has focused conceptually on food availability (both community

and consumer), and further refined this aspect of the food environment toward specific measures that can be applied to the availability of retail food outlets open to the general public, such as fast food, sit down restaurants, cafes, supermarkets and convenience stores and the foods they have on offer. Figure 1.3 illustrates the conceptual narrowing and specific types of measures that are the focus of this thesis, which helps to focus the dissertation and reduce the variation in evidence inherent in food environment literature. Specifically, this work is focused on 1) consumer food availability related to specific foods within a retail food outlet (to the exclusion of their price, placement etc.), and 2) person-centric spatial aspects of community food availability (to the exclusion of area-based spatial aspects).

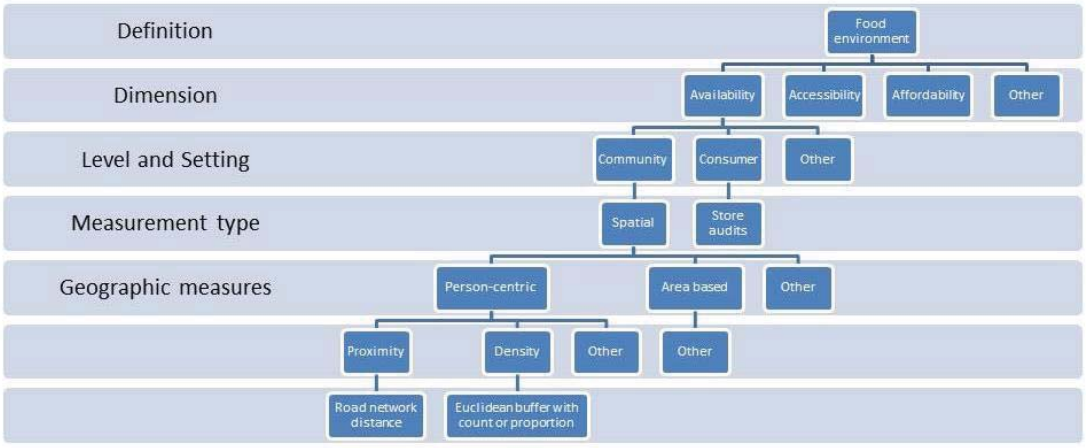


Figure 1.3 Illustration of the dimension and example measures of the food environment that are the focus of this work

For example, there is a great deal of community food environment studies that seek to explore neighbourhood effects, one aspect of the neighbourhood including the neighbourhood food environment.[51] These types of studies are based upon area-based measures that define neighbourhoods using different spatial boundaries and apply the aggregate exposure to all individuals within that given boundary; contrasted with person-centric measures that measure personal exposure within a behaviourally relevant boundary. This thesis is focused on understanding person-centric food environment exposure, rather than aggregate 'neighbourhood' effects. For example, person-centric exposure might include exposure specifically around the home, at the workplace, or along

commuting routes.[52] Similarly, consumer food environment research includes not only availability of food, but factors such as price, placement or promotions.[45] However, these additional characteristics are beyond the scope of this thesis (see 1.1.2.1 for an explanation).

1.2.2.4 Consumer food availability diet and obesity outcomes

Consumer food availability is a challenging food environment to characterise and measure, and report on in evidence synthesis. A recent systematic review examined fifty-six papers between 2000 and 2011 but reported that the results were inconsistent regarding the influence of the consumer food environment, dietary patterns and weight status.[48] The authors discussed the need for improved systematic measurement of food availability within a store, particularly across different store types (e.g. fast food, versus supermarkets or convenience stores). They also stated that improving our understanding of the complexities of the consumer food environment will require additional intervention and longitudinal studies to address the inconsistences in the evidence. For example, one study found a positive association between linear shelf space for vegetables of the closest supermarket, and servings of vegetables per day of residents[53], however other work has found no association between the presence of healthy foods in general[54], or fruits and vegetables in particular[55] at the closest food store and daily servings of fruits and vegetables of local residents.

1.2.2.1 Community food availability and diet and obesity related outcomes

While narrowed considerably (see Figure 1.3 for details) the evidence base for person-centric food availability, diet and obesity still reflects a variety of measures, exposures, outcomes and inconsistent results (**Table 1.1**). For example one study from the US found that greater distance to the nearest supermarket or small food store was associated with a lower in daily fruit and vegetable intake[56], while other work found that greater fresh vegetable availability within 100 meters (m) of the home was associated with higher vegetable intake.[53] Suggesting that the further you need to go for them, the less likely you will be to consume fruit and vegetables. However, a similar study from the UK demonstrated that distance to the nearest supermarket was not significantly associated with neither fruit nor vegetable consumption.[57] Similarly for fast food outlets, one study

Table 1.1 Selection of evidence for person-centric community food availability across different exposure and outcome measures for adults

Author (Year)	Country	Food outlet type	Person-centric geography	Exposure metric	Outcome	Result
Cross-Sectional						
Bodor et al. (2008)[53]	US	Small food store, supermarket	Home address	Distance to nearest, presence; 100 m, 1 km	Fruit servings per day, vegetables servings per day	+ve food availabilty, vegetable servings per day
Moore et al. (2009)[58]	US	Fast food	Home address	Density, 1 mile	Fast food => 1 / week, healthy diet	+ve fast food, -ve healthy diet
Paquet et al. (2010)[59]	CAN	Fast food	Home address	Count, 500 m	Fast food => 1 / week	No association
Pearson et al. (2005)[57]	UK	Supermarket	Home address	Distance to nearest; none	Fruit and vegetables servings per day	No association
Sharkey et al. (2010)[56]	US	Small food store, supermarket	Home address	Distance to nearest; none	Fruit and vegetables servings per day	+ve supermarket or any store with fresh fruit or vegetable
Thornton et al. (2009)[60]	AUS	Fast food	Home address	Density, variety, proximity; 3 km, distance to nearest	Purchase fast food in last month	No association
Cerin et al. (2011)[62]	US	Supermarket, convenience store, fast food	Home address	Count, Proximity; 0.62 miles	Overweight and obesity	No association
Chen et al. (2013)[63]	US	Fast food	Home address	Count; 0.5 miles	BMI	+ve density and BMI
Dubowitz et al. (2012)[61]	US	Supermarket, fast food	Home address	Density, 0.75, 1.5, 3.0 miles	Measured obesity, BMI	+ve density of fast food outlets and obesity , -ve density of supermarkets and obesity
Hickson et al. (2011)[65]	US	Fast food	Home address	Count, 5.0 miles	Measured BMI	No association
Reitzel et al. (2014)[64]	US	Fast food	Home address	Density, proximity; 0.5, 1, 2, 5 miles	Measured BMI	No association for density, +ve proximity and BMI
Burgoine et al. (2014)[68]	UK	Fast food	Home address, commute route, work address	Density; 1.0 mile	Take away food consumption, obesity	+ve consumption, obesity
Dunn et al. (2012)[66]	US	Fast food	Home address	Count; 1.0, 3.0 miles	Fast food consumption, obesity	+ve count, consumption, obesity (non-white only)
Gustafson et al. (2011)[54]	US	Small food store, supermarket	Home address	Presence access from home; < 5 miles (network distance)	Weight, Fruit and vegetable servings per day	+ve presence of supercentre and BMI. –ve supercentre and convenience (combo), fruit and vegetable s/d
Hattori et al. (2013)[67]	US	Supermarket, convenience store, fast food, restaurant	Home address	Count, 1.0, 1.5, 3.0 miles	Diet, overweight, obesity	No association
Jeffery et al. (2006)[69]	US	Fast food, restaurant	Home address, work address	Count, 2.0 miles	Frequency of fast food consumption, BMI	No association
Longitudinal						
Block et al. (2011)[71]	US	Supermarket, convenience, fast food, restaurant, bakery	Home address	Count, proximity; distance (driving) to nearest food store	Change in BMI	-ve with increased distance to closest fast food and decreased BMI (women only)
Boone-Heinonen et al. (2011)[70]	US	Supermarkets, small grocers, fast food	Home address	Density; < 1km, 1.0-3.0km, 3.0-5.0km, 5.0-8.0km	Fast food consumption, fruit and vegetable intake	+ve fast food and consumption

+ve: Positive association, -ve: Negative association, BMI: Body Mass Index, US: United States, UK: United Kingdom, AUS: Australia, CAN: Canada

from the US showed that for every standard deviation increase in fast-food exposure, the odds of consuming fast food near home increased 11%–61% and the odds of a healthy diet decreased 3%–17% (depending on adjustment).[58] Other studies from Canada[59] and the US, however, showed no association between density and proximity of exposure to fast food outlets and fast food purchasing after adjustment.[60]

For studies examining weight status or body mass index (BMI) as an outcome, similar inconsistencies emerge. A study of older women in the US found that an increase in supermarket availability (between top two deciles of exposure) was associated with a decrease in BMI by 0.30 kg/m^2. Conversely, as fast food outlet availability increased (again between top two deciles of exposure), BMI increased by 0.28 kg/m^2.[61] However another study in the US, while finding as association between the number of convenience stores and walking for errands, did not find a main association between food outlets and weight status.[62] In other work, looking at fast food outlet exposure and obesity, researchers found that the number of fast food outlets within 0.5 miles was associated with an increased BMI.[63] Another study in the US found that fast food outlet density at 0.5, 1, and 2 miles was positively associated with BMI, but only among adults with lower incomes.[64] Other work, however, found no consistent associations between population adjusted number of fast food outlets and BMI or waist circumference.[65] Authors of these studies, while reporting methodological limitations, did not report a clear, or consistent, explanation for the range of null findings.

Fewer studies, and no systematic reviews to date, have simultaneously examined diet and weight related outcomes, but those that have also provide a mix of findings. A study in the US found adults with the presence of a supermarket with 1 to 3 miles of their home weighed more than adults without one (2.40kg/m^2), and adults that had both a supermarket and convenience store consumed fewer servings of fruits and vegetables (-1.22servings/day).[54] More availability was not associated with either greater consumption of fast-food meals or a higher obesity risk among a sample of white adults. In contrast, greater availability of fast-food was positively associated with both the number of meals consumed for non-white rural residents and obesity.[66] However, another study in the US found that overall food outlets within walking distance (>=1.0 mile) were not strongly associated with dietary intake or BMI but, for distances greater than 1 mile, findings showed a significant associations between number of supermarkets and BMI.[67] Similarly, studies looking at fast food exposure were also inconsistent with a UK study reporting

that exposure to fast food outlets at home, at work and along commuting routes was positively associated with both an increase in consumption of fast food (5.7 g/day), increased body mass index (1.21 kg/m^2) and odds of obesity (odds ratio 1.80).[68] Other work in the US, however, failed to find any relationships between proximity to fast food outlets and obesity.[69]

1.2.2.2 Longitudinal evidence for community food availability

One suggested explanation for the evidence mix, beyond the use of a variety and quality of data sources, exposure and outcome measures, is the paucity of longitudinal study designs better equipped to account for additional confounding. Very few longitudinal studies have assessed food availability, particularly using person-centric community food availability exposure. One longitudinal study from the US found that greater supermarket availability was generally unrelated to diet quality and fruit and vegetable intake. While fast food availability was related to fast food consumption among low-income respondents, particularly within one to three kilometres of home.[70] Another longitudinal study found that for every kilometre increase in distance to the closest fast-food restaurant, BMI decreased by 0.11 units, but only for women.[71] These studies also reported additional methodological limitations, including the available data to estimate change in food availability exposure over time; however it is too early to draw overall conclusions, and instead highlights the need for additional longitudinal studies.

1.2.3 Addressing inconsistencies in the evidence base

As reviewed above, local food availability (i.e. adequacy of the supply of healthy food within the community and consumer context)[39] has been associated with less healthy diets and increased body weight in adults.[72,73] Overall the synthesis of this evidence remains mixed[40,74], with several systematic reviews conducted on the topic of food environment and diet behaviour[21,39,75–77], without definitive conclusions regarding the effectiveness of various strategies.

To address these inconsistencies, there have been recommendations for observational studies to improve exposure estimates and outcome measurement. Additionally, the reporting of longitudinal study designs is becoming more common. These suggestions are accompanied by calls to improve conceptual and theoretical clarity regarding *how*

availability of food outlets, and within-outlet food options, influence diet behaviour.[32,38] Typically, addressing this gap has led to a focus of systematic reviews of food environment literature to summarise observational studies regarding food environments, diet and obesity[39,78,79], identify food environment interventions and their effectiveness to improve diet or reduce obesity (i.e. small outlet interventions, prepared food outlet interventions)[75,77], synthesise evidence describing different potential strategies (i.e. change in food outlet offerings)[21,76], or focus on the methods used in food environment exposure (e.g. perceived or objective measures) and outcome assessment (e.g. food purchasing or diet quality).[39] However, much of this evidence has yet to result in any satisfying synthesis that can help to better understand inconsistencies in the literature.

1.3 Shifting the empirical paradigm: considering change in food availability as an event within a complex system

Chronic disease epidimiology throughout the latter half of the 20th centery was based upon a 'black box' paradigm, where isolating the relationship between exposure and outcome was the focus of conceptual and methodological development, often to the exclusion of intervening factors or theroetcial pathways of influence.[80] However the demands of moving beyond individual-level determinants toward policies and environments that elicit, maintain and distribute risk factors, such as healthy eating, across the population has brought to the surface several conceptual and methodological challenges for dietary public health.[81–84] Revealed by discordance between the observational and intervention literature, these challenges emerged as the field seeks consistent evidence for the role of food availability in diet and obesity. While the association between food availability and diet may well be null, it is difficult to ignore the positive results that have been found; however equally, null evidence is difficult to account for with methodological weaknesses alone.[49]

The conflicted evidence base could provide an important opportunity to reflect on the foundational assumption upon which this type of preventative research is based. In fact, the lack of suitability of the biomedical model of scientific inquiry for use as the basis for population-level prevention is echoed across the public health field more broadly.[85,86] One novel way to address these challenges, particularly those challenges related to gaps in theory and population level interventions, includes the conceptualisation of change

(intervention) to improve population health as an event within a complex system that stresses the importance of linkages, relationships and feedback loops.[87] To improve our knowledge of *how* food availability influences, diet and obesity, it may be important to consider the role of a broad system of factors, and explore possible methodologies to support the development of complex theories of change.

1.3.1 Complex systems

One of the most striking depictions of complexity, relevant for understanding the determinants of poor diet and obesity, was the Foresight obesity project systems map that reflects 'the sum of all the relevant factors and their interdependencies that determine the condition of obesity for an individual or group of people'.[88] It has been suggested that one of the most important contributions of this map is its use as a heuristic, illustrating the sub-systems and complex set of factors that contribute to dietary intake, physical activity and the development of obesity.[89,90] This suggests that obesity, and one of its primary behavioural risk factors (i.e. poor diet), may best be described as factors or properties of a larger complex system that has 'availability of food' as one potential causal pathway. In fact, population level obesity and diet behaviour has been described as 'the outcome of a complex web of social, cultural, environmental, biological and psychological influences', requiring a fundamental shift in epistemological perspective, away from an understanding guided by simplistic linear causal relationships.[86,90] Therefore, as interventions represent events of change, a change in food availability could be conceptualised as a complex intervention, which is described in the MRC Complex Intervention Framework as containing several interacting components (e.g. density, proximity, shelf space), a number of organisational levels (e.g. community and consumer) and a variety of outcomes (e.g. fruits and vegetable intake, overall diet quality, waist circumference, body mass index).[91]

1.3.2 Theories of change and realism

Given the need to incorporate the complex nature of food availability interventions into future research, a major challenge is to develop more sophisticated theories of change that lead to testable hypotheses and useful guidance for interventions that target both individual and environmental determinants.[92] Existing descriptive frameworks for food availability are often developed at a high level of abstraction (i.e. lack specificity) with limited attention paid toward hypothesizing mechanisms, specific contexts or moderating

influences.[93,94] This suggests that whilst social-ecological frameworks for the food environment expand our view of potential influences of diet behaviour, they often do so without the needed specificity to unpack complex pathways of influence, guide intervention strategy development or help to explain why interventions fail to produce expected effects.[95]

Realist review and synthesis is a method outlined in the Realist And Meta-narrative evidence Syntheses (RAMESES) publication standards[96], a theory-driven approach that holds its foundations in realist philosophy of science (Table 1.2).[97] The approach inherently provides a focus for understanding causation. Specifically, how causal mechanisms are shaped and/or constrained by a broader multi-levelled and complex context has yet to be applied to the topic of interventions to change local food availability. Although several systematic reviews have been conducted on the topic of food environment and diet behaviour[21,39,75–77], their conclusions regarding the effectiveness of various strategies are not definitive.

Table 1.2 A comparison between realist and positivist (i.e. traditional) approaches

Positivist approach	Realist approach
Causation and strength of evidence	
Logic of aggregation ‘to group’	Logic of configuration ‘to configure’
Causation is examined as A – B, consist in effect	Causation is theorised as Context + Mechanism = Outcome, variable in effect
Strength of evidence is replication of effect	Strength of evidence is reasoned logic
‘Did it work’, sometimes ‘For whom’	‘How, for who, under what circumstances and why’
Literature review and synthesis methods	
Linear strategy	Iterative strategy
Appraisal of methodological quality	Appraisal of relevance and available data
Data is numerical	Data can be both numerical and textual
Data includes formal research results (peer-review, outcome assessment)	Data includes formal results with other grey literature or expert input for additional context
Mode of synthesis is statistical	Mode of synthesis is narrative

One reason for this gap may be the most common synthesis method used to examine a range of heterogeneous food environment interventions. The focus of systematic reviews of food environment literature to date has been to summarise observational studies regarding neighbourhood food environments, diet and obesity[39,78,79], to identify food environment interventions and their effectiveness to improve diet or reduce obesity (i.e. small outlet interventions, prepared food outlet interventions)[75,77], to synthesize evidence describing different potential strategies (i.e. change in food outlet offerings)[21,76], or to focus on the methods used in food exposure and outcome assessment (i.e. food purchasing or diet quality).[39]

In addition, these reviews do not conceptually differentiate between different types of food environments, specifically studies focused on intervention strategies that target issues of availability and accessibility at both the community and consumer level (i.e. location of a food outlet with respect to where people live versus the food sold by an outlet). Typically, the latter intervention strategies do not necessarily target *what* food is sold but rather *how* food is sold including the use of promotions, placement or point of purchase information. However, both types of intervention strategies are often reviewed together, or in some cases the intervention itself makes use of these strategies simultaneously e.g., a premade food outlet intervention that introduces point of purchase information and additional healthy offerings), making the determination of relative contribution of different strategies, their potential interactions, or even the hypothesized mechanisms of influence, challenging to tease apart.

While it is necessary to summarize intervention strategies, examine effectiveness and critically evaluate methods, the complex nature of food environment interventions (and their direct relevance to healthy public policy) may require examination of the current evidence base from a new perspective. Employing a research synthesis capable of dealing with greater complexity, with a focus on *how, for whom and under what conditions* food availability interventions exert their hypothesized effects, could provide an opportunity for new insights. Realist synthesis is about building up a picture of how various combinations of such contexts and circumstance can amplify or mute the fidelity of an intervention theory, with some suggesting that explanations for the mixed evidence, particularly among complex interventions, often focuses on empirical methodological quality, to the exclusion of ensuring the development and use of sound theories that are

explicitly defined and testable.[98] Therefore it is important to develop and test a complex theory of local food availability diet and obesity to guide targeted empirical work.

1.4 Purpose and summary of thesis chapters

Local food availability, defined as the combination of the community and consumer food environments, is a necessary condition for improving diet quality and reducing chronic disease risk at the population level. However, *how* local food availability exerts an influence on diet and obesity remains poorly understood. Therefore, the study described in chapter 2 reports on a systematic review and realist synthesis that was used to generate a complex theory of change for food availability, diet and obesity. Theory development was designed to not be restricted by available data, but rather to be congruent with the context of complex public health intervention outlined in chapter 1. This involved integration of tacit knowledge from an expert panel with published literature related to food availability interventions. After theory development, it became clear that comprehensive testing would not be possible given the complexity, and a lack of appropriate data. In order to begin testing aspects of the complex theory, and to apply this testing to food availability with links to poor diet quality, a focus on away-from-home eating was used to explore two important mechanisms of influence in the theory. Specifically, these mechanisms represented outlet adoption (i.e. the selection or usage of a food outlet) and outlet exposure (i.e. the density of food outlets surrounding the home). Unfortunately not all important mechanisms could be explored, for example food exposure (i.e. the food availability within a food outlet), was not tested empirically but would be important in future work.

The study described in chapter 3 examines the adoption (i.e. use) of different away-from-home food outlets (i.e. fast food, restaurant and café), diet quality and obesity in a cross-sectional study of adults from the National Diet and Nutrition Survey. Next, given the potential importance of density of food outlets as a more distal mechanism along a pathway for food choice, the study described in chapter 4 examines density of away-from-home food outlets around residents' homes, food spending and obesity in a cross-sectional spatial study of adults from the first wave of the UK Household Longitudinal Study (UKHLS).

With the limitations of cross-sectional analyses to examine change in away-from-home food availability and outcomes, the study described in chapter 5 includes preliminary longitudinal analysis using adults from five waves of the UKHLS study to explore the utility of residential relocation as a means of examining the effect of change in exposure of food outlets on diet and obesity. An overall discussion is then presented in chapter 6, including reflection on both theory development and testing, and an overview of limitations and conclusions with supplementary material and glossary of terms in the appendices.

2 Development of a complex theory for food availability, diet and obesity

The protocol for this work was published as: Penney TL, Brown HE, Maguire E, Kuhn I, Monsivais P. (2015) *Local food environment interventions to improve healthy food choice in adults: a systematic realist synthesis protocol*. BMJ Open. 5(4) IF: 2.063, and presented as: Penney TL, Brown HE, Maguire E, Monsivais P. (2015) *Local food environment interventions to improve diet in adults: using a systematic search and realist synthesis to address the program theory gap*. International Society for Behavioral Nutrition and Physical Activity. June 2015; and accepted as Penney TL, Brown HE, Winpenny E, Maguire E, Adams J, Burgoine T, White M, Monsivais P (2017). *Development of a complex theory for local food availability interventions to improve diet and reduce obesity: a realist approach*. "We need to talk about complexity" Workshop, University of Oxford. June 2017. The final manuscript is in preparation.

2.1 Abstract

Background: Local food availability has been associated with less healthy diets and increased obesity in adults. Overall, observational evidence remains mixed, with several interventions reporting a lack of effectiveness, generating questions regarding the causal mechanisms underlying observational associations. Therefore, the purpose of this study

was to develop a theory of change to explore *how* local food availability might influence diet for the prevention of obesity and use literature from local food availability interventions to conceptually explore the theory of change.

Methods: A realist inspired concept mapping process using an expert panel was done to develop a complex theory of local food availability, diet and obesity. This was followed by a systematic search of the literature using independent screening based on study criteria (target population age 19-65 years, retail setting available to the general public, change in food availability via the introduction or limitation of new food stores or food items, measure of diet behaviour), and quality assessment using the Effective Public Health Practice Project tool. Coding and mapping of local food availability intervention literature, based upon emerging context, mechanism and outcome configurations to visualise tested and hypothesized pathways was completed. The review and synthesis was guided by the Realist And Meta-narrative evidence Syntheses: Evolving Standards publication standards, including scoping, transparent appraisal, synthesis, and drawing conclusions via consensus.

Results: The theory of change represents three different, but interrelated pathways of influence to describing the causal influence of food availability on diet and obesity; each pathway shows multiple levels of context converging on theorised mechanisms of action important to resulting dietary outcome patterns. The literature mapping demonstrates tested and hypothesised context, mechanism and outcome configurations from current local food availability interventions.

Conclusions: With the paucity of empirically-supported theories of change used in current local food availability interventions, this synthesis may be used to ground current observational and future intervention research, and allow for more sophisticated hypothesis involving how, for whom and under what circumstances these interventions may or may not work.

2.2 Introduction

Healthy diets are a critical component for the prevention of chronic diseases including cardiovascular disease[2–4], diabetes[5], certain types of cancer[6] and conditions such as overweight and obesity.[7,8] As a result, governments are seeking actionable evidence to

improve food choice across whole populations, propelling a shift in focus from individual level determinants to policies and environments that elicit, maintain and distribute risk factors across the population.[24–29] Factors beyond the individual have subsequently been posited within different social-ecological, or multi-levelled, frameworks that attempt to describe the totality of the food environment. These include conceptualisation of different settings like the home (i.e. food available in the home purchased elsewhere), the workplace (i.e. food sources at or near the workplace), the community (i.e. availability and accessibility of outlets in the neighbourhood or while travelling), or consumer outlets (i.e. availability of foods, prices and promotions within an outlet), information and media, or policy.[37,38,94,99–105]

While helpful as a method to provide scope to an emerging field and describe concepts and settings relevant for food environment research and intervention; the matter of *how* these concentric factors influence diet behaviour raises several conceptual and methodological challenges for existing frameworks.[81,84] Principle among these is the need to transform descriptive frameworks into theories of change that can accommodate the inevitable complexities that emerge within and between hypothesized pathways; and to *coherently integrate* a range of factors at the intrapersonal, interpersonal, institutional, community, and public policy levels that are grounded around a meaningful dietary public health intervention (i.e. an intervention that addresses the structural determinants of diet and health, rather than individual determinants).[34,35]

Therefore, the primary objective was to develop a theory of food availability to address the following questions: 1) how could a change in food availability influence diet? 2) for whom could a change in food availability influence diet? and 3) under what circumstances could a change in food availability influence diet? The secondary objective was to map relevant content from published local food availability intervention literature onto the theory. This provided the opportunity to reflect on the theory and consider possible explanations for the discordance within observational and intervention evidence.

2.3 Methods

The review protocol was registered with the International Prospective Register for Systematic Reviews (PROSPERO) CRD42014009808; the full protocol was published

prior to the review but is repeated here for completeness.[106] For the objectives of this work, a change in food availability was conceptualised as an event that occurs within a larger complex system. Therefore the methodology employed to create a complex theory of change (i.e. a causal map), with a focus on contexts and mechanisms of interest, was inspired by the methods of realist review and synthesis describe in the Realist And Meta-narrative evidence Syntheses (RAMESES) publication standards[96], a theory-driven approach that holds its foundations in realist philosophy of science.[97] The approach inherently provides focus on understanding causation and how causal mechanisms are shaped and/or constrained by a broader multi-levelled context. While this approach is typically applied to researcher- or practitioner-driven interventions, where strategies are developed and implemented by a team, we are applying it to the area of non-researcher led interventions that are sometimes policy driven (i.e. community food availability), and therefore not typically theorised explicitly prior to implementation. This approach provided the framework for two stages of this review and synthesis. The first involved the development of a realist inspired theory of change using an expert panel, and the second involved a systematic search for intervention studies to use as the basis of the realist synthesis and mapping.

2.3.1 Developing the theory of change

Theory development was grounded in the realist philosophy of science, specifically by conceptualising causal influence as a complex, context dependant phenomenon. Therefore, to facilitate theory development a workshop was organised where the realist philosophy, and the review and synthesis method was presented to attendees in advance of the specific exercised to develop the theory.

2.3.1.1 Concept mapping using nominal group method for generation and structuring theory

The theory was developed in two phases, utilising the tacit knowledge of the study team which included a group of public health scientists from the Centre for Diet and Activity Research, University of Cambridge with an interest in dietary public health. While the study team has common research interests, they reflect a range of expertise including psychology, geography, medicine and political science with research interests in

inequalities in diet, neighbourhood food access, and dietary public health intervention and evaluation.

The two phases were modelled after the first two steps in the concept mapping process[107], and included:

- Generation: a participatory step where the group addresses the focal question and generates a collection of items that will be used in subsequent analysis. Focal questions are designed to elicit information to address the primary research questions. Most often, data are obtained through open processes such as 'brain storming' sessions.
- Structuring: participants organise the list of generated items. They sort them into piles based on their perceived similarities or relationship to one another. Then each item is rated in terms of its importance or usefulness to the research question.

The first phase involved a workshop utilising a nominal group method[108] and methods employed in other research on health behaviour[109,110] to seek expert knowledge from the entire study team (i.e. generation).

The generation of different aspects of the system map were guided by questions such as:

- What factors are involved in changing food availability?
- What factors are likely contextual? Mechanisms?
- Why would food availability change diets? Why would it not?
    - What are possible pathways?
    - What might stop this from occurring or influence this effect?
- Who is likely to be affected differently by food availability? Why?
- What might change as the result of a change in food availability?

During the workshop, the study team brainstormed factors that might explain how a change in local food availability could affect food choice, and explored potential pathways of influence. The content was collected from the study team by their sharing known evidence related to the generation questions above, and observations from experiences conducting research in the field. The purpose was to generate as many factors and ideas as possible. Therefore, the study team was discouraged from reflecting critically on their contributions and reminded that critical assessment of these factors and

their relationships would occur during the next phase. During the workshop, factors that were generated were captured and loosely categorised (e.g. social or economic) and recorded by TLP along with field notes.

The second phase involved face-to-face meetings with each team member to structure and refine aspects of the initial theory of change (i.e. structuring).[107] Using field notes, the initial theory was created by assembling the factors, pathways, mechanisms and contexts discussed during the workshop, and then combined into a single diagram. This initial theory was then used as the basis for the face-to-face meetings between TLP and each member of the team, tracking the evolving configuration of the initial theory of change with each meeting. Each group member had the opportunity to provide new factors or question pathways with revisions integrated by TLP through discussions until consensus was reached.

2.3.2 Systematic search for local food availability intervention literature

In order to ensure the identification of relevant interventions, a systematic search was undertaken. This included a scoping stage that influenced the overall search strategy, followed by identification and screening of articles. This method deviated from traditional systematic reviewing in two primary ways. First, the scoping stage and the ability to refine the research questions as a result of the scoping search, and secondly the use of related intervention literature found using hand searching. This was done to maximise contextual details that are often not published as part of the primary evaluation paper.

2.3.2.1 Scoping stage

Given the complexity of the food environment intervention literature, scoping for this work helped further clarify the conceptualisation of food environment interventions that were the focus of the review and develop specific criteria. Using an initial snowball search of five review articles that focused on interventions in a range of settings was done[21,39,75–77], forming the basis of the search strategy.

2.3.2.2 Identification and screening of articles

A final systematic search strategy was conducted by a medical librarian and resulting literature was de-duplicated and exported to Endnote X7.2. The following databases were searched for articles published up to and including July 2014 with no limit on earliest year of publication; MEDLINE (Ovid SP), EMBASE (Ovid SP), PsychINFO (Ovid SP), EconLit (EBSCO), Applied Social Sciences Index and Abstracts (CSA Illumina) and Cochrane Database of Systematic Reviews (Wiley Online Library). The search strategy was common across databases (**chapter 2 appendix**).

A particular tenet of the realist synthesis approach is the inclusion of a range of evidence sources and an emphasis on an iterative search processes. Therefore, in addition to the screening for peer-reviewed outcome evaluations for interventions, hand searching was conducted for each intervention selected to identify a selection of 1) peer review publications that were secondary to the outcome evaluation including process evaluations, 2) secondary data analysis of intervention samples, and 3) final project reports or short articles discussing the context of the intervention being conducted.

All retrieved titles and abstracts were screened by the primary author (TLP), and relevant items duplicate screened by another author (ERM) with discrepancy in inclusion or exclusion resolved through consensus. Full text versions of selected articles from both the systematic and hand searching were obtained, and inclusion and exclusion criteria assessed (following a similar procedure as for titles and abstracts; duplicate screening and consensus discussion between TLP and ERM with disputes settled by a third author (HEB)).

2.3.2.3 Eligibility and quality assessment of articles

Primary intervention studies were screened for inclusion based on 1) the aim to improve diet through a change in the availability of outlets (i.e. the opening or removal of an outlet) or the availability of foods in outlets (i.e. new food items in an outlet); 2) included food outlets that did not have restriction of use including convenience outlets, small food outlets, grocery outlets, take away outlets or full service sit-down restaurants; 3) included adults aged >= 19 years at baseline; 4) reported on results from a measure of diet alone (i.e. diet quality or food purchasing), or diet and a measure of obesity (i.e. body mass index); and 5) had been published in a peer-reviewed journal or grey literature sources

(i.e. websites or programme reports) up to and including July 2014. Study designs could include randomised controlled trials, comparison trials and/or quasi-experimental studies. Interventions that *did not* report a measure of diet as the primary measure, but include a measure of body mass index alone were excluded. Studies of adults that represented special populations (including pregnant woman or clinical populations) were also excluded. Any interventions that examined aspects of the food environment in the absence of a change in food provision within a neighbourhood or an outlet were excluded as diet was the primary outcome (i.e. risk factor for obesity and chronic disease) of interest. These exclusion criteria were used to ensure results were congruent with the review objectives.

To enable reflection upon the quality of the evaluation (rather than as criteria for the exclusion of studies), quality assessment was conducted by the lead author (TLP) using the Effective Public Health Practice Project (EPHPP) Quality Assessment Tool for Quantitative Studies; this was duplicated by an additional author (ERM) and consensus reached. The EPHPP tool rates studies as 'strong', 'moderate' or 'weak' using six scales (selection bias, study design, confounders, blinding, data collection methods, and withdrawals and drop-outs). Studies are then rated to give an aggregate overall score of 'strong', 'moderate' or 'weak' ('strong' if no 'weak' individual-scale ratings are designated, 'moderate' if one, and 'weak' if two or more). The tool has been recommended for use in assessing public health interventions based on acceptable content and construct validity[111] and the results were reported for each of the primary intervention studies. Quality assessment of additional peer-reviewed process evaluation studies or grey literature articles were not undertaken, as these studies were used primarily as contextual details in the realist synthesis.

Summary data, regarding study participants, intervention setting and characteristics, and outcomes, were extracted by the primary author (TLP), and checked for accuracy by another author (ERM). Discrepancies were resolved through consensus discussion.

2.3.3 Mapping intervention related literature and realist synthesis

The purpose of mapping intervention literature was to provide an opportunity to reflect on the theory of change, to look for missing aspects from the concept mapping process, to identify implicit theories of change of the included interventions (i.e. those that have been

tested) and to examine the scope of hypothesized contexts or mechanisms that were not included in evaluation studies (i.e. factors or pathways that have been discussed or hypothesised). The process involved two stages, firstly reviewing and coding each paper for aspects of the theory that were tested or discussed, or to identify other factors that were not uncovered during the workshop. Secondly, the process involved mapping the resulting codes onto the theory of change to visually reflect aspects of the theory that were tested or hypothesised in published intervention literature.

2.3.3.1 Coding intervention and companion papers

In addition to the inclusion criteria used for the systematic search, the included studies were selected based upon the principles of 'relevance' (i.e. whether the data can contribute to theory building) and 'rigour' (i.e. whether the method used to generate the data is credible and trustworthy).[96] The purpose was to ensure as much contextual data as possible for the coding of intervention related papers, as this review was focused on the circumstances of the interventions and how they might work, rather than their effectiveness. To this end, each paper was considered a source of qualitative data that was analysed for reporting ‘how local food availability might influence food choice’, ‘for whom’ and ‘under what circumstances’. As a consequence, while the entire publication was read and coded, most codes were applied in the introduction and discussion sections of the papers where authors provided most of the context and any implicit theory of change. The reason for this coding approach, rather than simply summarising the contents of the papers in a narrative style review, was to allow for tracking the different aspects of the theory that were discussed in the article, and informing the synthesis (i.e. combining in a meaningful way) and mapping (i.e. adding what was found onto the theory diagram) that followed.

The qualitative data were coded from primary (i.e. outcome evaluation study) and secondary (i.e. process evaluation or other published work) intervention study publications using Atlas.ti qualitative analysis software (first by one author (TLP); and then reviewed by a second and third author (HEB and ERM)). Coding was guided by the initial theory and the review questions of how food environment interventions work, for whom and under what conditions, with the purpose of exploring data on context, mechanisms and outcome configurations, and patterns. Distinctions in coding were made between realist informed contextual or mechanistic aspects of the theory that were *tested*

(typically, reported in the results section of outcome evaluations) by the interventions versus those that were *hypothesised* (typically reported in the discussion section or in secondary papers).

2.3.3.2 Synthesis and mapping

Data synthesis involved examining the codebook and comparing with the existing theory of change. Codes were assigned to represent an implicit theory of change or different contextual or mechanistic factors described by authors. These codes were then reinterpreted to describe a context, mechanism and outcome pattern. For example – throughout an article the authors may mention the presence of a new supermarket in a low income community (identified as 'outlet exposure' in the theory – a mechanism), with a proliferation of fast food outlets (identified as 'density of outlets' in the theory – a context), and that the intervention did not implement a strategy to announce the new supermarket to encourage its use (identified as 'outlet adoption' in the theory – a mechanism) providing a possible explanation as to why the new supermarket did not impact the diet of residents (identified as 'food choice' – an outcome).

This was done iteratively and checked between three authors (TLP, HEB and EM) reviewing and coding the literature, reflecting on the different codes and what they described, comparing the theory of change and reviewing additional codes. Context, mechanism, outcome codes and combinations that created a configuration were then classified into tested (represented using a solid line in the theory diagram) and hypothesized codes (represented using a dotted line in the theory diagram) and cross-referenced against the theory of change developed by the study team. A code that represented either one factor or pathway (several factors in a chain) was highlighted on the diagram. All aspects of the theory that were not reflected in coding were 'greyed out' on the theory. Also, no additional factors were found in the intervention literature beyond those identified during the workshop.

2.4 Results

The findings are divided into two sections, first the outcome of the theory development; second the outcome of the systematic review for food availability interventions and their mapping onto the initially developed theory of change.

2.4.1 Theory of change for food availability, diet an obesity

The initial theory of change covers a broad range of contextual factors and mechanisms. These aspects of the theory clustered into three possible interrelated 'pathways' of causal influence and suggested a cyclical system of reinforcement between exposure to, adoption of and preference for particular foods and food outlets by adults in population (**Figure 2.1**).

Across these pathways, six possible mechanisms were identified, for which multiple levels of context represent precursors to the triggering of these mechanisms and therefore, a theorised change in food choice. These can be summarised as including concentric contextual factors, leading toward mechanisms across three conceptually different, but interrelated, pathways:

Exposure: this pathway was theorised to include all the contextual factors involved in the activity patterns of people that provide individuals an opportunity to select either a particular food outlet, or food within an outlet. These factors begin distally with the location of residence, work and leisure; the travel mode and infrastructure; followed by the existing mix of different outlet types and density of those outlets that provides a set of opportunities, or a *food outlet exposure* that people can select from. In addition, there is a set of contextual factors that may influence the location of food outlets (e.g. local zoning laws, consumer demand for particular foods, and shopping patterns) determining the mix and density of certain types of food outlets in which people are exposed. Food outlet exposure, is then followed by a repeating set of contextual factors, including the food within the outlet that may be influenced by the profit margin of the food outlet, the food supply network available to that outlet and the customer demand to be met by the food outlet, combining to trigger the type and amount of *food exposure* within an outlet that could (when coupled with in store sufficient conditions such as price, placement etc.) lead to food choice.

Adoption: this pathway was theorised to interrelate with, but operate separately from, exposure. Context for this pathway begins with the walkability of the area where outlets exist, and distance to the outlet could trigger a need for *convenience* within the individual. If the individual is aware of a convenient outlet and intends to purchase food at that location, they *adopt the outlet*. Once selected, that outlet, again depending on the drivers

of food exposure and a need for convenience, is faced with foods in the outlet resulting in food choice.

Preference: this pathway includes a set of contextual factors that again include a causal pathway with a starting point distal from food choice. While the colloquial term 'preference' gives a suggestion of pure agency, this pathway also includes needs that may be outside of the direct control of the individual but shape their preferences (e.g. deprivation or time sensitivity). Starting with level of deprivation and exposure to media and advertising to shape social norms; knowledge, skills, attitudes and appetite could influence *food preferences*. In turn, food preferences can then influence exposure by driving the individual toward a travel route and/or shape a shopping pattern that leads to a particular food outlet. However, food preferences can also influence *outlet* preferences depending on needs or preferences for food cost, variety, quality or tastes. This can help shape food *outlet preferences* that again drive people toward a route and give rise to a shopping pattern and therefore feed into the exposure pathway. Tangential to the interrelationship between preferences, needs and exposure is the influence of level of deprivation on time sensitivity, which can then influence a need for convenience. Additionally, once preferences (either outlet or food) drive people toward a food outlet, or particular food choices, the experience of that selection then proves either a reinforcing or disruptive loop with preferences and needs, exposure and adoption that again influence food choice patterns.

Outcome: Food choice, although conceptualised as an outcome for this work, was challenging to identify as a static outcome. That is, when applying a time dimension, arriving at *food choice* as the outcome would then change from an outcome to the context for the shopping experience. If it was a positive shopping experience, this may indicate the beginning or reinforcement of a particular food preference that influences a pattern of travel with exposure to outlets and foods, with similar needs for convenience, resulting in the same food choice in the future. Similarly, if it was a negative experience, this could mean the disruption of any habitual food choices and preceding contexts and mechanistic triggers – leading back to *food choice*.

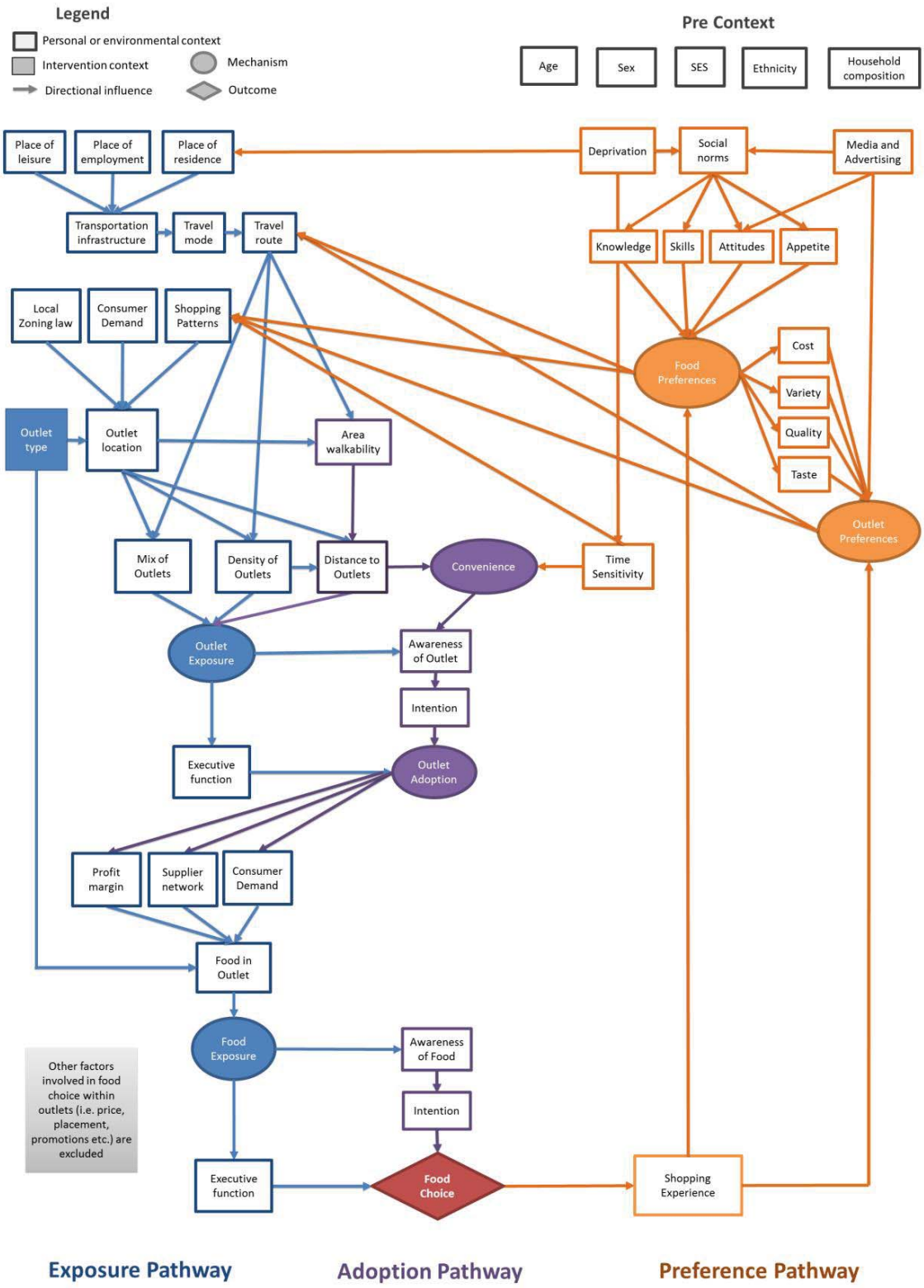


Figure 2.1 Theory of change based on concept mapping and expert panel

Pre-context: It is also recognised that individuals arrive at an intervention with a certain set of characteristics, or demographic factors that are not modifiable by the intervention. These are labelled as pre-context, meaning prior to the circumstances surrounding the intervention. These are likely intervention modifiers and include age, sex, socio-economic position, ethnicity and household composition.

It is also noted in this theory, that a range of other factors – particularly those that make up the environment within a food outlet have not been included in the theory. These could include specific food prices, food promotions and the placement of foods. However, with the focus on effects of the necessary conditions (i.e. effect of food availability on food choice), these are not included in the theory of change, which represents only aspects directly related to food availability of outlets and specific foods within an outlet (i.e. necessary condition), but not other sufficient conditions required for food choice.

2.4.2 Intervention characteristics

Figure 2.2 provides the results of the systematic search for intervention literature and hand searching for related articles. Six interventions met inclusion criteria with an additional 18 articles identified as providing additional context to the primary evaluations. The majority (n=3) included evaluations of a new supermarket opening in a neighbourhood with high levels of deprivation and limited access to supermarkets, namely Pennsylvania Fresh Food Financing Initiative (PFFF)[112], Leeds retail intervention (LIR)[113] and Glasgow Supermarket (GSM)[114]; one included a mobile food vending van with affordable fruits and vegetables in a communities with the greatest need, namely Mobile Food Store (MFS)[115], two included within-store interventions where improving food provision was one strategy among a range of other in-store strategies (e.g. signage or food placement), namely Baltimore Health Stores (BHS)[116] and Baltimore Healthy Carry-outs (BHC)[117].

Table 2.1 provides an overview of included studies and intervention effects. Local food availability was changed using two community-level intervention strategies (i.e. supermarket opening in neighbourhood and a mobile food store) across four of the included interventions (PFFF, LIR, MFS and GSM), and two consumer-level intervention

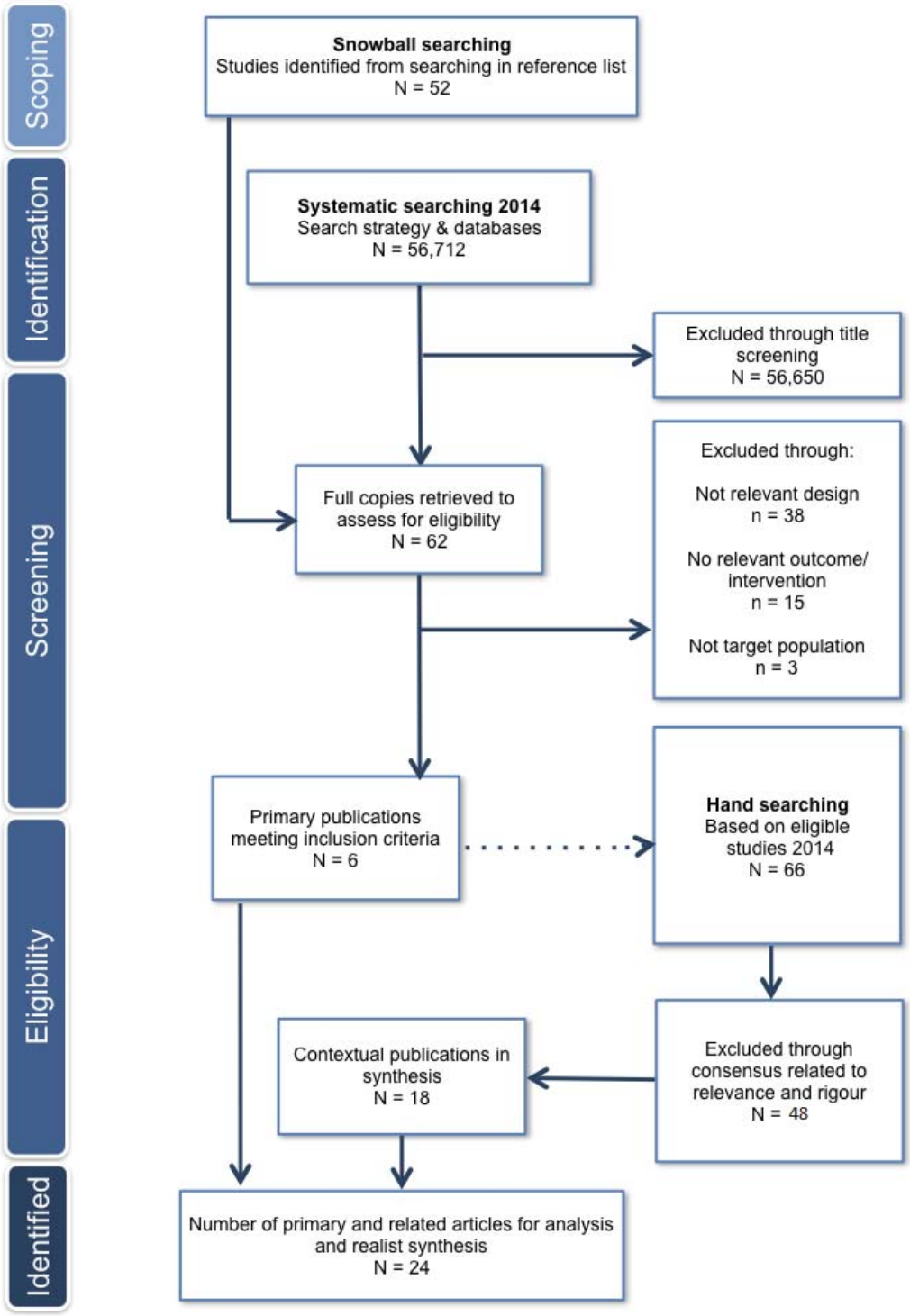


Figure 2.2 PRISMA flow chart including scoping and hand searching for contextual papers

Table 2.1 Summary table for extracted data from included intervention studies

Food outlet type and level	**Intervention Name** (primary citation)	**No. Context papers** (citations)	**Country, Year**	**Design** (evaluation design)	**Sample** (for primary analysis)	**Diet or body mass index (BMI) measure**	**Intervention strategy**	**Diet Outcome**	**EPHPP Score** (Global)[a]
Supermarket									
Community	Pennsylvania Fresh Food Financing Initiative (PFFF)[112]	2 [265,266]	United States, 2014	Controlled 2 group pre-post	625 (331 control, 294 intervention)	Total daily fruit and vegetable intake	Supermarket opening in neighbourhood	-0.05 daily fruit and vegetable intake in intervention group – not significant	2
	Leeds retail intervention (LIR)[113]	4 [267–270]	United Kingdom, 2003	Pre-post	615	7 day food diary	Supermarket opening in neighbourhood	Increase of 2.88 to 2.92 servings of fruits and vegetables – not significant	3
	Mobile Food Store (MFS) [115]	0	United Kingdom, 2012	Pre-post	255	Frequency of fruit and vegetables	Mobile food store arrive in community, selling affordable fruit and vegetable	Increase of 1.2 portions of fruit and vegetable per day - significant	3
	Glasgow Supermarket (GSM) [114]	3 [271–273]	United Kingdom, 2005	Controlled 2 group pre-post	412 (221 comparison, 191 intervention)	Daily fruit and vegetable consumption	Supermarket opening in neighbourhood	Increase 0.12 to 0.35 portions of fruit and vegetable per day – not significant	1
Convenience									
Consumer	Baltimore Health Stores (BHS) [116]	5 [118,274–277]	United States, 2010	Controlled 2 group pre-post	84	Store sale data	Multicomponent intervention including incentives for store owners to stock healthy foods	Specific effects of incentives to stock healthy foods not reported	3
	Baltimore Healthy Carry-outs (BHC) [117]	4 [278–281]	United States, 2013	Controlled 2 group pre-post	Not clear	Sales receipts	Multicomponent intervention including healthy sides and beverages	4.5 types of healthy items purchase in intervention stores, less than 1 healthy item purchased in comparison stores – significance unclear	2

[a] Modified global quality score: 1 = strong; 2 = moderate; 3 = weak (see supplementary material for score break down).

strategies (i.e. incentives for store owners to stock healthy foods in a convenience store and providing healthy sides at carry-outs) across the two remaining interventions (BHS and BHC). Of the six interventions, the MFS found a significant increase in 1.2 portions of fruit and vegetable intake per day post intervention[115], while PFFF[112], LIR[113] and GSM[114] interventions found no significant effects and BHS[116] and BHC[117] did not discern significant effects. All evaluations used a controlled (n=4) or uncontrolled (n=2) pre-post design from the USA and the UK. One intervention had no additional articles (MFS), with 2-5 relevant contextual papers for each of the remaining interventions. These papers provided a range of insights into intervention context. For example, the BHS process evaluation for a change in healthy offerings in a convenience store suggested that storeowners were very hesitant to change offerings if they conflicted with perceived consumer preferences, regardless of reimbursement during the intervention phase.[118] Study quality showed that half (n=3) studies were deemed 'weak', two 'moderate' and one 'strong', with the greatest challenges to quality including selection bias, confounding and participant drop-out (**chapter 2 appendix** for quality score breakdown).

Table 2.2 provides additional details of the intervention samples. The community level interventions included middle aged adults (40s or 50s depending on evaluation), disproportionally female (60-81% depending on evaluation), that tended to be ethnic minority populations with young children. In addition, most communities where interventions were conducted included different indicators of deprivation, including income, level of education or employment status. The specific indicators varied by intervention (see specific indicator in the Table 2.2), but consistently reflected communities with populations at the lower end of the income scale, with a lack of higher education and employment.

2.4.3 Mapping intervention related literature

These interventions displayed a surprising amount of consistency with regard to the tested context, mechanism and outcome configuration when mapped against the initial theory of change at the community level (inserting a supermarket in an area with limited access to healthy foods). Although the intervention strategies used at the consumer (i.e. store) level

Table 2.2 Personal characteristics of participants for primary intervention studies (where applicable)

Food outlet type and level	**Intervention Name** (primary citation)	**Country**	**Age** mean (sd)	**Sex** female n (%)	**SES** e.g. income, education, employment or other n (%) or % (where marked)	**Overall or other details**
Supermarket						
Community	Pennsylvania Fresh Food Financing Initiative (PFFF)[112]	United States, 2014	52.7, (14) control, 54.2 (16) intervention	229 (78) control, 267 (81) intervention	199 (60) control, 195 (66) intervention income <$40,000; 288 (87) control, 249 (85) intervention high school graduate; 160 (48) control, 131 (45) intervention employed	Mostly female, black, high school graduates, and either unemployed or economically inactive, with annual household income <$40,000.
	Leeds retail intervention (LIR)[113]	United Kingdom, 2003	not reported, largest group 54-64 and 35-44	517 female	101 (16.4) income < 50,00, 80 (13.0) income >= 20,000; 441 (71.7) GCSE or below, 116 (18.9) work full time, 171 (27.8) retired	Female, 45-64, retired or homemaker, children under 16 in household, GCSE or below, household income between 5 and 10,000, on benefits more than one year, renting, own car.
	Mobile Food Store (MFS) [115]	United Kingdom, 2012	not reported, largest group 35-54 and 65+	200 (78.4) female	Employment status, work and no benefits 16.5%, Index of multiple deprivation: Most deprived (41.8%, 29.7%, 42.1%, 2.2%, 2.2%) least deprived	Female over the age of 55, high levels of deprivation.
	Glasgow Supermarket (GSM) [114]	United Kingdom, 2005	not reported, largest group 45-54 and 65+	142 (64) control; 113 (59) intervention	251 not employed, 38 missing; 162 standard grade, 138 work based, 80 missing	Mostly female over age of 45, unemployed with standard grade education.
Convenience						
Consumer	Baltimore Health Stores (BHS) [116]	United States, 2010	Not reported	Not reported	Not reported	Not reported
	Baltimore Healthy Carry-outs (BHC) [117]	United States, 2013	Not reported	Not reported	Not reported	Not reported

varied greatly, again the context, mechanism and outcome configuration mapped similarly onto the theory shown in solid lines (**Figure 2.3**).

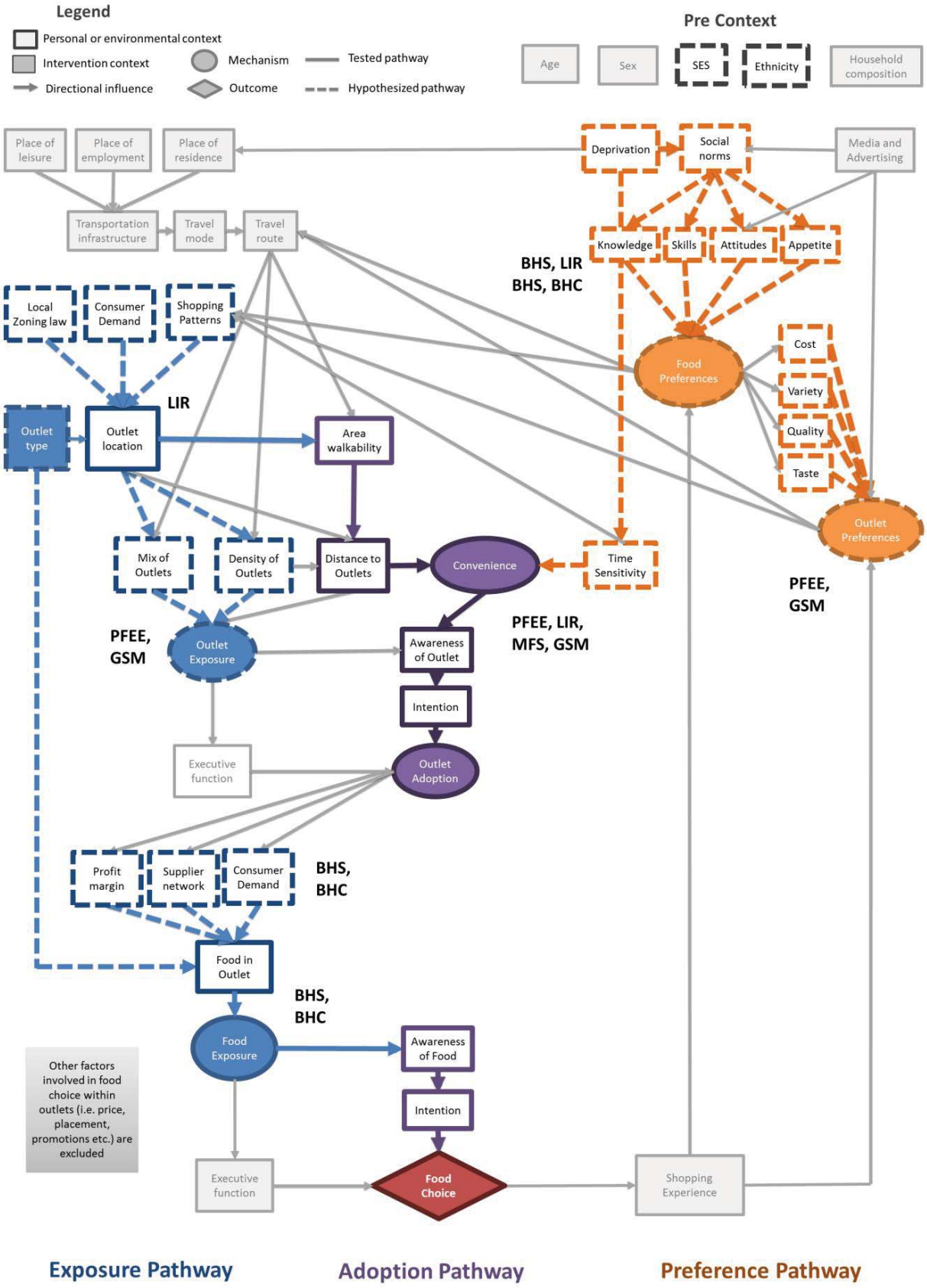
As many interventions were not found to result in a change in diet, authors provided many hypothesized reasons for their lack of detecting an effect, reasons relevant to theory development that were mapped included proliferation of other, often less healthy (e.g. fast food or convenience stores), choices in the area (i.e. exposure pathway) and the needs or preferences of the individuals and their existing shopping patterns (i.e. preferences and needs pathway) shown as dashed lines. For the two types of interventions (i.e. community and consumer), a set of context, mechanism, outcome patterns emerged that demonstrate the complex nature of potential programme theories for interventions of this type (**Figure 2.4**).

2.5 Discussion and synthesis

The purpose of this systematic review and realist synthesis was to generate a theoretical basis for grounding future research, evidence synthesis and conceptualising *how, for whom and under what circumstances* interventions to change food availability influence food choices. Specifically, it also sought to map food availability interventions against the theory to deepen understanding and to reflect on the current state of discordance within observational and intervention evidence regarding food availability and diet behaviour.

2.5.1 How food availability influences food choice: causal pathways and mechanisms

The theory put forward here has conceptualised the influence of local food availability on food choice as having three, interrelated and mutually supporting pathways of influence along with six identified mechanisms that may trigger dietary outcome patterns. These aspects of the theory clustered into three possible interrelated 'pathways' of causal influence and suggested a cyclical system of reinforcement between exposure to, adoption of and preference for particular foods and food outlets by the population. Across these pathways, mechanisms were described, for which multiple levels of context represent precursors to the triggering of these mechanisms, resulting in further contextual changes and a theorised change in food choice. Specifically, this theory includes some important



PFEE: Pennsylvania Fresh Food Financing Initiative; **LIR**: Leeds retail intervention; **MFS**: Mobile Food Store; **GSM**: Glasgow Supermarket; **BHS**: Baltimore Health Stores; **BHC**: Baltimore Healthy Carry-outs.

Figure 2.3 Theory of change with evaluation and contextual literature mapped

a) Supermarket, community level interventions

b) Convenience store, consumer level interventions

Figure 2.4 Tested context (rectangle), mechanism (oval), outcome (diamond) configuration chains for from the exposure (blue) and convenience (purple) pathways for supermarket and convenience store interventions

characteristics not yet presented in other food environment frameworks. Firstly, it is focused on one aspect of the food environment, local food availability, which was chosen to represent an aspect of food environment research and intervention expected to be of great relevance to dietary public health (i.e. low agency, environmental and structural changes that promote sustained, equitable healthy living for the population).[119] Focusing on this aspect of the food environment allowed for a more coherent synthesis of interventions, which was demonstrated by the consistent context, mechanism and outcome configurations found during the mapping of tested aspects of the included interventions. This is in direct contrast to the reporting of significant heterogeneity in other systematic reviews[40,74], which is often associated with an inability to report consistent findings.[21,39,75–77]

Secondly, the theory generated is not descriptive in nature, but was developed using questions that seek to understand *change* within the context of a larger social, economic and environmental system, supporting the perspective that complex public health interventions might be best considered an event within a wider complex system.[87] Therefore because the method used was not bound to previous conceptualisations of the food environment, the theory generated is not simplistic, with separate but interrelated pathways and reinforcement of these pathways depending on the outcomes. The realist approach used allowed the theory to distinguish between important contextual factors, and demonstrate their multi-levelled nature while still allowing for conceptual specificity.[97]

As such, this theory of change might challenge current traditional or positivist approaches to defining and supporting causal inference, related to food availability interventions in particular.[120,121] For example, an alternative view of causality within other fields dealing with complexity and causality (e.g. computer science and neuroscience) is called 'top-down' causation. Rather than seeking evidence that one factor directly and independently predicts another at the same level of operation, top-down causation describes causality within a complex, multi-levelled system by accounting for the restriction of outcomes available to an agent moving through concentric levels of that system. While no one level exerts a causal influence, the 'effect' of passing through each level represents an additive or multiplicative restriction of possible outcomes. When the agent reaches the end of the 'system', possible outcomes are few, and this restriction of possible outcomes – approximates a causal effect. This approach toward causality applied to the theory here

suggests that, while food choice has the appearance of a broad set of choices and outcomes, in reality, the effect of moving through multiple levels of context toward food availability will increasingly restrict or expand depending on your pre-contextual circumstances. For example, your level of deprivation, place of residence, travel routes each day, needs and preferences and convenience – by the time an individual arrives at an outlet, with a selection of foods to choose from, there may be little choice remaining.[122]

Lastly, the mapping of intervention evidence demonstrated other mechanisms of change that have not been incorporated into previous reviews of policy interventions for improving healthy eating by changing food availability. Specifically, this applied to the role of exposure to a mix and density of other food outlets, especially if individuals preferences or need for convenience, were hypothesized but not tested. This is an important consideration as when a new supermarket arrives in an existing neighbourhood, the current residents have already established preferences or needs for particular foods or outlets; and therefore have shopping patterns that do not include the supermarket (i.e. the habit discontinuity hypothesis).[123] One could hypothesize, as many authors did, that the addition of the supermarket did not change the distribution of food outlets surrounding the supermarket in any significant way (i.e. did not change exposure mechanism) and depending on the exiting preferences or needs of the communities, will not change individual shopping habits making a switch to the new supermarket unlikely. We also know that areas experiencing deprivation tend to have a less favourable distribution of healthy outlets, often called ‘food swamps’ to describe a proliferation of unhealthy food outlets.[124] Although the new supermarket may be closer to the previous food outlet option, we don’t know if it is truly *convenient* based on what other food outlet options (i.e. *exposure*) are available and the skills, knowledge and attitudes toward foods (i.e. *preferences or needs*) that exist within the popuatlion.[125]

In contrast to additional supermarkets, the mobile food vendor was the only intervention to demonstrate a significant improvement in fruit and vegetable consumption. It included a specific selection of healthy foods (fruits and vegetables) for a reduced price, delivered direct to the selected deprived areas.[115] For those with a preference for fruit and vegetables, convenience was increased and exposure to other options was decreased, resulting in a favourable change in food choice.

2.5.2 For whom and under what circumstances does food availability influence food choice

An important aspect of this work was to explore the context of these interventions - specifically, for whom and under what circumstances might food availability influence food choice. The interventions reviewed here were born out of a very specific context. They were developed within the UK and US to provide a response to 'food deserts', which represented large geographic areas without a supermarket and a high proportion of low income, ethnic minority, residents whom did not have sufficient access to healthy foods.[126,127] Related to these investments, other programmes were developed, particularly in the US that sought to also improve the healthy offerings within convenience stores, particularly in economically deprived communities that also suffered from poor access to healthy foods.[75]

As discussed briefly above, these policy interventions often were not accompanied by an explicit theory of change that acknowledged the complexity of implementation within a broader system, and when mapped against the theory developed here showed that they missed other potential, reinforcing or obstructing pathways of influence. The lack of breadth of these interventions is likely a reflection of their status as 'natural' interventions, in the sense that these were changes to the local environment born out of policy change that were then evaluated by researchers who did not have direct control of the intervention.[128,129] Even convenience store interventions, in particular within the process evaluations reviewed, often articulated the circumstances of interventions. Even those that were researcher driven included a lack of control over the dose and fidelity of environmental strategies to be implemented within the stores. The authors citied both hesitation and profit risk of the store owner, which persisted when the researchers were willing to reimburse store owners for losses.[118] Although this challenge could be viewed negatively, namely as store owners not being committed to health, the theory presented here suggests that this could be a legitimate concern of store owners. The theory puts forward possible factors that influence what types of foods are available in any given food outlet including the profit margin, supplier network and again customer demand of people using a food outlet; factors the store owner must consider to remain economically viable. Without an improved understanding of these factors, and the contributions of both in terms of supply and demand for particular foods at particular prices, we may be asking

storeowners to make changes that are not likely to succeed in the long term, even if they are willing to make short term changes.

Lastly, while these interventions are exclusively related to two food outlet types: large chain supermarkets and small independent convenience stores, it is important to consider other potential circumstances for food availability interventions. In the past two years, an increase in evaluation for food availability related to fast food outlets has increased, both their location within a local area; and improving their food provision. Therefore, this theory is best considered a work in progress that will include continued mapping of emergent evidence.

2.5.3 Methodological strengths and limitations

The primary strength of this work was that it sought to improve our causal understanding of how and why food availability intervention may influence food choice and therefore provide insights into why they may fail. To do this, local food availability was conceptualised as an event in a complex system and employed principles of realism to deal with some of that complexity. This work has some potential limitations. First among these is that theory development is only a starting point, and will require future testing. Additionally, the purpose of this realist synthesis is to focus on contextual factors and develop a theory of food availability and diet; however it has done so without directly assessing intervention effectiveness. Further, in order to provide the most comprehensive understanding of how the included food environment interventions work, this review was more inclusive of studies than traditional systematic reviews, giving rise to questions of the quality of included studies. Although studies of low quality according to our tool were not excluded, the quality score helped us during analysis and synthesis.

2.6 Conclusion and future work

With the paucity of empirically-supported theories of change used in current local food availability interventions this synthesis may be used to ground current observational and future intervention research, and allow for more sophisticated hypothesis involving how, for whom and under what circumstances these interventions may work and help to explain why interventions might fail.

This work involved the development of a complex theory that outlined *how* local food availability might influence food choice for the population from a realist perspective. Although this study relied on sources of tacit (i.e. the expert panel) and published (i.e. intervention related literature) knowledge to develop and reflect on the theory of change, future work could be done that moves beyond these sources. For example, the included studies could be used to examine the empirical evidence from interventions or other observational studies that can estimate associations between different aspects of the theory.

The included intervention studies were used to bound the selection of additional literature relevant to the theory; however, this could be expanded to include other observational studies as a source of qualitative data. Other rich sources of data, such as qualitative interviews, could be used to collect personal stories about how food availability influences food choices among different social groups. These data sources could similarly be analysed for context, mechanism and outcome patterns that might emerge from the experience of people as they navigate their environments and make food choices.

3 Adoption of away-from-home food outlets, diet quality and obesity

This work is submitted as: Penney TL, Jones N, Adams J, Maguire E, Burgoine T, Monsivais P (2017) *The utilization of specific retail-settings and differential associations with the DASH dietary pattern and obesity status*. American Journal of Preventive Medicine (under revision), and presented as: Penney TL, Jones N, Adams J, Maguire E, Burgoine T, Monsivais P (2016) *Are sit-down restaurant, fast food and café usage independently associated with diet and obesity?* European Public Health Conference, Nov. 2016. Vienna, Austria (oral).

The theory of change developed in the previous chapter, identified six mechanisms used to explain different causal pathways for patterns of food choice and diet. In order to begin testing aspects of the complex theory and to apply this testing to food outlets and demonstrated links with poor diet quality, a focus on available data relating to away-from-home eating was chosen to explore two important mechanisms for the influence identified in the theory. Specifically, these included the use of away-from-home food outlets (i.e. outlet adoption in the theory), and the density of away-from-home surrounding the home (i.e. outlet exposure in the theory). Chapter 3 examines the use of different away-from-home food outlets (i.e. fast food, restaurant and café), diet quality and obesity in a cross-section of adults from the National Diet and Nutrition Survey.

3.1 Abstract

Background: Frequency of eating away-from-home has been associated with reduced intakes of healthy nutrients, foods and increased body weight. However, unpacking independent associations for different types of food outlet locations, overall diet quality and obesity status using prospective measures to characterise away-from-home eating are needed. This study examined the associations of overall away-from-home eating, and specific food outlet locations including sit-down restaurants, fast food outlets and cafés with overall diet quality and obesity.

Method: A cross-sectional analysis of population representative data from the UK National Diet and Nutrition Survey (n=2083 adults aged >= 19y). Dietary intake and eating location were measured using 4-day food diaries. Height and weight were objectively measured. Exposures were the proportion of dietary energy consumed within all away-from-home locations, and three specific retail settings: fast-food, cafes, and sit-down restaurants. Outcomes were overall diet quality, indicated by accordance with the Dietary Approaches to Stop Hypertension (DASH) diet, and obesity status. Multivariable logistic regressions estimated associations between exposures, diet quality and obesity.

Results: A higher proportion of energy from away-from-home locations had lower odds of DASH accordance (OR 0.45; 95% CI [0.31, 0.67]) and higher odds of obesity (1.48 [1.10, 1.99]). After controlling for socio-demographics and other eating locations, only use of fast food outlets was significantly associated with lower odds of DASH accordance (0.48 [0.33, 0.69]) and higher odds of obesity (1.30 [1.01, 1.69]).

Conclusions: Eating away-from-home was associated with decreased diet quality and increased obesity. When specific locations were studied separately, only eating at fast food outlets, and not sit-down restaurants or cafes, was associated with diet quality and obesity. It may be useful to focus public health interventions on specific away-from-home food outlet types, however further research is required to better understand how and why individuals use different types of outlets.

3.2 Introduction

Poor diet and obesity are global epidemics that present a significant challenge for public health and the prevention of chronic disease.[130] In part, our obesogenic food environment

has been proposed as a potential point of public health intervention to improve healthy eating behaviour and reduce obesity at the population level.[39] Over the past few decades, frequency of meals consumed[131] and household food expenditure from food consumed away-from-home in outlets such as sit-down restaurants and fast food outlets has been increasing[132], and accounts for a growing proportion of daily energy intake across all age groups.[133–135] Evidence suggests that energy intake is partially determined by the energy density of foods and portion size[136,137], both of which are higher in foods purchased away-from-home.[138]

Systematic reviews have suggested that greater frequency of eating away-from-home is associated with poorer nutrient and dietary intake[73], increased adiposity and weight gain.[139] However much of the evidence synthesised to date characterises eating away-from-home using retrospective measurement[140–142], or focuses on particular locations such as restaurants[143,144] or fast food outlets.[145–148] Measurements in these studies are therefore subject to recall bias; and treat away-from-home eating locations as homogeneous in their potential associations with diet or health. Similarly, many studies use dietary outcomes that focus on individual nutrients (e.g. fat, cholesterol, sodium)[73,149], or foods (e.g. meat, takeaway, fruits and vegetables)[150] rather than measures of overall diet quality. In addition obesity is often assessed using self-reported height and weight[151], which are typically biased compared to objective measurement.[152] Thus, evidence based upon prospective measurement of a range of away-from-home eating locations could improve our understanding of the link between away-from-home eating, poor diet and obesity.

The aim of this work was to employ a prospective assessment of food consumption from all away-from-home eating locations, and three specific settings including restaurants, fast food outlets and cafés, to assess the association with overall diet quality and obesity.

3.3 Methods

3.3.1 Study design and population

The aim of this work was to employ a prospective assessment of food consumption from all away-from-home eating locations, and three specific settings including restaurants, fast food and cafés, to assess the association with overall diet quality and obesity.

3.3.1.1 Data sources and analytical sample

The data used were from 2083 adults aged 19 years and older from Year 1 - 4 (2008 to 2012) of the UK National Diet and Nutrition Survey (NDNS) rolling programme obtained from the UK Data Archive (February 2015 release).[153] NDNS is a yearly cross-sectional survey collecting information on the food consumption, nutrient intakes and nutritional and health status of individuals living in private households in the UK. Sampling, recruitment and data collection methods are constant from year to year to allow data to be combined across survey years. A detailed description of the multi-stage stratified random sampling procedure and design has been reported elsewhere.[12] In short, sampling for each wave is based upon the random selection of postcode sectors (i.e. primary sampling units) across the UK, followed by the selection of households within the postal sectors, and lastly the selection of up to one adult and one child within each household (**chapter 3 appendix**). Data collection involves a researcher interview collecting data on, amongst other things, socio-demographic variables and the completion of a four-day food diary; and a nurse visit including measurement of height and weight.

Overall, 91% of households eligible for inclusion agreed to take part in the first four waves of NDNS. Usable food diaries (three or four days completed) were collected from at least one household member in 58% of eligible households. At the individual level, 56% of those selected to take part completed usable food diaries, including 2083 adults.[12] NDNS was approved by Oxfordshire A Research Ethics Committee and written informed consent was obtained from all participants.[12]

3.3.2 Measurement and estimation

3.3.2.1 Dietary assessment

At the initial interviewer visit, participants were given instructions to record all food and beverages consumed in and out of the home over three or four consecutive days using unweighed food diaries. Portion sizes were estimated using household measures and weights from food package labels obtained online, by purchase or from participants. At the final interviewer visit, the food diaries were checked for missing information and further detail was added if possible before being returned to Medical Research Council – Human Nutrition Research for coding. The diaries were coded by trained assistants using

the in-house dietary assessment software, Diet In Nutrients Out (DINO), with nutrient values provided by the UK NDNS Nutrient Databank.[154]

3.3.2.2 Eating location assessment

Diary methods can be considered a form of ecological momentary assessment where the purpose is to collect frequent reports on eating events in real-time throughout the daily lives of participants and this can reduce recall bias.[155] In the 4-day food diary, each recording day was divided into seven timeslots (6am-9am, 9am-12pm, 12pm-2pm, 2pm-5pm, 5pm-8pm, 8pm-10pm and 10pm-6am). In each timeslot participants could report multiple food items. We defined eating occasions as a group of food items consumed within a single 'sitting'[156] and consumed by a participant on the same diary day, within the same timeslot, and within the same eating location (**chapter 3 appendix**).

Participants recorded the location where each food was consumed as free text in the diet diary (e.g. 'McDonalds', 'on the train', 'at a friend's house', 'Costa' etc.). Locations were initially coded and collapsed into 36 subcategories by NDNS. We further collapsed these into 5 eating location categories: 'Restaurants, pubs and night clubs', 'Fast food and takeaway', 'Cafes and sandwich shops', 'Other non-retail locations' (all non-home locations were considered 'Away-from-home') and 'Home' for this analysis (**chapter 3 appendix**). Although participants provided details on 'Where' eating occasions took place, these categories do not necessarily reflect where food was sourced. Therefore, reallocation of categories was used to better estimate food source using reported eating location. This included reallocating 'Work – food from home' from the 'Away-from-home' to the 'Home' category, and reallocating eating occasions where all food items were appended with a code reflecting 'take away' from any category to the 'Fast food and takeaway' category (e.g. takeaway food consumed 'on the train' was categorised as 'Fast food and takeaway'). The purpose was to improve the sensitivity of the categories.

3.3.2.3 Exposure: energy intake consumed at away-from-home locations

We calculated proportion of total Energy intake (kJ) acquired from home and all away-from-home locations over all available diary days. Away-from-home was subdivided into Sit-down Restaurants, Fast Food outlets, Cafés and other away-from-home locations, with corresponding total energy intake for each participant. Proportions of energy intake were then calculated for all eating locations (energy intake within eating locations / Total

energy intake), and then converted into levels of exposure. The tertiles (Low, Middle, High) were used for the total combined 'Away-from-home' (i.e. retail and other non-retail locations) category and the 'Other Non-Retail' subcategory. Retail location subcategories were dichotomised to reflect usage by participants (None, Any) for 'Restaurants, pubs and night clubs', 'Fast food and takeaway', and 'Cafés and sandwich shops' subcategories.

3.3.2.4 Dietary outcome: overall diet quality

Overall diet quality was assessed by quantifying accordance to the DASH dietary pattern using an existing index.[157,158] The score is based on consumption of eight food groups and nutrients, adjusted for energy using the residual method. The original food groups and nutrients used include fruits, vegetables, nuts and legumes, whole grains, low-fat dairy, red and processed meats, non-milk extrinsic sugars, and sodium. The eight DASH food groups and associated scoring are presented and described in the **chapter 3 appendixes** with additional details on assessing accordance to DASH. The DASH accordance score has a minimum value of 8 and a maximum value of 40. The continuous DASH score was then divided into quintiles, with diets in the top quintile coded as 1 (DASH-accordant) and lower quintiles coded as 0 (less DASH-accordant), a stratification used previously in epidemiological studies of the DASH diet in relation to cardiovascular disease and colorectal cancer.[158,159]

3.3.2.5 Anthropometric outcome: measured obesity

Trained interviewers collected measurements of height and weight during participant nurse visits. Participants were measured in minimal clothing and without shoes. Body mass index (BMI) was calculated from measured height and weight and categorised as obese which equates to a (BMI>=30 kg/m^2) or not.[160] The decision to focus on obesity was informed by the research question and purpose of the study. This included a focus on the associations between away-from-home food outlet usage with obesity (BMI>=30 kg/m^2) as a condition that presents a higher risk of all-cause morbidity and mortality.[161] Overweight (25<=BMI<30 kg/m^2) in contrast has been shown to have a lower risk compared to normal weight classification.[161] Therefore a binary outcome variable was preferable to a continuous measure of BMI.

3.3.2.6 Additional covariates

Self-report survey questions were used to assess demographic factors including age (continuous) and sex. Socio-economic status was represented using two indicators that were found to be patterned by both exposure and outcome variables. Educational attainment categorised as 'None, GCSE or equivalent', 'Further education' and 'Degree or equivalent'. Total household income was equivalised for household composition categorised as '£14,999 or below', '£15,000 – £24,999', '£25,000 - £34,999', '£35,000 – £49,999' and '£50,000 and above'. Smoking status categorised as 'Current smoker', 'Ex-regular smoker' or 'Never a regular smoker'. Survey year was categorised based on study year (1 to 4). Missing covariates values were also examined across all exposure variables, with no significant differences in percentages across exposure levels, then categorised for each variable and included in appropriate models to avoid case deletion. This approach is termed the 'missing indicator approach' and involves classifying missing data as an additional category for a categorical variable, and including the variable in regression models as an alternative to deleting full cases (which could introduce sources of non-response bias). For dealing with missing data, it may be particularly appropriate for covariates with less than 10% missing data where the impact of imputation may be challenging to determine.[162]

3.3.3 Statistical analysis

Descriptive statistics were used to summarise demographic, socio-economic, behavioural, diet, health and eating occasion variables across away-from-home eating and location specific exposures. Study weights, prepared by NDNS and provided with the data were used to account for participant non-response; therefore weighted mean percentages (with 95% CIs) are presented rather than raw frequencies. Binary logistic regressions were used to evaluate DASH accordance and obesity status by tertile of proportion of energy intake consumed Away-from-home (Crude). The model was then adjusted for demographic variables (age and sex) and other covariates (total energy (kJ), survey year and smoking status (for obesity outcome only)) (Model 1), then additionally adjusted for socio-economic variables (education and income) (Model 2). In a secondary analysis, logistic regression models were fitted to base models (Crude, Model 1 and Model 2) replacing 'Away-from-home' exposure with 'Restaurants, pubs and night clubs', 'Fast food and takeaway', 'Cafés and sandwich shops' respectively, mutually adjusting for each

respective retail location and 'Other non-retail locations'. The resulting odds ratios from the secondary analysis for DASH accordance and obesity were interpreted as independent associations of the Eating Location exposure being examined. NDNS's analytic weights were used to ensure that analyses accounted for non-response bias and account for the survey's complex sampling structure. All statistical analyses were carried out in STATA version 14.[163]

3.3.3.1 Sensitivity analyses

We also defined exposure using tertile of eating occasions, rather than tertile of energy consumed within eating locations, to examine possible influence of exposure and outcome being derived from diary data[164]. Alternative multivariable model structures for DASH accordance and obesity were explored for robustness. Additional covariate specifications were also examined for robustness, including occupational class (Routine and manual, Intermediate, Higher managerial, administrative and professional, never worked), ethnicity (White, all others) and country of residence (England, Scotland, Ireland, Wales). Additionally, although not the focus of this analysis but used for model adjustment, descriptive tables with odds ratios and 95% CIs for away-from-home non-retail locations (e.g. friend's house), DASH accordance and obesity were created.

3.4 Results

The overall unweighted sample included 2083 adults (901, 43.2% men) with representation from a range of socio-economic positions (42.3% with low educational attainment versus 23.5% with the highest; 18.5% from the lowest equivalised household income category (< £14,999) versus 13.2% in the highest (> £50,000)) (**Table 3.1**).

3.4.1 Characterising sample

The sample characteristics presented in **Table 3.2** indicate differences in several demographic, socio-economic, diet and health outcomes across tertiles of proportion of energy intake away-from-home. Those in the highest tertile of energy consumed away-from-home tended to be younger, belonged to the most socio-economically-advantaged groups (further education, income and occupational status) and smoked less, and were

Table 3.1 Weighted sample characteristics for full analytic sample (n=2083), percentage of participants across demographic, socio-economic, exposure and outcome measures with mean (95% CI) where indicated

		Men	Women	Total
	N (unweighted %)	901 (43.2)	1,182 (56.7)	2,083
Demographic [a]				
	Age	47.1 (45.8,48.4)	48.9 (47.5,50.2)	48.1 (47.1,49.0)
Socioeconomic				
Education	None, GCSE or equivalent	39.8	44.6	42.3
	Further education	26.1	25.0	25.5
	Degree or higher	25.4	21.8	23.5
	Missing	8.6	8.4	8.5
Equivalised household income				
	< £14,999	15.2	21.7	18.5
	£15,000 - £24,999	21.3	20.3	20.8
	£25,000 - £34,999	17.3	17.0	17.1
	£35,000 - £49,999	14.6	12.0	13.2
	£50,000 +	14.7	11.7	13.2
	Missing	16.6	17.1	16.9
% Food outlet usage [a]				
	% Restaurant outlet usage	5.38 (4.71,6.06)	5.25 (4.58,5.93)	5.32 (4.81,5.82)
	% Fast food outlet usage	4.43 (3.71,5.14)	3.65 (3.14,4.16)	4.03 (3.61,4.45)
	% Café food outlet usage	1.19 (0.96,1.41)	1.53 (1.28,1.77)	1.36 (1.21,1.52)
	% Other away from home locations	16.8 (15.6,18.1)	15.1 (13.9,16.1)	15.9 (15.1,16.7)
	% Total away from home food outlet usage	27.8 (26.2,29.4)	25.5 (24.0,27.0)	26.6 (25.5,27.7)
Diet				
	Energy Intake (kJ/day)	8827 (8622,9028)	6646 (6521,6767)	7706 (7575,7831)
	DASH Accordance (highest quintile)	13.0	19.9	16.5
Adiposity				
	Obesity (BMI >= 30 kg/m2)	26.2	29.9	28.1

[a] Weighted mean (95% confidence interval)

Note: Energy Intake (kcal/day) - Men: 2109 (2060-2157); Women: 1588 (1558-1617); Total: 1841 (1810-1871)

Table 3.2 Weighted sample characteristics as percentages (unless otherwise stated) by proportion of Energy intake (kJ) from all away-from-home locations (tertiles)

		Tertile of Away-from-home Exposure			
		Lowest	**Middle**	**Highest**	**Total**
	n	708	706	669	2083
	Proportion of Energy (kJ) (min – max)	0.00 – 0.14	0.14 – 0.34	0.34 – 1.0	0 – 1
Demographic					
	Age [a]	56.2	47.9	40.0	48.0
	Sex (% Male)	47.5	44.6	53.5	48.5
	Ethnicity (% White)	88.9	91.3	88.4	89.6
Socio-economic					
	Educational attainment (% Degree)	16.1	22.8	31.7	23.5
	Equalised Income (% > £35,000)	22.5	30.6	41.6	31.8
	Occupation (% Professional)	34.6	44.7	48.0	42.4
Behaviour					
	Smoking (% Never smoked)	53.4	55.8	57.1	55.4
Diet					
	Fruit and Vegetable (g/day) [a]	313 (298,328)	288 (273,302)	266 (253,280)	289 (280,298)
	DASH score (% Accordant)	21.2	16.8	11.7	16.6
	Energy Intake (kJ/day) [a]	7262 (7074,7455)	7568 (7333,7802)	8284 (8058,8505)	7706 (7576,7832)
Adiposity					
	% Normal BMI (18-25 kg/m^2)	28.8	30.4	33.4	30.9

[a] Weighted Mean % (95% confidence interval)

more likely to be normal weight, but also had less healthy dietary intakes (lower fruit and vegetable consumption, lower DASH accordance and more total energy intake (kJ/day)). For retail location usage, the sample characteristics presented in **Table 3.3** indicated differences in demographic, socio-economic, and diet outcomes across sit-down restaurant, fast food or café usage (i.e. any proportion of energy at eating location). Those in the most advantaged socio-economic groups were more likely to be sit-down restaurant and café users, and fast food non-users. Indicators of a healthy diet showed a mixed pattern between users and non-users across food outlet types. Users of fast food outlets had lower daily fruit and vegetable intake, a lower proportion of the sample that was the most DASH accordant, and higher total energy than non-users. This differs from restaurant and café users who tend to have fewer differences in fruit and vegetable intake or total energy between users and non-users, with a greater proportion of the sample reporting as the most DASH accordant. Health outcomes were stable across retail location usage, with users showing higher % normal BMI than non-user.

3.4.2 Characterising types of exposure

Figure 1a shows stacked weighted mean percentages by retail type stratified level of away-from-home energy intake. **Figure 1b** shows normalised weighted mean percentage contribution of combined retail type stratified by level of away-from-home energy intake. While mean % of energy across retail types was higher with additional away-from-home exposure (1a), the contribution of retail type toward total mean energy away-from-home varied across exposure level, with sit-down restaurant contribution increasing across tertiles of energy intake away-from-home exposure; café contribution decreasing across tertiles; and fast food remaining relatively constant across tertiles (1b).

3.4.3 Food outlet usage, diet quality and obesity

Regression analyses (**Table 3.4**) showed that the middle and highest proportion of energy intake from away-from-home were associated with lower odds of DASH accordance (OR=0.70, 95% CI [0.52, 0.95] and 0.45 [0.31, 0.67] respectively) and higher odds of obesity (1.41 [1.06, 1.89] and 1.48 [1.10, 1.99] respectively). For retail location use, crude models showed fast food use associated with a lower odds of DASH accordance (0.41 [0.29, 0.58] and sit-down restaurant use associated with a lower odds of obesity

Table 3.3 Weighted sample characteristics as percentages (unless otherwise stated) by proportion of Energy intake (kJ) for away-from-home retail locations including restaurant, fast food or cafe use (dichotomous)

	Retail Location Use					
	Sit-Down Restaurant		Fast Food		Café	
	None	Any	None	Any	None	Any
n	1399	684	1569	514	1675	408
Proportion of Energy (kJ) (<= max)	0.00	<= 0.85	0.00	<= 0.73	0.00	<= 0.30
Demographic						
Age [a]	48.7 (48.1,49.2)	46.7 (46.2,46.9)	50.6 (50.1,50.8)	40.8 (39.6,41.3)	47.8 (47.4,48.3)	49.1 (48.7,49.4)
Sex (% Male)	47.3	50.9	47.7	50.7	49.8	42.7
Ethnicity (% White)	88.9	90.9	89.7	89.2	88.5	94.3
Socio-economic						
Educational attainment (% Degree)	20.5	29.4	23.9	22.6	22.7	27.4
Equalised Income (% > £35,000)	28.3	38.5	33.2	28.0	30.3	38.6
Occupation (% Professional)	40.4	46.3	43.1	40.7	41.4	47.4
Behaviour						
Smoking (% Never smoked)	53.4	59.4	56.1	53.6	54.6	59.3
Diet						
Fruit and Vegetable (g/day) [a]	289 (278,300)	289 (275,303)	305 (295,315)	244 (229,260)	287 (277,297)	299 (282,316)
DASH score (% Most Accordant)	17.2	15.3	19.3	8.9	15.9	19.6
Energy Intake (kJ/day) [a]	7541 (7292,7610)	8204 (7999,8405)	7467 (7342,7597)	8363 (8037,8690)	7668 (7526,7806)	7873 (7626,8120)
Adiposity						
% Normal BMI (18-25 kg/m^2)	30.0	32.6	30.0	33.2	30.4	32.8

[a] Weighted Mean % (95% confidence interval)

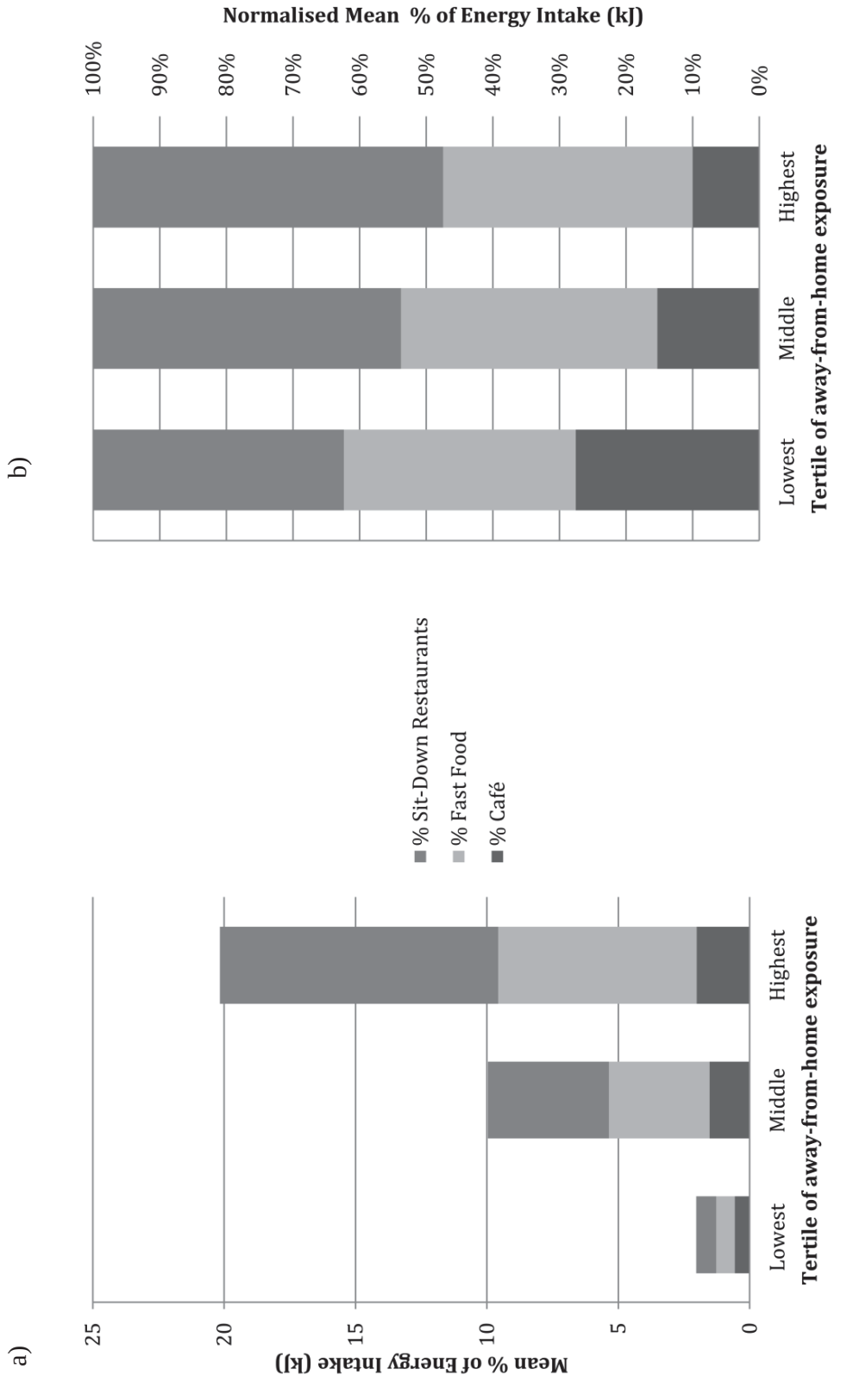


Figure 3.1 a) Stacked weighted mean % of energy intake (kJ) for tertile of away-from-home exposure for each retail location; b) Normalised contribution of weighted mean energy intake (kJ) for retail locations by proportion of away-from-home exposure tertiles

Table 3.4 Odds ratios and 95% confidence intervals for DASH accordance (n = 2083) and obesity (n = 1902) by Energy intake (kJ) away-from-home exposure level and for specific retail locations including restaurant, fast food and cafe use

Proportion of Energy Intake (kJ)	***Odds of DASH Accordance*[1]			***Odds of Obesity*[2]		
	Crude	*Model 1*[3]	*Model 2*[4]	*Crude*	*Model 1*[3]	*Model 2*[4]
Away-from-home						
Lowest	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)
Middle	0.75 [0.56, 1.01]	0.80 [0.60, 1.08]	**0.70** * [0.52, 0.95]	1.18 [0.9, 1.54]	**1.33** * [1.01, 1.76]	**1.41** * [1.06, 1.89]
Highest	**0.49** *** [0.34, 0.69]	**0.59** *** [0.41, 0.84]	**0.45** *** [0.31, 0.67]	1.10 [0.77, 1.32]	**1.34** * [1.00, 1.79]	**1.48** ** [1.10, 1.99]
Retail Location Use[5]						
Sit-Down Restaurant						
None	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)
Any	0.87 [0.64, 1.18]	0.89 [0.65, 1.2]	0.78 [0.56, 1.07]	**0.73** * [0.58, 0.93]	**0.78** * [0.61, 0.99]	0.81 [0.64, 1.03]
Fast Food						
None	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)
Any	**0.41** *** [0.29, 0.58]	**0.44** *** [0.30, 0.64]	**0.48** *** [0.33, 0.69]	1.08 [0.84, 1.40]	**1.34** * [1.02, 1.74]	**1.30** * [1.01, 1.69]
Cafe						
None	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)
Any	1.29 [0.94, 1.77]	1.27 [0.92, 1.75]	1.14 [0.81, 1.61]	0.86 [0.65, 1.15]	0.85 [0.63, 1.14]	0.88 [0.65, 1.18]

[1] DASH accordance score was divided into quintiles, with the highest quintile being most DASH accordant
[2] Obesity included participants with a BMI >= 30 kg/m^2
[3] Adjusted for age, sex, total energy (kJ), survey year (and smoking status for obesity models);
[4] Additionally adjusted for education and equivalised income;
[5] Model 1 additionally adjusted for proportion of energy from restaurant, fast food, café and other away-from-home non-retail locations (as appropriate);
* p<0.05, ** p<0.01, *** p<0.001

(0.73 [0.58, 0.93]. However, for sit-down restaurant use, these associations were attenuated and were not significant in Model 2 (0.81 [0.64, 1.03]. In crude models, use of fast food outlets was associated with lower odds of DASH accordance but not with obesity. Adjustment for confounders attenuated the association with DASH accordance, but revealed that fast food outlet use was associated with higher odds of obesity (1.30 [1.01, 1.69]). In crude and adjusted models, café use was not associated with either DASH accordance or odds of obesity.

No significant differences between the resulting odds ratios using the two potential exposures, percentage eating occasions versus percentage energy intake, across eating locations were found, so energy intake exposure alone was reported. Alternative multivariable models using occupational class, ethnicity and country of residence did not significantly alter results (results not shown). Additionally, although not the focus of these analyses, descriptive tables with odds ratios and 95% CIs for away-from-home non-retail locations (e.g. friend's house), DASH accordance and obesity are available in **chapter 3 appendix**. The results show significantly lower odds of DASH accordance for the highest tertile of away-from-home non-retail exposure (0.68 [0.29, 0.58]) and no association with odds of obesity.

3.5 Discussion

Using prospective assessment of away-from-home eating, this analysis examined associations with diet quality and obesity, and confirmed some findings of previous studies.[143,145,146] Specifically we observed that overall energy intake away-from-home was inversely associated with diet quality and positively associated with obesity. The associations demonstrated that the highest exposure group showed a 55% reduced odds of a DASH-accordant diet and 48% higher odds of obesity. Moving beyond previous research, we examined usage of three different away-from-home eating locations including sit-down restaurants, fast food outlets and cafés, revealing differential associations with diet quality and obesity depending on location and adjustment for confounding factors. Fast food outlet usage was significantly and inversely associated with diet quality (52% reduced odds) and positively associated with obesity (30% higher odds), regardless of model adjustment. In adjusted models, sit-down restaurant usage and café usage were not significantly related to diet quality or obesity.

3.5.1 Away-from-home eating locations, diet and obesity are not homogeneous

These results suggest that while much of the existing literature provides evidence of a detrimental role of eating away-from-home on diet and weight status[143,145,146], those results may be missing important differential contributions of specific classes of retail food outlet.[73,151] While eating outside the home may be associated with reduced odds of a healthy diet and higher odds of excess weight, our examination of retail location usage revealed that much of these associations could be attributed to fast food use[143], independent of other away-from-home eating locations. Moreover, the usage of specific retail locations was differentially patterned by socio-economic status[165]. While restaurant and café users tended to belong to higher socio-economic groups, fast food users tended to be less socio-economically advantaged. The importance of this patterning also emerged during model adjustment for individual level social and economic factors and the attenuation of the association between restaurant usage and reduced odds of obesity. In unadjusted models, we found that regular use of restaurants was associated with reduced odds of obesity. However, this apparent protective influence of restaurant use was attenuated after adjustment for individual-level socio-economic factors.

3.5.2 Potential influences of away-from-home eating location use

There is some suggestion that away-from-home eating can be balanced, healthy and inexpensive.[166,167] There is also significant evidence, confirmed by this work, that eating away-from-home, particularly for fast food users[141,147], is associated with poor diet and obesity outcomes.[143,146] Proposed reasons for the effect of eating within fast food outlets, and adverse outcomes include the larger portion sizes of foods that tend to be energy dense and nutrient-poor.[136,137,168] Consumers also report preferences for fast food outlets that are convenient, easy to access and provide tasty foods, with availability of nutritious foods being the least important factor.[169] Additionally, it has been suggested that individual preferences are socio-economically patterned with socio-economically-advantaged individuals possessing more material-, psychosocial- and time-related resources, to more easily make healthier choices related to food outlets and food items.[170,171] A better understanding of how the individual needs and preferences of

different socio-economic groups are likely an important area of consideration for any future public health intervention strategies.

3.5.3 Methodological considerations and limitations

An important consideration includes the pre-existing categorisation of eating locations within the NDNS data. These categories were primarily based upon criteria set out by the NDNS study team and, if modified, may yield different results. For example, the fast food and sit-down restaurants were distinguished by NDNS based on the method of service and didn't account for the healthiness of foods available within outlets, which may vary substantially[136] with restaurants providing options that can be as unhealthy as those sold in fast-food outlets.[137] We also dichotomised the usage of the three food retail types in order to deal with the skewed nature of the underlying data, which may have reduced our sensitivity to detect associations compared to the use of continuous variables.

In addition to characterising the exposure, a limitation of dietary assessment is that energy intake is often underreported, which can lead to overestimation of the association between exposure and outcome. Our use of data from a 4-day food diary reduces underreporting, but it is unlikely to have been eliminated.[172] Also, in the obesity models we were unable to adjust for energy expenditure or level of physical activity, which may be important confounders.

This work has several strengths, including a prospective measure of away-from-home eating, and restaurant, fast food and café usage, overcoming limitations of retrospective measures that are subject to recall bias, which may misrepresent an individual's actual frequency of use of away-from-home locations. Additionally, 4-day diet diaries were used to estimate DASH accordance, and measured height and weight were used to assess obesity status for a nationally representative sample of UK adults.

3.6 Conclusion

Our findings indicate that while greater reliance on eating away-from-home overall is associated with less-healthy diets and obesity, these retail outlets are not homogeneous in terms of their independent associations with outcomes. These results suggest that population-level health interventions, designed to modify retail usage, may be most

effective if focussed on specific outlet types. Further research is required to better understand how and why individuals use specific outlets within a broader social, economic and environmental context.

4 Exposure to away-from-home food outlets, food spending and obesity

This work has been invited to be part of the 'Special Session for geographically linked data' at the Understanding Society 2017 conference as: Penney TL, Burgoine, T and Monsivais P. T *Local food outlet exposure, food spending and obesity in England*. Understanding Society Conference. University of Essex, UK. June 2017 (oral). A manuscript is in development for submission.

After testing the associations between usage of different away-from-home food outlets (i.e. outlet adoption in the theory) with diet and obesity in chapter 3, chapter 4 examines associations between the density of away-from-home food outlets around residents' homes (i.e. outlet exposure in the theory) with food spending and obesity in a cross-sectional spatial study of adults from the first wave of the UK Household Longitudinal Study (UKHLS).

4.1 Abstract

Background: With the combined increase in prevalence of food outlets for eating away-from-home and a time constrained population, it is no surprise that eating away-from-home is rising in the UK, with an ever increasing proportion of household food spending

being directed toward prepared meals. Proliferation of away-from-home food outlets in one's neighbourhood has been shown to be associated with diet intake and obesity. Currently, this evidence has been restricted to regional geographies and focused on one aspect of the foodscape (i.e. fast food outlets). The purpose of this study is to determine if there is an independent association between the away-from-home outlet density around the home, household food spending and obesity.

Method: A cross-sectional analysis of data from Wave 1 of the UK Household Longitudinal Survey (n=35,632 adults aged >= 19y). Exposures were density of three away-from-home food outlets: fast food, cafes, and sit-down restaurants. Outcomes included away-from-home food spending and obesity status. Logistic regression was used to estimate associations between away-from-home food outlets exposures, away-from-home food spending and obesity.

Results: Higher density of away-from-home location was associated with higher odds of high away-from-home food spending (OR 2.26 95% CI [1.04, 1.30]) and lower odds of obesity (0.85 [0.76, 0.95]). After controlling for socio-demographic characteristics and other eating locations, higher density of fast food outlets were associated with higher odds of obesity (1.34 [1.18, 1.51]). Also a higher density of restaurants and cafes were associated with a lower odds of obesity (0.78 [0.69, 0.88] and (0.84 [0.74, 0.95], respectively).

Conclusions: Exposure to away-from-home food outlets was associated with higher odds of away-from-home food spending, and fast food exposure associated with greater odds of being obese. When specific locations were studied separately, restaurants and cafes exposure were negatively associated with obesity. It may be useful to focus public health interventions on specific away-from-home food outlet types, however further research is required to better understand how and why individuals use different types of outlets.

4.2 Introduction

Poor diet and obesity are global epidemics that present a significant challenge for public health and the prevention of chronic disease.[130] With the combined increase in prevalence of food outlets for eating away-from-home[43] and a time-constrained population[171], it is no surprise that eating away-from-home is rising in the UK.[131,132,173] This eating pattern, and

more precisely eating takeaway two times a week or more[72] rather than cooking one's own meals[174] has been linked with a reduced diet quality and higher body weight.[73,139,175,176] Two systematic reviews have confirmed these results, finding overall that eating away-from-home is associated with diets higher in fat and energy intake, and lower micronutrient content, and with obesity.[73,176] Additionally, these associations may be different across different types of food outlets, with restaurants and fast food outlets being examined most frequently.[177]

A range of individual and economic factors, including time scarcity in general[171], time and skills for cooking[178,179], and food costs[180] are likely to influence the choice to eat away-from-home. However, structural factors have also been shown to contribute to both diets and weight status. Specifically, exposure to a density (proliferation) of food outlets in one's neighbourhood has been shown to be associated with diet intake and obesity.[66,68,181,182] For example, one study from the US showed that for every standard deviation increase in fast-food exposure, the odds of consuming fast food near home increased 11%–61% and the odds of a healthy diet decreased 3%–17% (depending on adjustment).[58] Another study in the US found that fast food outlet density at 0.5, 1, and 2 miles was positively associated with BMI, but only among adults with lower incomes.[64]

Fewer studies looking at fast food exposure, diet and obesity have been conducted in the UK. One study reported that the total number of fast food outlets available around the home, work and along commuting routes was positively associated with an increase in consumption of fast food (5.7 g/day), body mass index (1.21 kg/m^2) and odds of obesity (odds ratio 1.80).[68] While providing some evidence for the potential role of availability of fast food outlets, poor diet and obesity, this evidence has been restricted to the US context and UK regional geographies[68,182], rather than nationally representative studies; and typically focused on one type of food outlet[66,68,182], rather than comparing associations across different types of food outlets – particularly those most commonly used for meals consumed away-from-home.

The purpose of this study is to determine if there is an independent association between the away-from-home foodscape, away-from-home household food spending and obesity. Specifically to answer is a person's exposure to density of away-from-home food outlets associated with household food spending and individual body mass index? Does the association between exposures to food outlets differ by food outlet type?

4.3 Methods

4.3.1 Study design and population

This work included a cross-sectional analysis of a representative sample of adults living in England, United Kingdom.

4.3.1.1 Data source and analytical sample

Data from the UK Household Longitudinal Study (UKHLS) was used.[183] UKHLS is an annual panel survey of each adult member of a nationally representative UK sample which began in 2009 including over 40,000 UK households (57% household and 82% individual response rates).[184] Details of the study and its sampling strategy are reported elsewhere.[185] In short, participants are surveyed annually to collect information regarding their demographic factors, socio-economic circumstances, and health related factors using a computer assisted personal interview with the household questionnaire answered by a reference person, and a main individual questionnaire answered by each adult within the household.[184]

For these analyses, Wave 1 adults (aged >= 19 years) living in England from the general population sample were included (approximately 25,500 responding households across wave 1). As the study investigated two different outcomes, body mass index (BMI) and proportion of away-from-home household food spending; two separate analytic samples were used. These two analytic samples were restricted firstly to those with complete data for body mass index via self-reported height and weight for each adult individual living in England (N=35,632 of 40,775 individual respondents), and secondly to those who had complete data for household food spending within the home, and away-from-home reported by the reference respondent for each household (N=22,417 of 24,711 household respondents with complete BMI data) (**chapter 4 appendix** for sample flow diagram). The two analytic datasets were found to be representative of one another with no significant differences in the distribution of all analytic variables used (data not shown). Therefore, in interest of brevity, only descriptive analysis of the individual sample (N=35,632) is presented. Ethical approval was not required for the analysis of secondary data presented here, but was obtained by UKHLS for their data collection.

4.3.2 Measurement and estimation

4.3.2.1 Exposure: proportional density of total away-from-home, restaurant, fast food and café food outlets

4.3.2.1.1 Food outlet data and classification

Data for the location of food outlets were obtained through the Points of Interest (POI) database from Ordnance Survey. Each feature is provided with national grid coordinates. The data is resupplied four times per year with this data representing POI from June-August 2014. POI data are provided with a range of variables, methods of measurement and sources including a unique reference number, feature name, classification code, latitude, longitude, positional accuracy rating and address verification. The use of ordnance survey as a secondary data source for determining food environment exposure has been found to have reasonable agreement to 'ground truth'.[42,186,187] Away-from-home food outlets were classified based on previous work[42], and divided into three subcategories: restaurants, fast food and cafés. Example restaurant outlets include Bella Italia, Wetherspoon or Nando's, fast food outlets includes McDonalds, Burger King or burger vans, and cafés outlets include Café Nero, Pret a Manger and Costa. All other food outlets (e.g. supermarkets, convenience and green grocers etc.) were classified as 'Other' (**chapter 4 appendix** for food outlet frequency and classification). Food outlets where food provision was not their primary purpose, or did not sell directly to the public were excluded (e.g. workplace cafeterias, cinemas or recreation facilities).

4.3.2.1.2 Estimation of exposure to food outlet density

Food outlet density was estimated using home neighbourhood, defined as a buffer with a 1 mile Euclidean (straight line) radius centred on participant British National Grid postcode grid reference (at 1 meter resolution) for the unit postcode of each household surveyed, derived from the ONS National Statistics Postcode Directory, provided through UKHLS secure data access. This distance is based upon previous work suggesting a reasonable reflection of food purchasing behaviours for adults in the UK.[50] The number of food outlets was then counted within participant neighbourhood as a measure of outlet density using ArcGIS. This work was focused on person-centred exposure instead of neighbourhood exposure defined using administrative boundaries. The total number of food outlets surrounding a person's home is likely influenced by population density. To

account directly for the effect of population density on the total number of food outlets, a proportion of the food outlet of interest was created in relation to total food outlets within the person-centred boundary. Specifically, proportions of food outlet density were calculated for total away-from-home outlets, then away-from-home food outlets separately for restaurant, fast food and café (density of food outlets / total food outlets) divided into Quintiles (Q1 = Lowest and Q5 = Highest) of estimated neighbourhood food outlet exposure.

4.3.2.2 Household food spending outcome: high away-from-home food spender

Household food expenditure was measured using two questions in the survey: 'About how much has your household spent in total on food and groceries in the last four weeks from a supermarket or other food shop or market? Please do not include alcohol' and 'And about how much have you and other members of your household spent in total on meals or snacks purchased outside the home in the last four weeks?'. Self-report household spending is subject to recall bias; therefore data were top-coded. Specifically, monthly household food spending data were equivalised against household size using OECD modified equivalence scale[188], and capped at the limit of the second highest decile (£500/month) with all values >= £500 recoded at that value. Mean home and away-from-home spend were then compared to household spending based upon Living Costs and Food survey for 2009. A proportion of away-from-home food expenditure was calculated against based upon household food expenditure, and divided into tertiles with the highest tertile (T3) representing 'High Spender' (approximately 25% or more away-from-home spending).

4.3.2.3 Individual anthropometric outcome: self-report obesity

Participants were asked to self-report their height (without shoes) and weight. Body mass index (BMI) was calculated from self-reported height and weight and categorised as obese which equates to a (BMI >= 30 kg/m^2) or not.[160] The decision to focus on obesity was informed by the research question and purpose of the study. This included a focus on the associations between away-from-home food outlet density with obesity (BMI >= 30 kg/m^2) as a condition that presents a higher risk of all-cause morbidity and mortality.[161] Overweight (BMI>=25<30 kg/m^2) in contrast has been shown to have a lower risk

compared to normal weight classification.[161] Therefore a binary outcome variable was preferable to a continuous measure of BMI.

4.3.2.4 Additional covariates

Self-report survey questions were used to assess demographic factors including age (continuous) and sex. Socio-economic status was represented using three indicators that were found to be patterned by both exposure and individual outcome variables. Educational attainment was categorised as 'None, GCSE or equivalent', 'Further education', 'Degree or equivalent'. Household income equivalised for household composition was categorised as '£14,999 or below', '£15,000 – £24,999', '£25,000 - £34,999', '£35,000 – £49,999', '£50,000 and above'. Occupation was categorised as 'Routine or manual', 'Intermediate' and 'Higher managerial'. Self-reported general health was categorised as 'Excellent', 'Good, Fair or Poor'. Missing covariate values were also examined across all exposure variables, with no significant differences in percentages across exposure levels. They were then categorised for each variable and included in appropriate models to avoid case deletion.[162]

4.3.3 Statistical analysis

Descriptive statistics were used to summarise demographic, socio-economic, health and household food spend variables across total away-from-home food outlet exposures, and the three subcategories (i.e. restaurant, fast food and café). Study weights for wave 1 cross-sectional analysis, prepared by UKHLS and provided with the data were used to account for participant non-response and clustered study design; therefore weighted mean percentages (with 95% CIs) are presented rather than raw frequencies.

Binary logistic regression was used to evaluate high proportion of away-from-home food spending and obesity status by quintile of proportion of total away-from-home food outlet density; and (for obesity only) restaurant density, fast food density or café density (Crude). Analyses were adjusted for demographic variables (age and sex) and other important covariates (total number of other food outlets and mutually adjusting for respective proportions of away-from-home outlets as necessary, total equivalised food spend and general rated health (for obesity outcome only)) (Model 1). They were then additionally adjusted for socio-economic variables (education, income and occupation)

(Model 2). The resulting odds ratios from the restaurant, fast food and café analysis for obesity were interpreted as independent associations of the food outlet density exposure being examined.

4.3.3.1 Sensitivity analysis

Alternative multivariate model structures for high away-from-home household food spending and obesity were explored for robustness. Additional covariate specifications were also examined for robustness, including ethnicity (White, all others) and rurality (Urban or Rural). Additionally, although not the focus of this analysis, descriptive tables with odds ratios and 95% CIs for high away-from-home food spending and obesity were examined (**chapter 4 appendix**). Lastly, although not the primary purpose of this work, to better understand the utility of food spending as a proxy for diet quality, data from UKHLS wave 2 was used to examine associations between tertile of proportion of away-from-home food spending, odds of high weekly fruit and vegetable intake, consuming low fat dairy or whole grain bread were examined (**chapter 4 appendix**). All statistical analyses were carried out in STATA version 14.[163]

4.4 Results

The overall unweighted sample included 35,632 adults (16,280, 45.6% men) with representation from a range of socio-economic positions (46.7% with lowest educational attainment versus 23.4% with the highest; 37% from the lowest equivalised household income category (< £14,999) versus 5.9% in the highest (> £50,000) (**Table 4.1**).

4.4.1 Characterising sample

The sample characteristics presented in **Tables 4.2 to 4.5** indicate differences in several demographic, socio-economic and health variables across quintiles of proportion of total away-from-home, restaurant, and fast food or café food outlet exposure. Those in the highest quintile of food outlet exposure tended to be younger, belonged to the most socio-economically-advantaged groups (Further education, income and occupational status) were more likely to be normal weight, and spend a greater proportion of household food spend on away-from-home sources. This pattern was consistent across away-from-home, restaurant, and café food outlet exposure; however fast food outlet exposure demonstrated

Table 4.1 Weighted sample characteristics for full analytic sample (n=35,632), percentage of participants across demographic, socio-economic, exposure and outcome measures from wave 1 with mean (95% CI) where indicated

		Men	Women	Total
	N (unweighted)	16,280	19,352	35,632
	N (weighted)	16,275	19,350	35,632
Demographic [a]				
	Age in years	47.2 (46.8,47.6)	48.9 (48.5,49.2)	48.1 (47.7,48.3)
Socioeconomic				
Education	None, GCSE or equivalent	43.1	50.4	46.7
	Further education	31.0	28.3	29.6
	Degree or higher	25.6	21.2	23.4
	Missing	.30	.11	.20
Equivalised household income				
	< £14,999	33.7	40.3	37.0
	£15,000 - £24,999	31.3	30.1	30.6
	£25,000 - £34,999	17.2	15.1	16.1
	£35,000 - £49,999	10.9	8.9	9.9
	£50,000 +	6.6	5.3	5.9
	Missing	.23	.16	.19
% Food outlet exposure [ab]				
	% Restaurant outlet density	28.9 (29.4,29.3)	28.7 (28.3,29.2)	28.8 (28.4,29.2)
	% Fast food outlet density	22.4 (22.1,22.8)	22.5 (22.2,22.8)	22.5 (22.2,22.8)
	% Café food outlet density	8.1 (7.9,8.3)	8.1 (7.9,8.3)	8.1 (7.9,8.3)
	% Total away from home food outlet density	59.4 (59.2,60.0)	59.3 (59.1,59.8)	59.4 (59.1,59.9)
Food Spending [ab]				
	£/Month equivalised food spending	206 (204,208)	203 (202,205)	205 (203,206)
	% Away from home monthly food spending	18.7 (18.4,19.1)	17.0 (16.7,17.2)	17.9 (17.6,18.1)
Adiposity				
	Obesity (BMI >= 30 kg/m2)	18.6	18.4	18.5

[a] Weighted mean (95% confidence interval)
[b] subsample for household food spending (n=22,417)

Table 4.2 Weighted sample characteristics as column percentages (unless indicated) by quintile of proportion of away-from-home food outlet density (number within 1mile of home)

	Quintile of % Away-from-home Food Outlet Exposure					
	Q1 = Lowest	Q2	Q3	Q4	Q5 = Highest	Total
N	7,740	7,143	7,214	6,909	6,626	35,632
Proportion of away-from-home outlet density (min-max)	0 - 0.50	0.50 - 0.57	0.57 – 0.63	0.63 – 0.69	0.69 - 1	0 – 1
Demographic						
Age [a]	49.5 (48.9–50.2)	47.4 (46.8–48.1)	47.9 (47.2–48.5)	47.8 (47.0-48.5)	47.4 (46.6–48.3)	48.1 (47.7–48.3)
Sex (% Male)	49.5	50.8	49.2	50.5	51.2	50.2
Ethnicity (% White)	91.2	85.4	87.4	91.4	93.0	89.8
Urban (% living in urban area)	64.7	90.1	88.9	87.4	72.7	80.4
Socio-economic						
Education (% Degree)	18.3	20.7	22.3	25.0	30.8	23.4
Equalised Income (% > 35,000)	13.5	13.2	14.5	16.8	21.0	15.9
Occupation (% Professional)	22.1	22.8	24.9	26.0	30.0	25.2
Household food spending						
£/month Equivalised food spend [ab]	202 (199-205)	196 (193-200)	202(199-205)	206 (203-210)	217 (213-220)	205 (203-206)
% Away-from-home monthly spend [a]	16.2 (15.7-16.8)	16.6 (16.0-17.2)	18.2 (17.6-18.7)	18.7 (18.2-19.2)	19.7 (19.1-20.3)	17.9 (17.6-18.1)
Adiposity & Health						
% Normal BMI (18-25 kg/m^2)	41.7	42.2	42.9	44.5	49.4	44.1
General Health (% Excellent or good)	48.6	48.2	49.0	50.5	54.9	50.2

[a] weighted mean (95% Confidence Interval)
[b] home food spending (N = 22,417)

Table 4.3 Weighted sample characteristics as column percentages (unless indicated) by quintile of proportion of restaurant outlet density (number within 1mile of home)

	Quintile of % Restaurant Food Outlet Exposure					
	Q1 = Lowest	Q2	Q3	Q4	Q5 = Highest	Total
N	7,413	6,988	7,286	6,881	7,064	35,632
Proportion of restaurant outlet density (min-max)	0 - 0.16	0.16 - 0.22	0.22 – 0.28	0.28 – 0.36	0.36 - 1	0 – 1
Demographic						
Age [a]	47.4(46.9-48.2)	47.4(46.7-48.1)	47.6(47.0-48.2)	48.3(47.5-49.1)	49.2(48.4-50.0)	48.1(47.7-48.3)
Sex (% Male)	50.4	49.2	50.2	50.7	50.5	50.2
Ethnicity (% White)	87.1	85.4	89.6	91.9	94.1	89.8
Urban (% living in urban area)	80.6	92.8	89.7	87.0	54.6	80.4
Socio-economic						
Education (% Degree)	16.3	19.8	22.7	26.4	30.5	23.4
Equalised Income (% > 35,000)	11.4	12.4	14.5	17.3	22.5	15.9
Occupation (% Professional)	18.9	12.1	24.9	27.5	30.4	25.2
Household food spending						
£/month Equivalised food spend [ab]	196 (193-199)	194 (191-198)	202 (200-205)	207 (203-210)	222 (218-226)	205 (203-206)
% Away-from-home monthly spend [a]	16.2 (15.5-16.8)	16.9 (16.2-17.5)	17.7 (17.1-18.2)	18.8 (18.1-19.4)	19.5 (19.0-20.1)	17.9 (17.6-18.1)
Adiposity & Health						
% Normal BMI (18-25 kg/m^2)	39.7	42.3	43.2	45.8	49.0	44.1
General Health (% Excellent or good)	46.5	49.1	49.1	50.9	55.1	50.2

[a] weighted mean (95% Confidence Interval)
[b] home food spending (N = 22,417)

Table 4.4 Weighted sample characteristics as column percentages (unless indicated) by quintile of proportion of fast food outlet density (within 1mile of home)

	Quintile of % Fast Food Outlet Exposure					
	Q1 = Lowest	Q2	Q3	Q4	Q5 = Highest	Total
N	7,760	6,826	7,078	6,919	7,049	35,632
Proportion of fast food outlet density (min-max)	0 – 0.16	0.16 - 0.22	0.22 – 0.26	0.26 – 0.31	0.31 - 1	0 – 1
Demographic						
Age [a]	50.4 (49.7-51.1)	47.2 (46.4-47.9)	47.2(46.6-47.9)	47.4(46.7-48.1)	47.3(46.6-48.1)	48.1(47.7-48.3)
Sex (% Male)	49.8	51.1	50.3	50.3	49.9	50.2
Ethnicity (% White)	94.7	87.5	86.0	88.3	90.9	89.8
Urban (% living in urban area)	45.5	88.5	91.8	95.2	90.9	80.4
Socio-economic						
Education (% Degree)	29.1	28.5	22.6	19.3	16.2	23.4
Equalised Income (% > 35,000)	22.6	17.5	14.3	12.1	11.1	15.9
Occupation (% Professional)	29.5	25.7	25.3	23.2	21.1	25.2
Household food spending						
£/month Equivalised food spend [ab]	222 (219-226)	206 (203-209)	199 (196-202)	197 (194-200)	195 (192-198)	205 (203-206)
% Away-from-home monthly spend [a]	19.1 (18.4-19.6)	18.7 (18.0-19.4)	17.6 (17.1-18.1)	16.8 (16.2-17.4)	16.9 (16.3-17.6)	17.9 (17.6-18.1)
Adiposity & Health						
% Normal BMI (18-25 kg/m^2)	47.4	47.4	43.9	41.9	39.5	44.1
General Health (% Excellent or good)	54.0	52.3	50.3	47.6	46.3	50.2

[a] weighted mean (95% Confidence Interval)
[b] home food spending (N = 22,417)

Table 4.5 Weighted sample characteristics as column percentages (unless indicated) by quintile of proportion of cafe outlet density (number within 1mile of home)

	Quintile of % Cafe Food Outlet Exposure					
	Q1 = Lowest	Q2	Q3	Q4	Q5 = Highest	Total
N	7,588	7,014	7,098	7,004	6,928	35,632
Proportion of cafe outlet density (min-max)	0 - 0.02	0.02 - 0.06	0.06 – 0.10	0.10 – 0.13	0.13 - 1	0 – 1
Demographic						
Age [a]	51.0 (50.3-51.7)	48.1 (47.3-48.8)	47.7 (47.0-48.4)	47.1 (46.3-47.8)	45.8 (45.1-46.4)	48.1 (47.7–48.3)
Sex (% Male)	50.0	49.8	49.8	51.1	50.4	50.2
Ethnicity (% White)	96.5	89.2	87.5	86.3	88.0	89.8
Urban (% living in urban area)	45.7	94.3	89.9	91.7	88.1	80.4
Socio-economic						
Education (% Degree)	19.7	17.9	21.4	26.3	32.3	23.4
Equalised Income (% > 35,000)	15.9	21.1	13.6	16.7	20.7	15.9
Occupation (% Professional)	24.4	22.2	23.9	26.1	29.1	25.2
Household food spending						
£/month Equivalised food spend [ab]	210 (206-214)	196 (193-199)	201 (198-205)	201 (198-204)	214 (210-218)	205 (203-206)
% Away-from-home monthly spend [a]	17.1 (16.5-17.7)	16.6 (16.1-17.2)	17.8 (17.2-18.3)	18.2 (17.7-18.7)	19.8 (19.1-20.5)	17.9 (17.7-18.1)
Adiposity & Health						
% Normal BMI (18-25 kg/m^2)	41.9	40.9	42.9	45.6	49.8	44.1
General Health (% Excellent or good)	49.9	47.4	49.5	50.1	54.2	50.2

[a] weighted mean (95% Confidence Interval)
[b] home food spending (N = 22,417)

the opposite pattern with those in the highest quintile belonging to the least socio-economically-advantaged groups (lower education, income and occupational status).

4.4.2 Characterising types of exposure

In addition to the descriptive sample characteristics the percentage contribution made by each food outlet exposure type (i.e. restaurants, fast food and cafés) to overall away-from-home exposure is summarised. **Figure 1a** shows stacked weighted mean percentage for away-from-home food outlet type stratified by level of away-from-home food outlet exposure. **Figure 1b** shows normalised weighted mean percentage contribution of combined retail type stratified by level of away-from-home energy intake. While mean percentage of food outlet exposure was higher with greater away-from-home exposure (1a), the contribution of food outlet type toward total mean away-from-home density across exposure levels, with restaurant and café contribution being higher with greater away-from-home food outlet exposure; and fast food lessening across tertiles (1b).

4.4.3 Food outlet exposure, food spend and obesity

Regression analyses for total away-from-home food outlet exposure (**Table 4.6**) showed the two highest quintiles were related to higher odds of being a high away-from-home food spender (OR=1.12, 95% CI [1.00,1.24] and 1.16, [1.04,1.30], respectively) and lower odds of obesity (0.86, [0.76,0.96] and 0.85, [0.76,0.95], respectively).

For subcategories of away-from-home food outlets (**Table 4.7**), adjusted models showed that the highest level of fast food exposure was associated with higher odds of obesity (1.34, [1.18, 1.51]). However, the highest levels of restaurant and café exposure were associated with lower odds of obesity (0.78 [0.69, 0.88] and (0.84 [0.74, 0.95], respectively. Adjusting models for confounding factors attenuated the magnitude of associations; all remained statistically significant after adjustment.

Alternative multivariable models adding ethnicity and rurality of residence did not significantly alter results (results not shown). Additionally, although not the focus of this analysis, descriptive tables with odds ratios and 95% CIs for away-from-home food spending and obesity status are available in **chapter 4 appendix**. Results showed lower odds of obesity for the highest tertile (‘high spender’) of away-from-home food

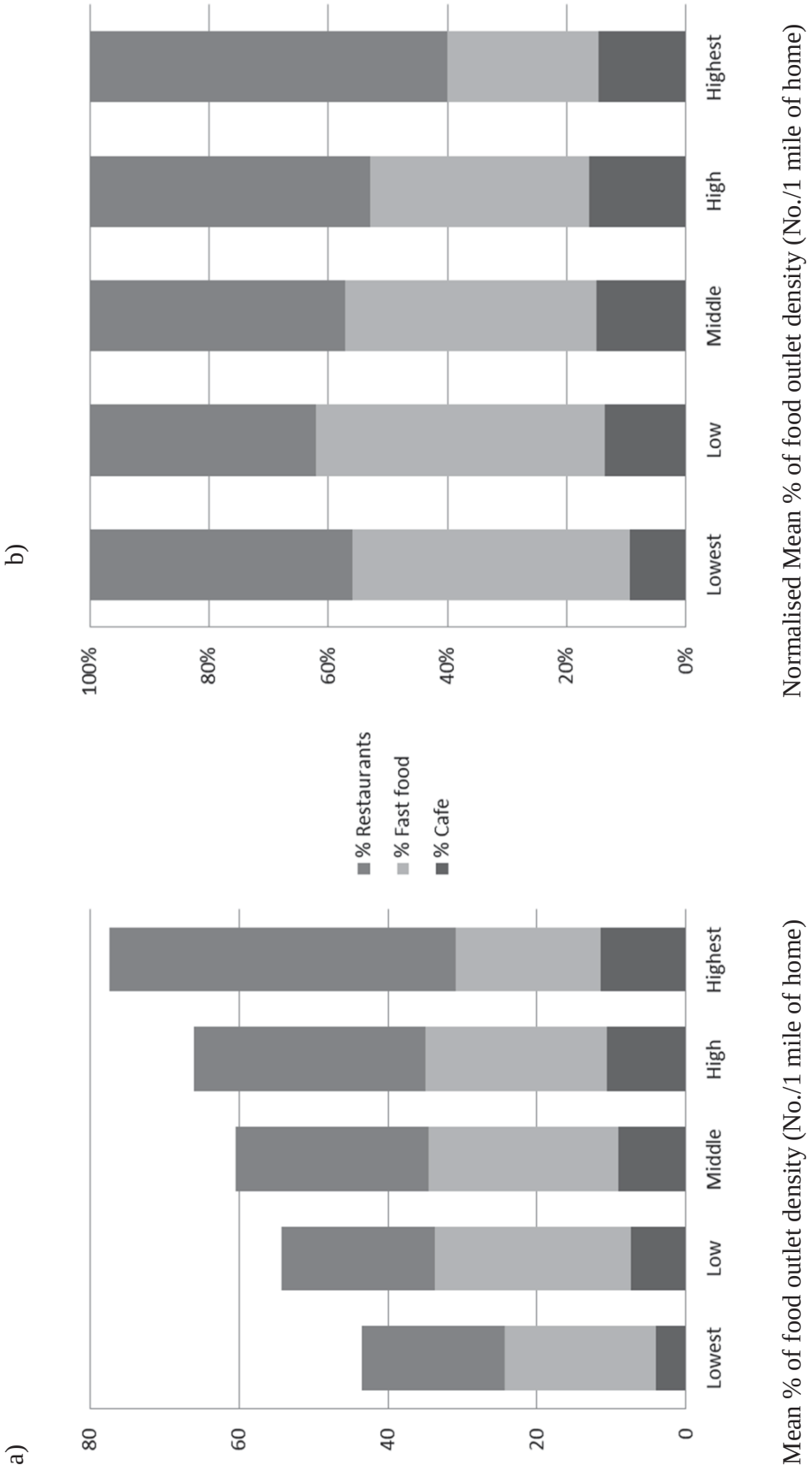


Figure 4.1 a) Weighted stacked mean percentage food outlet density for quintile of away-from-home exposure for each food outlet type, b) normalised contribution of mean percentage food outlet density for type of food outlets by proportion of away-from-home exposure quintile

Table 4.6 Odds ratio and 95% confidence intervals for high (top tertile) % of away-from-home food spending (n = 22,417) and obeisty (n = 35,632) by quintile of proportion of total away-from-home food outlets exposure

Proportion of total away-from-home density	Odds of high monthly % away from home food spending [1]			Odds of obesity [2]		
	Crude	Model 1 [3]	Model 2 [5]	Crude	Model 1 [4]	Model 2 [5]
Q1	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)
Q2	0.99 [0.89, 1.09]	0.96 [0.87, 1.07]	0.96 [0.85, 1.06]	0.98 [0.89, 1.08]	0.98 [0.88, 1.08]	0.98 [0.89, 1.08]
Q3	1.17 ** [1.06, 1.3]	1.12 * [1.01, 1.25]	1.09 [0.98, 1.21]	0.93 [0.84, 1.03]	0.93 [0.84, 1.03]	0.94 [0.84, 1.04]
Q4	1.28 *** [1.16, 1.42]	1.19 *** [1.07, 1.32]	1.12 * [1, 1.24]	0.83 ** [0.75, 0.92]	0.84 ** [0.76, 0.94]	0.86 ** [0.78, 0.96]
Q5	1.51 *** [1.36, 1.68]	1.26 *** [1.13, 1.41]	1.16 ** [1.04, 1.3]	0.74 *** [0.67, 0.81]	0.82 *** [0.73, 0.92]	0.85 ** [0.76, 0.95]

[1] % of away from home food spending was divided into tertiles, with the highest tertile being 'high' in % of away-from-home food spending
[2] Obesity included participants with a BMI >= 30 kg/m^2
[3] Adjusted for age, sex, total number of food outlets for restaurant, fast food, cafe, other and equivalised total food spend
[4] Adjusted for age, sex, total number of food outlets for restaurant, fast food, cafe, other, and reported general health
[5] Additionally adjusted for education, equivalised income and occupation
*p<0.05, **p<0.01, ***p<0.001

Table 4.7 Odds ratios and 95% confidence intervals for obesity (n = 35,632) by quintile of proportion of restaurant, fast food and cafe outlet exposure

Proportion of away-from-home food outlet density	Odds of obesity [2]		
	Crude	Model 1 [3]	Model 2 [4]
Restaurants			
Q1	1.00 (-)	1.00 (-)	1.00 (-)
Q2	0.91 [0.82, 1.01]	0.94 [0.85, 1.05]	0.95 [0.85, 1.05]
Q3	0.85 ** [0.77, 0.94]	0.88 * [0.79, 0.97]	0.89 * [0.8, 0.98]
Q4	0.78 *** [0.7, 0.86]	0.84 ** [0.75, 0.94]	0.86 ** [0.77, 0.96]
Q5	0.65 *** [0.58, 0.72]	0.74 *** [0.66, 0.84]	0.78 *** [0.69, 0.88]
Fast food			
Q1	1.00 (-)	1.00 (-)	1.00 (-)
Q2	1.09 [0.98, 1.22]	1.14 * [1.02, 1.28]	1.13 * [1.01, 1.26]
Q3	1.26 *** [1.14, 1.4]	1.25 *** [1.12, 1.4]	1.19 *** [1.08, 1.35]
Q4	1.31 *** [1.18, 1.46]	1.24 *** [1.1, 1.41]	1.21 ** [1.05, 1.35]
Q5	1.51 *** [1.37, 1.67]	1.40 *** [1.24, 1.58]	1.34 *** [1.18, 1.51]
Cafe			
Q1	1.00 (-)	1.00 (-)	1.00 (-)
Q2	1.08 [0.99, 1.18]	1.05 [0.95, 1.15]	1.04 [0.94, 1.14]
Q3	1.03 [0.94, 1.14]	1.03 [0.93, 1.14]	1.03 [0.93, 1.14]
Q4	0.90 * [0.82, 1]	0.91 [0.82, 1.02]	0.93 [0.83, 1.03]
Q5	0.75 ** [0.68, 0.83]	0.82 ** [0.72, 0.92]	0.84 * [0.74, 0.95]

[1] % of away-from-home food spending was divided into tertiles, the highest tertile being 'high' in % of away-from-home food spending
[2] Obesity included participants with a BMI >= 30 kg/m^2
[3] Adjusted for age, sex, total number of food outlets for restaurant, fast food, cafe, other, and reported general health
[4] Additionally adjusted for education, equivalised income and occupation
*p<0.05, **p<0.01, ***p<0.001

spending (0.85 [0.78, 0.93]). Results of regression models examining associations between a 'high spender' and diet from wave two of the UKHLS is also provided in the appendix, which showed no association between high away-from-home food spending and decreased fruit and vegetable consumption.

4.5 Discussion

Using a nationally representative sample of adults, and the novel measure of household food spending, the purpose of this work was to examine associations between exposure to density of away-from-home food outlets, away-from-home food spending and obesity. Specifically, we observed that the greatest away-from-home food outlet density around the home was associated with greater odds of being a high away-from-home food spender, and lesser odds of obesity. Associations demonstrated those in the highest exposure group were at a 16% higher odds of being a high away-from-home food spender and 15% lower odds of being obese. In addition to overall away-from-home food outlet exposure, we examined associations between three different away-from-home food outlets: restaurants, fast food outlets and cafés, revealing differential associations with obesity regardless of model adjustment. Those in the highest fast food outlet exposure group were positively associated with obesity (34% higher odds), while those in the highest restaurant and café exposure group were negatively associated with obesity (22% and 16% lower odds, respectively).

These results are novel, suggesting that the greater the exposure to away-from-home food outlets, the more likely it is that people have a greater proportion of household food spend directed toward away-from-home food sources. However, when examining the association between total away-from-home food outlet exposure and obesity, a negative association was found. This was partly explained by the differential associations between types of food outlets; the overall negative association between away-from-home food outlet exposure and obesity was driven by both restaurant and café exposure. Density of fast food outlets was the only outlet with a positive association with obesity. This is also congruent with previous research examining total number of fast food outlets around the home and along commuting routes with obesity.[66,68,182] While restaurants and cafés exposure tended to be greatest for the more socio-economically advantaged, fast food exposure was greatest among less socio-economically advantaged people. While the

apparent protective effect of exposure to restaurants or cafés was not eliminated during model adjustment for education, income or occupation, the importance of this pattern may suggest residual confounding. For example, the built environment may have other factors that could confound the relationship between food outlet density and obesity. An intermediary factor between food outlet density and usage could be other neighbourhood characteristics that encourage or discourage residents' from using food outlets, such as safe surroundings, community walkability and aesthetics.[189]

Residual confounding is a common challenging in research that examines structural factors and health. Few studies have used longitudinal data to explore mechanisms or issues of causality[39,190,191] including self-selection or reverse causation (i.e. individual preferences drive selection of a neighbourhood that provides a built environment that supports their preferences).[192] However, a more recent and methodologically-robust study found that exposure to takeaway food outlets at home, work and along commuting routes was positively and systematically associated with greater consumption of takeaway food, body mass index and odds of obesity.[193] These geographic approaches provide some promise, however current evaluations of the effects of local neighbourhood planning policies on health are currently lacking.[194]

In addition to structural factors alone, there is evidence to suggest that personal preferences may interact to drive away-from-home food consumption.[195] Consumers report preferences for fast food outlets that are convenient, easy to access and provide tasty foods, with availability of nutrition foods being the least important factor.[169] Additionally, it has been suggested that individual preferences are socio-economically patterned with socio-economically-advantaged individuals possessing more material, psychosocial and time-related resources, to select food outlets and food items regardless of what is on the menu or ease of access and creating constraints for socio-economically-disadvantaged individuals.[170,171] Therefore, is has been suggested that more effort should be applied toward isolating the less healthy aspects of meals served at these locations, and addressing them directly through improving food provision.[196,197] However, the policy levers for this avenue of public health intervention are unclear, requiring the direct cooperation of the commercial sector.

4.5.1 Methodological considerations and limitations

This work has several strengths, including a nationally representative sample of adults to examine density of away-from-home food outlets, with data to unpack away-from-home food outlets into restaurants, fast food and cafes. However, food outlet exposure was estimated based upon neighbourhoods, defined as within 1 mile of participant's home address. This may overestimate some forms of outlet exposure, particularly if there are physical barriers in the environment not accounted for using the buffer method, and underestimate other forms of exposure, particularly if individual use of these outlets are done from the workplace or while commuting between locations.[52] Additionally, the ONS POI data for food location is not a routinely validated data set, 60% of the data is reported as 'ground truthed', however given the size of the data it is often not feasible to check each location. It is also unknown how quickly food outlets change, and we used 2014 data and made an assumption that the time lag between UKLHS and ONS POI data was not enough to change quintile of food environments, however this assumption is not based on a validation study for the UK.

Additionally, a second limitation of this work was the use of self-report data. This included estimates of household food spending, and height and weight. In order to improve spending data, mean household food spend was benchmarked against Living Cost and Food data. It is also known that individuals overestimate their height and underestimate their weight leading to a likelihood of underestimation of obese individuals within this sample compared with national averages. This however should not alter findings or assumptions, as this work sought to identify associations, which suggest these results could be conservative. For example, people often overestimate their height and under estimate their weight, resulting in an underreporting of body mass index suggesting this sample may be an underestimation of obesity status in the general population.[198]

Also, in the obesity models, we were unable to adjust for energy expenditure or level of physical activity, which is likely an important confounder. Finally, smoking status was not available for this wave of understanding society; therefore general reported health was included in obesity models to attempt to capture a correlate of physically active, non-smoking individuals.

4.6 Conclusion

Our findings suggest that while a higher level of away-from-home food outlet exposure is associated with high away-from-home food spending, associations with obesity are not as straightforward. Specifically, obesity was found to be exclusively associated with higher exposure to fast food outlets, regardless of socio-economic position. These results suggest that population-level health interventions, designed to modify exposure to outlets to reduce their usage, may be most effective if focussed on specific outlet types. Further research is required to better understand how and why individuals use specific outlets within a broader social, economic and environmental context.

5 Exploring change in exposure to away-from-home food outlets using residential relocation

This work has been accepted for presentation as: Penney TL, Coulter R, Monsivais P (2017) *Can we use residential relocation to study change in local food outlet exposure? Getting at causality in built environments and health*. ISBNPA Conference 2017. Victoria Canada. June 2017 (oral). A manuscript is in development for submission.

With the limitations of cross-sectional analyses to examine change in away-from-home food availability and outcomes, chapter 5 involves preliminary longitudinal analysis using adults from five waves of the UKHLS study to explore the utility of residential relocation as a means of examining the effect of change in exposure to food outlets on diet and obesity.

5.1 Abstract

Background: Local food availability has been linked with diet and weight status in adults. However, unpacking causal factors related to changing food environments across the population is a challenge. One possible approach is to use naturally occurring

residential relocation to track changes in food environment exposure, while accounting for accompanying life events that could confound potential associations. This study explores the utility of residential relocation within a longitudinal panel survey, linked with national food outlet data, to examine socio-demographic, socio-economic differences across movers and non-mover, and direction of change food outlet density for movers.

Method: A descriptive analysis of longitudinal data from a pool of unique participants across Waves 1-5 of the UK Household Longitudinal Study (UKHLS) (n=55,527 adults aged >= 19y) linked with food outlet exposure data from Ordnance Survey. Differences in baseline and change in socio-demographics, socio-economic factors, and baseline food outlet exposure for movers and non-movers are summarised. For movers only, direction of change in food outlet exposure and changes in their socio-demographic, socio-economic circumstances are also summarised.

Results: Movers and non-movers differed across several demographic and socio-economic circumstances at baseline. Movers were more likely to experience a change in demographic characteristics (OR 3.49 95% CI 3.23-3.78) or socio-economic circumstances (OR 3.11 95% CI 2.95-3.29) compared to non-movers. Movers and non-movers did not differ in their baseline food outlet exposure, and movers with a change in food outlet exposure (54%) were distributed equally between an increase (27%) and decrease (27%) in exposure after relocation.

Conclusions: For movers who experience a change in food outlet exposure, increases and decreases in exposure were evenly distributed. However, movers differ from non-movers on a range of baseline demographic characteristics and socio-economic circumstances and experience more changes in life circumstances than non-movers. This should be accounted for when using residential relocation to study the effect of change in local food environment exposure on behaviour and health outcomes.

5.2 Introduction

Poor diet and obesity are global epidemics that present a significant challenge for public health and the prevention of chronic disease.[130] Addressing unhealthy diets and the development of obesity at the population level requires a shift from a focus on individual

determinants toward the policies and environmental forces that shape behaviour and health for everyone[199,200], with our current obesogenic food environment as a potential point of public health intervention.[39]

Meals consumed away-from-home including at restaurants, fast food outlets and cafes are thought to contribute to an unhealthy dietary pattern and obesity[73,139] through increased portion sizes and the availability of meals low in macronutrients but high in fat, sodium and calories.[143,145,146] Given an increasingly time-constrained population[171] and increased frequency of meals eaten away-from-home[132], characteristics of the built environment represent an important structural context for food related decisions[201,202]. The proliferation of away-from-home food outlets[43], particularly the density of these outlets surrounding individuals at home may act as a precursor to food choice, diet and obesity.[190,203–205] However, improving our causal understanding of how the availability of food outlets might influence diet behaviour and weight status at the population level includes a complex set of factors that may require a novel approach to the study of built environments effects on health.

5.2.1 Causality, the built environment and health: challenges for studying change in the local food availability of away-from-home food outlets

An increasing number of empirical studies have contributed to improving our understanding of how the built environment could support dietary behaviour and health. In particular, while positive associations between the spatial aspect of local food availability (i.e. the density of food outlets surrounding home), poor diet and obesity have been reported[66,68,181,182], much of the evidence synthesis concludes that the evidence base is inconsistent, with an over reliance on cross-sectional evidence, raising questions about the causal relationships that underlie these correlations.[39,190,191]

To address this mixed evidence, some reviews and studies have begun focusing on methodological issues including the heterogeneity of exposure estimation, taking into account spatial measures, geographic units, and buffers around individual addresses[39,190], the quality of dietary measurement[39,191] and the use of measured height and weight to estimate obesity.[190,191] However, to date, few studies have addressed the limitation of study design, particularly the potential to use longitudinal studies to explore mechanisms or issues of causality[39,190,191] including self-selection or reverse causation (i.e. individual

preferences drive selection of a neighbourhood that provides a built environment that supports their preferences).[192]

However, the paucity of longitudinal study designs or studies involving causal explanation or causal estimation is not surprising, and reflects challenges reported in the built environment literature more broadly.[202,206–208] Among the more practical barriers to improved causal understanding and examining mechanisms, is the availability of longitudinal built environment data[209], particularly valid and reliable data[210] that can then be linked to individual level behaviour and health data with important covariates, potential moderators and mediators. Particular to the field of local food availability, while there is evidence to suggest that the 'foodscape' (i.e. the number and composition of food outlets) changes over time, it is likely to happen slowly, with any change large enough to affect health occurring over decades.[211,212] This makes exploration of causal effects related to the number and composition of food outlets on behaviour and health impractical.

An alternative approach relies on the evaluation of naturally occurring environmental changes as the result of policy interventions, also called 'natural experiments'.[129,213] For example, the effect of introducing a supermarket in a deprived area could be evaluated to assess the impact of a rapid change in the food environment on the diet behaviour and health of local residents.[114] However, employing this approach for the study of away--from-home food outlets (as opposed to outlets that people use to purchase food for preparation at home like supermarkets and green grocers) is likely to present additional challenges. For example, any policy driven intervention for the proliferation of 'unhealthy' food outlets, such as fast food outlets, would fall under the jurisdiction of local zoning regulations to restrict their growth, rather than the direct removal or introduction of outlets.[194] From the point of view of evaluating this kind of 'natural experiment', the dose is the absence of new outlets, which may not provide the amount of measurable change needed to explore causality.[214] Therefore, studying change in availability of food outlets that contributes to away-from-home eating is likely to require a more novel approach. One such approach could include the use of naturally occurring residential relocation to study change in food availability, diet and health.

5.2.2 Residential relocation for studying change in away-from-home local food availability, diet and health

Exploring the compositional and contextual circumstance of residential mobility is a long-standing field of study[215], with mobility having its own complex relationship with health outcomes.[216] Some residential mobility and health studies suggest that mobility is positively associated with health[217]; while other studies demonstrate a negative association[218], suggesting that the factors driving mobility and residential relocation are complex and multi-factorial.[219] There is evidence to suggest that age[220], indicators of socio-economic position[221–223], housing tenure[224] and marital status[225] are linked with relocation, and are largely the same factors that determine patterning of health outcomes more broadly, heavily confounded by underlying latent differences between groups of people and their life stage. Therefore, in order to use residential relocation to explore causation for the built environment and health, we need to better understand the differences between movers and non-movers, not just in relation to their environmental exposure, but also the life circumstances that surround moving house in general.

With respect to environmental exposure, it is not yet known if people move to more supportive of less supportive food environments, and depending on that polarity – whether the food environment is a consequence of deliberate or incidental selection. Some evidence suggests that any systematic change in exposure to food outlets as the result of a move is likely an incidental outcome of neighbourhood selection, given that the primary drivers of neighbourhood choice include dwelling characteristics (i.e. costs, housing size etc.), and he ethnic composition and physical characteristics of the neighbourhood.[226,227] However, this has yet to be explored empirically.

Therefore, the purpose of this study is to determine the utility of residential relocation to examine the effect of change in the built environment for food on diet and health. Specifically, to examine if movers and non-movers differ by 1) demographic and socio-economic factors 2) changes in socio-demographic or socio-economic factors within the same time period, 3) local food outlet density, and 4) if people who relocate move to neighbourhoods that have an increase, decrease or no change in fast food outlet density. Fast food outlets were selected as the result of the previous chapters demonstrating the link between fast food use and exposure, and poor diet and obesity.

5.3 Methods

5.3.1 Study design and population

This work included a descriptive analysis of a longitudinal sample of adults living in England, United Kingdom.

5.3.1.1 Data source and participants

Data from the secure access UK Household Longitudinal Study (UKHLS) were used.[228] UKHLS is an annual panel survey of each adult member of a nationally representative sample which began in 2009-2010 including over 40,000 UK households at baseline (57% household and 82% individual response rates).[184] Details of the study and its sampling strategy are reported elsewhere.[185] In short, participants are surveyed annually to collect information regarding demographics, socio-economic circumstances, and behavioural and health related factors using a computer assisted personal interview with the household questionnaire answered by a reference person, and a main individual questionnaire answered by each adult within the household.[184]

Wave 1 of the UKHLS is followed up annually with Wave 5 collection occurring in 2013-2014, with additional members joining the panel based on changes in relationships and living arrangement of the original sample members. For these analyses, adults (aged >= 19 years) from Wave 1 to 5 living in England from the general population sample were included (n=55,527). The study sought to investigate participants whom experienced at least one move (i.e. change in home grid reference) any time between Wave 1 and Wave 5 (n=7,411) compared to those who did not (n=48,116) (**chapter 5 appendix** for sample flow diagram). Ethical approval was not required for the analysis of secondary data presented here, but was obtained by UKHLS for their data collection.

5.3.2 Measurement and estimation

5.3.2.1 Demographic, socio-economic characteristics

Self-report survey questions were used to assess socio-demographic characteristics including age categorised as ’19-24’, ’25-35’, ‘35-44’, ‘45-54’, ’55-64’ ‘65+’, sex and marital status categorised as ‘Single or never married’, ‘Married or partnered’, ‘Divorced

or separated', 'Widowed'; children < 16 years in household as 'No children', '1 child', '2 children' or '3 or more children'. Socio-economic circumstances were represented using three indicators including educational attainment classified as 'None', 'GCSE or equivalent', 'A-Level', 'Further education', 'Degree or equivalent'; household income equivalised for household composition, classified as '£14,999 or below', '£15,000 – £24,999', '£25,000 - £34,999', '£35,000 – £49,999', '£50,000 and above'; occupation, classified as 'Routine or manual', 'Intermediate' and 'Higher managerial'; being in paid employment, classified as 'Yes' or 'No', employment status, classified as 'Full time', 'Part time', 'Not applicable'; home ownership, classified as 'Owned', 'Renting' or 'Other' and lastly, missing values were categorised as required.[162]

5.3.2.2 Change in demographic and socio-economic circumstances

Change in marital status, children <16 within the household, equivalised household income, occupational class, paid employment, employment status and home ownership was calculated as any change in variable category between any of the five waves. For example, if a participant moved from 'Full time' to 'Part time' between Wave 2 and 3, they were counted as having a change in paid employment. Similarly if a participant moved from '£15,000-£24,999' income range to '£35,000-£49,999' they were counted as having a change in household income. As the purpose of this work was to explore the utility of residential mobility to study change in neighbourhood food environment exposure, the direction and magnitude of change in circumstances was not captured at this stage.

5.3.2.3 Exposure to food outlet density

5.3.2.3.1 Food outlet data and classification

Data relating to the location of food outlets were obtained through the Points of Interest (POI) database from Ordnance Survey. Each feature is provided with a national grid coordinates. The data are resupplied four times per year with data representing POI from June-August 2014. POI data are provided with a range of variables, methods of measurement and sources including a unique reference number, feature name, classification code, latitude, longitude, positional accuracy rating and address verification. The use of ordnance survey as a secondary data sources for determining food

environment exposure has been found to have reasonable agreement to 'ground truth'.[42,186,187]

Away-from-home food outlets were classified based on previous work[42], and divided into three subcategories: restaurants, fast food and cafés. Example restaurant outlets include Bella Italia, Weatherspoon or Nando's, fast food outlets include McDonalds, Burger King or burger vans, and cafés outlets include Café Nero, Pret a Manger and Costa. All other food outlets (e.g. supermarkets, convenience and green grocers etc.) were classified as 'Other' (**chapter 5 appendix** for food outlet frequency and classification). Food sources where food provision was not the primary purpose or there was no service directly available to the public were excluded (e.g. workplace cafeterias, cinemas or recreation facilities).

5.3.2.3.2 Estimation of exposure to food outlet density

Food outlet density was estimated using home neighbourhood, defined as a buffer with a 1 mile Euclidean (straight line) radius centred on participant British National Grid postcode grid reference (at 1m resolution) for the unit postcode of each household surveyed, derived from the ONS National Statistics Postcode Directory, provided through UKHLS secure data access. This distance is based upon previous work suggesting a reasonable reflection of food purchasing behaviours for adults in the UK.[50] Number of food outlets were then counted within participant neighbourhood as a measure of outlet density using ArcGIS. Proportion of food outlet density was calculated for total away-from-home outlets, and then away-from-home food outlets separately for restaurant, fast food and café (e.g. density of restaurant food outlets / total food outlets) divided into Quintiles (Q1 = Lowest and Q5 = Highest) of estimated neighbourhood food outlet exposure.

5.3.2.4 Change in exposure to food outlet density

Change in food outlet exposure was calculated using two metrics: change in proportion and change in quintile. Specifically, subtracting the proportion of food outlets after move from the proportion before the move, and subtracting quintile of exposure after move, from the quintile before the move.

5.3.3 Statistical analysis

Summary statistics were used to report percentages of movers and non-movers at baseline and with changes across socio-demographic characteristics, socio-economic circumstances or food outlet density at baseline or those with a decrease, no change or increase in food outlet density for movers only. Binomial logistic regression was used to examine odds of change in socio-demographic and socio-economic circumstances for movers versus non-movers. All statistical analyses were carried out in STATA version 14.[163]

5.4 Results

The overall unweighted sample included 55,527 adults (26,328, 47.2% men) with representation from a range of socio-economic positions (45.7% with low educational attainment versus 22.3% with the highest; 38.4% from the lowest equivalised household income category (< £14,999) versus 5.4% in the highest (> £50,000) (**Table 5.1**).

5.4.1 Baseline and change in demographic and socio-economic circumstances

The sample characteristics presented in **Figure 5.1** indicate that at baseline (i.e. the first wave a participant was included) those who went on to become movers differed from those who did not become movers on a range of socio-demographic and socio-economic indicators. In particular, movers tended to be younger and single, never married, more highly educated, in paid employment, full-time employment, a higher occupational class and renters. **Table 5.2** shows that movers were also more likely to experience any change in demographic characteristics including category of marital status (OR 3.49 95% CI 3.23-3.78), children at home under the age of 16 (OR 2.88 95% CI 2.72-3.06), or socio-economic circumstances including a change in category of equivalised household income (OR 3.11 95% CI 2.95-3.29), paid employment (OR 2.29 95% CI 2.16-2.43), full time status (OR 2.75 95% CI 2.61-2.91), occupational class (OR 2.24 95% CI 2.13-2.35) or house ownership (OR 40.8 95% CI 37.0-45.0) compared to non-movers.

Table 5.1 Sample characteristics for full analytic sample (n=55,527), percentage of participants across demographic, socio-economic and food outlet density measures from baseline wave (mean (95% CI) where indicated)

		Men	Women	Total
	N	26,238	29,289	55,527
Demographic [a]				
	Age	44.6 (44.4,44.8)	44.9 (44.7,45.1)	44.8 (44.6,44.9)
Socioeconomic				
Education	None	13.9	17.4	15.8
	GCSE or equivalent	29.4	30.4	29.9
	A-level	23.1	18.8	20.8
	Other further	8.9	11.7	10.4
	Degree or higher	23.9	21.0	22.3
	Missing	.66	.49	.57
Equivalised household income				
	< £14,999	35.9	40.6	38.4
	£15,000 - £24,999	30.9	30.1	30.4
	£25,000 - £34,999	17.0	15.4	16.1
	£35,000 - £49,999	10.0	8.5	9.2
	£50,000 +	5.9	5.1	5.4
	Missing	.19	.15	.17
% Food outlet density [a]				
	% Restaurant outlet density	28.3 (28.1,28.5)	28.4 (28.2,28.6)	28.4 (28.2,28.5)
	% Fats food outlet density	23.1 (23.0,23.3)	23.2 (23.1,23.3)	23.2 (23.1,23.2)
	% Café food outlet density	8.43 (8.31,8.42)	8.43 (8.33,8.51)	8.44 (8.36,8.51)
	% Total away-from-home food outlet density	59.2 (59.1,59.4)	59.2 (59.0,59.3)	59.2 (59.1,59.3)
Moving between any wave				
	Stayed non-mover	47.5	52.4	86.65
	Become mover	45.4	54.5	13.35

[a] Mean (95% confidence interval)

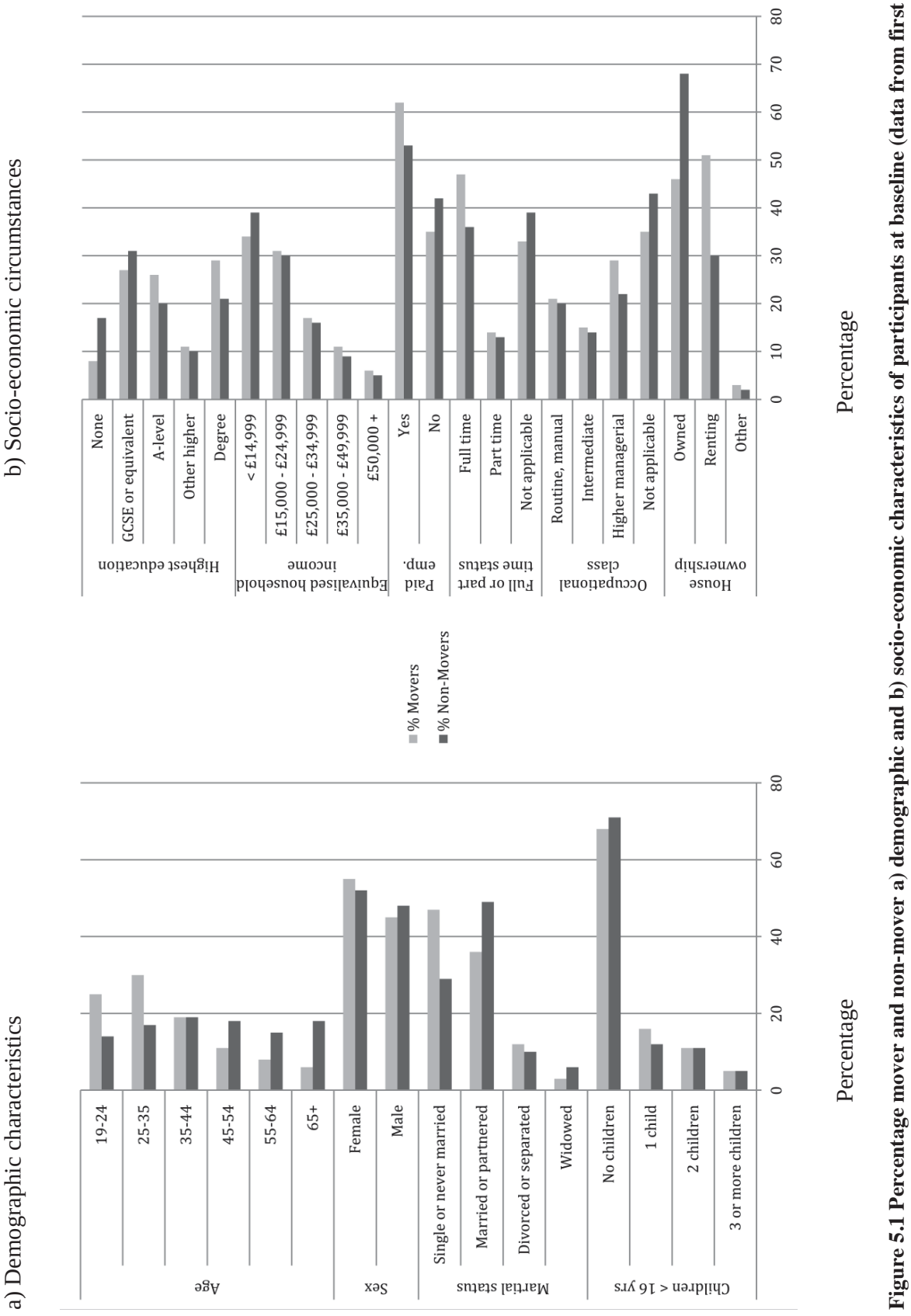


Figure 5.1 Percentage mover and non-mover a) demographic and b) socio-economic characteristics of participants at baseline (data from first identifiable wave)

Table 5.2 Change in demographic and socio-economic circumstances between Wave 1 and Wave 5 (n=55,527) across non-movers (n=48,116) and movers (n=7,411), with crude odds and 95% CI for movers experiencing change

Change any wave		% Non-Movers	% Movers	% Total	Odds	(95% CI)
Demographic						
	Martial status	5	15	6	3.49	[3.23-3.78]
	Children < 16 years	11	27	13	2.88	[2.72-3.06]
Socio-economic						
	Equivalised household income	47	74	50	3.11	[2.95-3.29]
	Paid employment	12	25	14	2.29	[2.16-2.43]
	Full or part time status	49	72	52	2.75	[2.61-2.91]
	Occupational class	23	40	25	2.24	[2.13-2.35]
	House ownership	1	32	5	40.8	[37.0-45.0]

5.4.2 Baseline and change in food outlet density

Food outlet density at baseline presented in **Table 5.3** indicated no differences in mean proportion of away-from-home food outlets, or specific away-from-home outlets including restaurants, fast food or café outlets for movers and non-movers. Similarly, there were no difference in those least (quintile 1) or most (quintile 5) exposed.

Figure 5.2 shows the percentage of movers with an increase, decrease or no change in food outlet density before and after residential move. The results in figure a) show the proportion of the sample with a percentage change in food outlet density, and figure b) shows the proportion of the sample with a change in quintile of food outlet density. The results calculated using percentage of change in food outlet density include a smaller proportion of the sample being categorised as experiencing 'no change' in exposure (18% for all away-from-home outlets, 20% for restaurants, 21% for fast food outlets and 23% for cafés) compared to the results calculated as a change in quintile. These showed a larger proportion of the sample being categorised as experiencing 'no change' in exposure (46% for all away-from-home outlets, 48% for restaurants, 50% for fast food outlets and 51% for cafés). The proportion of the sample that experienced a decrease or increase in food outlet density after relocation was relatively consistent. For example, 41% of the sample of movers experienced a decrease or an increase in percentage change in away-from-home outlet density.

5.5 Discussion

Using a longitudinal panel survey, we examined the utility of naturally occurring residential mobility to investigate causality to inform future research for understanding the relationship between the local food environment, diet and health. With respect to a range of baseline socio-demographic and socio-economic factors, we found systematic differences between people who became movers compared to those who did not. Additionally, those who experienced changes in social or economic circumstances were also more likely to be movers, suggesting that moving may be a direct precursor or consequence of other important life events. These results support much of the literature that examines the effect of residential relocation and mobility on health and the motivations for relocation.[216] Although we found that change in a range of circumstances was more likely in movers, we did not explore the polarity of those changes, which are

Table 5.3 Food outlet density (mean proportion (sd) and N (%) for lowest quintile (1) and highest quintile (5) of food outlet density around the home) for participants at baseline wave (N-55,527) for movers (N=48,116) and non-movers (7,411)

	Mean Proportion (sd) of food outlet density		N (%) Lowest Proportion of food outlet density		N (%) Highest Proportion of food outlet density	
Food outlet type	**Non-Movers**	**Movers**	**Non-Movers**	**Movers**	**Non-Movers**	**Movers**
Restaurants	28 (16)	29 (15)	9,720 (22)	1,394 (19)	9,344 (20)	1,510 (21)
Fast food	23 (10)	23 (10)	9,102 (19)	1,363 (19)	9,501 (20)	1,385 (19)
Cafe	8 (7)	9 (6)	9,071 (19)	1,298 (18)	9,584 (20)	1,679 (23)
Away-from-home	59 (15)	60 (15)	9,720 (20)	1,394 (19)	9,344 (20)	1,510 (21)

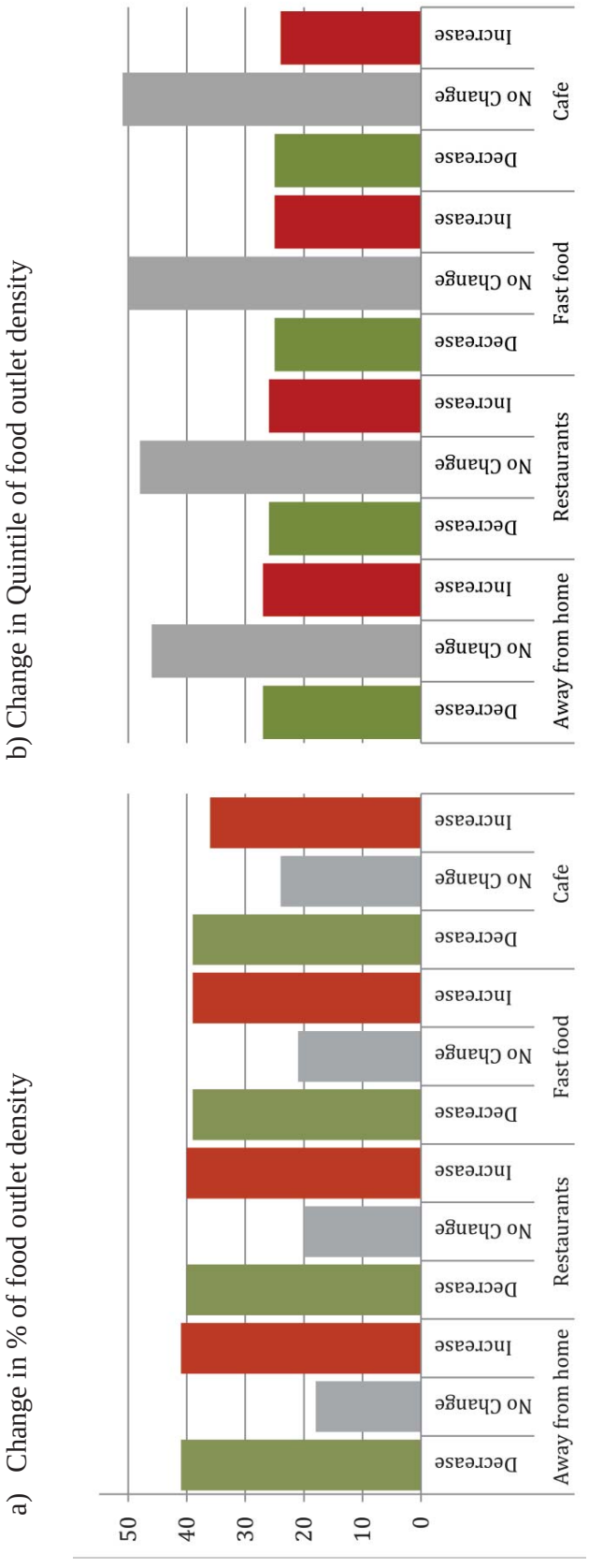


Figure 5.2 Type of change in food outlet density (%, Quintile) movers (n=7,411)

likely to have differential effects on outcomes. For instance, it is expected that if the direct motivating force behind relocation is a positive event (i.e. a job promotion or marriage) versus a negative event (i.e. job loss or death of a partner) than any effects of the built environment on behaviour and health are likely confounded by these significant life events.[221,222,225,229] Further work will need to explore these changes in more detail including their directionality. For example, diet quality and food outlet exposure has been shown to heavily socio-economically patterned[230,231], with additional evidence of effects in change in some socio-economically indicators including employment acting as a precursor to weight gain.[232]

Local food outlet density was examined using both the percentage of total away-from-home food outlets, and categorised by outlet type including restaurants, fast food outlets, cafes and ranked from highest exposure (quintile 5) to lowest exposure (quintile 1). These metrics of food outlet exposure did not vary greatly at baseline between movers and non-movers or by away-from-home food outlet type. This suggests that while the magnitude of exposure was varied, baseline exposure was similar for movers and non-movers. Similarly, a higher percentage of movers experienced some change in food outlet exposure (i.e. an increase or decrease). Those with a change in exposure were evenly distributed between an increase (i.e. more away-from-home food outlet density) and decrease (i.e. less away-from-home food outlet density) in exposure. As one would expect, using percentage rather than quintile as a metric for change quantified a higher percentage of changes in exposure, while using a change in quintile, quantified less change. Given the cross-sectional nature of the food outlet data, and the yet unknown amount of regular food outlet change[211,212], the latter is likely a more reasonable estimate of meaningful change in food outlet exposure, particular where previous cross-sectional analysis shows a greater odds of obesity for increasing levels of fast food exposure.[66,182]

Collectively, these results suggest that using residential relocation to study change in food outlet exposure has merit. However, it is important to examine the directionality and magnitude of change in food outlet exposure and demographic and socio-economic circumstances. This will allow future work utilising residential relocation to better account for the socio-demographic and socio-economic differences between movers and non-movers in order to provide population representative results and conclusions.

5.5.1 Methodological considerations and limitations

This work had several strengths; it included a longitudinal analysis of a large nationally representative sample of adults to examine movers and non-movers. Analysis of the UKHLS also allowed an objective estimate of moving based upon secure access to home locations rather than self-reported moving, with which to link food outlet data and derive spatial density of food outlets within the neighbourhood and unpack away-from-home outlets into the three most common types (i.e. restaurant, fast food and café). However, food outlet exposure was estimated based upon neighbourhoods, defined as within 1 mile of participants' home address. This may overestimate some forms of outlet exposure, particularly if there are physical barriers in the environment not accounted for, and underestimate other forms of exposure, particularly if individuals use most of these outlets while commuting between locations. Environmental exposure is a consequence of where people travel to and from in their everyday lives, suggesting that data on daily activity spaces would provide the best estimates of food outlet exposure.[234] However these data requires a method of detailed tracking using a global positioning system or similar; a data collection method with high participant burden that is also time consuming and expensive to process[234,235] limiting the number of studies employing this method.

Additionally, the ONS data for food location is not a routinely validated data set, 60% of the data is reported as 'ground truthed'. Given the geographic range covered by the data it is often not feasible to check each location. It is also unknown how quickly food outlets change. We used 2014 data and made an assumption that the time lag between US and OS data was not enough to change quintile of food environments. However, this is not based on a validation study of the ONS POI data for the UK. Lastly, as the purpose of this study was not to develop representative estimates, survey data was unweighted.

5.6 Conclusions and future work

Increases and decreases in food outlet exposure as a result of residential mobility were evenly distributed for movers. However, movers differ from non-movers on a range of baseline and socio-demographic and socio-economic circumstances. They also experience more changes in other social and economic circumstances than non-movers, which should be accounted for when using residential mobility to study the effect of change in local food environment exposure on outcomes.

The results of this work, which include evidence that change in food availability does vary before and after relocation, provides an encouraging foundation for studying the influence of change in food outlet density on diet and health outcomes. However, many questions remain that could be important for examining causal associations in the future. Firstly, while change in food availability was explored for movers, movers and non-movers were different with respect to accompanying life events that might confound future work to explore causal associations. While the assessment of movers versus non-movers for change in life events was crude in this analysis (existence of change, rather than direction or magnitude of change), it remains an important next step to better understand how movers and non-movers differ from each other and the general population.

Secondly, once movers are better understood with respect to how they differ from the general population, classifying different change trajectories might also be an important next step. The realist inspired theory developed in chapter 2 suggests that the effects of a change in food outlet density could be different for different people in different circumstances. For example, characterising people and their circumstances before and after relocation may extend beyond whether or not there was simply a 'move'. It could be important to understand what precipitated the move (e.g. a low income family with young children that moved to a more affordable home after a separation versus a middle income single professional that moved after a promotion). In an effort to uncover causal association, and staying oriented toward the realist view of causation, characterising the circumstances before and after a change in food outlet exposure might help to explain different diet and health outcome patterns that might be observed.

Finally, when movers and their circumstances before and after relocation are better clarified, there are a series of possible approaches that could help to explore causal association. For example, if people in particular circumstances consistently move to less supportive food environments, it will be important to attempt to account for those circumstances. This will help determine if a change in diet or health is attributable to the circumstance of the relocation, versus the less supportive food environment that is the result of the relocation.

6 Overall discussion

6.1 Summary of findings

The overall purpose of this dissertation was to develop and test aspects of a complex theory of how food availability influences food choice and diet for the prevention of obesity, in particular from a perspective of, and using a method congruent with, the population level approach to chronic disease prevention. As each chapter covers a range of topics, in depth discussion of the findings in relation to the literature can be found in each chapter. However, there are also overall reflections worth exploring. As discussed in detail in chapter 2, the development of a complex theory demonstrated that while multiple pathways, levels of influence, mechanisms and contextual factors are involved in understanding how a change in food availably influences food choice, there is value in specifying and mapping these specific characteristics to ground evidence synthesis and generate testable hypotheses that can then be related back to the theory. This can deepen our understanding and progress the field, and hopefully improve intervention – whether policy or researcher driven.

Identifying a starting point for testing a complex theory proved a challenging undertaking. After the development of the theory, it became clear that comprehensive testing was not possible given a lack of appropriate data and limitations in available epidemiological methods for dealing with the analysis of complex systems. Therefore, two specific realist mechanisms (food outlet adoption and food outlet exposure) were selected for testing in relation to the context of different food outlet types and their

association with diet and weight status, each discussed in detail in chapters 3 and 4. Overall these results, while somewhat inconsistent across type of food outlet, showed some consistency with the role of fast food outlets specifically for both fast food outlet adoption (or use of fast food outlets) and fast food outlet exposure (density of these outlets around the home) in relation to diet and obesity. Other types of outlets including both sit-down restaurants and cafes, however, showed null or negative associations with outcomes (summarised in **Figure 6.1**). These patterns are difficult to tease apart, likely due to the complexity of the causal chain between food outlet type and diet and health, as demonstrated in the theory developed in chapter 2. Reflecting back toward the complex theory, it becomes clear that individuals can exercise agency with respect to what food source they select, this is theorised as preferences – which could not be explored in the data available. Additionally, most exposures and outcomes were patterned by socio-economic position across both datasets, and as discussed within chapter 3 and 4, likely played a large part in the patterning of outcomes by different food outlet types.

To attempt to improve future *theory of change* testing, rather than cross-sectional testing of exposure and outcomes, a novel approach to overcome the limitations of studying change in food outlet exposure at the community level was explored. Residential mobility was used as a method for studying change in food outlet exposure, while attempting to understand if movers and non-movers differed in ways that may confound future conclusions. The results of this work discussed in detail in chapter 5 provided important insights for future work. Residential mobility has the potential to examine change in food outlet exposure; specifically that people tend to experience a change in food outlet exposure after moving, and that this change is equally distributed between an increase and decrease in away-from-home food outlet exposure. However, this work also demonstrated the additional complexities that accompany this kind of research, with various life events co-occurring with residential moves. These should be considered in future research, including change in marital status, employment or occupation.

6.2 Methodological considerations

While several specific methodological considerations are outlined within the appropriate chapters, there are also considerations for the overall approach taken in this dissertation, related to the development and testing of complex theory.

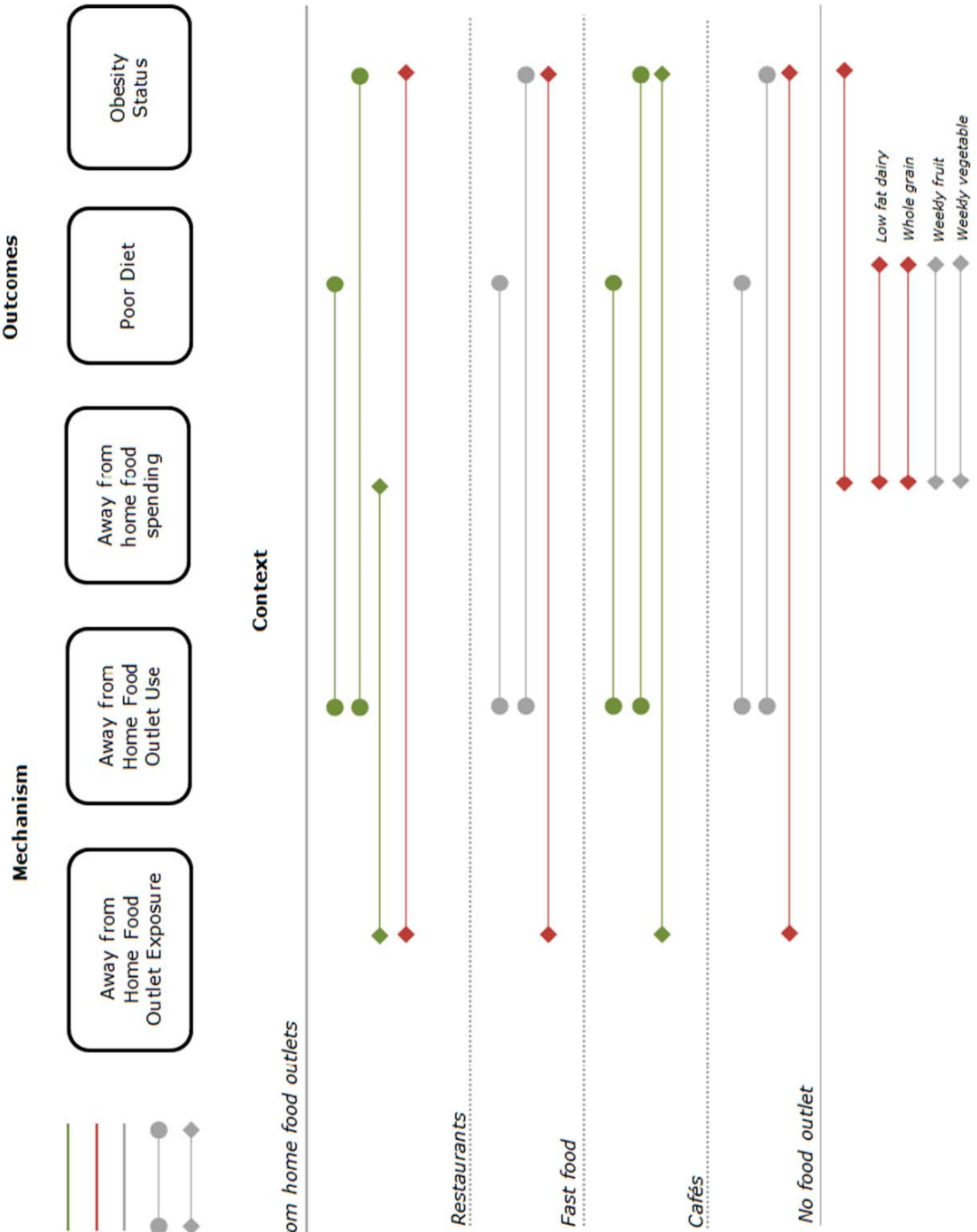


Figure 6.1 Summarising results of testing theorised adoption and outlet exposure mechanisms across different food outlet types from complex theory for food availability and food choice

6.2.1 Theory development

The primary strength of this work was to seek to improve our conceptual understanding of *how and why* food availability interventions may influence food choice and therefore provide insights into *why they may fail*. To do this, change in food availability was conceptualised as an event in a complex system using principles of realism to generate a theory of change. This approach also has some potential limitations. First among these is the use of complexity as a way to understand population health intervention and disease. Although much of the discourse about public health intervention is moving in that direction[121,236,237], there is some discussion regarding the utility of this approach as an organising principle. For example, does applying the principles of complexity to understanding public health problems include the abandonment of current empirical methods that are based on examining linear relationships?[238] Should we favour methods such as dynamic modelling, network analysis or agent based modelling which emerged outside of established epidemiological and public health methods?[239–241]

In addition to issues related to the use of the complexity lexicon, theory development is also an endeavour questioned for its utility. However, with the need to improve our understanding of the complex nature of reality to improve public health interventions, it could be argued that mapping complex theories of change is an essential first step in the process. Indeed, the MRC complex interventions framework begins with Theory Development as its initial stage.[91] However, given that many population health interventions are implemented outside of the academic sphere (i.e. represent natural experiments)[242], this guideline may go unaddressed as a first step in a larger intervention development and evaluation process, unless public health researchers begin to use explicit theories specific to future intervention strategies that will be implemented by other sectors as the foundation for their programmes; a kind of 'theoretical public health intervention science'. It is also important to reiterate that theory development is but the first step in intervention development. As recommended in the MRC framework, the next step requires testing and modelling the assumptions and hypotheses put forth in the theory[91], which also has its own challenges regarding availability of methods of analysis for theory that has several long causal chains, and interrelated pathways of influences, like the theory presented here.

In addition, the use of realism as the foundation of theory development can provide clarity with respect labelling different parts of a causal pathway as either contextual or mechanistic. However, the use of this approach can also increase obfuscation with the introduction of a new set of terminology which may or may not map onto current epidemiological conventions, and there is some debate in the literature as to whether or not realism is simply relabelling traditional methods.[243,244] For the purpose of this work, the use of the realist 'mechanism' was different than traditional mechanisms in epidemiology. For example, testing for a traditional mechanism would include an analytical approach that sought to examine an intermediate variable that accounts for a main effect.[245] In this sense, the testing of adoption and outlet exposure in this thesis did not test that constructs as a mechanism between an exposure and outcome. The realist definition of mechanism suggests an emergent factor, possibly latent and unmeasurable, that if absent would not allow for contextual factors to influence an outcome, creating patterns of outcomes.[97] From this point of view, realist mechanisms are essentially necessary elements that have the ability to change the outcome. However, there is ongoing debate regarding the definition of a realist mechanism, with some suggesting that there is no single definition.[246]

Also, the use of realist synthesis included intervention related literature; however it did not directly assess or synthesise intervention effectiveness. Although this is acceptable in realist reviews and synthesis, which gives priority to a breadth of content,[96] it is important to keep this assumption in mind when interpreting the theory. Further, in order to provide the most comprehensive understanding of how the included food environment interventions work, this review was more inclusive of studies than traditional systematic reviews, giving rise to questions of the quality of included studies. Although studies of low quality, according to our tool, were not excluded, the quality score helped us during analysis and synthesis. The utility of this theory can be furthered by broadening the literature to primary studies without any a priori restrictions.

6.2.2 Theory testing

Theory testing was a challenging undertaking given the approach taken in this dissertation. As mentioned, the most coherent strategy might be to treat data analysis completely differently, using systems science methods and approaches. However, exploring the utility of traditional methods to provide insights into complex theory was

used instead. It may be important to find ways of integrating different methods and approaches to empirical work; beyond those restricted by systems science (i.e. dynamic modelling, network analysis and/or agent based modelling). Therefore, the methodological considerations follow those of traditional epidemiological studies that are also reviewed in detail within chapters 3 – 5, and a brief overview below.

6.2.2.1 Study design, confounding and chance

6.2.2.1.1 Study design

The analyses in chapters 3 and 4 included cross-sectional study designs that did not allow for causal conclusions, or demonstrate the direction of association. However, the purpose of both chapters 3 and 4 within the context of this thesis was to examine the association between different contexts (food outlet types) and diet and/or obesity outcomes. By demonstrating different associations depending on the type of food outlet, the cross-sectional study designs were able to provide evidence that, while the associations may not be causal in their effect, the associations were not homogeneous. While chapter 5 did not examine outcomes the outcomes of interest in this thesis (i.e. diet or obesity), there is evidence that using residential relocation to study change in exposure and resulting changes in outcomes has merit. Using this approach would help to move our understanding of differential associations toward demonstrating a causal link if examined.

6.2.2.1.2 Confounding

Cross-sectional study design is a limitation regarding causal inference. It can also be an important contributor to residual confounding – particularly with respect to the analyses in chapters 3 and 4. Chapter 3 analysis demonstrated the link between socio-economic position and use of different food outlets types, in particular by the attenuation of the association between restaurant use and obesity after adjustment for socio-economic position. Chapter 4 associations between exposure to restaurants and obesity, however, did not attenuate, even after adjustment for individual level socio-economic circumstances – which is most likely due to residual confounding related to unmeasured aspects of material deprivation or affluence. Several other unmeasured factors that could confound associations between food outlet usage (NDNS – chapter 3), or density of food outlets (UKHLS – chapter 4) and diet and obesity were considered important *a priori* regarding the moderation of these associations. However, data availability did not allow

for an examination of their relationships with exposures and outcomes of interest. For example, personal characteristics such as preference for quick service, good taste and a desire to socialise while eating away-from-home may be stronger determinants of fast food usage than density of outlets.[169] Other neighbourhood characteristics such as safe surroundings, community walkability and aesthetics may moderate the association between density of outlets, their use, and therefore their influence on diet and obesity.[189] While the primary exposures and outcomes of interest were available in the population level surveys used in this thesis, the ability to account for other unmeasured variables was a limitation for both NDNS and UKHLS.

Additionally, it is also possible that psychology plays an important role in understanding environmental influences on diet behaviour.[247] Social cognitive factors (for example self-efficacy, self-regulation and outcome expectations) have been used to explain health behaviour in general and nutrition behaviour in particular.[19] These factors are also regularly used as intermediate factors in behaviour change interventions related to diet and physical activity.[248] However, the role of social cognitive factors in explaining associations between environmental exposures, such as food outlet density and diet related behaviour, is not yet well understood. Even less common, and arguably more relevant to influences of food outlet density on diet (i.e. possibly an influence that does not require agency on the part of the population) is evidence for 'unconscious' psychological factors. Cognitive ability[249], or more specifically one's executive function, is being explored as an important component of understanding diet behaviour[250] and represents the extent to which one can control behaviour, emotion and thought, and therefore guide your food choices and resulting diet. Also, in the obesity models we were unable to adjust for energy expenditure or level of physical activity, which may be important confounders. However, it is expected that much of the variation in BMI explained by physical activity is likely to be captured by age and sex covariates. Finally, smoking status was not available for this wave of understanding society; therefore general reported health was included in obesity models to attempt to capture a correlate of physically active, non-smoking individuals.

6.2.2.2 Error and bias in measurement

6.2.2.2.1 Exposures (classification and estimation)

The study described in chapter 3 included 4-day food diaries to determine energy intake at different food outlets providing a prospective measure of away-from-home eating, and restaurant, fast food and café usage as the primary exposure of interest. This addressed the limitations of retrospective measures of frequency of use of away-from-home locations that are subject to recall bias. Another consideration related to exposure classification in chapter 3, includes the pre-existing categorisation of eating locations within the NDNS data. These categories were primarily based upon criteria set out by the NDNS study team and if modified may yield different results. For example, the fast food and sit-down restaurants were distinguished by NDNS based on the method of service and didn't account for the healthfulness of foods available within outlets, which may vary substantially [136] with restaurants providing options that can be as unhealthy as those sold in fast-food outlets [137]. Also, for the three food retail types, we dichotomised usage in order to deal with the skewed nature of the underlying data, which may have reduced our sensitivity to detect associations compared to the use of continuous variables. Similarly, for chapters 4 and 5, food outlet classification was based on existing market driven classifications provided by Ordnance Survey. The impact of this could be twofold, first that the classification of some outlets becomes difficult, as they may service purposes that cross classification boundaries. For example, an Indian restaurant can provide both full service dinning as a sit-down restaurant, or quick takeaway as a fast food outlet. If the classification decision (e.g. if outlet types that serve particular types of foods) are systematically misclassified as fast food outlets, then this could make it more likely to be associated with poorer diet although the outlet is also a sit-down restaurant. A more comprehensive survey of what foods are available within outlets would be needed to improve classification, which is a time and resource intensive.

Also for the studies described in chapters 4 and 5, person-centric exposure to food outlets was estimated based upon the proportion of a single type of food outlet in relation to all food outlets within 1 mile of the participant's home. While a common exposure measurement, this may overestimate some forms of outlet exposure; particularly if there are physical barriers in the environment not account for, and underestimate other forms of exposure, particularly if individuals use most of these outlets while commuting between

locations. Environmental exposure is a consequence of where people travel to and from in their everyday lives, suggesting that data on daily activity spaces would provide the best estimates of food outlet exposure [234]. However, these data require a method of detailed tracking using a global positioning system or similar; a data collection method with high participant burden that is also time consuming and expensive to process[234,235] limiting the number of studies employing this method.

6.2.2.2.2 Outcomes

The studies described in chapter 3 involved 4-day food diaries and a limitation of dietary assessment is that energy intake is often underreported of intake, which can lead to overestimation of the association between exposure and outcome. Our use of data from a 4-day food diary reduces underreporting, but it is unlikely to have been eliminated[172] for the estimation of DASH accordance. Obesity in the NDNS sample was estimated using measured height and weight allowing for more accurate estimated outcomes. However, outcomes (household food spending and estimated obesity) for the UKHLS study described in chapter 4 were based upon self-report data. This included estimates of household food spending, and height and weight. In order to improve spending data, mean household food spend was benchmarked against Living Cost and Food data. It is also known that individuals overestimate their height and underestimate their weight leading to a likelihood of underestimation of obese individuals within this sample compared with national averages.

6.2.2.3 Generalisability

External validity of the study samples in the NDNS and UKHLS studies described in chapters 3 – 5 is an important consideration. The study in chapter 3 included a nationally representative sample of the UK population, with non-response weights to improve estimation. However, this sample likely differs from the general population based on lower representation from more disadvantaged socio-economic groups, and less ethnic diversity than the generation population in the UK. Similarly, for the cross sectional UKHLS study in chapter 4 and the descriptive longitudinal study in chapter 5, while the sample included a larger proportion of lower socio-economic groups, ethnic diversity was low.

6.3 Implications for public health policy

There are direct policy implications for the independent investigation of food availability as a necessary condition for healthy diets, and to support reductions in levels of obesity. Currently, there is discourse related to using regulatory mechanisms to address built environments that do not support a healthy diet and weight.[253,254] This includes a debate focused on policy intervention should lie, either with location and types of food outlets (e.g. zoning or new supermarket), or changing what is sold within outlets (i.e. food provision) and how (e.g. pricing, promotions and labelling). This argument posits that 'to affect population health, food policy must go beyond action that promotes some types of outlets and curbs others. In the food environment, what matters is the menu - what food is offered, at what price - not the venue'[255]. Although this is possibly a false choice, or worst still, unrealistic given the free market forces driving what outlets sell and at what price[256]; effective strategies are likely to lie with a combined effort. Regardless of the debate, there are still further issues regarding conceptual clarity and exploration of causality and moderation needed regarding the concepts of food environment availability and accessibility.

Also, a range of strategies (e.g. new supermarkets in communities, zoning laws to restrict fast food outlet growth) are being implemented currently, even with the existing inconsistencies within the evidence base. This is actually a worrying development, as many current failures of existing evaluations of policy driven intervention could be interpreted as the 'food environment' not being important for food choice, when this could be due to theoretical or methodological failures, rather than representing no credible causal influence. Although no specific evidence has yet arisen in the UK, a regulation banning new fast-food establishments for one year in Los Angeles, California, US was implemented in 2008 out of a desire to take action to reduce obesity rates. A paper examining the context of the law concluded that it was unlikely to have a positive impact given the density of fast food outlets in the area were not the highest in the state and the authors conclude that in-store labelling and promotion may provide more success [194]. However, without a comprehensive evaluation it is difficult to conclude that the zoning law was a failure and why, and whether its failure was the result of an ineffective strategy (i.e. zoning in general) or its successful application to inhibit fast food outlets (i.e. to an already saturated foodscape) or timeframe (i.e. 1 year). There was also no

indication if this policy had differential effects on different socio-economic groups or potential negative consequences for any group. Therefore, from a public health point of view, the dimension of the food environment that seeks to increase the availability and accessibility of healthy foods within communities and outlets holds a great deal of promise not only to restructure the 'foodscape' to one that supports healthy diets for the population regardless of personal characteristics, but also for this effect to be greater in more vulnerable groups facilitating a reduction in health inequalities.[257–259]

While the evidence related to an independent association of local food environments (i.e. retail food availability) on diet is unclear, the role of conceptual clarity, methodological confusion regarding the conceptualization and measurement of the local food environment, and the role of other social, economic and psychological factors could use additional focus. This conceptual clarity may also support not only better scientific understanding of mechanisms of action, but also more effective evaluation of complex public health interventions – which have been criticized for resulting in too much noise and too little harmony, leading to uncertainly over which actions to take[260], and the reduction of health inequalities.[261]

6.4 Future work

Food availability is likely one aspect of a complex system of social, economic and environmental factors that influence food choice. Future work would benefit from approaching empirical and intervention related research following the MRC Complex intervention framework, specifically firstly developing a detailed complex theory, followed by modelling, testing and piloting.[91] This dissertation provides a potential model for this approach, while attempting to develop theory congruent with the principles of complex science and realism. However, this is a time consuming and challenging undertaking, and current grant funding schemes do not seem organised to allow for considerable theory development time. Given the paucity of studies involving the development of theory, a public health science focused on the development of appropriate theories to guide research and intervention does not seem to be in development.

Regarding our understanding of the causal influence of food availability on diet, and therefore its potential to prevention obesity and other chronic disease; there is a significant need for longitudinal studies. However, as discussed in detail in chapter 5, the

limited number of longitudinal studies examining causal explanation or causal estimation is not surprising, and could reflects challenges reported in the built environment literature more broadly.[202,206–208] Among the more practical barriers to improved causal understanding and examination of mechanisms, is the availability of longitudinal built environment data[209], particularly valid and reliable data[210] that can then be linked to individual level behaviour and health data with important covariates, potential moderators and mediators. Particular to the field of local food availability, while there is evidence to suggest that the 'foodscape' (i.e. the number and composition of food outlets) changes over time, it is likely to happen slowly, with any change large enough to effect health occurring over decades[211,212], making exploration of causal effects related to the number and composition of food outlets on behaviour and health impractical. As discussed at the end of chapter 5, the use of residential relocation to assess change in food outlet exposure could allow for analyses that classify people and their social and economic circumstances in a sophisticated way. Characterising people and their circumstances before and after a relocation may extend beyond whether or not there was simply a 'move', toward what was being experienced by different people before and after relocation (e.g. a low income family with young children that moved to a more affordable home after a separation versus a middle income single professional, that moved after a promotion). In an effort to uncover causal association, and staying oriented toward the realist view of causation, characterising the circumstances before and after a change in food outlet exposure might help to explain different diet and health outcome patterns. For example, if people in particular circumstances consistently move to less supportive food environments, it will be important to attempt to account for those circumstances. This will help to determine if a change in diet or health is attributable to the circumstance of the relocation, versus the less supportive food environment that is the result of the relocation.

Finally, the number and multidimensional nature of the contextual factors illustrated as part of the complex theory presents a challenge for future analysis to unpack how these factors interrelate. One possible analytic method that might support the creation of new characterisations of context, related specifically to a particular public health intervention like food availability, includes latent class modelling.[262] Currently, most demographic and socio-economic factors are conceptualised as confounders or moderators of main effects, however if the theory is to be tested, it may be wise to create classifications of people beyond demographics and socio-economics.[263] For example, perhaps a set of

contextual factors combine to create 'biographies' of people[264] that could further enlighten our understanding food availability such as single, low income residents, who travel by car a great distance to work and have at least one child have a different food choice pattern given different food outlet exposure than married, high income residents, who cycle to work alone. Exploring novel conceptualisations of context and testing new methods of characterising this context in relation to mechanism and outcomes may help us to test complex theories without the use of complex system science methods alone.[241]

6.5 Overall conclusions

Collectively, this work demonstrates that complex theory development and empirical testing can provide a solid conceptual foundation to improve our understanding of how food availability influences unhealthy diet and obesity, for different groups of people and across a range of circumstances. The application of this systems based approach could lead to a more nuanced view of mechanisms of action and thereby more effectively address complex public health problems.

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8 Appendices

Appendix 1: Academic outputs and professional development

Most broadly, my research interests are to develop theory to support population health research and intervention to address change in complex systems that integrate both individual and environmental factors to positively influence health behaviour for the prevention of chronic disease. Therefore, in addition to my dissertation I have contributed as co-investigator on other population health intervention research projects and as co-author on related work. During my PhD I was involved in the following scholarly activities, outputs and training.

Funding as co-investigator

Awarded

Graduate School of Life Science (GSLS) University of Cambridge Funding. £3,000.00, 2015 Title: 'The Future of Diet and Nutrition'. Local Organizing Committee, Nutrition Society Conference.

CIHR Population Health Intervention Research Operating Grant $198,080.00, 2015-2017 Title: 'Building on successes and learning from challenges: A comprehensive evaluation of the school food and nutrition policy in Nova Scotia'

CIHR Population Health Intervention Research Operating Grant $199,833.00, 2013-2015 Title: 'Comprehensive school health initiatives: the influence of implementation on school culture and children's health behaviors'

Publications and Abstract/Presentations

Submitted publications

Winpenny E, **Penney TL**, Corder K, White M and vanSluijs E (2016) How is longitudinal change in diet conceptualised and measured in the period from adolescence to early adulthood? A systematic scoping review of longitudinal studies. Obesity reviews (submitted). IF: 5.086.

McIssac JL, **Penney TL**, Kirk SFL, Ata N, Sigfridsson L, Cunningham J, Veugelers V, Storey K, Ohinmaa A, Kuhle S (2016) Evaluation of a health promoting schools program in a school board in Nova Scotia, Canada. Preventative Medicine (submitted). IF: 3.086.

Penney TL, Jones N, Adams J, Maguire E, Burgoine T, Monsivais P (2016) Which food outlets drive associations between eating away from home, diet quality and obesity? A nationally-representative sample of UK adults. International Journal of Obesity (submitted). IF: 5.337.

Penney TL, McIsaac JL, MacLeod K, Kontak J, Ata N, Kuhle S and Kirk SFL (2016) Examining the context of health promoting schools: a translational approach. Health Promotion International (submitted). IF: 2.046.

Maguire ER; Burgoine T; **Penney TL**; Forouhi NG; Monsivais P (2016) Is exposure to the food environment socio-economically patterned? Comparing area-based and person-centred metrics in the Fenland Study, UK. International Journal of Behavioral Nutrition and Physical Activity (submitted). IF: 4.111.

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Kontak J, McIssac JL, **Penney TL**, Kuhle S, Kirk SLF (2016). The picture of health: Examining school-based health environments through photographs. Health Promotion International. 2016: daw027. IF: 2.046

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Riley BL, Robinson KL, Gamble J, Finegood DT, Sheppard D, **Penney TL**, Best A. (2015) Knowledge to action for solving complex problems: Insights from a review of nine international case studies. Health Promotion and Chronic Disease Prevention in Canada: Research, Policy and Practice. 35(3). IF: 1.52.

Kirk SFL, Price S, **Penney TL**, Rehman L, Lyons R, Piccinini-Vallis H. & Vallis M, Curran J, Aston M. (2014) Blame, shame and lack of support: Health system implications of a multi-level study on obesity management. Qualitative Health Research. 24(6): 790-800 IF: 1.625.

Penney TL, Almiron E, Shearer C, McIsaac JL , Kirk SLF (2014) Modifying the food environment for childhood obesity prevention: challenges and opportunities. Proceedings of the Nutrition Society. 73(2): 226-36. IF: 3.674

Penney TL, Rainham D, Dummer TJ, Kirk SFL. (2014) A spatial analysis of community level overweight and obesity. Journal of Human Nutrition and Dietetics. 27 (Supp 2): 65-74. IF: 1.789

Conference abstracts

***Penney TL,** Jones N, Adams J, Maguire E, Burgoine T, Monsivais P (2016) Are sit-down restaurant, fast food and café usage independently associated with diet and obesity? European Public Health Conference, Nov. 2016. Vienna, Austria (oral).

Ziauddeen N, *Kirk SFL, **Penney TL**, Monsivais P, Nicholson S, Page P and Almiron-Roig E. (2016) "Are we where we eat? Eating at food outlets, leisure settings and "on the go" is associated with less healthy food choices than home. UKCO 2016, Aug. 2016. Nottingham, UK (poster).

Penney TL, *McIsaac JL, Kontak J, Ata N, Kuhle S, Kirk SFL (2016) Characterizing support school ethos for student health and wellbeing: the development of a multi-dimensional support school ethos score. Canadian Public Health Association Conference. June 2016 (poster).

*Maguire E, **Penney TL**, Burgoine T, Monsivais P. (2015) Measuring socioeconomic variation in the food environment. MRC Epidemiology Unit Research Day, December 2015 (oral).

***Penney TL**, Brown HE, Maguire E, Monsivais P. (2015) Local food environment interventions to improve diet in adults: using a systematic search and realist synthesis to address the program theory gap. International Society for Behavioral Nutrition and Physical Activity. June 2015.

*McIssac JL, Kuhle S, **Penney TL**, Kirk SFL. (2015) The association between diet, physical activity and student achievement. International Society for Behavioral Nutrition and Physical Activity. June 2015.

*McIsaac JL, **Penney TL**, MacLeod K, Ata N, Kuhle S, Kirk SFL (2015) Bridging connections and building relationships: the role of knowledge translation and exchange in comprehensive school health research. KT Canada Scientific Meeting, May 2015.

*Kontak J, McIsaac JL, **Penney TL**, Kuhle S, Kirk SFL. (2015) A picture is worth a thousand words: Examining school-based health environments through photographs. Canadian Public Health Association Conference. May 2015.

*McIsaac, JL, **Penney TL**, MacLeod K, Shearer S, Kuhle S and Kirk SFL (2014) Measuring "form" and "function" in complex school-based population health interventions. Canadian Obesity Network Student and New Professional Meeting. May 2014 (oral)

Training

2016 DECIPHer Development and evaluation of complex interventions course

2015 Springboard: A women's development programme, University of Cambridge

Analysis weights for longitudinal panel data**,** Institute for Social and Economic Research

2014 Food Science Communication – Media Training, MAITRE at University of Cambridge

Good clinical practice for non-trialists, Medical Research Council, University of Cambridge

Realist review methodology, Centre for Advancement in Realist Evaluation and Synthesis

Nutritional Epidemiology Modules, Cambridge University Institute of Public health

Policy Brains Workshop, Cambridge University Science and Policy Exchange

Appendix 2: Supplementary material for chapter 2

Search strategy for Ovid SP databases

1. food secur$.ab,ti.

2. food insecur$.ab,ti.

3. food poverty.ab,ti.

4. food sufficien$.ab,ti.

5. food insufficien$.ab,ti.

6. food desert$.ab,ti.

7. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$1 or grocer$ or restaurant$1 or fast food$1 or take away$1) adj3 environment$).ab,ti.

8. ((food or garden$ or cook$) adj3 skill$).ab,ti.

9. (food adj5 (prepar$ or budget$ or shop$ or purchas$ or buy$ or acquisition or acquir$) adj5 skill$).ab,ti.

10. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$1 or grocer$ or supermarket$1 or grocery store$1 or food store$1 or food shop$1 or corner store$1 or cafeteria$1 or canteen$1 or food outlet$1 or or restaurant$1 or fast food$1 or take away$1) adj3 access$3).ab,ti.

11. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$1 or grocer$ or supermarket$1 or grocery store$1 or food store$1 or food shop$1 or corner store$1 or cafeteria$1 or canteen$1 or food outlet$1 or or restaurant$1 or fast food$1 or take away$1) adj3 access$).ab,ti.

12. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$1 or grocer$ or supermarket$1 or grocery store$1 or food store$1 or food shop$1 or corner store$1 or cafeteria$1 or canteen$1 or food outlet$1 or or restaurant$1 or fast food$1 or take away$1) adj3 availab$).ab,ti.

13. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$1 or grocer$ or supermarket$1 or grocery store$1 or food store$1 or food shop$1 or corner store$1 or cafeteria$1 or canteen$1 or food outlet$1 or or restaurant$1 or fast food$1 or take away$1) adj3 cost$3).ab,ti.

14. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$1 or grocer$ or supermarket$1 or grocery store$1 or food store$1 or food shop$1 or corner store$1 or cafeteria$1 or canteen$1 or food outlet$1 or bodega$1 or tienda$1) adj3 pric$).ab,ti.

15. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$ or grocer$ or diet or dietary) adj3 variet$).ab,ti.

16. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$ or grocer$) adj4 (supply or supplies)).ab,ti.

17. ((fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$ or grocer$) adj3 (purchas$ or expenditure$1 or spend$ or spent)).ab,ti.

18. ((food$1 or fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$ or grocer$ or supermarket$1 or cafeteria or corner store$1 or canteen$1 or meal$1) adj5 sale$1).ab,ti.

19. (food$1 adj3 (environment$ or access$ or cost$ or availab$ or pric$ or variet$ or supply$ or supplies or purchas$ or expenditure$1 or spend or spent or spending) adj5 (fresh or health$ or unhealthy$ or junk$ or nutriti$ or adequate or quality or sufficient or insufficient or secure or insecure$ or safe)).ti,ab.

20. (food$1 adj (environment$ or access$ or cost$ or availab$ or pric$ or expenditure$1 or spending$1)).ti,ab.

21. (food system$1 and (fresh or health$ or unhealthy$ or junk$ or nutriti$ or adequate or quality or sufficient or insufficient or secure or insecure$ or safe)).ab,ti.

22. ((policy or policies) adj3 (food$1 or fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$ or nutritio$ or grocer$ or meal$1)).ab,ti.

23. ((council$1 or coalition$1 or co-op$1 or co-operative$1) adj3 (food$1 or fruit$ or vegetable$1 or nutritio$ or fat$1 or salt$1 or sugar$ or grocer$)).ab,ti.

24. (((deliver$ or transport$ or distribut$) adj3 (grocer$ or meal$1 or fruit$1 or vegetable$1 or fat$1 or salt$1 or sugar$)) and (outreach or service$ or scheme or program$ or policy or policies or project$ or nutritio$ or home$1 or communit$ or neighbour$ or neighbor$ or rural$ or urban$ or provide$ or choice or control)).ab,ti.

25. (((deliver$ or transport$ or distribut$) adj2 food$1) and (outreach or service$ or scheme or program$ or policy or policies or project$ or nutritio$ or home$1 or communit$ or neighbour$ or neighbor$ or rural$ or urban$ or provide$ or choice or control)).ab,ti.

26. ((public transport or transport* service* or transport* scheme or mobile or ((transport* or travel) and (infrastructure or local or access or communit*))) and (food store* or food shop* or food retail* or supermarket or grocer*)).ab,ti.

27. ((payment$1 or benefit$1 or money or purchas$ or buy$ or welfare or financ$ or cash or income) adj5 (food$1 or grocer$ or fruit$1 or vegetable$1 or nutritio$ or meal$1) adj5 (supplement$ or assist$ or extra or aid or support or help)).ab,ti.

28. ((tax or taxes or taxation or subsid$ or voucher$1 or coupon$1) adj3 (food$1 or grocer$ or fruit$1 or vegetable$1 or nutritio$ or meal$1)).ab,ti.

29. (garden$ adj3 (communit$ or food$1 or nutritio$ or kitchen$1 or home$1 or school$1)).ab,ti.

30. (market$1 adj3 (garden$ or food$1 or nutritio$ or produce or fruit$1 or vegetable$1 or farm$ or grower$)).ab,ti.

31. ((food$1 or meal$1) adj3 service$1).ab,ti.

32. ((community nutrition or public health nutrition) adj3 (project$1 or program$)).ab,ti.

33. ((agricultural polic$ or land us$3 or land zone$1 or land zoning or urban planning or town planning) and (food$1 or grocer$ or fruit$1 or vegetable$1 or nutritio$ or meal$1)).ab,ti.

34. (urban agriculture or edible landscape$1 or civic agriculture).ab,ti.

35. (community supported agriculture or community shared agriculture).ab,ti.

36. ((commun$ or collective or farm$) adj3 kitchen$).ab,ti.

37. food for work.ab,ti.

38. (food stamp$ or WIC or supplemental nutrition program or supplemental nutrition assistance program).ab,ti.

39. grow$ your own.ab,ti.

40. (veg* box* or food box* or food basket* or fruit basket* or veg* basket*).ab,ti.

41. (diet/ or food/ or cookery/) and (health promotion/ or health policy/ or public health/) and (poverty/ or social class/ or socioeconomic factors/ or social welfare/)

42. Food supply/st, es, td, og, sn, ec, cl

43. Food Industry/st, es, td, og, sn, ec

44. (Vegetables/ or food industry/ or fruit/) and exp marketing/

45. exp Food Services/ and ((supply$ or supplie$ or secur$ or insecur$ or access$ or availab$ or fruit$ or vegetable$ or nutritio$).ti,ab. or (health promotion or fruit or vegetables or poverty areas or poverty or social welfare or hunger or social responsibility or food habits or food supply).sh.)

46. or/1-45

Study design filter

None, inclusion criteria to determine study design exclusion.

Human filter

47. not human/

High-income countries filter

None, inclusion criteria to determine regional study inclusion.

Table 1: EPHPP Scores by dimension and global score

Intervention Name (primary citation)	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and drop-out	EPHPP Score (Global)[a]
Pennsylvania Fresh Food Financing Initiative (PFFF)[112]	3	2	1	2	1	3	2
Leeds retail intervention (LIR)[113]	3	2	3	3	1	2	3
Mobile Food Store (MFS) [115]	2	2	3	3	1	3	3
Glasgow Supermarket (GSM) [114]	3	2	1	2	1	2	1
Baltimore Health Stores (BHS) [116]	3	2	3	2	3	3	3
Baltimore Healthy Carry-outs (BHC) [117]	3	2	3	2	1	n/a	2

[a] Modified calculation of global score to reflect study designs available to types of evaluations: 1 = one weak rating; 2 = two weak ratings; 3 = three or more weak ratings.

Appendix 3: Supplementary material for chapter 3

Calculating Eating Occasions and DASH food group scoring and modifications

In contrast to eating occasions derived strictly on change in time between food items consumed (e.g. >= 15 minutes, or >= 1 hour), derivation of an eating occasion for this analysis was based on larger timeslots, while incorporating change in location within time slots to allow flexibility and reduce the likelihood that eating occasions would be overestimated for away-from-home locations. In particular the locations that are the focus of this work, i.e. where participants are not in control over the timeliness of food service (e.g. sit-down restaurants).

Initially, each row of data represented a single food item or ingredient consumed by the participant, the total number of food entries was 220,905 over the four day recording period. The new variable 'eating occasion' (EO) was used to aggregate food items within a single sitting as defined and operationalised above.

The total number of EOs across all away-from-home locations generated after aggregation was 12,256 (25.2% of total EOs) of which 12% of EOs occurred in sit-down restaurants, 1% in fast food outlets, 5% in cafés and the remaining 82% in non-retail away-from-home locations (e.g. a friend's house) described below.

Modifying the DASH score for NDNS

The score used here is developed from one first used by Fung and colleagues,[1] measuring accordance to the DASH diet based upon the following food groups: fruits, vegetables, nuts and legumes, whole grains, low-fat dairy, sodium, red and processed meats, and sweetened beverages (see Supplementary Table 2). This score was modified to include all non-milk extrinsic sugars in the diet, whereas in the study by Fung and colleagues this was limited to sugar-sweetened beverages.

Consumption of each food group was adjusted for dietary energy using the residual method and the resulting residuals were used to rank individuals into

quintiles (normally distributed without need for transformation).[2] For each component of the score, a score of 1-5 could be earned based on the quintile of intake, with a 5 indicating higher intake of food groups to encourage. For foods that are discouraged ('-' in table above) this scoring system was reversed so that a score of 5 was given for the lowest intake and 1 for the greatest intake. The overall score had a range of 8 to 40 and higher scores indicate a diet which has greater accordance to the DASH pattern.

[1] Fung TT, Chiuve SE, McCullough ML, et al. Adherence to a DASH-style diet and risk of coronary heart disease and stroke in women. Arch Intern Med 2008;168:713–20. doi:10.1001/archinte.168.7.713 [2] Willett WC. Nutritional Epidemiology. Third. New York: : Oxford University press 2013.

Table 1: DASH food group scoring

DASH accordance scoring

Food Group	Foods Included	Scoring [1]
Fruits*	All fresh, dried and tinned fruit, fruit juice and smoothies	+
Vegetables*	All vegetables excluding beans and potatoes	+
Nuts and legumes	All beans*, nuts (including peanut butter) and seed	+
Whole grains	Wholegrain bread, wholegrain breakfast cereals, wholegrain pasta, brown rice	+
Low fat dairy products	Low fat yoghurt (less than 3% fat), Low fat cheese (less than 3% fat), skimmed milk, 1% fat milk	+
Red and processed meats	All red meat* and processed poultry*	-
Non-milk extrinsic sugars*	All non-milk extrinsic sugars	-
Sodium*	Dietary sodium	-

[1] Scoring of "+" indicates food groups that are positively scored; "-" indicates food groups that are negatively scored (i.e., greater consumption of these groups is associated with a lower score). * Indicates that the NDNS reports the amount consumed including when the food appears in composite dishes

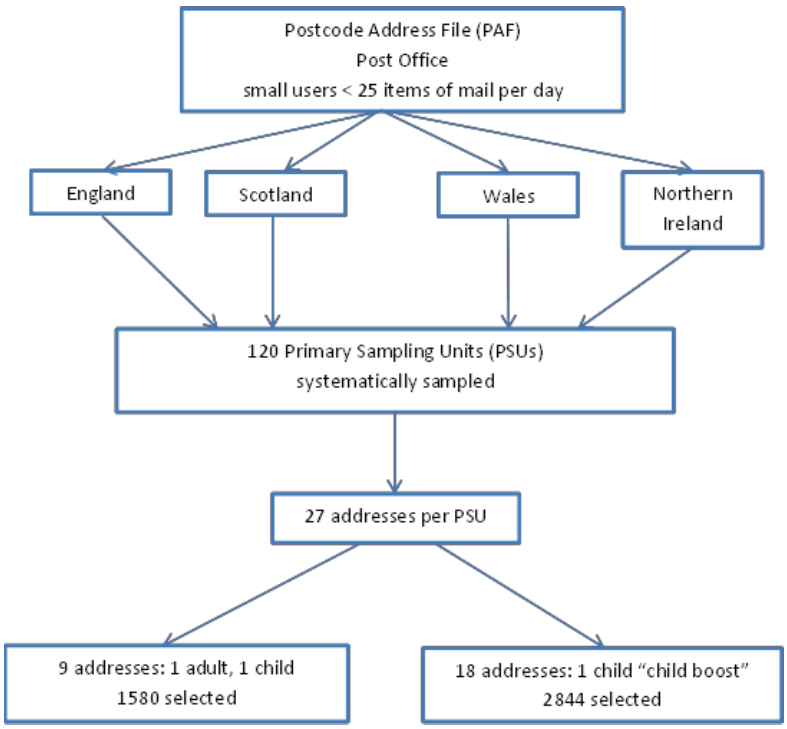

Figure 1: Sampling strategy used in NDNS

Table 2: Mapping of NDNS' original 36 'Where' categories to five eating location categories used in this study

Study labels		Aggregated to 5 Categories	Original 36 NDNS 'Where' Categories
Away from Home Locations	**Retail Locations**	Fast food	Fast food outlet (e.g. Burger King, Dominos, McDonalds, KFC, burger vans, fish and chip shops)
		Sit-down restaurant	Restaurant, pub, night club (e.g. Carluccio's, ASK, Pizza Express, Zizzi, Nando's, Prezzo, Frankie and Benny's, Bella Italia, Café Rouge, TGI Fridays, Hungry Horse, Wetherspoon, Harvester, Toby Carvery, Beefeater, Brewer's Fayre)
		Cafés	Coffee shop, cafe, shop, deli, sandwich bar (e.g. Café Nero, Pret a Manger, Greggs, Starbucks, Subway, Costa Coffee)
	Non-retail Locations	Other	Work - Desk
			Work - Other
			Work - Canteen - Other
			Work - Canteen - Bought food
			School - Classroom
			School - Canteen - Other
			School - Canteen - Bought food
			School - Playground
			School - Other
			Bus, car, train
			Street
			Outside - Other
			Friend's or Relative's house
			Community Centre/Day Centre/Drop-in
			Place of Worship
			Public Hall/Function Room
			Sports club, sports leisure venue
			Leisure Activities, shopping, tourist attractions, cinema, places of interest
			Holiday Accommodation
			Nursery/Kindergarten
			Carer's home
			Not At Home - Unspecified
			Unspecified
			Other place
Within the Home		Home	Home - Living Room
			Home - Kitchen
			Home - Other
			Home - Garden
			Home - Dining Room
			Home - Bedroom
			Home - Unspecified
			Work - Canteen - Food from home
			School - Canteen - Food from home

Table 3: Weighted sample characteristics as percentages (unless otherwise stated) with odds ratios and 95% confidence intervals for DASH accordance (n = 2083) and obesity (n = 1902) by Energy Intake (kJ) for away from home non-retail locations (tertiles)

		Tertile of Non-Retail Away from Home Exposure		
		Lowest	**Middle**	**Highest**
	n	692	711	680
	Proportion of energy (kJ) (min – max)	0.00 – 0.03	0.03 – 0.20	0.20 – 1.0
Demographics				
	Age [a]	56.3 (54.7,57.9)	47.8 (46.3,49.2)	40.0 (38.7,41.2)
	Sex (% Male)	48.3	43.4	53.8
	Ethnicity (% White)	88.8	91.3	88.6
Socio-economics				
	Educational attainment (% Degree)	16.1	25.4	29.2
	Equalised Income (% > £35,000)	19.7	33.0	42.1
	Occupation (% Professional)	35.0	42.95	49.4
Behaviour				
	Smoking (% Never smoked)	50.9	58.6	56.8
Diet				
	Fruit and Vegetable (g/day) [a]	289 (274,304)	301 (287,314)	277 (262,292)
	DASH score (% Most Accordant)	17.4	19.9	12.4
	Energy Intake (kJ/day) [a]	7304 (7112,7501)	7652 (7459,7844)	8158 (7911,8405)
Adiposity				
	Self-reported health (%Very Good)	26.2	33.9	41.6
	Body Mass (% Normal)	26.0	30.9	35.7
Odds of DASH Accordance[1]				
	Crude	1.00 (-)	1.18 [0.85, 1.64]	**0.67 *** [0.47, 0.95]
	Model 1[3]	1.00 (-)	1.35 [0.97, 1.87]	0.85 [0.60, 1.20]
	Model 2[4]	1.00 (-)	1.19 [0.84, 1.70]	**0.68 *** [0.47, 0.98]
Odds of Obesity[2]				
	Crude	1.00 (-)	0.84 [0.63,1.11]	0.82 [0.62,1.07]
	Model 1[3]	1.00 (-)	0.95 [0.71,1.26]	1.07 [0.80,1.42]
	Model 2[4]	1.00 (-)	1.01 [0.75,1.35]	1.19 [0.88,1.59]

[a] Weighted Mean % (95% confidence interval)
[1] DASH accordance score was divided into quintiles, with the highest quintile being most DASH accordant
[2] Obesity included participants with a BMI >= 30 kg/m^2
[3] Adjusted for age, sex, total energy (kJ), survey year (and smoking status for obesity models);
[4] Additionally adjusted for education and equivalised income; proportion energy (kJ) from restaurant, fast food and café locations.
* $p<0.05$

Appendix 4: Supplementary material for chapter 4

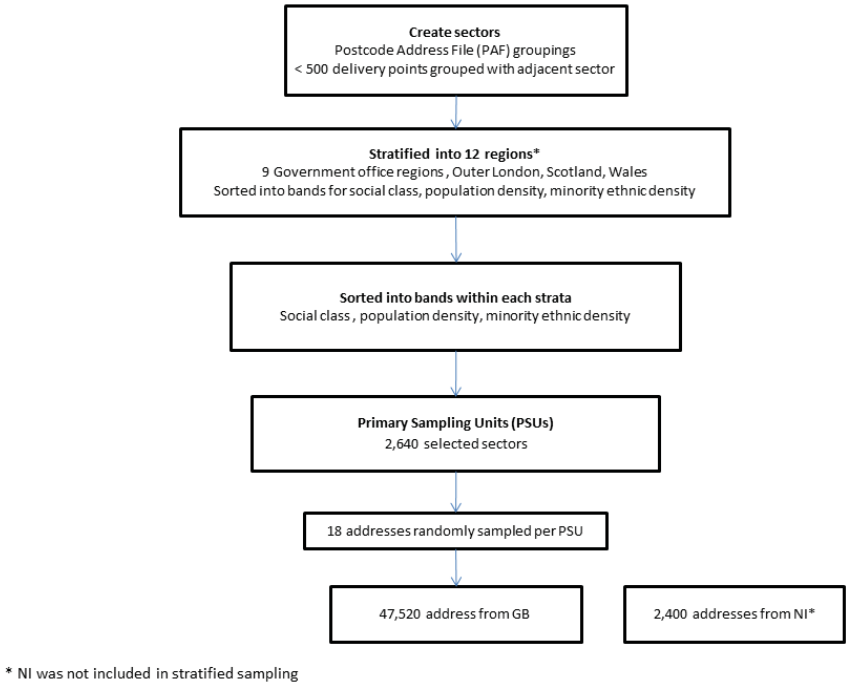

Figure 1: Sampling strategy for UKHLS

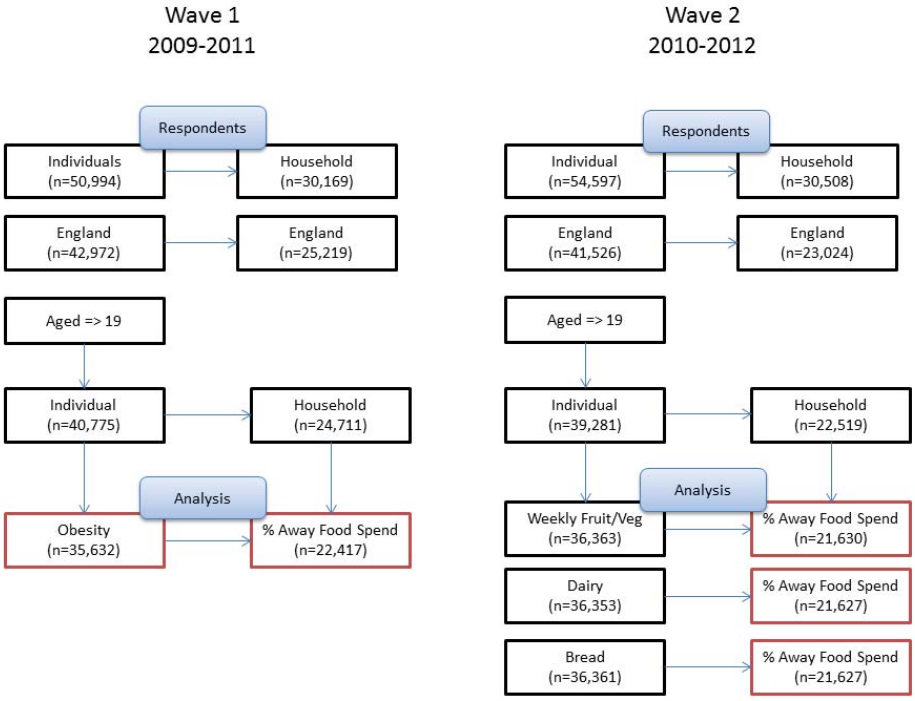

Figure 1: Analytic sample for Chapter 4, for primary analysis (Wave1) and supplementary analysis (Wave 2)

Table 1: Distribution by OS Food outlet classification and away from home food outlet groups for England, UK

Food outlet type		**Frequency**	**%**
Away from home			*64*
	Restaurants, Pubs and Bars	66,776	31
	Fast food, Takeaway, Fish & Chip	46,011	22
	Cafe and sandwich	23,135	11
All others			*36*
	Supermarket chains	10,541	5
	Convenience and Independent	36,110	17
	Baking and confection	11,039	5
	Special grocers	18,907	9
		212,519	**100**

Table 1: Associations between food spending and obesity (N = 22,417)

% Away from home spender [4]	Odds of obesity [1]		
	Crude	**Model 1 [2]**	**Model 2 [3]**
Low or moderate spender	1.00 (-)	1.00 (-)	1.00 (-)
High spender	0.77 *** [0.71, 0.83]	0.82 *** [0.75, 0.89]	0.85 *** [0.78, 0.93]

[1] Obesity included participants with a BMI >= 30 kg/m^2
[2] Adjusted for age, sex, total number of food outlets for restaurant, fast food, cafe, other and equivalised total food spend
[3] Additionally adjusted for education, equivalised income and occupation
[4] % of away from home food spending was divided into tertiles, with the top tertile being a high spender
*p<0.05, **p<0.01, ***p<0.001

Table 2: Weighted sample characteristics as percentages (unless otherwise stated) by tertile of proportion of away from home food spending (N=21,956) from Wave 2 (N=39,281)

		Tertile of % Away from Home Food Spending			
		Low Spend	Middle Spend	High Spend	Total
	N	7,945	7,134	6,877	21,956
	Proportion of away from food spending (min-max)	0 - 0.10	0.10 - 0.23	0.23 – 1	0 – 1
	Mean Equivalised monthly food spend (£) [a]	180 (78)	209 (82)	247 (111)	211 (89)
Demographics					
	Age [a]	55 (17)	48 (15)	47 (16)	48 (17)
	Sex (% Male)	40	41	48	43
Socio-economics					
	Education (% Degree or equiv)	25	35	45	35
	Equalised Income (% £35,000 or above)	6	14	24	14
Diet					
	Weekly fruit intake (% high >= 4 times/week)	65	66	67	66
	Weekly vegetable intake (% high >= 4 times/week)	77	78	80	78
	Fat free dairy (%)	72	77	79	76
	Whole grain bread (%)	75	79	81	78

[a] Mean (standard deviation)

Table 3: Associations between food spending and diet for high weekly fruit consumption (N=21,630), high weekly vegetable consumption (N=21,629), low-fat dairy consumption or whole grain bread consumption (N=21,627) from Wave 2.

	Odds of high weekly fruit intake [1]		**Odds of high weekly vegetable intake [1]**		**Odds of low fat dairy intake [1]**		**Odds of whole grain bread intake [1]**	
% Away from home spender [3]	**Crude**	**Model 1 [2]**	**Crude**	**Model 1 [2]**	**Crude**	**Model 1 [2]**	**Crude**	**Model 1 [2]**
Low spend	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)
Middle spend	1.03 [0.97, 1.11]	1.03 [0.96, 1.11]	1.06 [0.98, 1.15]	1.01 [0.93, 1.1]	1.29 *** [1.19, 1.38]	1.23 *** [1.14, 1.33]	1.31 *** [1.22, 1.42]	1.24 *** [1.15, 1.35]
High spend	1.09 * [1.01, 1.16]	0.97 [0.9, 1.05]	1.22 *** [1.15, 1.32]	0.99 [0.91, 1.08]	1.46 *** [1.36, 1.58]	1.26 *** [1.16, 1.37]	1.52 *** [1.41, 1.65]	1.28 *** [1.17, 1.4]

[1] High fruit and vegetable intake included consuming FV 4-6 times or more per week, regular consumption of low fat diary and regular consumption of whole grain bread

[2] Adjusted for age, sex, education, equivalised income and equivalised total food spending

[3] % of away from home food spending was divided into tertiles, with the top tertile being a high spender

*p<0.05, **p<0.01, ***p<0.001

Appendix 5: Supplementary material for chapter 5

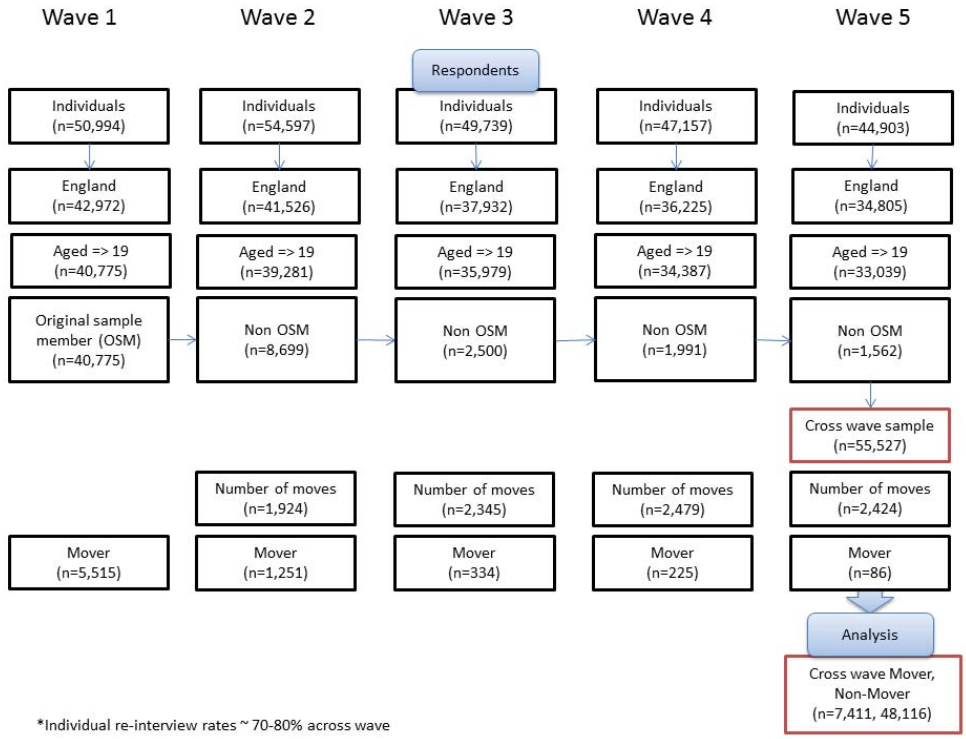

Figure 1: Analytic sample for Chapter 5, for analysis (Wave1 to 5) of movers versus non-movers

Appendix 6: Glossary of terms

General terminology

Social ecological model	Depicts behaviour as determined by multi-levelled factors including intrapersonal, interpersonal, institutional, community and public policy.
Theory	An attempt to organize the facts – some 'proven', some more conjectural – within a domain of inquiry into a structurally coherent system.
Public health	Encompassing those factors, interventions, policies or programs that 'shift the distribution of health risk by addressing underlying social, economic and environmental conditions

Food environment and geographic terminology

Food access	A multidimensional measure of the influence of the local food environment, which is likely to include issues beyond geographic availability and accessibility alone including price and in store features.
Food availability	An adequacy of the supply of healthy food, for example the existence, number and density of food outlets within a specified geographic area or scale
Food accessibility	Ease of getting to supply of healthy food, for example proximity, connectivity and methods of mobility for reaching food outlets from a geographic point within a specified geographic area or scale
Food affordability	Food prices and perceptions of worth relative to cost
Food acceptability	People's attitudes about local environment
Food accommodation	How well local food sources meet needs of residents, examples include store hours and types of payment accepted
Feature	An abstraction of a real-world object. It is not the real world object itself.
Point Feature	A feature representing a real-world object. The geometry of a point feature is a single point (a pair of coordinates) with optional size and orientation.
Positional Accuracy	The accuracy of the feature geometry relative to the coordinate spatial reference system.
National Grid	A unique referencing system that can be applied to all Ordnance Survey maps of Great Britain at all scales. It provides an unambiguous

	spatial reference for any place or entity in Great Britain.
Geocoding	The process of matching raw address information with a digital spatial dataset that includes all addresses within the area of interest mapped to latitude and longitude coordinates.
Ecometric validity	Validity assessed via direct observation undertaken by fieldwork auditors who visit neighbourhoods to make observations or complete an audit tool
Scale	Spatial scale or the size and shape of the geographic boundary selected.
Buffer	Boundaries placed around areas or points using a predefined scale via a straight line (Euclidean) or network distance.
Centroid	A single point representing the centre of a spatial unit.

Realist synthesis terminology

Realism	Realism as a general logic of social science, as a tool for understanding how social programmes work, and as a framework for understanding their complexity
Realist synthesis	Thus, realist synthesis is a theory-driven method and iterative process aimed at uncovering the theories that inform decisions and actions. In this review, we followed a process, which is now detailed in published reporting standards of realist reviews
Context	Modifies the effectiveness of an intervention. Social or geographic feature, features affecting the implementation of programs, make-up of participants or population profile, conditions in which people seek to enact their choices. Context is likely to change over time. Want to define which elements of context relate to or influence which mechanisms.
Mechanism	The explanation for variability around outcomes. Mechanisms are being triggered in a specific context, producing a specific pattern of outcomes; and when triggered in another context, produce a different pattern of outcomes. They are not visible, but must be inferred from the observable data; they are context sensitive and they generate outcomes. Not variables or correlates which associate with one another, rather trying to explain how the association itself comes about. The mechanism is responsible for the relationship itself. It is not expressible as properties of the individual.
Outcome	The resulting pattern when a particular context acts upon a specific mechanism

CMO configuration	A statement, diagram or drawing that spells out the relationship between particular features of context, particular mechanisms and particular outcomes. They take the form of "In X context, Y mechanism generates Z outcome". The CMO configurations can also be linked together through the influence of an outcome in changing the context and therefore triggering additional mechanisms, for example c1 - > m1 -> o1 -> c2 -> m2 -> 02 -> c3 ...
Demi-regularities	Because the range of choices is limited and determined by the context of the study, for any intervention patterns (or demi-regularities) occur. While the context may change, these demi-regularities tend not to. Middle range theories example these demi-regularities. The key goal of a realist review is to uncover these middle range theories.
Programme (or middle range) theory	In simple terms, a programme or middle range theory that is at the level of abstraction to be 'useful' and 'testable'.