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Exploring the conceptualisation of 'variety' and its effects on food intake: A mixed methods approach

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Declaration

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STATEMENT 1

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Dedication

This thesis is affectionately dedicated to the memory of Robert Diatan (Gransha), who was the most enthusiastic reader of this work and the greatest source of inspiration throughout my academic studies.

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Abstract

'Food variety' is a dietary factor with a potentially double-edged influence on consumer health. Though variety is known to support diet quality, it is also recognised as a contributing factor to overconsumption, and variety remains a concept requiring further refinement in the literature. The overarching aim of this thesis was to explore the conceptualisation of variety and its effects on food intake.

Chapter 1 provides a narrative review of theoretical frameworks relevant to the concept of variety, and **Chapter 2** presents a systematic review and meta-analysis of experimental studies that have explored effects of variety as a driver of meal intake. Results supported a small-to-medium effect, but highlighted significant heterogeneity across studies.

Chapter 3 includes findings from two qualitative studies focussed on the consumer understanding of variety. Results showed that consumers have an awareness of variety when discussing hypothetical preferences, but that participants generally defined 'variety' only in the context of the whole diet.

Chapters 4 and **5** further explored effects of variety *within* foods, specifically when measuring portion size selection using a novel online tool. Though no significant differences were found across levels of variety, key methodological issues specific to investigating effects of composite foods were highlighted.

Chapter 6 reports effects of dietary variety on body weight using prospective data from the UK Biobank. Dietary variety was a significant predictor of portion size. There was also some evidence of a significant, negative association between dietary variety and body weight, though portion size as a mediator and energy density as a moderator did not significantly influence this relationship.

Overall, this thesis supports variety as a robust driver of food intake. Results provide novel insight into the conceptualisation of variety from a researcher and consumer perspective, highlighting implications for tailoring future research focussed on variety to the modern eating environment.

Dissemination of Research

Publications:

Embling, R., Pink, A. E., Lee, M. D., Price, M., & Wilkinson, L. L. (2020). Consumer perception of food variety in the UK: an exploratory mixed-methods analysis. *BMC public health*, 20, 1449. https://doi.org/10.1186/s12889-020-09548-x **(Study 2 and Study 3)**

RE, LLW, ML, and MP designed research; RE completed data collection and analysed data; RE and AEP conducted independent data checks; RE drafted the manuscript with supervision from LLW; LLW, ML, MP, and AEP provided editorial comments; and all authors were responsible for final content and read and approved the final manuscript.

Embling, R., Pink, A. E., Gatzemeier, J., Price, M., D Lee, M., & Wilkinson, L. L. (2021). Effect of food variety on intake of a meal: A systematic review and meta-Analysis. *American Journal of Clinical Nutrition*, *113*(3), 716–741. https://doi.org/10.1093/ajcn/nqaa352 **(Study 1)**

RE, LLW, MP, and ML designed research; RE and AEP screened and selected articles for review; RE extracted data; RE and JG conducted independent data checks; RE analysed data; RE drafted the manuscript with supervision from LLW; LLW, MP, ML, AEP, and JG provided editorial comments; and all authors were responsible for final content and read and approved the final manuscript.

Embling, R., Lee, M. D., Price, M., & Wilkinson, L. L. (2021). Testing an online measure of portion size selection: a pilot study concerned with the measurement of ideal portion size. *Pilot and feasibility studies*, *7*, 177. https://doi.org/10.1186/s40814-021-00908-x **(Study 4)**

RE developed study materials, completed data collection, and analysed data; RE drafted the manuscript with supervision from LLW; LLW, MDL, and MP: provided editorial comments; and all authors designed research, were responsible for final content, and read and approved the final manuscript.

Embling, R., Price, M., Lee, M. D., Jones, A., & Wilkinson, L. L. *Associations between dietary variety, portion size, and body weight: Prospective evidence from 35 449 UK Biobank participants*. Manuscript submitted for publication. **(Study 7)**

RE, LLW, MP, ML, and AJ designed research and methodology; RE and LLW managed project administration; RE and AJ prepared data; RE analysed data; RE drafted the manuscript with supervision from LLW; LLW, MP, ML, and AJ provided editorial comments; and all authors were responsible for final content and read and approved the final manuscript.

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Embling, R. (2020, March 11). Using food variety to manage how much we eat. Three Minute Thesis (3MT) competition heats. Swansea University, Swansea, UK.

Embling, R., Pink, A. E., Lee, M. D., Price, M., & Wilkinson, L. L. (2021, January 13–14). *Consumer perception of food variety in the UK: an exploratory mixed-methods analysis*. UKSBM Annual Scientific Meeting, virtual congress. **(Study 2 and Study 3)**

Embling, R., Pink, A. E., Gatzemeier, J., Price, M., D Lee, M., & Wilkinson, L. L. (2021, March 31–April 1). *Effects of food variety on intake of a meal: A systematic review and meta-analysis*. British Feeding and Drinking Group Annual Meeting, University of Leeds, virtual congress. **(Study 1)**

Embling, R., Price, M., Lee, M. D., Jones, A., & Wilkinson, L. L. (2021, May 11–14). *Associations between daily dietary variety, portion size, and body weight: Prospective evidence from 35,524 UK Biobank participants*. ECO Online Conference, virtual congress. **(Study 7)**

Embling, R., Price, M., Lee, M. D., Jones, A., & Wilkinson, L. L. (2022, April 12–14). *Associations between dietary variety, cumulative portion size, and body weight: Prospective evidence from 35,449 UK Biobank participants*. British Feeding and Drinking Group Annual Meeting, University of Leeds, virtual congress. **(Study 7)**

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"Food variety", Nutrition and Behaviour Unit, University of Bristol, November 20, 2020 (with Dr Laura Wilkinson). http://www.bristol.ac.uk/psychology/research/brain/nbu/superstars/

"Developing an open-source research tool: A success story for open research", Loughborough ReproducibiliTea, Loughborough University, September 7, 2021 (with Dr Laura Wilkinson). **(Study 4)**

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Abbreviations

BF: Body fat percentage

BIS: Barratt Impulsiveness Scale

BMI: Body mass index

BSSS: Brief sensation seeking scale

DEBQ: Dutch eating behaviour questionnaire

dlPFC: Dorsolateral prefrontal cortex

DVS: Dietary variety score

DVS-B: Dietary variety between food groups score

DVS-W: Dietary variety within food groups score

FFM: Fat-free mass

FFQ: Food frequency questionnaire(s)

IMD: Index of Multiple Deprivation scores

OFC: Orbitofrontal cortex

PRISMA: Preferred reporting items for systematic reviews and meta-analysis guidelines

SRQR: Standards for Reporting Qualitative Research

TFEQ-R18: Three-factor eating questionnaire-R18

VARSEEK: Variety-seeking scale

VAS: Visual analogue scale

vmPFC: Ventromedial-prefrontal cortex

1. Chapter 1 – General Introduction

The overarching aim of this thesis was to further explore the effect of food variety on consumption within the current 'obesogenic' food environment. Food variety is a dietary factor with a potentially double-edged influence on consumer health. Though the consumption of a varied diet has been a longstanding recommendation in nutritional guidelines (Kennedy, 2004), food variety has also been identified as a key driver of food intake (Rolls et al., 1984; Rolls, Rowe, et al., 1981). In recent years, this has led to food variety being recognised as a defining feature of the obesogenic food environment, linked to overconsumption and the development of overweight and obesity (Johnson & Wardle, 2014). However, there may be some inconsistencies between the conceptualisation of variety in dietary guidelines, the extant research literature on effects of variety relating to food intake, and the presence of variety in the real world (from a consumer and product perspective).

This chapter will provide an overview of the 'obesity epidemic' in relation to malnutrition and the obesogenic food environment. Within this context, key literature on the role of cognitive processes influencing appetite control will be discussed, as they relate to the influence of variety on food intake. Effects of variety that are relevant to both overconsumption and diet quality will be reviewed.

1.1. A 'double burden' of overweight, obesity, and malnutrition

On a global scale, 1.9 billion adults and 39 million young children are living with overweight and obesity (World Health Organisation, 2021). Current trends show that by 2026, prevalence of obesity alone is projected to reach maximum levels across Europe and USA, with the highest prevalence expected in the USA (44%) and UK (37%) respectively (Janssen et al., 2020). Overweight and obesity have been widely associated with increased chronic health risks, including type 2 diabetes, musculoskeletal disorders, cardiovascular diseases, and cancers (Guh et al., 2009; Wang et al., 2011; Webber et al., 2014). This has led to the identification of overweight and obesity as a significant public health concern, requiring intervention to tackle increasing health and social care costs (Wang et al., 2011). For this reason, it is essential that effective strategies focussed on the reduction and prevention of overweight and obesity continue to be developed.

In particular, there are growing concerns regarding the ‘double burden’ of overweight and obesity coinciding with malnutrition. On the one hand, this has been used to describe populations where both undernutrition (dietary deficiencies in energy and nutritional content) and overnutrition (overconsumption of energy and/ or nutritional content primarily affecting energy balance) remain significant health concerns that coexist within the same community (World Health Organisation, 2017). Evidence suggests that 8.8% of adult males and 9.7% of adult females are classified as ‘underweight’ worldwide (NCD Risk Factor Collaboration, 2016), and similar to overweight and obesity, undernutrition increases disease risks and susceptibility to illness (Kim et al., 2019). Importantly, this means that such countries bear the health and social care costs of underweight, overweight, and obesity. For example, in India alone, over 200 million adults are classified as underweight, whilst more than 30 million adults are also living with obesity (NCD Risk Factor Collaboration, 2016).

On the other hand, the double burden of overweight and obesity coinciding with malnutrition can be used to describe effects at an ‘individual’ level. In particular, consuming a diet largely composed of high energy-dense foods (those high in fat, sugar and salt content), that are otherwise poor in nutritional quality, may result in an overconsumption of energy that also produces micronutrient deficiencies (Tanumihardjo et al., 2007; World Health Organisation, 2017). For instance, in countries such as the UK and USA, where overweight and obesity continue to show upward trends (Jaacks et al., 2019; Janssen et al., 2020; Shields et al., 2011; Wang et al., 2011), data suggests that these populations are also failing to meet recommended amounts of micronutrients such as vitamins D, A, and C (Millen et al., 2016; Richardson & Lovegrove, 2021).

1.2. Defining features of the modern 'obesogenic' food environment

Overweight and obesity is known to be a multifactorial disease, with many biological, psychological, behavioural, economic, and social factors influencing development (Foresight systems map, 2007). Tackling the 'obesogenic' food environment in particular has become the focus of public health strategies in recent years (Commission of the European Communities, 2007; Department of health and human services Centers for Disease Control and Prevention, 2009; Department of Health and Social Care, 2020). Considering the complexity of the multifactorial systems involved, difficulties defining characteristics of the obesogenic environment (and doing so consistently) have been identified in the literature (Kirk et al., 2010; Townshend & Lake, 2017). For the purpose of this discussion, 'obesogenic food environment' is broadly used to refer to the influence of external food-related drivers on dietary intake and weight-related outcomes (Townshend & Lake, 2017).

In both developed and developing countries, evidence suggests that dietary patterns have shifted towards the consumption of more palatable and energy-dense foods (Johnson & Wardle, 2014; Kearney, 2010; Popkin et al., 2012). Highly-processed or 'ultra-processed' foods – that typically contain industrial-use ingredients and additives – are widely consumed in substantial amounts and contribute significantly to energy intake (Monteiro et al., 2019). Portion sizes appear to have increased in recent years, particularly for palatable and energy-dense foods including main meal dishes and sides (such as French fries, hamburgers, and pasta), salty snacks, confectionary, and soft drinks (Nielsen & Popkin, 2003; Young & Nestle, 2002). Such foods tend to be low-cost, convenient, and easy to access, but high in added sugars and fat content (Drewnowski & Specter, 2004).

It is notable that food availability has expanded over time to include a wider variety of items (Foster & Lunn, 2007; Gallo, 1997; USDA Foreign Agricultural Service, 2016; Vadiveloo et al., 2021), with total daily energy availability per capita increasing across Europe and the USA since the 1960s and 1970s, respectively (Balanza et al., 2007; Barnard, 2010; Carden & Carr, 2013). Most introductions of food products today offer consumers new flavours, colours, shapes, and sizes, as well as reformulations of items to address health concerns (e.g., to lower salt/ sugar content) (Gallo, 1997). Such changes in the availability of variety is likely to be both industry- and consumer-led. For instance, in the consumer and marketing literature, the development of new products is recognised to be one strategy used to sustain financial and capital growth by increasing total outputs (Yilmaz, 2016), whilst manufacturers and retailers are also known to respond to trends in consumer preferences for variety (Davis & Stewart, 2002).

In a recent study, McCrory and colleagues (McCrory et al., 2019) found some concurrent evidence that both ‘portion size’ and ‘variety’ have increased when eating outside of the home. Using US national survey data, assessments of fast-food restaurant menus showed that portion sizes offered for entrees and desserts increased in both weight and energy content from 1986 to 2016, and the number of different items available had risen by over 200% across outlets, suggesting an average increase of 22.9 items per year for a single restaurant (McCrory et al., 2019). In a similar study of restaurant menus in the UK (Huang et al., 2021), the number of items available to consumers had increased by 19% across large chain cafes, fast-food outlets, and sit-down restaurants in a single 12-month period.

Coinciding with changes in portion size, it is then suggested that some of these changes in the obesogenic environment may relate to a varied, energy-dense, and palatable food supply (Johnson & Wardle, 2014). Such effects in combination may significantly increase the risk of overconsumption. However, it is acknowledged that this is by no means a complete summary of external effects in the obesogenic environment today, and that other environmental, social, economic, political, cultural, and individual factors, have important effects on consumption and body weight (Kirk et al., 2010; Townshend & Lake, 2017). In particular, it is important to acknowledge that other vulnerabilities play a role in the development of obesity and nutritional deficiencies, as demonstrated by the complex relationships between food scarcity, food insecurity, and socioeconomic status (Caldwell & Sayer, 2019; Moradi et al., 2019), as well as interactions between genetic susceptibility, appetite, and the environment (Llewellyn & Wardle, 2015), in relation to obesity.

1.3. Biopsychological influences on appetite

It is widely recognised that appetite control is influenced by interactions between homeostatic and hedonic systems, highlighting a role for psychological processes in determining food intake and energy balance (Higgs et al., 2017). As modelled in the 'Satiety Cascade' (reported in (Chambers et al., 2015)), satiety – or relief from hunger after eating – occurs as the result of cognitive, sensory, and physiological processes that influence both food choice and satiation (feeling of fullness derived from eating). During the cephalic phase, cognitive and sensory experiences of foods prompt post-ingestive and post-absorptive signals to occur that stimulate the digestive processing of nutrients, including the release of gastrointestinal hormones and gastric acid secretion (Chambers et al., 2015). This means that even prior to ingestion, perception of a food's characteristics can influence cascading signals leading to satiety. For instance, studies have shown that bypassing the cognitive and sensory aspects of an eating episode by using intragastrical infusion (tube feeding) has little effect on hunger, desire to eat, and fullness ratings (Cecil et al., 1998; Stratton et al., 2003), and also fails to suppress subsequent food intake in healthy individuals (Stratton et al., 2003). Cues relating to the appearance, taste, texture, and smell of foods have then been found to influence food choice, meal size, eating rate, satiation, and food intake (Mccrickerd & Forde, 2016).

In a recent extension of this model, Cunningham and Rolls (Cunningham & Rolls, 2021) developed the 'Satiation framework' to specifically illustrate the social influences, sensory experiences, and physiological changes that are likely to promote the termination of a meal and increase satiation. According to this model, the hedonic decline in the appeal of eaten foods, and an increased feeling of physical fullness, are related to a decreased priority for eating during meal consumption (i.e., decline in desire/ motivation to eat). Prior to when a meal begins, decisions associated with planned meal size are also recognised as having a direct influence on the point at which consumers will decide to stop eating, with self-consciousness in relation to the perceived appropriateness of portions highlighted as a particular example.

There are two broad forms of learning that have been discussed in the literature. First, non-associative learning refers to the gradual change in responding to a stimulus that occurs overtime with repeated exposure when experiences are not associated with rewarding or aversive consequences. Of note is that this includes habituation, whereby the response initially prompted by a given stimulus diminishes with repeated exposure (Thompson, 2009). Most relevant to effects on food intake discussed here, habituation relates predominantly to the following parameters (Epstein, Temple, et al., 2009; Thompson, 2009); 1) behavioural, hedonic, and physiological responding to sensory food cues declines with repeated consumption, 2) habituation effects can generalise to other foods with the same/ similar sensory characteristics, 3) introducing 'novel' sensory food cues to an eating episode leads to a recovery in responding that also applies to the 'habituated' food (i.e., dishabituation), and 4) 'spontaneous recovery' in responding will occur after a washout period (i.e., no exposure to the habituated food). In the absence of dishabituation, a recovery of responding for the novel food (but not the habituated food) may represent effects of 'stimulus specificity' (Havermans, 2012). For a comprehensive review of models relating to habituation for foods, see (Epstein, Temple, et al., 2009).

Second, associative learning – or classical conditioning – refers to when an association is formed between a previously neutral stimulus and a specific consequence when these are repeatedly paired overtime. Where non-associative learning is 'innate', associative learning requires memory and recall for prior experiences relevant to a stimulus. In the context of food-related responding, 'anticipated consequences' can relate to the liking and disliking of foods, post-ingestive physiological effects, as well as social/ cultural beliefs associated with eating (Rozin & Zellner, 1985). This means that expectations and beliefs that are formed about foods can influence behavioural and hedonic responding to meals.

Consistent with these models of satiety and satiation, this section will introduce key cognitive processes of interest with reference to relevant homeostatic, reward, and metabolic mechanisms (specifically as these relate to satiety and satiation) (for an overarching review, see (Higgs et al., 2017)).

1.3.1. Expectations of satiety and satiation before a meal: A role for associative learning

Portion size appears to have a curvilinear effect on food intake, whereby larger portions (up to a 'peak' relative point) are expected to result in greater consumption, with adults consuming 39% more food when presented with larger portions across studies (Zlatevska et al., 2014). This 'portion size' effect has been shown to be relatively consistent across multiple food types and categories, meal settings, and sample characteristics (Diliberti et al., 2004; Fisher et al., 2003; Kelly et al., 2009; Rolls et al., 2002; Spill et al., 2010). As such, portion size itself has been highlighted as a potential contributing factor to overweight and obesity (Kral & Rolls, 2011; M. B. E. Livingstone & Pourshahidi, 2014).

When concerned with the influence of expectations on consumption before eating, experimental studies have typically used a psychophysical computer-based task to measure selected portion size (see (Brunstrom & Rogers, 2009)). In such tasks, participants are presented with an array of photographs for each food item of interest that are displayed consecutively onscreen and vary in portion size. Participants respond to each image by choosing whether to increase or decrease the portion size displayed, and participants are asked to select the portion that they would most like to consume in a specified setting (e.g., their preferred 'ideal' portion size for a specific food). Using this measure, participants' ideal portion size has been shown to be a significant predictor of actual consumption when selected before eating (Wilkinson et al., 2012), and sensitive to clinical differences in expected portion size (Hamm et al., 2020). This reflects findings that self-selected portions are mostly eaten to completion (Fay et al., 2011; Hinton et al., 2013).

Adaptations of this task have also been used to measure expected satiety and expected satiation, specifically (Brunstrom, 2014). For example, using a 'method of constant stimuli', participants are asked to select their chosen portion in each trial when comparing a fixed portion for one 'standard' food item to portions of another 'comparator' food item that are manipulated across trials. Using a 'method of adjustment', participants are shown a fixed portion for a standard food alongside a comparator food. Participants can choose to increase or decrease the portion displayed onscreen for the comparator food (giving rise to an 'animated' change in portion size). Across these tasks, participants are asked to select the portion that would be most satiating or filling, or to match the standard and comparator foods for expected satiety or expected satiation, respectively. Expectations for the food of interest can then be calculated as the number of calories selected to match the standard food.

In several studies by Brunstrom and colleagues, expectations of satiety and satiation have been identified as significant predictors of meal size (Brunstrom, Collingwood, et al., 2010; Brunstrom & Rogers, 2009; Brunstrom & Shakeshaft, 2009; Labbe et al., 2017; McLeod et al., 2020; Wilkinson et al., 2012), and actual satiety (Brunstrom et al., 2011; Brunstrom, Shakeshaft, et al., 2008). Moreover, the influence of expected satiety and expected satiation on selected portion size has been shown to be stronger than that of other identified drivers of food intake, such as liking (Brunstrom & Rogers, 2009; Wilkinson et al., 2012), though it should be noted that portions derived from expected satiation may not always represent the quantity of food that participants actually choose to consume (Guillocheau et al., 2018).

Evidence suggests that such expectations are likely to be the result of associative learning over time, though most studies within this specific domain have been conducted by members of the same research laboratory. Across a range of snacks and main meal foods, expectations of satiety and satiation have been shown to significantly vary between items (Brunstrom, Collingwood, et al., 2010; Brunstrom, Shakeshaft, et al., 2008; Brunstrom & Rogers, 2009; Hogenkamp et al., 2011), and 'experience' with consuming specific foods has been highlighted as a key factor influencing development. For example, Irvine et al. (Irvine et al., 2013) showed that frequently eating a food to fullness was significantly associated with participants' expected satiety, and that actually consuming a food to satiety in a recent eating episode subsequently increased expected satiety for the same food item a few days later. In a similar study of expected satiation, Wilkinson and Brunstrom (Wilkinson & Brunstrom, 2009) manipulated the formulation of a novel Jell-O based dessert to be 'low' (61 kcal/ 100 g), 'intermediate' (97.6 kcal/ 100 g), or 'high' (152.7 kcal/ 100 g) in energy density, and otherwise matched formulations for taste, appearance, and satiation. After consuming the high energy density dessert one-day prior, expected satiation increased by 17.4%, though expected satiation decreased by 4.6% for the low energy density dessert. Both studies suggest that 'one-trial learning' can influence shifts in evaluations of foods relating to post-ingestive effects. Such findings are consistent with studies demonstrating a strong association between perceived familiarity of foods and expectations of satiation and satiety, with more familiar foods generally being expected to be more satisfying/ satiating (Brunstrom, Shakeshaft, et al., 2008, 2010).

It is notable that learned effects of expected satiety and expected satiation may be influenced by energy density (Wilkinson & Brunstrom, 2009), as well as sensory characteristics of foods including texture and viscosity (Hogenkamp et al., 2011; McCrickerd et al., 2012). 'Flavour-nutrient learning' is a form of associative learning whereby the repeated experience of a food's sensory characteristics is conditioned to post-ingestive effects, and has been discussed in relation to driving changes in food preferences and intake respectively (Martin, 2016; Yeomans, 2012). As suggested by Higgs and colleagues (Higgs et al., 2017), these learned associations may benefit the individual by encouraging consumption or avoidance of foods in response to metabolic needs, discussed in relation to hypothalamic areas of the brain in particular (Timper & Brüning, 2017; Waterson & Horvath, 2015). First, in relation to flavour-nutrient 'hedonic' learning (relevant to the development of liking, specifically), Sclafani and colleagues have shown that when flavoured water is paired with intra-gastric infusion of fats, sugars, proteins, or carbohydrates, versus intra-gastric infusion of water, rats develop a preference for the flavour associated with the nutrient solutions (higher energy density), and drink from these water sources more frequently (Ackroff et al., 2005; Azzara & Sclafani, 1998; Pérez et al., 1996). Experiencing a state of food deprivation – relating to deficiencies in energy or nutrients – can increase activity in reward-based networks, and encourage responding to relevant food cues (Higgs et al., 2017). Such behaviours may be goal-directed (e.g., relating to knowledge of the nutritional benefits of foods) (Booth, 1985; Higgs et al., 2017).

Second, in relation to flavour-nutrient 'satiety' learning (or 'conditioned satiety/ satiation'), food intake may be moderated by the ability to anticipate the satiating effects of foods, as exposure to conditioned sensory characteristics inhibits eating responses (Booth, 1985). For example, Birch and Deysher (Birch & Deysher, 1985) presented preschool children (aged 3 – 5 yrs) with a series of conditioning trials, whereby a specific flavour (chocolate or vanilla) was paired with either a high energy density or low energy density preload. In a series of extinction trials, both flavours were then paired with a preload that had an intermediate energy density. Results showed that during both conditioning and extinction trials, *ad libitum* snack intake was lower following consumption of the flavour paired with the high energy density versus low energy density preload, supporting that the children were anticipating its satiating effects.

However, past reviews have noted that evidence of flavour-nutrient learning is generally less consistent in humans (Martin, 2016; Yeomans, 2012), and even more recent studies of flavour-nutrient learning have failed to support an effect when the novelty of foods and beverages was high (Attuquayefio et al., 2020; Brunstrom et al., 2015). One explanation is that the modern food supply characterised by greater variability – particularly in terms of energy density for specific food types – results in 'inconsistent' associations with satiation and satiety across eating experiences (Martin, 2016). For example, evidence from studies with rats have shown that pairing a low energy density premeal with a sweet taste and high fat content (characteristics typically associated with the satiating effects of high energy density foods), results in increased food intake and reduced compensation for premeal consumption (Swithers et al., 2011; Swithers & Davidson, 2008).

There is also some evidence that individuals expect more energy dense foods to deliver less satiation and be poorer at staving off hunger between meals (Brunstrom, Shakeshaft, et al., 2008; Brunstrom & Rogers, 2009). Individuals appear to underestimate the satiating effects of foods with a higher energy density (particularly when >3 kcal / g) (Brunstrom et al., 2018). Likewise, foods with a lower energy density are generally found to be more satiating compared to foods with a higher energy density (Holt et al., 1995). This has been related to post-ingestive effects of macronutrient contents of these foods on satiety (Chambers et al., 2015). For example, the majority of studies indicate that protein has the most satiating effects on appetite, whilst the higher fat content in more energy dense foods is associated with lower satiety, likely due to differences in volume when foods are energy-matched (Chambers et al., 2015; Drewnowski, 1998). This may also be reinforced by the tendency to consume high energy dense foods in smaller portions that may not result in satiation or strong satiety (e.g., as snack foods) (Brunstrom, 2011), particularly as portion size selection and food intake can be driven by perceived 'norms' (Robinson & Kersbergen, 2018). However, partially distinguishing effects from perceived volume/ weight alone, a unique proportion of the variance associated with selected portion size has been specifically attributed to expected satiation (Brunstrom, Collingwood, et al., 2010). More specifically, expected satiation may be more likely to be driven by perceived volume when food variety is increased (as variety is expected to increase difficulty when evaluating expectations for different foods within a meal), particularly when familiarity with foods is low (Keenan et al., 2015).

Therefore, there is strong evidence for the influence of learned expectations on selected meal size and subsequent food intake, particularly relating to satiety and satiation. Though exact mechanisms underlying these effects warrant further exploration, expectations appear to be highly practiced and conditioned overtime, and play a key part in appetite control prior to when eating begins.

1.3.2. Habituation and sensory-specific satiety during a meal: A role for non-associative learning

Reward-based mechanisms appear to play a central part in appetite control during a meal. ‘Palatability’ refers to the pleasantness derived from sensory characteristics of foods, and is typically discussed in relation to hedonic evaluations of taste/ flavour (i.e., self-reported liking, enjoyment, and pleasantness). Palatability is typically higher for more energy dense foods (Holt et al., 1995), and has been associated with increased food intake (Sørensen et al., 2003). Responsivity to rewarding stimuli (including highly palatable foods) involves activation in specific reward centres of the brain (e.g., striatum, orbitofrontal cortex (OFC)), metabolic signalling linked to dopaminergic pathways (e.g., hormones relevant to appetite, such as ghrelin), as well as attenuation of other systems associated with negative feedback signals (Carnell et al., 2012; Higgs et al., 2017). Greater activity in the OFC in particular has been shown to occur in response to ‘high incentive’ food cues (Arana et al., 2003), whereas increased activity in the dorsolateral prefrontal cortex (dlPFC) has been associated with reduced activity in reward-based circuitry and greater inhibitory control in the presence of food cues (Thomas et al., 2015).

Palatability experienced for foods is known to change over the course of eating. 'Alliesthesia' refers to the general change in pleasantness that is derived from stimuli in response to physiological changes in the internal state, and relative 'utility' of the stimulus to restoring homeostasis (Cabanac, 1971, 1988). As such, 'positive alliesthesia' may relate to an increase in the pleasantness of foods in response to hunger, whilst 'negative alliesthesia' may relate to a decrease in the pleasantness of foods in response to satiation/ satiety. For example, ratings of liking and wanting for food related stimuli (odours and images) have been shown to significantly decline when in a satiated state (after eating) compared to when in a 'hungry' state (before eating), a change that is not observed for non-food related stimuli (Jiang et al., 2008). Alliesthesia has also been shown to occur in response to some deprivation states relating to nutritional deficiencies. For example, rats demonstrate a preference for salty tastes when experiencing a state of sodium deficiency, despite salt otherwise being an aversive stimulus (Booth, 1985; Morales & Berridge, 2020). Food deprivation has also been suggested to increase activity in the OFC (Siep et al., 2009; Thomas et al., 2015), whilst satiation increases activity in the dlPFC (Thomas et al., 2015).

Where alliesthesia refers to changes in the pleasantness experienced for all foods, 'sensory specific satiety' (also termed 'sensory specific satiation' (Cunningham & Rolls, 2021; Hendriks-Hartensveld, Rolls, et al., 2022; Remick et al., 2009)) refers to the gradual decline in palatability that occurs in response to repeated consumption of a particular 'eaten' food item, relative to 'uneaten' foods that differ in sensory characteristics (Rolls, Rolls, et al., 1981). To measure sensory specific satiety, participants are asked to provide hedonic ratings for samples of all test foods both before and after eating a 'test meal' or 'preload' (consisting of select sample test foods), either *ad libitum* or in a fixed amount (Hetherington & Rolls, 1996; Remick et al., 2009). Pre-meal hedonic ratings are then subtracted from post-meal hedonic ratings for eaten and uneaten test foods to calculate the relative decline.

For example, in a seminal paper, Rolls et al. (Rolls, Rolls, et al., 1981) asked participants to rate the pleasantness of eight different foods (e.g., chicken, walnuts, chocolate, potatoes). Participants consumed one of these foods to fullness (the 'eaten' food), and repeated ratings for all foods 2-mins and 20-mins after eating. Across participants, results showed that pleasantness declined at a significantly greater rate for the eaten food compared to uneaten foods, from before to after eating.

Sensory specific satiety has been shown to occur early within a meal. Pleasantness ratings for the taste, smell, texture, and appearance of eaten foods sharply decline within 2-mins of tasting (Hetherington et al., 1989). This means that sensory specific satiety occurs immediately in response to oro-sensory exposure to foods (experience of foods in the mouth), and can occur in the absence of post-ingestive effects. For example, modified sham-feeding studies have shown that the post-meal decline in palatability and desire for eaten foods occurs irrespective of whether or not foods are swallowed (Nolan & Hetherington, 2009; Smeets & Westerterp-Plantenga, 2006), reflecting findings that sensory specific satiety is not influenced by energy density or a food's 'satiating' effects (Remick et al., 2009). More specifically, Hendriks et al. (Hendriks et al., 2019) demonstrated that reducing oro-sensory exposure time (as a result of alternating tastes of multiple different foods) results in weaker sensory specific satiety effects for an eaten food. Imaging studies have also shown that activity in the OFC is associated with responding to taste (Kringelbach et al., 2003; O'Doherty et al., 2001), and relative reductions in neural activity are consistent with the decline in subjective ratings of pleasantness observed for foods eaten to satiety (Kringelbach et al., 2003).

Sensory specific satiety also has an important influence on the individual's decision to stop eating (Cunningham & Rolls, 2021; Hetherington, 1996), and effects persist at the end of a meal (Hetherington et al., 1989; Rolls et al., 1988; Rolls, Rolls, et al., 1981). For example, demonstrating that hedonic responding had not yet recovered in the post-meal interval, one study showed that the eaten food remained significantly less pleasant than uneaten foods 60-mins after eating, though there were no significant differences in food intake when presented with the same or different food for a subsequent second course (Hetherington et al., 1989). Most evidence suggests that sensory specific satiety does not have longer-term effects across meals (Hetherington et al., 2000, 2002; Miller et al., 2000). In other words, responding recovers between testing days, such that the relative change in pleasantness for eaten foods is generally consistent over time in response to each meal session. Similar findings have been reported in animal research, as rats consume significantly less of a pre-fed flavoured water solution and more of a different flavour when bottles are presented up to 2 hrs after pre-consumption, but this preference is no longer evident after 5+ hrs (González et al., 2022).

Other studies have provided some evidence that the magnitude of sensory specific satiety may change over the course of several weeks. In one early study, Rolls and de Waal (Rolls et al., 1985) reported effects of 'long-term sensory specific satiety' in an Ethiopian refugee camp. Individuals who had been staying at the camp for approximately 6-mths demonstrated stronger liking for 'uneaten' foods that differed to those regularly eaten within the camp (after consuming 'regular' foods for breakfast), whereas liking did not significantly differ between foods for individuals who had only very recently arrived, though change from pre-consumption ratings was not specifically tested. Using a randomised-controlled parallel-arm design, Tey et al. (Tey et al., 2012) assigned participants to consume either no snack (control condition), or a hazelnut, chocolate, or potato chip snack on a daily basis for 12 weeks (repeated exposure condition). During pre-exposure (baseline) and post-exposure tasting sessions (week 12), all participants completed a standard sensory specific satiety paradigm; they provided ratings of liking for six sample snack foods, before and after consuming one of these snacks *ad libitum* (in accordance with their assigned group). Results showed that sensory specific satiety scores in tasting sessions significantly declined from baseline to week 12, indicating that the relative change in liking for eaten foods versus uneaten foods was smaller following repeated exposure. Similar results have also been reported in an intervention setting, as hedonic ratings significantly declined for chosen foods when adults had been asked to consume a single snack food over several weeks as part of a weight-loss intervention trial (Raynor et al., 2006, 2012). However, across these studies, it is difficult to distinguish effects of sensory specific satiety from effects of monotony or 'stimulus satiation' in such studies, as liking for 'eaten' foods in response to repeated exposure linearly declines over time (Hetherington et al., 2002).

Sensory specific satiety is noted to have conceptual similarities to habituation, and this has led to the belief that habituation (or stimulus specificity) underpins effects on food intake (Epstein, Temple, et al., 2009; González et al., 2022; Havermans, 2012; Wilkinson & Brunstrom, 2016). Where sensory specific satiety refers to the relative decline in hedonic responding for a food following consumption, habituation refers to a decline in responding to a food in response to repeated exposure over time, a subtle but notable distinction. Epstein and colleagues have demonstrated habituation to foods in both adults and children (Epstein et al., 1992, 1993, 2003, 2005; Myers Ernst & Epstein, 2002; Temple et al., 2007, 2008). For instance, when repeatedly presented with lemon juice, both salivation and liking steadily declined in response to exposures over several trials, but subsequently increased following presentation of lime juice, indicating a recovery of physiological and hedonic responding for the 'habituated' taste of lemon juice in response to a 'dishabituator' (Epstein et al., 1992). Similar results have been found irrespective of energy density during habituation trials (Epstein et al., 1993; Temple et al., 2008), and in relation to motivated responding to earn foods (e.g., by completing a point-based task) (Epstein et al., 2003; Myers Ernst & Epstein, 2002; Temple et al., 2007, 2008). Habituation has also been shown to be slower when repeated exposure to stimuli is disrupted, e.g., by including distractor tasks between trials (Epstein et al., 1992, 2005; Temple et al., 2007), or increasing the number and variety of food stimuli presented (Myers Ernst & Epstein, 2002; Temple et al., 2008). In the latter case, presenting a variety of foods also significantly increased energy intake by over 30% (Temple et al., 2008).

There is also clear evidence that sensory specific satiety may occur in the absence of top-down processing. In a key study with amnesiac patients (Higgs, Williamson, Rotshtein, et al., 2008), Higgs and colleagues showed that despite being unable to recall meals immediately after eating, these patients showed a similar pattern of sensory specific satiety to that of control participants, as ratings of liking and desire to eat for sandwiches consumed to satiety were significantly lower than ratings for uneaten sample foods across groups. Such evidence has been used to support the notion that sensory specific satiety reflects a form of non-associative learning akin to habituation.

In a more recent study, González et al. (González et al., 2022) explored evidence for habituation parameters using a sensory specific satiety paradigm in three experiments with rats. Consistent with habituation, they demonstrated that rats spontaneously recovered responding for a pre-fed flavour solution after a period of non-exposure, and that effects of sensory specific satiety – whereby rats drank less of the pre-fed versus non pre-fed flavour – were no longer evident in the later phases of the inter-meal period. However, presentation of a distractor solution during the pre-consumption phase did not weaken the expression of sensory specific satiety for the pre-fed versus non pre-fed flavour solutions after drinking. Presentation of a dishabituator (salty solution) also did not prompt a recovery of responding to the pre-fed flavour, and did not influence the magnitude of sensory specific satiety.

Prior research with human participants has also failed to support dishabituation of sensory specific satiety effects. In one study, Havermans (Havermans, 2012) induced sensory specific satiety for a food using a 10-min signalled exposure task, in which participants were instructed to look at, taste, smell, and chew bite-size portions of the food before swallowing.

Participants then completed a signalled exposure task for a different food, or played a computer game. Following signalled exposure, mean hedonic ratings for both exposed foods (but not other control foods) significantly declined, demonstrating sensory specific satiety. Presentation of the different food or computer task did not increase ratings for the first exposed food (as would be expected if dishabituation occurred). Other studies have found similar results, as sensory specific satiety remains evident for eaten foods even after presenting ‘different’ foods for consumption (Havermans et al., 2010; Meillon et al., 2013). Similarly, Hendriks et al. (Hendriks et al., 2021) did not support the use of a ‘context switch’ as a dishabituator – in which the appearance, smell, and feel of the eating environment was changed after consuming a food – as this did not increase food intake in a subsequent course (though hedonic ratings were not re-measured).

Havermans and colleagues (Havermans, 2012; Havermans et al., 2010) then suggest that sensory specific satiety is a demonstration of a ‘stimulus specific’ response, a process that Wilkinson and Brunstrom (Wilkinson & Brunstrom, 2016) have generally referred to as “a more basic form of learning”. Whether or not this constitutes a form of habituation per se – without demonstrating dishabituation as a core parameter in particular – has been debated in the literature and warrants further attention (for a recent discussion, see (González et al., 2022)). Nevertheless, stimulus specificity indicates that the decline in responding to an exposed food stimulus is not because of sensory fatigue relating to perception of the stimulus, and evidence suggests that this process is not solely dependent on associative learning requiring memory for eating events (Higgs, Williamson, Rotshtein, et al., 2008).

Contrasting with this position, ‘higher’ cognitive processes have been suggested to modulate the occurrence of sensory specific satiety (Hetherington & Rolls, 1996). Top-down processes may differentially guide attention towards food cues that are consistent with sensory specific satiety and appetite state (e.g., by decreasing motivated attention to meal-congruent food cues after eating) (Davidson et al., 2018; Zoon et al., 2018). Exploration of such processes has related to consumer beliefs about food properties (e.g., relating to nutritional and satiating effects of foods) (Hendriks-Hartensveld, Rolls, et al., 2022; Miller et al., 2000; Rolls et al., 1992), as well as the perception of variety and 'perceived value' of different foods (e.g., by manipulating perceived availability of uneaten foods) (Havermans & Brondel, 2013; Wilkinson & Brunstrom, 2016).

However, with the exception of Rolls and colleagues (Rolls et al., 1992) who looked at effects in a clinical sample, little evidence has been found to support effects of such cognitive manipulations on sensory specific satiety. They found that though there were individual differences in food intake, patients with anorexia nervosa (with bulimic features) reported a decrease in desire to eat for a high but not low energy salad when consumed as a preload, whereas patients with bulimia nervosa reported a decrease in desire to eat for a low but not high energy salad when consumed as a preload (Rolls et al., 1992). This pattern of sensory specific satiety appeared to reflect patients' disordered eating traits and cognitions associated with restrictive and binging behaviours around high energy foods, respectively. As such, it may be useful to further explore between-group differences to identify potential top-down moderating influences on sensory specific satiety.

Therefore, sensory specific satiety – relating to the change in hedonic and behavioural responding for eaten relative to uneaten foods – has been identified as a key influence on consumption and appetite control during meals. This effect appears to occur because of a basic learning mechanism, potentially relating to habituation. However, top-down processes influencing consumption of specific foods may be relevant to potential between-group differences. Wilkinson and Brunstrom (Wilkinson & Brunstrom, 2016) also specifically highlight 'anticipatory processes' before eating begins as a highly important cognitive influence on satiety, satiation, and related mechanisms within a mealtime context that may account for some differences in effects of sensory specific satiety (see **Section 1.3.1**).

1.3.3. ***Cognitive influences on satiety after a meal: A role for memory***

Memory for eating events has been shown to have an important influence on satiety between meals. For example, Higgs and colleagues have shown that asking participants to recall recently eaten foods decreases snack intake (Higgs, 2002; Higgs, Williamson, & Attwood, 2008), and that patients with amnesia who report no memory for eating events will experience a period of hyperphagia despite sensory specific satiety being intact (i.e., patients still exhibit a decline in liking for eaten foods) (Higgs, Williamson, Rotshtein, et al., 2008). Moreover, memory of the 'perceived' portion size at the beginning of a meal has a marked influence on subsequent satiety and later expectations of satiation for a given food item (Brunstrom et al., 2012). Such effects have been linked specifically to episodic memory and activity in the hippocampus (Higgs et al., 2017). This indicates that meal size and post-ingestive effects of foods are not only 'remembered', but that they are used to inform meal planning and experiences of current eating events, and influence the development of associative expectations (see **Section 1.3.1**).

1.4. An overview of 'variety' as a driver of meal intake

When investigating food variety as a driver of food intake, 'variety' tends to be defined within the context of an eating session (as opposed to several eating sessions over a longer period of time). In a recent review, Raynor and Vadiveloo (Raynor & Vadiveloo, 2018) identified the predominant features that should be considered when measuring food variety. First, consistent with a previous taxonomy of variety (Meiselman et al., 2000), it is suggested that variety should be defined by the 'period of consumption'. This includes the consumption of different foods in a meal within or across days, and different foods within a single eating session (e.g., as part of a single or multiple courses). Second, the characteristics that constitute variety should be identified; variety may be defined as consuming foods from between or within food groups, as consuming foods that vary in energy or nutrient density, or as consuming foods that differ in their sensory characteristics (i.e., appearance, taste, smell, texture).

In experimental studies of eating behaviour, food variety (as defined above) has been shown to increase the amount of food consumed (coined the 'variety effect') (Rolls et al., 1982, 1984; Rolls, Rowe, et al., 1981). In a seminal study of this effect in humans (Rolls, Rowe, et al., 1981), Barbara Rolls and colleagues served four successive courses of sandwiches on two separate occasions to female student nurses. For each course, participants were either presented with a 'new' flavour (i.e., four different fillings across courses), or the same flavour repeatedly (i.e., single filling across courses). When asked to consume each course *ad libitum*, results showed that total meal intake was significantly higher when participants were offered sandwiches with a variety of fillings compared to a single filling, irrespective of whether or not participants were allocated their 'favourite' flavour in the control condition. Rolls and colleagues subsequently replicated this 'variety effect' across courses, using different test foods, by varying different sensory characteristics (e.g., pasta shapes), and in both males and females (Rolls et al., 1982, 1984; Rolls, Rowe, et al., 1981); though two studies have failed to demonstrate significant effects in males when manipulating variety for ice cream flavours in a single eating session (Beatty, 1982), and the type of snack food offered across days (Raynor et al., 2006)).

Studies have also shown that variety increases food intake within a single course. For example, Pliner and colleagues (Pliner et al., 1980) served participants a selection of hors d'oeuvres, including pizza slices, sausage rolls, and pork and shrimp egg rolls. Participants consumed a significantly greater number of pieces when offered all three types in the variety condition (M = 19.4 pieces), compared to when offered a single type in the control condition (M = 15.8 pieces). Furthermore, effects of manipulating variety within a single course across meals served over several days have also been reported. Meiselman (Meiselman et al., 2000) measured intake of a baseline meal on study days 1 and 5, consisting of a single course of Swedish-style meatballs, mashed potatoes, green beans, and gravy. On intermediate days, participants were offered either a variety of meals (each composed of a different meat/ fish, vegetable, and starch component), or the same baseline meal in a 'monotonous' condition. Results showed that where intake increased from day 1 to day 5 for all components of the baseline meal in the variety condition, intake significantly decreased in the monotonous condition for green beans and Swedish-style meatballs. However, no significant difference was found for gravy or mashed potatoes. The authors highlight that 'staple' foods within meals may be less susceptible to monotony effects as a result of repeated consumption, and similar conclusions have been drawn for other staple foods across studies (e.g., bread and butter, potatoes, and French fries) (for a review, see (Remick et al., 2009)).

Such effects of variety have generally been associated with satiation, as variety may serve to prolong enjoyment and delay satiation arising from repeated experiences of an item (Sevilla et al., 2019). From a consumer choice perspective, a 'direct' drive for variety in particular has been discussed in relation to 'product boredom'; as indifference towards a particular food – or aversion and disliking – gradually increase for a product, product boredom (and a lack of stimulation) may encourage a desire to seek out other stimulating experiences to maintain 'optimum' levels of arousal (Ha & Jang, 2013; Köster & Mojet, 2007). For example, framing the repeated consumption of a product as 'boring' leads to greater variety being selected (Fishbach et al., 2011), and switching between product attributes (e.g., flavours, brands) increases with perceived boredom (Inman, 2001). Such 'variety' may be particularly relevant today given that leading supermarkets regularly stock thousands of product lines (USDA Foreign Agricultural Service, 2016). It should be noted that such 'variety seeking' (in relation to food switching) differs from the personality traits of neophobia and neophilia – the willingness to avoid or try novel and unfamiliar foods, respectively – as this behaviour can relate to familiar and regularly consumed items (Lenglet, 2018).

More specific to effects on food intake, variety is believed to disrupt the process of sensory specific satiety (Rolls, Rolls, et al., 1981) (see also **Section 1.3.2.**). Uneaten foods that offer greater 'variety' in terms of sensory characteristics have been shown to increase the magnitude of sensory specific satiety (e.g., pleasantness experienced for uneaten 'sweet' foods declines more in response to eaten 'sweet' versus 'savoury' foods) (Rolls et al., 1984). This means that sensory specific satiety can encourage increased consumption in the presence of different foods within a meal (Brondel et al., 2009; Hendriks et al., 2019, 2021; Hetherington et al., 2006; Rolls, Rolls, et al., 1981). For example, Hetherington and colleagues interrupted a meal to ask participants to taste-test a different, similar, or identical food (to that of the eaten food); participants rated the eaten food more favourably, and intake was greater, when foods with a different or similar taste were presented as opposed to the identical food (Hetherington et al., 2006).

In line with these effects, there is also some evidence that individuals may anticipate the variety effect during meal planning (i.e., *before* eating). In a key study, Wilkinson and colleagues (Wilkinson et al., 2013) asked participants to select their ideal portion size for the second course of a hypothetical meal, and rate this second course for expected pleasantness. Results showed that when courses were sensorially different (e.g., 'savoury' followed by 'sweet' food), participants expected the second course to be significantly more pleasant compared to when courses were similar (e.g., 'sweet' followed by another 'sweet' food) or the same food presented twice. Participants also selected significantly larger portions for the second course when foods were different, and selected significantly more energy overall when they were free to select portions for both courses. Across trials, these decisions were made in less than 15s. This indicates that participants may account for judgements and effects of variety on the experience of foods when self-selecting meals, and that this is a relatively 'undemanding' cognitive process. Similar findings have been found using other 'practical' tasks to measure portion size selection. For example, when participants self-selected hypothetical portions to consume from a 'fake food buffet' – consisting of replicas that closely matched real foods in terms of appearance, weight, and theoretical energy content – they served themselves a greater amount of vegetables when presented with more than one option (carrots and green beans) (Bucher et al., 2011, 2014).

1.5. Experimental studies on the 'variety effect': Potential moderators

It is important to acknowledge that potential inconsistencies in the variety effect have been discussed in the literature (Raynor & Epstein, 2001; Raynor & Vadiveloo, 2018; Remick et al., 2009). Several factors have been tested as potential moderators in previous work, particularly relating to sensory specific satiety (Remick et al., 2009). However, more specific to the variety effect, key differences between studies relate to the 'form' of variety manipulated, energy density of foods, sensory characteristics varied, behavioural traits relevant to eating, and participant demographics.

1.5.1. Form of variety

It is notable that the timing of the period of consumption for variety has differed across studies – particularly within single eating sessions – as foods may be presented separately across multiple courses (Rolls et al., 1982, 1984; Rolls, Rowe, et al., 1981), or together within a single course (Beatty, 1982; Pliner et al., 1980). The variety effect has generally been supported across these presentations. However, few studies have directly compared effect size across different periods of consumptions, and studies that have compared potential effects within meals have found inconsistent results.

For example, in one study (Spiegel & Stellar, 1990), sandwiches with different fillings were presented either 'simultaneously' (i.e., within each single course) or 'sequentially' (i.e., across multiple courses), and compared to a control condition (i.e., same single food in each course). Where food intake was significantly higher in the simultaneous presentation condition (M = 48.7, SEM = 5.5 units) compared to control (M = 37.2, SEM = 4.3 units), there were no significant differences in total food intake between the sequential variety condition (M = 43.4, SEM = 4.6 units) and simultaneous or control conditions, respectively. Using a similar study design, Rolls and colleagues failed to demonstrate an effect of simultaneous or sequential variety on food intake across courses (relative to a control condition) when manipulating the colours of chocolate candies (Rolls et al., 1982), though it should be noted that studies otherwise manipulating the 'simultaneous' presentation of variety within meals typically do so in a single course only (Beatty, 1982; Domínguez et al., 2013; Meengs et al., 2012; Pliner et al., 1980; Wijnhoven et al., 2015).

1.5.2. Energy density

It should be noted that energy density and energy intake are two separate but related concepts (Rolls, 2009). Energy density is the amount of energy derived per unit measurement of food (e.g., kilocalories or Kilojoules per gram). As the total energy content of a food is determined by its macronutrient content, energy density increases when foods are higher in fat (9 kcal/ g), protein (4 kcal/ g), carbohydrate (4 kcal/ g), and alcohol content (7 kcal/ g) (associated values reported in line with energy conversion factors (Holland et al., 1991)). Energy density then also decreases with added weight from water, meaning energy intake can be reduced for the same volume of food if energy density is lower. Energy density itself is positively associated with energy intake (Karl & Roberts, 2014), as well as palatability (Drewnowski, 1998).

Though energy density does not appear to affect sensory specific satiety (Remick et al., 2009), there is some evidence to suggest that effects of variety on food intake may be less consistent for low energy density foods across studies (for a detailed narrative review on this discussion, see (Raynor & Vadiveloo, 2018)). Typically, studies have focussed on increasing intake of fruits and vegetables in an intervention setting when concerned with effects of variety for low energy density foods, particularly with children. For instance, Dominguez et al. (Domínguez et al., 2013) manipulated the number and choice of vegetables that were offered to children as a snack in their usual classroom setting during school hours. In the control condition, children were either asked to choose between one of two vegetables (green beans or zucchini), or served one type of vegetable (without a choice). In the variety condition, children were served both vegetables. Results showed that the weight of vegetables consumed was significantly higher in the variety condition compared to the control condition, but only when children were given no choice between the two vegetables.

In two additional studies, variety was manipulated for vegetables as part of a main meal (with a meat, starch, and/ or dessert component), but had no significant main effect on children's intake for any of the meal components served (Carney et al., 2018; Zeinstra et al., 2010). Though liking of vegetables did not significantly differ across conditions, individual differences in the relative intensity of sensory properties may be related to acceptance/ rejection of variety (e.g., children identified as PROP (propylthiouracil) tasters were likely to consume a greater proportion of vegetables when offered a variety of seasonings that differed in flavour (Carney et al., 2018)). More generally, the presence of other meal components that offer variety may also compete with children's selection of vegetables (Chawner et al., 2022).

Reflecting findings in studies with children, some studies have also failed to find a significant main effect of variety on fruit and vegetable intake in adults (Parizel et al., 2017; Raynor & Osterholt, 2012; Vadiveloo et al., 2019), even when served as the only component in an eating session (Raynor & Osterholt, 2012; Vadiveloo et al., 2019). For example, using a similar study design to Dominguez et al. (Domínguez et al., 2013), one study manipulated the choice of vegetable side dishes served with a main course of ham; participants were either given three side dishes simultaneously without a choice, offered a choice of up to three side dishes simultaneously, given one randomly-selected side dish without a choice, or offered a choice of one side dish only (Parizel et al., 2017). Though serving a variety of side dishes increased liking for vegetables, results showed that there were no significant differences in weight or energy consumed for vegetables during the meal, and choice did not significantly interact with variety to influence food intake.

In contrast, several studies have supported an effect of variety when using test foods other than fruits and vegetables, that are higher in energy density, and served in a similar meal context (e.g., (Beatty, 1982; Guerrieri et al., 2012; Hollis & Henry, 2007; Norton et al., 2006; Pliner et al., 1980; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Spiegel & Stellar, 1990)).

1.5.3. Sensory characteristics

Across studies, the number (and type) of sensory characteristics varied has been identified as a potential external moderator of the variety effect, particularly when concerned with differences between/ within similar food items (Raynor & Vadiveloo, 2018). For example, Rolls and colleagues have tested effects of manipulating variety for multiple (and single) sensory characteristics for foods. In one of these studies (Rolls, Rowe, et al., 1981), food intake was found to be higher when participants were presented with a variety of yoghurts that differed in flavour, colour, and texture across courses, relative to when they were presented with the same yoghurt across courses. However, in a separate study, no effect of variety was found on food intake when yoghurts differed only in flavour (and colour/ texture were controlled) (Rolls, Rowe, et al., 1981). Other studies have also failed to find an effect of variety when manipulating only the colour of candies (Guerrieri et al., 2007; Rolls et al., 1982) or fruits/ vegetables (Vadiveloo et al., 2019). For this reason, it has been suggested that the variety effect may be most apparent when multiple sensory characteristics are manipulated (i.e., when greater sensory differences are present within/ between foods) (Raynor & Vadiveloo, 2018).

Considering the importance of differences in sensory characteristics to effects of variety, some studies have attempted to manipulate the *perception* of sensory characteristics to increase/ decrease consumer attention toward variety (and encourage/ inhibit effects associated with variety). In one study, Redden (Redden, 2008) used labels to manipulate the categorisation of ‘jellybeans’ (candies that vary in flavour/ colour). Whilst standardising food intake and eating rate, each jellybean was presented with a corresponding label on a computer screen that either emphasised differences in flavour between pieces (e.g., ‘cherry’ followed by ‘orange’), or generalised the pieces to the same category (i.e., 'jellybean'). Results showed that enjoyment and desire to eat ratings were higher whilst consuming jellybeans in the presence of flavour-specific rather than generalised labels, suggesting that drawing attention to variety in sensory characteristics can delay satiation (without increasing the number of sensory characteristics varied).

However, more recent studies do not support the use of labelling/ priming manipulations to influence the perception of variety as it relates to actual food intake (Embling et al., 2019; Vadiveloo et al., 2019). For example, using a similar approach to Redden (Redden, 2008), Embling et al. (Embling et al., 2019) found no significant differences in ideal portion size or expected satiation across multiple foods when these were presented with 'high variety' labels that emphasised differences in ingredients within foods (e.g., 'Chicken noodles with beansprouts, cabbage, red peppers, carrots and onion'), 'low variety' labels that referred to general names for food items (e.g., 'Chicken chow mein'), or no label. They also found no significant differences between groups when measuring *ad libitum* snack intake in the laboratory. In a randomised pilot study, Vadiveloo et al. (Vadiveloo et al., 2019) asked participants to complete one of three priming tasks; a 'thought listing' task that directed attention towards differences between fruits and vegetables (emphasising variety), a 'thought listing' task that directed attention towards similarities between fruits and vegetables (generalising the food category), or a 'word scramble' task with neutral stimuli. When manipulating the sensory variety present within an assortment of pears and peppers (by varying colour and shape), priming alone did not significantly interact with sensory variety to influence food intake. Taken together, such research suggests that the experience of sensory characteristics (e.g., visual appearance and tasting of foods) may be most important to the variety effect, as 'actual' variety may override other priming influences.

1.5.4. Behavioural traits relevant to eating

Evidence suggests that both 'impulsivity' (i.e., relating to poor response inhibition, and greater consideration for short-term rather than long-term consequences) and 'food cue reactivity' (i.e., responding to food cues with greater physiological and psychological sensitivity) are positively associated with food intake and body weight (van den Akker et al., 2014). Similarly, self-control – or more specifically, lower disinhibition in eating (i.e., lesser tendency for overconsumption in response to food cues) and higher dietary restraint (i.e., controlling eating behaviour to align with motives/ goals) – are traits that may be linked to inhibitory feedback mechanisms and more successful dieting (Higgs et al., 2015). As such, some studies have investigated traits relating to impulsivity and responsivity to food cues as potential moderators of the variety effect (Guerrieri et al., 2007, 2008, 2012; Haws & Redden, 2013; Mok, 2010; Pliner et al., 1980; Rafieian et al., 2021). However, mixed results have been observed across studies.

Using behavioural measures of impulsivity and food cue reactivity, Guerrieri, Nederkoorn, and Jansen (Guerrieri et al., 2008) asked children to complete a 'bogus taste test' with a 'low' variety candy assortment (white-pink marshmallows only) or 'high' variety candy assortment (five types of marshmallows that varied in appearance, flavour, texture, and form). A 'stop-signal task' was used to measure response inhibition, and a 'door opening task' was used to measure reward sensitivity (a point-based game in which participants weigh up consequences of searching for rewards versus receiving penalties). Though there was no main effect of variety on food intake, and no significant interaction with response inhibition, children who scored higher on reward sensitivity consumed significantly more marshmallows in the variety condition (M = 209 kcal ± 18 kcal), compared to children who scored lower on a measure of reward sensitivity (M = 162 kcal ± 14 kcal).

In two similar studies conducted with female undergraduate students (Guerrieri et al., 2007, 2012), the same authors supported a potential moderating effect of reward sensitivity on the variety effect (using the 'Iowa gambling task'), but only when participants self-reported higher ratings of hunger (hungry participants who demonstrated greater reward sensitivity consumed significantly more food when served a variety of sweet snacks in a 'bogus taste test') (Guerrieri et al., 2012). They failed to find evidence of an effect in a sample of healthy women when manipulating the colours of chocolate candies, and when using a self-report measure of impulsivity (the 'Barratt Impulsiveness Scale' (BIS; (Patton et al., 1995)) (Guerrieri et al., 2007).

A similar pattern of results has also been observed when looking at effects of self-control and dietary restraint on food intake. Mok (Mok, 2010) presented participants with a different chocolate snack in each of three courses, or their most liked chocolate snack for each course, and dietary restraint was measured using the 'Dutch Eating Behaviour Questionnaire' (DEBQ; (van Strien et al., 1986). On average, participants who scored lower than the 40th percentile for dietary restraint (M = 286.72 KJ, SE = 0.18) consumed significantly more chocolates across courses in the variety condition than participants who scored higher than the 40th percentile for dietary restraint (M = 226.47 KJ, SE = 0.18). However, Pliner (Pliner et al., 1980) reported no differences in the variety effect between small groups of dieters and non-dieters based on dietary restraint scores.

In relation to portion size selection, Haws and Redden (Haws & Redden, 2013) manipulated variety for a 'hypothetical' snack, whereby participants were presented with an assortment of three varieties for a food (e.g., multiple types of crisps that vary by brand, texture, flavour, and appearance) or a single variety for a food (e.g., a single type of crisps belonging to one brand). In both studies, participants selected more food to consume when presented with a variety of snacks versus a single snack, and this variety effect was greater for individuals reporting a general tendency towards lower self-control using a self-report questionnaire measure, but no evidence was found to support a moderating effect of dietary restraint specifically (using the DEBQ). A recent pre-print (reporting results from 6 studies) also highlighted that participants may be less likely to choose a variety of ‘indulgent’ snacks when prompted to consider a weight-loss goal, which in turn generally increased motivation to improve self-control in the presence of unhealthy foods, though desirability bias may be a methodological concern (Rafieian et al., 2021).

Taken together, some studies suggest that individuals who have greater sensitivity towards responding to food cues may be more susceptible to the variety effect. Such effects appear to be consistent with neural correlates of sensory specific satiety that are particularly relevant to reward-circuity and appetite control (see Section **1.2.2.**). However, methodological differences across studies make it difficult to synthesise results in light of conflicting findings.

1.5.5. Age

Similar to studies with children, several studies have investigated effects of variety in relation to potential dietary interventions for older adults. Sufficient intake of protein in older adulthood is necessary to help maintain bone and muscle mass, and combat effects of chronic diseases including sarcopenia and osteoporosis (De Souza Genaro & Martini, 2010). As energy intake declines by approximately 20% from young to older adulthood (Giezenaar et al., 2016), older adults are often at greater risk of undernutrition (Ahmed & Haboubi, 2010). For this reason, Wijnhoven et al. (Wijnhoven et al., 2015) manipulated the presence of variety in meals for women with a self-reported poor appetite with the aim of stimulating food intake. They found that serving a meal with three different meats/ fish, three vegetables that varied in colour, and three preparations of a starch component (e.g., boiled potatoes, fried duchesse potatoes, fried potato slices) significantly increased the amount of food consumed relative to a control condition consisting of a single component in each category. Similar findings have been reported when serving meals to older adults with and without additional seasonings/ sauces to manipulate variety (Appleton, 2009, 2018; Best & Appleton, 2011; Van Wymelbeke et al., 2020).

However, the size of the variety effect may differ between age groups, particularly as dietary variety has been reported to be lower in older adults (Roberts & Rosenberg, 2006; Rolls, 1999). Hollis and Henry (Hollis & Henry, 2007) served participants either a variety of sandwich fillings, or the same sandwich filling, for each of four courses. Though there was a significant effect of variety on food intake in both young adult (M age = 25.0 yrs, SD = 4.0) and older adult (M age = 72.0 yrs, SD = 6.0) groups overall – whereby participants consumed more sandwiches in the 'variety' meal – there was also evidence of an interaction between age group and variety. Older adults consumed more sandwiches in the control condition compared to young adults, but this difference was reversed in the variety condition, meaning the variety effect may be smaller in older adults. Similar effects have been observed in relation to monotony, whereby the expected decline in food intake, liking, and desire to eat for repeatedly consumed foods was not observed in older adults (Essed et al., 2006; Pelchat & Schaefer, 2000).

Likewise, the magnitude of sensory specific satiety may also be reduced in older adults. In one study, Rolls and McDermott (Rolls & Mcdermott, 1991) found that for adolescent (aged 12 – 15 yrs) and adult (aged 22 – 35 yrs and 45 – 60 yrs) groups, desire to eat and pleasantness ratings declined significantly more for yoghurt (after eating a fixed serving) compared to 'uneaten' foods, demonstrating sensory specific satiety. There was no significant difference in ratings for eaten and uneaten foods reported by older adults (aged 65 – 82 yrs), though a decline in desire to eat was observed following *ad libitum* intake of the eaten food. This has been linked to associated declines in sensory perception in older adulthood (e.g., diminished sense of smell and taste) that may impact signalling during the cephalic phase of eating, though further research is needed to clarify effects across samples (for reviews on this topic, see (Roberts & Rosenberg, 2006; Rolls, 1999)).

1.5.6. Body weight

In addition to age, multiple studies have also investigated whether the variety effect may differ between groups according to body weight. Research has previously predicted that the magnitude of the variety effect – and sensory specific satiety – may differ between lean participants and participants with overweight, as overeating may be related to weaker effects of sensory specific satiety (relevant to 'delaying' the end of a meal), or greater susceptibility to switching between foods (in the presence of variety) that encourages increased food intake (Remick et al., 2009). Multiple studies have then explored potential interaction effects between body weight and variety conditions (Pliner et al., 1980; Roemmich et al., 2010; Spiegel & Stellar, 1990; Stubbs et al., 2001; Vadiveloo et al., 2019).

Though sample size is small (e.g., <10 participants per body weight group (Spiegel & Stellar, 1990; Stubbs et al., 2001)) or smaller than the target sample size (e.g., (Vadiveloo et al., 2019)) in some of these studies, only two studies found evidence of a significant interaction. In a residential trial setting, Stubbs et al. (Stubbs et al., 2001) reported that daily energy intake significantly increased for males in the lean body weight group (Body mass index; BMI M = 23.6 Kg/ m^2, SD = 1.1) when they were provided with a greater number of meal and snack options at each eating occasion over the course of several days, but there were no significant differences in daily energy intake for participants in the overweight group (BMI M = 28.1 Kg/ m^2, SD = 0.5). However, as part of exploratory analyses, Vadiveloo et al. (Vadiveloo et al., 2019) found that food intake was higher for participants with an 'overweight' self-report BMI when served a greater variety of colours for fruits (but not vegetables), compared to participants with a 'lean' self-report BMI, after adjusting for effects of participant age and sex. As such, based on the limited and contrasting evidence available, it is difficult to draw conclusions about the direction of possible subgroup effects based on body weight.

1.5.7. Interim summary

Therefore, despite multiple narrative reviews summarising study results (Raynor & Epstein, 2001; Raynor & Vadiveloo, 2018; Remick et al., 2009), it is notable that the size of the variety effect on food intake remains unclear. This may in part be due to differences in results across studies where potential moderating effects have been reported (resulting in inconsistent evidence of effects). It may also be due to difficulties synthesising results across studies that have taken different approaches to manipulating variety, as well as different definitions of variety, to investigate effects across multiple periods of consumption in the literature.

1.6. Disambiguating the concept of variety

Given the breadth of the taxonomies described to define variety (Raynor & Vadiveloo, 2018), it is notable that the concept of variety is inconsistently conceptualised in the literature.

The term 'variety' is often used interchangeably with other relevant concepts, and methodological investigations of effects can overlap, meaning it can be difficult to distinguish the features that disambiguate one concept from another. The parameters within which variety may be defined are also unclear, as different approaches to manipulating variety have been adopted across studies. In addition to variety, there are four related concepts (and experimental paradigms) that are highlighted here; sensory specific satiety, monotony, repeated exposure, and perceived sensory complexity.

1.6.1. *Sensory specific satiety*

Given the evidence presented thus far, it is clear that variety is often manipulated within studies of sensory specific satiety. Typically, these studies involve asking participants to provide intermittent ratings of palatability whilst consuming a food, usually to fullness (*ad libitum*) (Hetherington & Rolls, 1996). As sensory specific satiety is concerned with sensory experiences that are specific to the eaten food, a variety of 'uneaten' foods are presented as part of these paradigms to compare effects over the course of a meal. This means that food intake is often disrupted, with the inclusion of additional taste tests to map changes across foods presented in otherwise 'low' and 'high' variety conditions, and palatability (in addition to food intake) is explored as the primary outcome variable (e.g., (Rolls et al., 1982, 1984)). Such taste tests with *different* foods have been shown to increase food intake relative to a control condition with a single food across tasting trials (Hetherington et al., 2006).

1.6.2. Monotony

'Monotony' is also a term that is used in the literature to describe effects and mechanisms relating to variety. Monotony can be defined as a decline in the palatability experienced for foods as they are repeatedly consumed over time (Remick et al., 2009). Typically, monotony has been investigated over a longer period than effects of 'sensory specific satiety' and 'variety' per se (e.g., several days as opposed to within a single eating session). Studies predominantly focus on measurements of liking (as an indicator of acceptance) and consumption, with multiple studies exploring effects of prescribing a monotonous diet to US army employees specifically (de Graaf et al., 2005; Hirsch et al., 2005; Kramer et al., 2001; Meiselman et al., 2000).

However, it is notable that no clear parameters have been used to categorise the presence of monotony versus variety in the literature, and monotony/ variety have generally been used as differential conditions across studies exploring effects on food intake. For instance, studies have directly compared effects of consuming a 'monotonous' single food/ meal versus a 'variety' of foods/ meals on food intake (e.g., (Meiselman et al., 2000; Zandstra et al., 2000)). In an intervention setting, Raynor and colleagues have also explored effects of reducing variety (and increasing monotony) within diets to support weight management (see **Section 1.8.** below) (Epstein et al., 2015; Raynor et al., 2012; Raynor & Wing, 2006).

1.6.3. Repeated exposure

Similar to monotony, studies of 'repeated exposure' are concerned with measuring acceptance in infants or young children in response to repeated tastings of foods over time, usually for fruits and vegetables (Spill et al., 2019). Using these paradigms, it is noted here that studies have sometimes manipulated the level of variety within or across exposures, so that children are given either a single test food or multiple test foods to consume, and food intake is measured as an outcome (Spill et al., 2019). For example, Ahern et al. (Ahern et al., 2019) repeatedly exposed pre-school children to either a single-vegetable snack (baby sweet corn, celery, or red pepper) or a variety-vegetable snack (baby sweet corn, celery, red pepper, green pepper, and radish) over the course of 3 weeks. Similarly, Mennella et al. (Mennella et al., 2008) repeatedly exposed infants to fruits/ vegetables for several days; they were either given the same fruit/ vegetable (peaches or green beans), or a different fruit or vegetable (peaches, prunes, apples; or pureed squash, spinach, carrots) for each exposure. Though similar in design to studies of the 'variety effect', such studies are testing different theoretical effects of increasing familiarity with foods. Possible effects of novelty (associated with variety) on inhibiting acceptance within this setting has then been discussed in relation to 'learned safety' for foods, rather than increased food intake, and focus specifically on repeated consumption across conditions (Ahern et al., 2019).

1.6.4. Perceived sensory complexity

'Perceived complexity' is also a concept that has been inconsistently defined in the literature (Lévy et al., 2006; Palczak, Blumenthal, Rogeaux, et al., 2019; Spence & Wang, 2018a). Across sensory modalities, perceived complexity has been identified as having a curvilinear effect on hedonic responses to a stimulus relating to optimal arousal (Berlyne, 1973), whereby liking is expected to increase with discernible complexity until a peak relative point, after which liking decreases in response to further increases in complexity (Lévy et al., 2006; Palczak, Blumenthal, Rogeaux, et al., 2019).

Specific to eating behaviour, foods and beverages have been described as having increased perceived 'sensory' complexity if they consist of multiple sensations that are experienced in a single mouthful, such as the 'flavour notes' in wine (Spence & Wang, 2018a, 2018b), herbs and spices in curry (Spence & Wang, 2018a), or flavourings/ extracts used in product recipes (Lévy et al., 2006; Soerensen et al., 2015; Weijzen et al., 2008). Such differences tend to be subtle and may not be recognisable as individual flavours, but rather are likely to contribute to a 'blended' taste (Spence & Wang, 2018a). However, it should be noted that others have defined complexity in relation to more apparent differences within foods, whereby components 'mixed' together would reflect complexity, and components presented 'separately' would reflect variety (Hendriks-Hartensveld, Brodock, et al., 2022).

Though 'variety' has predominantly been used to describe *very clear* sensory differences present between foods (classified either within or between food groups), research on the topic of food variety has begun to shift focus from this 'food-based' approach to an 'ingredient-based' approach (Raynor & Vadiveloo, 2018). This is because it is increasingly recognised that mixed dishes and individual food products (that consist of multiple ingredients) can contribute to sensory variety in the diet and potentially increase food intake (Raynor & Vadiveloo, 2018; Wilkinson et al., 2022). For example, in an observational study, Vadiveloo and colleagues (Vadiveloo, Campos, et al., 2016) showed that greater seasoning variety (relating to additions of spices and vegetables as ingredients) increased intake of beans and rice in urban residents. From a nutritional perspective, recent expansions of food composition tables have also increased recognition of composite dishes and brands available for food items to calculate dietary intake (Carter et al., 2016; Marconi et al., 2018), particularly as composite dishes account for a notable proportion of the consumer diet (Bailey et al., 2021; Branum & Rossen, 2014). See also **Section 1.6.5.** below.

Given the overlap between definitions of these concepts, applications of one term over another can be ambiguous in the literature, particularly as some test foods may be relevant to studies of both complexity and variety. For example, 'ice cream with chocolate chips' (Hendriks-Hartensveld, Brodock, et al., 2022), 'layered chocolate desserts' (Palczak, Blumenthal, & Delarue, 2019), and even fruit and vegetable assortments (Mielby et al., 2012), have recently been operationalised as high-complexity foods, with perceived differences in appearance, texture, and/ or flavour (See **Figure 1**). Such foods may also be considered a form of variety using an ingredient-based approach if fillings/ pieces are recognisable as *individual* components, and vary in sensory characteristics (Raynor & Vadiveloo, 2018; Wilkinson et al., 2022). Where effects of complexity are typically concerned with preference or hedonic experiences of a food, food intake (or portion size) is the most common outcome variable when focussing on effects of variety.

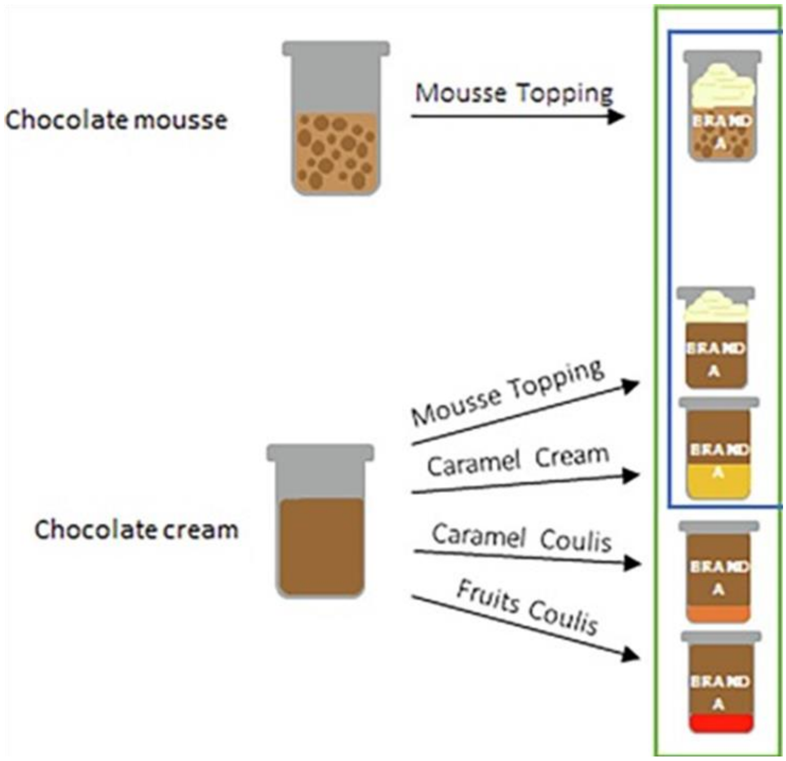

Figure 1. An example of a 'layered-chocolate dessert' used to indicate 'perceived complexity', with discernible components that vary in texture, flavour, and appearance. Figure cropped, from (Palczak, Blumenthal, & Delarue, 2019).

1.6.5. 'Dietary variability' and 'multi-component foods' as modern forms of variety

Given the discussion of experimental studies on the variety effect thus far, it is apparent that there are two main 'forms' of variety that have received less attention in the literature, that may be overlooked when focussing on the period of consumption alone and a food-based approach to defining variety. First, in addition to choosing between distinct food types/ items, consumers can choose between specific brands and varieties for a particular food (e.g., pizzas in different flavours, from across multiple brands). Second, single food items may consist of multiple components in and of themselves that constitute variety (e.g., a single pizza with multiple toppings).

There may be some debate as to whether dietary variability and multi-component food items can be considered forms of 'variety'. This is because even if foods differ in terms of energy density or nutritional quantities, they are unlikely to indicate nutritional diversity in and of themselves (Meiselman, 2017). Some multi-component foods may also arguably represent an increase in perceived complexity rather than variety, depending on the conceptualisation of perceived complexity that is adopted (though these two concepts may not be distinct from one another, see **Section 1.6.4.**). It is suggested here that the conceptualisation of dietary variability and multicomponent foods is consistent with manipulations of the variety effect; 1) the number of distinguishable sensory characteristics (or nutrients) present within foods vary, 2) sensory differences are likely to be apparent to the consumer, and 3) current evidence suggests that the presence of variety (in these forms) may significantly increase food intake from a theoretical perspective.

When discussing effects on food intake, the term 'dietary variability' has been used to refer to the availability of multiple brands and product variations for a particular food item, that vary in energy and/ or nutritional content (Hardman et al., 2015; Martin, 2016). 'Brand switching' is noted to be a form of variety seeking in the consumer and marketing literature (Sevilla et al., 2019). Some evidence also suggests that this dietary variability increases food intake across the diet. For a single food item (pepperoni pizza), Hardman et al. (Hardman et al., 2015) found that participants were consuming an average of 5.2 brands a year, with energy content across pizzas varying by up to 594 kcal. When participants were invited to consume pepperoni pizza as a standardised preload before consuming snacks in the laboratory, participants reporting the highest pepperoni pizza variability (widest range of energy content in consumed pizza brands) expected the pepperoni pizza to be significantly less satiating. Total meal intake also increased after consuming the preload (relative to no-preload condition), indicating that participants overcompensated for the energy content in the pepperoni pizza. This suggests that brand variety may undermine associative learning of expectations for post-ingestive effects of foods, and increase overconsumption (Martin, 2016).

Variety *within* foods has also very recently been highlighted as an important but under-researched topic in relation to eating behaviour (Raynor & Vadiveloo, 2018; Wilkinson et al., 2022). Multi-component foods consist of multiple food elements that are combined during food processing to be classified as 'one whole', with elements that remain perceivable as distinguishable 'parts'. For instance, Wilkinson et al. (Wilkinson et al., 2022) provides the example of 'chocolate chip cookies' produced via baking, or 'cereal bars' produced via industrial processing. Though effects on food intake in relation to multi-component food items have yet to be explored directly, research on the presence of variety in assortments provides some initial evidence of an effect on consumption (as components that would be combined in a single food are mixed together and presented as a 'composite' dish or item) (Wilkinson et al., 2022).

Studies manipulating the presentation of assortments in relation to food consumption have produced mixed results (Wilkinson et al., 2022). Hale and Varakin (Hale & Varakin, 2016) showed that participants consumed more candy from a bowl consisting of multiple colours as opposed to a single colour when assortments were offered side-by-side, and participants were likely to state 'variety' as a reason for their preference. Studies that have explored effects of variety on portion size have also shown that participants choose to consume more of a hypothetical snack when simultaneously presented with an assortment of multiple varieties (e.g., crisps that vary by brand, texture, flavour, and appearance) versus a single variety (Haws & Redden, 2013; Rafieian et al., 2021) (see earlier descriptions of this evidence in **Section 1.5.4.**). This may be because participants are likely to underestimate the size of portions when foods are perceived to be 'high variety', and manipulated to consist of multiple colours versus a single colour (Kinard & Kinard, 2016; Redden & Hoch, 2009). However, other studies that have included similar assortments of sweet snack foods have failed to support a main effect of variety on food intake (Guerrieri et al., 2007, 2008, 2012; Rolls et al., 1982), though it is notable that manipulations of assortments have generally focussed on varying a single sensory characteristic (namely colour/ appearance).

1.7. Dietary variety and effects on body weight

It is important to acknowledge that literature on the effects of variety often discuss implications for improving diet quality and health, and for supporting body weight management. Diet quality has been highlighted as a key target for interventions that aim to reduce population disease risk (Burden et al., 2019; Hemmingsen et al., 2017; Palmer et al., 2018; Potter et al., 2016; Verghese et al., 2019). This is because diet quality is considered to be a modifiable risk factor with potential for wide-reaching health benefits, having been associated with lower risk of cardiovascular diseases (Fung et al., 2018; G. Liu et al., 2018; K. M. Livingstone et al., 2021; Xu et al., 2020), diabetes (Conklin et al., 2016; De Koning et al., 2011; Ley et al., 2016), and cancers (Mai, 2004; Park et al., 2017), as well as overweight and obesity (Asghari et al., 2017).

Though specific dietary guidelines vary across countries according to cultural differences in food consumption, they traditionally share similar recommendations relating to eating a 'variety' or 'balance' of multiple foods as part of the whole diet (Herforth et al., 2019; Kennedy, 2004; Ross, 1993; Vadiveloo & Parekh, 2015). For instance, in the UK, the 'Eatwell guide' allocates foods to four main food groups (fruits and vegetables, starchy carbohydrates, dairy/ dairy alternatives, and meats/ fish/ other proteins), and encourages consumers to choose portions of foods from within each group in moderation (Public Health England, 2018). This is because dietary variety is believed to be an effective indicator of nutritional adequacy (Foote et al., 2004; Meng et al., 2018; Nair et al., 2016).

Dietary variety scores (or dietary diversity scores) typically refer to the number of different food items consumed in a recall period, with total scores calculated across or within defined food groups (Drewnowski et al., 1997). Observational studies within this area of research tend to rely on self-report measures of food intake, such as food diaries, 24-hr recall questionnaires, and food frequency questionnaires (FFQs). Previous research has shown that higher dietary variety scores are associated with healthier eating patterns, such as reduced intake of sugar, salt, and saturated fat (Drewnowski et al., 1997). Similarly, a greater tendency towards food neophobia has been associated with reduced dietary variety and diet quality in both men and women, particularly relating to vegetable consumption (Hazley et al., 2022;

Jaeger et al., 2017; Knaapila et al., 2015; Sarin et al., 2019). As such, dietary variety is often a component used in calculations of other indices of diet quality (e.g., the 'Healthy Eating Index') (Kennedy, 2004).

Associations between dietary variety and body weight are inconsistent in the literature, particularly when using 'overall' dietary variety scores calculated across food groups (for a systematic review of 'sufficiently' powered observational studies, see (Vadiveloo et al., 2013)). Some evidence suggests that greater overall dietary variety may be related to increased body weight (Azadbakht et al., 2005, 2006; Bernstein et al., 2002; de Oliveira Otto et al., 2018; Ponce et al., 2006; Tian et al., 2016; Zhang et al., 2017). For example, in one prospective cohort study using a measure of food dissimilarity based on the 'berry index', greater overall dietary diversity was associated with poorer diet quality, and waist circumference measurements were found to have more than doubled for individuals with the highest food dissimilarity scores during a 5-yr period (De Oliveira Otto et al., 2015). However, other observational studies have reported negative associations between overall dietary variety and body weight (Azadbakht & Esmaillzadeh, 2011; Ishikawa et al., 2017; Tande et al., 2010), or non-significant relationships (Bernstein et al., 2002; Gregory et al., 2009; Heidari-Beni et al., 2021; McCabe-Sellers et al., 2007; Mohindra et al., 2009; Royo-Bordonada et al., 2003; Tande et al., 2010). Such overall scores (when investigated in isolation) may obscure differences between energy dense foods and nutrient dense 'healthful' foods, as associations between dietary variety and body weight may be in opposing directions within food groups.

Reflecting evidence from experimental studies, energy density has been identified as a potential moderator of associations between dietary variety and body weight, particularly when exploring effects within food groups (for a review, see (Vadiveloo & Parekh, 2015)). In a key cross-sectional study of 71 'healthy' men and women in the US (McCrory et al., 1999), dietary variety within food groups was calculated using a 6-mth FFQ and expressed as the percentage of items consumed for each group. Results showed that consuming a greater variety of foods from within each food group was significantly and positively related to energy intake, with small-to-medium associations reported across categories (r = 0.27 – 0.56). After controlling for age and sex, variety within more energy-dense food groups (including 'sweets, snacks, and carbohydrates') was also significantly associated with greater percentage body fat (partial R = 0.22 – 0.28). Likewise, consuming a variety of less energy-dense foods (i.e., vegetables) was significantly associated with lower energy intake per kilogram of body weight, and reduced body fatness (partial R = -0.21). Since then, several cross-sectional studies have supported positive associations between dietary variety scores and dietary intake in energy or weight of food consumed (Azadbakht & Esmaillzadeh, 2011; Bernstein et al., 2002; Gregory et al., 2009; Heidari-Beni et al., 2021; Marshall et al., 2001; Moraeus et al., 2020; Roberts et al., 2005; Royo-Bordonada et al., 2003; Vadiveloo, Dixon, et al., 2015; Zhang et al., 2017). Studies have also reported favourable effects of dietary variety within 'recommended' food groups on body weight and body adiposity (Azadbakht & Esmaillzadeh, 2011; Tande et al., 2010; Vadiveloo, Dixon, et al., 2015; Vadiveloo, Parkeh, et al., 2015; Vadiveloo, Sacks, et al., 2016).

Though experimental evidence of the variety effect over a longer period is limited, there are examples of dietary intervention trials focussed on weight management in the literature that have manipulated dietary variety – typically for high energy dense foods – and reported effects on food intake (Epstein et al., 2013, 2015; Raynor et al., 2006, 2012; Stubbs et al., 2001). With the exception of Stubbs et al. (Stubbs et al., 2001) who only reported changes in average daily consumption during the whole intervention period, reducing dietary variety (e.g., by limiting the number of options available for a meal or food category) has been shown to decrease food intake over several weeks. In the longest of these intervention trials, Raynor et al. (Raynor et al., 2012) reported a significant decline in overall energy intake at 6-mths when individuals were prescribed a diet limiting variety for energy dense snacks compared to a control intervention, though participants appeared to compensate for this reduced energy intake by consuming more energy from across other food categories in later months (for which variety limits were not prescribed).

Effects of these interventions on body weight have had mixed success (Epstein et al., 2015; Raynor et al., 2006, 2012; Stubbs et al., 2001). In one trial, Epstein and colleagues (Epstein et al., 2015) reported that parents and children with overweight and obesity completing family-based treatment (including regular group meetings, counselling, guidelines to support healthy eating/ physical activity, and behavioural treatment to reinforce healthy behaviours within families) had greater weight loss at 6-mths when prescribed additional dietary guidelines to limit variety for high energy dense foods (i.e., by repeating meals/ using leftovers, and choosing one energy dense entrée and snack food per month). Percentage of children above the 50th percentile for BMI reduced by 15.4%, and parent BMI declined by 3.7 kg/m^2, a difference of 6.5% and 1.4 kg/m^2 when compared to family-based treatment alone. However, Raynor and colleagues (Raynor et al., 2006, 2012) reported no significant difference between treatments for weight loss when using a similar dietary prescription for variety, versus limiting the number of daily food servings or completing a lifestyle intervention (including a cognitive behavioural intervention, dietary guidelines, and physical activity guidelines), though weight loss overtime was significant across intervention groups in both studies. Stubbs et al. (Stubbs et al., 2001) reported no significant body weight changes across participants when assigned to receive a 'low variety', 'medium variety', or 'high variety' menu that varied the number of items available at each meal in a residential setting, though this trial was conducted over a considerably shorter period (seven experimental days per menu).

It is notable that across both observational and intervention studies within this literature, food intake and body weight are typically treated as separate outcomes, and few studies have explored potential causal pathways. This is despite evidence that variety is a driver of food intake (and portion size selection) that may increase risk of overconsumption (intermediate outcome), and in turn affect body weight and body adiposity over a longer period when energy density is high (final outcome). Roberts and colleagues (Roberts et al., 2005) in particular have highlighted a potential mediating role of food intake in the relationship between dietary variety and body weight, as including energy intake as a predictor within models reduced the strength of dietary variety measures as predictors of BMI. However, to my knowledge, such a role for food intake is yet to be directly explored in a prospective model of effects of dietary variety and energy density on body weight outcomes.

Therefore, there appears to be a need to help consolidate dietary effects of variety on body weight management, as this relates to public health and overconsumption. On the one hand, there is the position that variety benefits the consumer as a diverse range of foods within the diet helps maintain nutritional adequacy and improve diet quality. On the other hand, there is evidence that when consuming a greater variety of foods – particularly within more energy-dense food groups – variety is linked to higher energy intake and potentially poorer dietary patterns. In order to better understand the effects of variety in today's food environment, it is important that both perspectives are accounted for when considering effects of variety on consumption and body weight in longer-term predictive models.

1.8. Overall aims

Taken together, it is clear that there is a rich and extensive literature on the dietary effects of food variety, in relation to both diet quality and food intake. Utilising the effects of food variety has then been highlighted as an important avenue to explore in relation to benefitting consumer health, with particular implications for malnutrition and overweight and obesity. However, 'food variety' remains a concept that requires further refinement to support conclusions drawn across studies with large scope, and there is a need to adapt the current conceptualisation of variety to better reflect food development in today's changing environment. As such, there are three main aims of this thesis.

First, there is a need to further explore the conceptualisation of variety within the literature, and corroborate the robustness of the effect of variety on food intake. In **Study 1**, a systematic review and meta-analysis is conducted to help synthesise results across studies focussed on the variety effect in different meal contexts, to quantify the average size of this effect on food intake, and identify potential moderating factors across studies. In **Studies 2 and 3**, the consumer understanding of variety is compared to the conceptualisation of variety in the literature using a mixed-methods approach, to identify the consumer recognition of variety as this relates to proposed dietary interventions and dietary guidelines.

Second, it is evident that the presence of variety *within* single food items has received little attention in the current literature, despite these foods being particularly relevant to the theoretical understanding of the variety effect in today's food environment. To further investigate the effect of variety on consumption, **Studies 4 and 5** focus on the measurement of portion size during meal planning (in response to the need to develop remote 'proxy' measures of food intake as a result of the COVID-19 pandemic). **Study 6** then tests the influence of manipulating variety within foods on portion size selection (including assortments and multi-component food items).

Third, there are some inconsistent results between studies focussed on dietary variety in relation to longer-term effects on body weight. For this reason, **Study 7** will investigate the possibility of a mediated moderation effect of variety in the diet on BMI and weight-related outcome measures, considering the roles of both portion size and energy density as factors related to overconsumption, using secondary data from the UK Biobank cohort.

2. Chapter 2 – Reviewing the "variety effect": A systematic review and meta-analysis (Study 1)

The systematic review and meta-analysis presented in this chapter has been published in the *American Journal of Clinical Nutrition* (Embling, Pink, et al., 2021).

2.1. Introduction

As outlined in **Chapter 1**, several experimental studies have provided evidence that eating a variety of foods is one factor that can increase food intake. In the current literature, experimental studies have focused on the presence of variety within meals (where foods are presented in single or multiple courses at one sitting), and across meals (where foods are presented in meals across multiple sittings, in a single day or several days) (Raynor & Vadiveloo, 2018). These studies typically vary the number of different foods or sensory characteristics present in meals, and examine effects on *ad libitum* food intake in the laboratory. However, multiple narrative reviews on the variety effect have identified potential moderating factors, and for this reason, the average size of the effect of variety on food intake has remained unclear (Raynor & Epstein, 2001; Raynor & Vadiveloo, 2018; Remick et al., 2009). There is also yet to be a summative assessment of experimental evidence supporting the variety effect.

Therefore, the aim of this systematic review and meta-analysis was twofold. First, this review aimed to examine the effect of variety within- and across-meals on food intake, and formally synthesize data across experimental studies. Second, meta-analysis was used to help quantify the size of the effect of variety on total meal intake (in weight and energy consumed), and assess differences in this effect when potential moderators were considered via subgroup analyses. For this work, 'food variety' is considered to be a continuous metric, so that a 'high variety' condition has a comparatively greater number of components and/or sensory characteristics than a 'low variety' control condition in the same study (from a conceptual viewpoint).

2.2. Method

2.2.1. Search strategy

To conduct a formal search of the literature, six electronic databases were searched for relevant articles during November and December 2019, including both published findings and relevant grey literature: PubMed, Cochrane Library, Web of Science, ClinicalTrials.gov, PsycINFO, and OpenGrey. Searches used a combination of key terms relating to food variety and intake (see **Appendix A**), as well as the period of consumption (i.e., specific mealtimes). All searches were limited to include studies that were published in English, with human participants, between January 1980 and the date of the search in line with when seminal research on this effect was first published (Rolls, Rowe, et al., 1981). To help minimise bias and increase rigour, it is recommended that more than one reviewer is involved in the article selection process (Page et al., 2021). For this reason, both myself and a second reviewer independently screened and selected articles for review using titles and abstracts, and independently assessed full texts for eligibility. Any disagreements were discussed and revised accordingly, and if needed, a third-party was available to resolve outstanding discrepancies. Agreement rate was not recorded, as conflicts were discussed at intervals.

To reduce risk of publication bias, an invitation to provide any relevant published or unpublished work was shared with corresponding authors of included articles, posted on social media, and circulated via mailing lists of groups with relevant research interests. The database search was updated to include any potential new articles in September 2020, and a hand-search was also conducted in June 2020; reference lists of included articles were scanned for eligible studies, and relevant peer-reviewed journals were searched for articles published after the date of our initial search conducted in November/ December 2019.

This systematic review and meta-analysis is reported in line with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines, and was preregistered in the PROSPERO database (International prospective register of systematic reviews; registration number: CRD42019153585). The web-based software 'Covidence' was used to manage and screen references (https://www.covidence.org).

2.2.2. Study eligibility criteria

Experimental, quasi-experimental or intervention studies, using either a within- or between-subjects design were eligible. There were no restrictions on the age of participants included in studies, nor weight status. Studies were included if they manipulated the level of variety within or across meals, and if they assessed how much food participants subsequently consumed in weight, energy, or number of pieces. Studies were required to have at least two experimental conditions consisting of a high variety, a comparatively lower variety, and/ or no variety condition. This could include manipulations of the number of different foods presented, or the number of different sensory characteristics included within a single food item or assortment. Studies that involved participants with chronic diseases, illnesses, or eating disorders; that used only measures of food choice, food ratings, portion size selection, perceived volume, or self-reported intake (e.g., food diaries and questionnaires); and that manipulated only the perception of food variety (e.g., by changing the presentation of foods but not the components present in the meal, or by using labels/ vignettes), were excluded in order to focus on effects on actual food intake (pertaining to seminal research on the variety effect (Rolls, Rowe, et al., 1981)).

Studies that were designed to measure sensory specific satiety were included only if they had a comparator condition and if the measurement of food intake was not disrupted (e.g., by asking participants to provide ratings of liking/ satiation by tasting samples midway through a meal). Studies that otherwise met the inclusion criteria but asked participants to 'earn' food servings as part of a habituation task were excluded, because food intake was disrupted by the need to gain points (e.g., (Epstein, Robinson, et al., 2009)). Relevant studies that were designed to measure early food acceptance in young children and infants were also excluded (e.g., (Birch et al., 1998; Gerrish & Mennella, 2001)), as foods in both the variety and comparator conditions were presented to participants over a series of repeated exposure trials.

2.2.3. Data extraction

After extracting information from all eligible studies for review, a second reviewer checked that the extracted data was consistent with information reported in articles. Both myself and the second reviewer also independently extracted information from 20% of included studies; the initial agreement rate was 82%, all conflicts were resolved after discussion, and extracted information from all articles was rechecked for consistency in line with any additional changes made. Where necessary, corresponding authors of included articles were contacted to provide missing data required for the meta-analysis (e.g., means, SDs, sample size), and data was extracted from figures using the online Programme 'WebPlotDigitizer' (https://apps.automeris.io/wpd/). If standard errors and means were reported, standard deviations were calculated (*SEM * sqrt[N]*). In order to allow for comparisons across studies, analyses focused on effects on total meal intake (i.e., all components of a meal), as assessments of effects on individual components (e.g., single food within a course consisting of multiple foods) differed greatly between articles. See **Table 1** for a list of extracted information.

Table 1. List of information extracted from included articles for each study.

Information	**Description**
Sample characteristics	Including the country where the study was conducted, sample size, age, sex, and BMI
Study design	Between-subjects or within-subjects
Study setting	Laboratory or field
Study intervention	Form of variety manipulated, number of sensory characteristics manipulated, and comparator condition(s) used
Study outcome	Procedure to measure food intake, test foods eaten, and unit of measurement reported
Main findings	Results reported for main effect of variety on total food intake, and if available, individual components of a meal
Moderating variables	Interactive effects of identified moderators on food intake
Quality assessment	Including assignment to conditions, control procedures prior to manipulation, measurement and control of appetite and food ratings, additional variables controlled in data analyses

2.2.4. Meta-analysis

All analyses were calculated using the software 'Comprehensive Meta-Analysis v3' (Biostat, Englewood, NJ). A random effects model was used for all analyses, as the design, quality, measures, and samples used differed across studies. Data for effects on total meal intake were entered for each identified comparison in the main analysis. Sample sizes, means, and standard deviations were used to calculate effect size. Hedge's *g* is reported, as it uses the standardised mean difference to account for the reporting of different units of intake across studies, corrects bias associated with very small samples (Lakens, 2013), and has been used in a similar meta-analysis where food intake was the outcome (Buckland et al., 2018). Where studies reported intake in both energy and weight, only information on weight consumed was extracted (to avoid issues with multiplicity and account for potential differences in energy density across these studies). For all studies, a positive effect size indicates that food intake was greater in the high variety condition relative to the control condition, whereas a negative effect size indicates that food intake was greater in the control condition relative to the high variety condition. Effect sizes were interpreted as: <0.2 is 'trivial', 0.2 is 'small', 0.5 is 'medium', and 0.8 is 'large' (Cohen, 1992). Heterogeneity was assessed using the I^2 statistic, and as an approximate guide, was interpreted as: <30% is 'low' heterogeneity, 30-50% is 'moderate' heterogeneity, 50-75% is 'substantial' heterogeneity, and >75% is 'considerable' heterogeneity across studies (Higgins et al., 2019).

Sensitivity analyses (exploratory) were conducted to check for potential issues with study inclusion; a "one study removed" analysis was performed, and analyses were rerun with adjusted imputed values for missing data. Planned subgroup analyses were conducted to investigate potential moderating effects of the form of variety manipulated, and to test the boundaries of the variety effect according to; the number of sensory characteristics varied, the test foods used, and participant demographics (age, sex, and body weight). To account for multiple comparisons, Bonferroni corrected *p*-values are also reported.

To calculate effect sizes where multiple datapoints within a study referred to the same participant, authors were contacted to provide the correlation between conditions for each comparison. Authors of eight studies were able to provide this information, and the mean was imputed for all other studies after conducting relevant sensitivity analyses (*r* = 0.67) (see exploratory analyses described above for details of method of imputation). Where necessary, a single summary effect was computed for each study reporting multiple comparisons for the same participants by calculating the mean effect size and variance of the mean effect size (Borenstein et al., 2009). In this case, this meant that for studies reporting separate comparisons for single food control conditions (e.g., variety vs apple, variety vs pear), and where effects for more than two levels of variety were reported, control conditions were combined to form a single comparison group (i.e., high variety vs single foods; high variety vs medium and low variety).

2.2.5. Risk of bias

Both myself and a second reviewer independently assessed risk of bias using the Cochrane Collaboration's tool (Higgins et al., 2016), and disagreements were resolved in discussions. Following Buckland and colleagues (Buckland et al., 2018), risks associated with the following were considered; participant and experimenter awareness of the study aim and assignment to conditions, the control of confounding variables that could influence food intake, the use of procedures to control for baseline differences in appetite, the use of procedures to measure food intake, and the order of tasks in study protocols (see **Appendix B** for details on assessment criteria).

2.3. Results

Unless otherwise stated, M ± SD is reported. See **Table 2** for a description of each study eligible for review.

Table 2. Characteristics of studies included for review (*N* = 37). Means are reported for sample characteristics, or where possible, the range is given if no other descriptives are reported. For BMI, z-scores or percentiles were extracted if kg/m^2 was not reported.

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
Appleton (2009), UK (Appleton, 2009)	Field (Nursing home); Within-subjects; Order of conditions counterbalanced across nursing homes, but method is unclear. Sample = 28 older adults (21 females). Age range = 65+ yrs. BMI = Not reported. No exclusions.	Variety manipulated within a single course; sauces were provided with a main meal of the day consisting of a meat, two vegetables and potatoes. In each condition for each nursing home, participants were served two meals (usual portion sizes presented for each nursing home, but energy/weight per serving varied depending on the meal served and condition). Variety: Participants served main meal with one sauce; either white sauce, gravy, chasseur (vegetable-based) sauce, or mustard sauce. Control: Participants served main meal (same as main meal	Significant effect of variety, but only when energy intake is reported; participants consumed more food in the variety condition compared to control.	Energy consumed from protein and fat components was significantly higher in meals with sauce compared to no sauce. No significant differences in energy consumed from carbohydrate or vegetable components were found. No significant differences were found in weight consumed for any individual components.	No significant variety X 'expectancy of effect' interaction found for meal intake.	No sample size calculation; Control procedures included a washout period between conditions, and presenting the test meal at the standard meal time in the nursing home; Baseline assessment of hunger and desire to eat before each meal reported; Pleasantness and familiarity assessed after meal; No cover story was used; Participants were tested in a communal dining hall (social setting is a potential confound); Participant expectations of effects of sauce (would affect intake vs do not know) were included in model, and no significant differences were found between conditions for hunger, desire to eat, pleasantness, familiarity, and energy provided.

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
		presented in the variety condition), without sauce. Outcome: Grams (weighed). Energy consumed (kJ) also reported. Intake was averaged across the two test meals for each condition.				
Appleton (2018), UK[2] (Appleton, 2018)	Laboratory; Within-subjects; Randomized order of conditions, but method is unclear. Sample = 56 older adults (31 females). Age = 71.1 yrs, SD = 4.6. BMI = 25.8 kg/m^2, SD = 2.5. Exclusions N = 4 (N = 2 did not return for second visit, N = 2 self-reported failure to follow	Variety manipulated within a single course; sauces were provided with a lunch meal consisting of chicken (300g), sweetcorn (250g), carrots (250g), and mashed potatoes (325g) (whole meal serving excluding sauce = 3900kj). In both conditions, participants were also served an evening meal 4.5h after lunch on each test day that was not manipulated for variety (consisting of a selection of cold buffet meal foods and	Significant effect of variety for both energy and weight consumed; participants consumed more food in the variety condition compared to control.	No significant effect of variety for energy or weight consumed when intake from sauce in the variety condition was excluded from analyses. Weight consumed from protein, fat, and carbohydrate was significantly lower in the control condition compared to the variety condition (including intake from sauce). When intake from sauce was excluded from analyses, a significant difference was found for protein only; weight consumed	Significant variety X protein intake interaction (participants grouped as increased protein intake versus decreased protein intake in response to sauce); participants who had increased protein intake had significant increases in energy, protein, and fat in the variety condition compared to control (when intake from sauce was excluded from analyses), and significant increases in weight, energy, protein, fat, and carbohydrate in the variety condition	No sample size calculation; Control procedures included a washout period between conditions, presenting the test meal at a standard meal time, instructions to consume the same breakfast on each test day and abstain from eating/drinking between breakfast and lunch (excluding water), instructions to refrain from drinking alcohol or doing heavy exercise one day prior to or on the day of the test session, and participants self-reported compliance with control procedures; Pre-post

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
	experimental procedures).	condiments, serving = 17, 890 kJ). Variety: Participants served lunch with one sauce; chicken gravy (212 kJ). Control: Participants served lunch (same as main meal presented in the variety condition), without sauce. Outcome: Grams (weighed). Energy consumed (kJ) also reported.		from protein was significantly lower in the control condition compared to the variety condition.	compared to control (when intake from sauce was included in analyses). Participants who had decreased protein intake had significant decreases in energy, protein, fat, and weight in the variety condition compared to control (when intake from sauce was excluded from analyses), and significant decreases in energy and protein and significant increases in weight in the variety condition compared to control (when intake from sauce was included in analyses).	assessment of hunger, desire to eat, thirst, and desire to drink for each meal reported; Pleasantness, tastiness and familiarity assessed after each meal; No information about cover story; No additional confounds identified; No significant differences were found between conditions for location, but significant differences in pleasantness, tastiness, familiarity and desire to eat were reported (variables were not included in model for main effect).
Beatty (1982), US[3] (Beatty, 1982)	Laboratory; Between-subjects; Random assignment to conditions, but no method given. Sample = 22 students (12 females).	Variety manipulated within a single course; test meal included ice cream only (portion self-selected by participant). Variety: Three flavours of ice cream that participants liked the	Significant effect of variety for females but not males; females in the variety condition consumed more ice cream than females in the control condition.	None reported.	None reported.	No sample size calculation reported; Control procedures included instructions to eat a normal dinner and skip dessert the evening before the study; No assessment of appetite reported; Liking and frequency of consumption

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
	Age = Not reported. BMI = Not reported. No exclusions.	most out of four possible choices, served in a single mixed bowl. Control: One flavours of ice cream that participants liked the most, served in a single bowl. Outcome: Grams (weighed).				assessed before study; No cover story was used; Food intake was assessed in groups (social setting is a potential confound), and portions self-selected (potential confound); No additional variables controlled in models.
Bergamaschi (2016), DK[4] (Bergamaschi et al., 2016)	Field (School); Within-subjects; Randomized order of conditions, but no method given. Sample = 153 children (63 females). Age = 9.6 yrs, SEM = 0.05. BMI = 17.2 kg/m^2, SEM = 0.2.	Variety manipulated within a single course; test meal included fruits and vegetables only (serving = approx. 200g). Two sets of stimuli were served; 'classical variety' varied the number of different test foods presented, and 'perceived variety' varied the shape of test foods only. High variety, classical: Carrot, green apple,	Significant effect of variety only when the classical variety set was presented; intake was higher in the control condition compared to the high and medium variety conditions respectively. There were no significant differences in intake between conditions when presented with the perceived variety set.	None reported.	None reported.	No sample size calculation reported; Control procedures included a washout period between conditions, instructions to parents to not give snacks to children before the study, and food intake measured at usual snack time in usual setting; No assessment of appetite reported; Food liking, familiarity, and frequency of consumption was assessed before and after the main study sessions;

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
	Exclusions N = 18 (included in pilot study only).	plum, white cabbage, dried cranberry, almond. High variety, perceived: Carrot (chunks, slices, sticks), green apple (chunks, slices, triangles). Medium variety, classical: Carrot, green apple, white cabbage, dried cranberry. Medium variety, perceived: Carrot (chunks, sticks), green apple (chunks, slices). Control, classical: Carrot, green apple. Control, perceived: carrot (chunks), green apple (chunks). Outcome: Grams and kcal (weighed), expressed as %.				No information about cover story; Food intake was assessed in groups (social setting is a potential confound), and significant differences in liking between test foods (potential confound, does not appear to have been controlled for in models); 'Children' and 'Class' were considered as random factors, Age and BMI z-score were considered as covariates in models.
Best (2011), UK (Best &	Laboratory; Within-subjects; Counterbalanced	Variety manipulated within a single course; choice seasonings and	Significant effect of variety for both energy and weight consumed;	Intake (in grams) from protein and carbohydrate were	None reported.	No sample size calculation; Control procedures included a

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
Appleton, 2011)	order of conditions, but method is unclear. Sample = 18 older adults (14 females). Age = 77.0 yrs. BMI = 30.0 kg/m^2. No exclusions.	sauces were provided for a main meal consisting of chicken, two types of vegetables, and mashed potatoes (portion sizes for each food item was double the 'usual' portion for adults, two teaspoons of seasoning were added to chicken, and approximately 100g of sauce was added to chicken). Variety, seasoning: Participants given a choice of one seasoning to be added to meal: chargrilled chicken seasoning, Cajun seasoning, smoky bacon seasoning, lemon and herb peri-peri seasoning rub, lime and coriander peri-peri marinade, or sun-dried tomato and basil peri-peri marinade. Variety, sauce: Participants given a	participants consumed more energy in the seasoning and sauce variety conditions compared to control, and participants consumed more weight of food in the sauce variety condition compared to the seasoning variety and control conditions respectively. No significant differences in energy intake between seasoning and sauce variety conditions, and no significant differences in weight of food consumed between the seasoning variety and control conditions.	significantly greater in the seasoning and sauce variety conditions compared to control, total fat intake was significantly greater in the sauce variety condition compared to the seasoning variety and control conditions, and total fat intake was significantly greater in the seasoning variety compared to control conditions. Weight of chicken consumed was significantly greater in the seasoning and sauce variety conditions compared to control. All other comparisons were not significant for energy/weight consumed from individual food components. When intake from seasonings and sauces was excluded from analyses, no significant differences were found		washout period between conditions, presenting the test meal at a standard meal time, and instructions to consume the same breakfast at the same time on each test day; Pre-post assessment of hunger and desire to eat reported; Pleasantness and familiarity assessed after each meal; No information about cover story; Food intake was assessed in groups (social setting is a potential confound, though participants were seated in individual booths and asked not to communicate with other participants); No significant differences were found between conditions for hunger, desire to eat or familiarity, but significant differences in pleasantness and flavours intensity were reported (variables were not included in model for main effect).

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
		choice of one sauce to be added to meal: chicken gravy, onion gravy, honey and mustard sauce, creamy mushroom sauce, creamy stroganoff sauce, or tomato and basil sauce. Control: Participants served meal with no sauce or seasoning. Outcome: Grams (weighed). Energy consumed (kcal) also reported.		between conditions for carbohydrate intake or weight of food consumed, and between sauce and seasoning variety conditions for fat intake.		
Carney (2018), US (Carney et al., 2018)	Laboratory; Within-subjects; Counterbalanced order of conditions, but no method given. Sample = 44 children (19 females). Age = 54.2 mnths, SD = 8.2. BMI z-score = 0.2, SD = 1.0.	Variety manipulated within a single course; test meal included macaroni and cheese (175g), unsweetened applesauce (115g), carrots (3 x 40g servings), and one energy-containing beverage (milk). Variety: Carrots seasoned with three different spice blends	No significant effect of variety on food intake.	No significant effect of variety on the amount of individual meal items consumed (macaroni and cheese, apple sauce, carrots). Also, no significant effect of variety on beverages consumed (milk, water).	Significant PROP status X variety interaction reported for carrots consumed; children categorized as PROP tasters consumed more carrots in the variety condition compared to PROP non-tasters, and PROP non-tasters consumed more carrots in the control condition compared to tasters,	No sample size calculation reported; Control procedures included a washout period between conditions, and meals given at usual time for lunch or dinner; Pre-post assessment of fullness and liking reported, and parents completed questionnaires on their child's usual eating habits; No information about cover

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
	Exclusions N = 35 (N = 15 did not meet eligibility criteria, N = 16 had scheduling conflicts, N = 4 refused participation and/or would not eat the test foods).	(Cinnamon-Nutmeg-Ginger, Cardamom-Cumin-Allspice, and Garlic-Black Pepper-Oregano). Each flavours was presented in a separate bowl and served as side dishes at the meal. Control: Carrots were all served with the cinnamon spice blend, but participants were again presented with three servings in separate bowls to be consistent with the variety condition. Outcome: Grams (weighed). Energy and proportion consumed also reported.			but only when intake was expressed as a proportion. No significant differences in intake between conditions within groups of tasters or non-tasters.	story; No additional confounds identified; Age, sex, BMI z-score, meal order, meal time, and selection of the cinnamon carrot as the favourite were considered as potential covariates, but removed from final models if not significant.
Carstairs (2018), UK (Carstairs et al., 2018)	Field (Children's nursery); Within-subjects; Counterbalanced order of conditions using Latin Squares for each nursery group, and by	Variety manipulated within a single course; test meal included a cheese sandwich (117g or 70g, depending on serving size condition) and vegetables (120g). Grapes (40g) and	No significant effect of variety on food intake.	Significant effect of variety on vegetable intake; participants consumed more vegetables in the variety condition compared to the control condition. No	No significant portion size (large or small sandwich) X variety interaction effect found for total meal, sandwich, or vegetable intake.	Target sample N = 48 reported (effect size = 0.5, 1−β = 0.80, α = 0.05); Control procedures included a washout period between conditions, and meals given at the usual time for lunch in normal

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
	alternating first portion size block. Sample = 43 children (23 females). Age = 3.9 yrs, SEM = 0.6. BMI = 16.5 kg/m^2, SEM = 1.3. Exclusions N = 15 (N = 7 did not attend lunch sessions, N = 2 withdrew from the study, N = 6 ate <10% of meal).	yogurt (120g) were served after the test meal. Variety: Vegetables include equal servings of cucumber, tomato and carrot to accompany cheese sandwich. Control: Either cucumber, tomato or carrot served to accompany cheese sandwich. Outcome: Grams (weighed). Energy consumed (kcal) also reported. Mean single vegetable intake (collapsed across three sessions) reported for control condition.		significant effect of variety on sandwich intake.		setting; No assessment of appetite reported; Baseline rating of liking assessed, and parents completed questionnaires on their child's usual eating habits; No information about cover story; Food intake was assessed in groups (social setting is a potential confound, though food sharing/dropped items were monitored); No additional variables controlled in main model, regression analysis was used to identify additional predictors of HED and LED intakes (mean intakes, age, BMI, eating traits and parental feeding practices).
Divert (2015), FR[56] (Divert et al., 2015)	Field (Nursing home); Within-subjects; Counterbalanced order of conditions using a method of alternation. Sample =	Variety manipulated within a single course; test meal menu composed of a starter, a main course, a dairy product and a dessert. Variety was	Significant effect of vegetable variety on food intake; total meal intake was greater when participants were served vegetables in the variety condition	A significant effect of condiment variety was found on garnish intake (rice), but no effect was found for meat, dairy product, or dessert; participants ate more	None reported.	No sample size calculation reported; Control procedures included a washout period between conditions, and meals given at the usual time for lunch in usual

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	42 older adults (29 females). Age = 86.6 yrs. BMI = Not reported. Exclusions N = 12 (did not complete all conditions).	manipulated for the main course vegetable accompaniment (serving = 150g) and condiments (freely available throughout meal). Variety, vegetables: Served green beans and zucchinis. Control, vegetables: Served green beans only. High variety, condiments: Offered salt, pepper, mustard, butter, vinaigrette, tomato sauce, mayonnaise, garlic, shallot, lemon, parsley (11 condiments). Medium variety, condiments: Offered salt, pepper, mustard, butter, vinaigrette, tomato sauce, mayonnaise (7 condiments).	compared to the control condition. No significant effect of condiment variety on total meal intake.	rice when offered 7 or 11 condiments compared to 3 condiments. A significant effect of vegetable variety was also found for meat intake; intake was greater when participants were given two vegetables compared to when they were given a single vegetable.		setting; Baseline assessment of hunger reported; Meal enjoyment assessed after eating; No information about cover story; Food intake appears to be assessed in groups (social setting is a potential confound), alternative food products were given to participants with chewing/bowel issues (influence on satiation is a potential confound), and piece count increases risk of researcher bias; No additional variables controlled in models.

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		Control, condiments: Offered salt, pepper, mustard (3 condiments). Outcome: Grams (weighed), reported as energy consumed (kcal). Piece count used to measure condiment intake.				
Domínguez (2013), ES (Domínguez et al., 2013)	Field (School); Between-subjects; Method of assignment to conditions is unclear. Sample = 152 children (Sex not reported). Age range = 4 – 6 yrs. BMI = Not reported. Exclusions N = 61 (N = 2 were Vegetarians, reason for exclusion unclear for N = 59).	Variety manipulated within a single course; test meal included vegetables only (serving = 149g). Variety: Served both green beans and zucchini. Control, choice: Given a choice of either green beans or zucchini. Control, no choice: Served either green beans or zucchini. Outcome: Grams (weighed).	Significant effect of variety on food intake; children ate significantly more vegetables in the variety condition compared to control (no choice), and they also ate significantly more vegetables when given a choice compared no choice in the control condition.	None reported.	Interactions explored with school, age, and sex; no significant interaction effects were found.	No sample size calculation reported; Control procedures included meals given in the usual setting for lunch in school environment; No assessment of appetite reported; Baseline assessment of liking reported, and this was used to select test foods for the main study; No information about cover story, though efforts were made to conceal condition allocation from children (e.g., children in the same class were assigned to the same condition); Food intake assessed in groups (social setting is a

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						potential confound, as parents and teachers were present); School, age, and sex were controlled in models.
Epstein (2013), US [Study 1][7] (Epstein et al., 2013)	Laboratory; Between-subjects; Random assignment to conditions stratified by sex, but no method given. Sample = 31 children (14 females). Age = 10.4 yrs, SD = 1.3. BMI z-score = 1.8, SD = 0.5. Exclusions N = 3 (did not follow experimental procedures).	Variety manipulated across meals; baseline test meal of Kraft macaroni and cheese was served on days 1 and 5 across conditions, and high energy-dense foods were served on days 2 - 4 (meal serving = 1200kcal). High variety: Served one of three of their highest rated energy dense foods on each test day (foods rated at baseline; chicken nuggets, four cheese pizza, mozzarella sticks, cheeseburgers, fish sticks). Foods were served with condiments (30kcal portions of honey mustard, pizza	Across days 2-4, there was a significant effect of variety on food intake; children consumed significantly more energy each day in the high variety condition compared to the medium variety and control conditions. There were no significant differences between the medium variety and control groups.	For days 2-4, the effect of variety was unchanged when calories from condiments were excluded from analyses.	Significant variety X session interaction for days 1 and 5; children in the control and medium variety groups reduced their intake from session 1 to 5, where children in the variety group increased their intake from session 1 to 5. There were no differences in intake between the medium variety and control groups.	No sample size calculation reported; Control procedures included instructions to eat a normal breakfast and lunch on each test day, instructions to abstain from eating and drinking for 3h prior to the test session (excluding water), abstain from eating test foods for 24hr prior to test day, abstain from eating macaroni and cheese for whole study period (dietary recall questionnaires were completed to check compliance), and testing during usual dinner time; Pre-post assessments of hunger reported for each test session; Liking of test foods assessed on days 1 and 5; No information about cover story; No additional confounds

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		sauce, barbeque sauce, and tomato ketchup). Medium variety: Served one of three of their highest rated macaroni and cheese dishes on each test day (foods rated at baseline; Kraft Spiral, SpongeBob SquarePants, Cheddar Explosion, Whole Grain and White Cheddar Macaroni and Cheese). Control: Served Kraft Macaroni and cheese on each test day. Outcome: Grams (weighed), reported as energy consumed (kcal).				identified; Baseline hunger ratings controlled in models.
Guerrieri (2007), NL (Guerrieri et al., 2007)	Laboratory; Between-subjects; Random assignment to conditions, but no method given.	Variety manipulated within a single course; test meal included candies only (serving = 1600g).	No significant effect of variety on food intake.	None reported.	No significant impulsivity X variety interaction effect found when participants were categorized as high or	No sample size calculation; Control procedures included instructions to eat a small meal/snack 2hr before the

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	Sample = 86 students (Females only). Age = 20.2 yrs, dispersion = 3.4 (measure of variability unclear). BMI = 21.8 kg/m^2, dispersion = 3.0 (measure of variability unclear). No exclusions.	Variety: Served 14 different colours of sugar beans. Control: Served plain white sugar beans only. Outcome: Grams (weighed).			low impulsive, for food intake.	test session, and to otherwise abstain from eating and drinking prior to test session (excluding water); No indication of measurement of appetite on the test day, but participants self-reported compliance with control procedures; No assessment of food liking; Cover story was used but no indication as to whether this was believed by participants; No additional confounds identified; No additional variables controlled in main model.
Guerrieri (2008), NL[8] (Guerrieri et al., 2008)	Field (school); Between-subjects; Random assignment to conditions via coin toss. Sample = 78 children (33 females). Age = 9.0 yrs, dispersion = 0.6	Variety manipulated within a single course; test meal included candies only (serving = 350g). Variety: Five sorts of marshmallows served in a single bowl; white-pink marsh-mallows, pink marshmallows covered in coconut, white marshmallows	No significant effect of variety on food intake.	None reported.	There was a significant reward sensitivity X variety interaction effect found; children in the variety condition who were more reward sensitive consumed greater energy than the less reward-sensitive children. There was no difference in food intake between more- and less-reward	No sample size calculation; Children asked to self-report intake on the test day and a day before, and children were tested between school break times; Baseline hunger assessed; Liking assessed during Bogus Taste Test, but this data does not appear to have been included in data analyses; Cover story was

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	(measure of variability unclear). BMI = 17.4 kg/m^2, dispersion = 2.6 (measure of variability unclear). No exclusions.	covered in coconut, marshmallows covered in milk chocolate and yellow and green marshmallows in different forms. Control: White-pink marshmallows only, served in a single bowl. Outcome: Grams (weighed), reported as energy consumed (kcal).			sensitive children in the control group. There was no significant response inhibition X variety interaction effect, or three-way interaction effect (response inhibition X reward sensitivity X variety).	used, but no indication as to whether this was believed by participants; No additional confounds identified; Age controlled in main model as a significant covariate (hunger, BMI and sex were also assessed as potential covariates).
Guerrieri (2012), NL (Guerrieri et al., 2012)	Laboratory; Between-subjects; Random assignment to conditions, but no method given. Sample = 80 students (Females only). Age = Not reported. BMI = 22.8 kg/m^2, dispersion = 3.4 (measure of variability unclear).	Variety manipulated within a single course; test meal consisted of an assortment of cookies (serving = 400g). Variety: Chocolate chip cookies, coconut macaroons, sponge-like biscuits filled with orange jam and covered in bitter chocolate, and milk chocolate-covered	Variety was a significant predictor of food intake (no descriptive statistics reported).	None reported.	The interactions reward X variety and hunger X variety were not significant. However, there was a significant three-way interaction (hunger X reward X condition), as participants would consume more food when hungry if they were more reward sensitive, but only in the variety condition.	No sample size calculation; Control procedures included instructions to eat a small meal/snack 3hr before test session, to otherwise abstain from eating and drinking prior to test session (excluding water), and participants self-reported compliance with control procedures; Baseline assessment of hunger; No assessment of food liking; Cover story was used, and participant awareness of

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	Exclusions N = 3 (did not indicate hunger levels).	cookies filled with vanilla cream. Control: Chocolate chip cookies only. Outcome: Grams (weighed), reported as energy consumed (kcal).				aims/conditions was checked; No additional confounds identified; No additional variables controlled in main model.
Hollis (2007), UK (Hollis & Henry, 2007) [9]	Laboratory; Within-subjects; Counterbalanced order of conditions, but no method given. Sample = 36 young and older adults (18 females) (Participants grouped by age). Young adults age = 25.0 yrs, SD = 4.0. Older adults age = 72.0 yrs, SD = 6.0. Young adults BMI = 22.7 kg/m^2, SD = 2.6.	Variety manipulated across courses; test meal included sandwiches only (serving size unknown). Variety: Sandwiches with a different filling in each of 4 courses; grated cheese, cream cheese and cucumber, ham, turkey. Control: Sandwiches with cheese filling for each of 4 courses. Outcome: Grams (weighed).	Significant effect of variety on food intake; both young and older adults consumed more sandwiches in the variety condition compared to control.	None reported.	Significant age X variety interaction; older adults consumed more sandwiches in the control condition compared to young adults, and young adults consumed more sandwiches in the variety condition compared to older adults. Significant course X variety interaction; food intake at each course declined more during the control condition compared to the variety condition.	No sample size calculation; Control procedures included screening for eating disorders, restraint, and depression, a washout period between conditions, and instructions to eat usual breakfast and fast for 3h before session on test day; Baseline assessment of hunger, thirst, and fullness reported; Liking assessed during study screening; Cover story was used, but no indication as to whether this was believed by participants; No additional confounds identified; No additional

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	Older adults BMI = 26.5 kg/m^2, SD = 3.8. No exclusions.					variables controlled in main model (no significant differences in hunger, thirst, or desire to eat were identified).
Kerr (2019), AU (Kerr et al., 2019)	Laboratory; Between-subjects; Random assignment to conditions according to test day by independent statistician. Sample = 1274 parents (86% female), and 1299 children (50% female). Adult age = 43.9 yrs, SD = 5.1. Children age = 11.4 yrs, SD = 0.5. Adult BMI = 27.8 kg/m^2, SD = 6.1. Children BMI z-score = 0.3, SD = 1.0.	Variety manipulated within a single course; test meal consisted of snack assortment (serving for children = 181g control, or 240g variety) (serving for adults = 207g control, or 266g variety). Variety: Children received a small or larger box containing 8 snacks; peaches or fruit salad, flavoured rice crackers, miniature wheat fruit bites, cheese wedge, mini animal-shaped biscuits, fruit muesli/granola bar 1, miniature milk chocolate bar 1, miniature milk chocolate bar 2. Adults received the same items excluding mini animal-shaped biscuits,	Significant effect of variety for children; children consumed more food in the variety condition compared to control. Significant effect of variety for adults, but only when intake was measured in kJ; adults consumed more energy in the variety condition compared to control.	None reported.	No significant interaction for the box size X variety for children, but a significant interaction for adults. In the control condition, adults consumed less food when presented with a large rather than small box. In the variety condition, adults consumed more food when presented with a large rather than small box.	No sample size calculation; Control procedures included a semi-fasting venepuncture 5-30mins before the test session; Baseline assessment of hunger reported; No assessment of liking; Cover story was used, and participant awareness of aims/conditions was recorded; Food intake appears assessed in groups, though participants were seated separately (social setting is a potential confound), and participants able to complete other activities whilst eating (e.g., reading, look at phone); No additional variables controlled in main model, but sensitivity analyses adjusted for age, sex, socioeconomic status,

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	Exclusions N = 41 children, 60 adults (food allergies).	and additionally received mini Oreo biscuits and fruit muesli/granola bar 2 (for a total of 9 items). Control: Children received a small or larger box containing 5 snacks; peaches or fruit salad, flavoured rice crackers, cheese wedge, mini animal-shaped biscuits, miniature milk chocolate bar 1. Adults received the same items excluding mini animal-shaped biscuits, and additionally received mini Oreo biscuits and fruit muesli/granola bar 1 (for a total of 6 items). Outcome: Grams (weighed). Energy consumed (kJ) also reported.				BMI, puberty status, baseline hunger, fasting times, and duration spent in the session. Separate analyses also removed participants that expressed awareness about being monitored, had >10% of food wrappers missing from their box after eating, had fruit salad instead of peaches, or had 11g rather than 13g chocolate bars.
Levitsky (2012), US [Study 1][10]	Laboratory; Within-subjects; Randomized order of	Variety manipulated within a single course; one of two meals with	Significant effect of variety for intake in both energy and grams;	Energy and gram intake varied across conditions for	No significant interaction for test meal (1 or 2) X individual	No sample size calculation; Control procedures included a

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(Levitsky et al., 2012)	conditions, but no method given. Sample = 27 students (4 females). Age range = 18 – 21 yrs. BMI = Not reported. Exclusions N = 8 (did not complete the study).	a protein (91g in meal 1 and 78g in meal 2), carbohydrate (86g in meal 1 and ½ cup in meal 2), and vegetable component (81g in meal 1 and 89g in meal 2), served in separate bowls, was presented. Variety, composite: Participants served protein, carbohydrate, and vegetable in each meal; chicken tenders, potato tots and green beans in meal 1; chicken filets, rice, and peas in meal 2. Control, low carb: Participants served protein and vegetable component in each meal; chicken tenders and green beans in meal 1; chicken filets and peas in meal 2. Control, vegetarian: Participants served carbohydrate and vegetable component	total food intake averaged across meals was greater in the variety condition (3 components in a composite meal) compared to when participants were served the low carb or vegetarian meals (2 components in a meal).	individual components; protein and vegetable intake were significantly greater in the low carb meal compared to the composite meal, and carbohydrate and vegetable intake was significantly greater in the vegetarian meal compared to the composite meal.	components (protein, vegetable or carbohydrate) on food intake.	washout period between conditions, instructions to eat the same food in the same amount prior to the session on each test day, and instructions to maintain the same level of physical activity on each test day; No assessment of appetite reported; No assessment of liking reported; Cover story was used, but referred to caloric intake as a measure of interest; Food intake was assessed in groups (social setting is a potential confound); No additional variables included in models.

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		in each meal; potato tots and green beans in meal 1; rice and peas in meal 2. Outcome: Grams (weighed). Energy consumed (kcal) also reported. Intake was averaged across the two test meals for each condition.				
Meengs (2012), US[11] (Meengs et al., 2012)	Laboratory; Within-subjects; Counterbalanced order of conditions using a Latin square. Sample = 69 adults (34 females). Male age = 27.4 yrs, SEM = 1.2. Female age = 25.5 yrs, SEM = 0.6. Male BMI = 25.5 kg/m^2, SEM = 0.6. Female BMI = 23.3, SEM = 0.6.	Variety manipulated within a single course; test meal included pasta with sauce (600g), and cooked vegetables (600g) on a single plate. Variety: Served three vegetables to accompany pasta; broccoli, baby carrots, and snap peas. Control: Served one of three vegetables to accompany pasta; broccoli, baby carrots, or snap peas.	Significant effect of variety on total meal intake for both men and women; participants consumed more in the variety condition compared to control, but only when intake was reported in grams. Total meal energy intake was only significantly different for men, but this was unrelated to vegetable intake.	Significant effect of variety on vegetable intake for both men and women; participants consumed more in the variety condition compared to control (for all three individual vegetables, and when compared to most preferred vegetable). There was no significant effect of variety on pasta intake (in grams or kcal).	There was a significant sex X variety interaction, as pasta intake differed across conditions for men; they consumed more pasta and greater energy overall in the variety and peas-only conditions compared to carrots-only and broccoli-only in the control. However, this was unrelated to vegetable intake.	No sample size calculation; Control procedures included a washout period between conditions, a standard breakfast at least 3h before the test session, instructions to abstain from eating/drinking between breakfast and test session (excluding water), and participants self-reported compliance with control procedures; Pre-post assessment of hunger, fullness, nausea, and prospective consumption reported; Baseline assessment of

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	Exclusions N = 3 ('highly variable' food intake).	Outcome: Grams (weighed). Energy consumed (kcal) also reported.				pleasantness reported, and participants ranked vegetables for preference at the end of the final test session; No information about cover story; No additional confounds identified; 'Participant' was treated as a random effect, and sex and study week were included as fixed effects in main model.
Meiselman (2000), US (Meiselman et al., 2000)	Laboratory; Between-subjects; No information about allocation to conditions. Sample = 47 adults (9 females). Variety group age = 44.8 yrs. Control group age = 44.8 yrs. Variety group weight = 82.5 kg, and height = 174.7 cm.	Variety manipulated across meals; baseline meal of Swedish-style meatballs (150g), mashed potato (215g), green beans (120g) and gravy (55g) served on days 1 and 5 across conditions, and meals containing a main dish of meat/fish, vegetable, and starch served on days 2 – 4 (50% above package serving recommendation for each meal). Variety: Day 2 meal composed of Veal	None reported.	Significant pre-post change in intake for the baseline meal in both conditions. In the variety group, intake significantly increased for meatballs, green beans and mashed potatoes from Day 1 to Day 5. In the control group, intake significantly decreased for meatballs and green beans from Day 1 to Day 5.	None reported.	No sample size calculation; No control procedures; No assessment of appetite; Liking/acceptance measured for each food and each overall meal on each day; No cover story, as participants responded to an advert for a free meal from the 'Food Acceptance Laboratory', but it is mentioned that participants were unaware of food weighing; Food intake assessed in groups (social setting is a potential confound); No

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	Control group weight = 85.2 kg, and height = 177.4 cm. No exclusions.	parmigiana with tomato sauce, potato wedges, and mixed vegetables; Day 3 meal composed of Crunchy fish fillets, deep fries, and broccoli; Day 4 meal composed of chicken nuggets, macaroni and cheese, broccoli, cauliflower and carrots. Control: Served baseline meal of Swedish-style meatballs, mashed potato, green beans, and gravy on days 2 – 4. Outcome: Grams (weighed).				additional variables controlled in main model.
Mok (2010), SG (Mok, 2010)	Laboratory; Within-subjects; Counterbalanced order of conditions using Latin square. Sample = 63 students (Females only).	Variety manipulated across courses; test meal consisted of chocolates only (serving = 200g). Variety: Participants given a serving of a different chocolate for	No significant effect of variety.	None reported.	There was a significant restraint X variety interaction; participants categorized as 'unrestrainers' (N = 12) ate significantly more chocolate in the variety	No sample size calculation; Control procedures included a washout period between conditions, meals given at usual time for lunch or dinner, instructions to abstain from all foods and drinks for at least 2h

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	Age range = 18 – 20 yrs. BMI range = 17.4 – 26.5 kg/m². Exclusions N = 39 (N = 21 did not sign up for main study after screening, N = 16 did not meet study criteria, N = 2 declined participation).	each of three courses; M&Ms, Kinder Bueno, Swiss dark Toblerone. Control: Participants given a serving of their favourite chocolate in all three courses; M&Ms, Kinder Bueno, or Swiss dark Toblerone (determined during study screening for liking of test foods). Outcome: Grams (weighed), converted to kilojoules consumed.			condition than in the plain condition. There was no significant interaction reported for course X variety.	before the test session, instructions to arrive on each test day in approximately the same state of hunger, and participants self-reported their intake at lunch before the first test session; Baseline assessment of hunger reported; Acceptance of test foods was measured before the main study, and pre-post meal assessment of pleasantness reported; Cover story was used, but no indication as to whether this was believed by participants; Eating behaviour questionnaire completed before intake was measured (potential confound); No additional variables controlled in main model.
Norton (2006), UK (Norton et al., 2006)	Laboratory; Within-subjects; Counterbalanced order of conditions using Latin square.	Variety manipulated within a single course; test meal included sandwiches with different fillings, served after either a	Significant effect of variety for intake in both energy and grams; total food intake was greater in the variety	Significant effect of preference within the variety condition; intake of the fourth preferred filling was significantly lower than	No significant interaction for soup preload X variety, sex X variety, DEBQ X variety, TFEQ X variety, or sex X	Target sample N = 20 reported (effect exceeding 15% reduction in intake by preload volume, 1−β = 0.80, α = 0.05); Control procedures included a

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	N = 30 adults (15 females). Age = 29.5 yrs, SD = 12.6. BMI = 23.6 kg/m^2, SD = 3.1. Exclusions N = 1 (outlier in data analyses).	low- or high-volume soup preload (serving = 2216kcal for men, and 1662kcal for women). Variety: Participants served sandwich quarters with their second, third and fourth preferred fillings; cheese, salami, tuna, or chicken. Control: Participants served sandwich quarters with their second preferred filling; cheese, salami, tuna, or chicken. Outcome: Grams (weighed). Energy consumed (kcal/kJ) also reported.	condition compared to the control condition.	the second and third preferred fillings. However, in the variety condition, the tendency to consume all three fillings was significant.	variety X preload on food intake.	washout period between conditions, instructions to fast from midnight the night before each test day until arrival at the laboratory, a standardized breakfast served on the morning of each test day, instructions to abstain from eating and drinking between breakfast and lunch (excluding 1.5l water), and compliance with procedures was checked; Pre-post assessment of hunger, fullness, desire to eat, and prospective consumption reported (following soup preload and sandwich lunch); Baseline assessment of liking before main study reported; Cover story was used, but no awareness check was reported; No additional confounds identified; BMI was included as a between-subjects factor.

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Parizel (2017), FR (Parizel et al., 2017)	Laboratory; Within-subjects; Counterbalanced order of conditions using Williams Latin square. Sample = 59 adults (47 females). Age = 27.4 yrs, SD = 6.8. BMI = 21.7 kg/m^2, SD = 2.1. Exclusions N = 5 (N = 2 did not attend all sessions, N = 3 underestimated their weight and had a BMI > 26 kg/m^2).	Variety manipulated within a single course; test meal included a main course of ham (served amount that they had consumed ad libitum in the first session), and vegetables (serving = 400g). After the test meal, participants were served apple puree (350g), and a cup of flavoured tea. Variety, no choice: Served three vegetable dishes side by side during the main course; spinach, green beans, and zucchini. Variety, choice: Presented with three vegetable dishes during the main course, and participants could choose to have one, two, or all three vegetables. Control, no choice: Served one vegetable	No significant effect of variety.	None reported.	There was no significant interaction reported for choice X variety.	No sample size calculation; Control procedures included a washout period between conditions, instructions to have the same breakfast on each test day, a standardized meal time across participants, and instructions to abstain from eating or drinking for at least 3h before the test session (except water); Assessment of hunger before eating, after the main course, and after each total meal reported; Liking for each vegetable dish assessed after the meal and at the end of the last session; Cover story was used, but no indication as to whether this was believed by participants; Food intake assessed in groups (social setting is a potential confound, though participants were seated in individual booths to reduce influence); 'Participant' included as a random

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		dish during the main course, randomly selected from spinach, green beans, and zucchini. Control, choice: Presented with three vegetable dishes, and participants could choose to have one vegetable only. Outcome: Grams (weighed). Energy (kcal) consumed also reported for total meal intake.				factor, and order of sessions was included as a fixed factor in models; Sensitivity analyses adjusted for plate clearers.
Pliner (1980), CA[12] (Pliner et al., 1980)	Laboratory; Between-subjects; No information about allocation to conditions. Sample = 103 students (Males only) (Participants grouped by weight and dieting status).	Variety manipulated within a single course; test meal consisted of an assortment of hors d'oeuvres (serving = 30 pieces). Variety: Served three types of hors d'oeuvres; sausage rolls, pork and shrimp egg rolls, and pizza slices.	Significant effect of variety; across weight classification groups, participants ate more hors d'oeuvres in the variety condition compared to control.	None reported.	There was no significant interaction reported for weight classification X variety.	No sample size calculation; Control procedures included instructions to abstain from eating for at least 4h before the test session; Pre-post assessment of hunger, and time of last eating reported; Liking assessed for food assortment after the test meal; Cover story was used, but no indication as to whether this was

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	Participants in 'obese weight' group age = 19.5 yrs. Participants in 'lean weight' group age = 19.8 yrs. Participants in 'obese weight' group weight = 197.9lbs, and height = 69.5 inches. Participants in 'lean weight' group weight = 152.7lbs, and height = 69.5 inches. Exclusions N = 31 (N = 12 did not meet criteria for weight classifications for the study, N = 6 had median scores on the dieting scale, N = 8 consumed only one type of hors d'oeuvre in the variety condition, N = 5 were randomly excluded for equal groups).	Control: Served one type of hors d'oeuvre; either sausage rolls, pork and shrimp egg rolls, or pizza slices. Outcome: Piece count (No. hors d'oeuvres eaten).				believed by participants; Food intake assessed using piece count (a potential confound); No additional variables controlled in main model (though it is reported that there were no significant differences in hunger or time of last eating between conditions).

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Raynor (2006), US (Raynor & Wing, 2006)	Laboratory, with at-home participation; Between-subjects; Random allocation to conditions, but no method given. Sample = 29 students (Males only). Control group age = 20.2 yrs, SD = 2.0. Variety group age = 20.7 yrs, SD = 2.5. Control group BMI = 23.3 kg/m^2, SD = 1.9. Variety group BMI: 22.9 kg/m^2, SD = 2.4. Exclusions N = 8 (N = 4 indicated liking <50 for one of the test foods; N = 2 had a BMI >30, N = 1 did not attend first session; N = 1 did not follow study instructions).	Variety manipulated across meals; baseline snack of crumb cake (serving = 375g) to eat in the laboratory on days 1 and 4 across conditions, and snacks were served on days 2 – 4 in the laboratory and taken home on days 1 - 3 (serving = 375g for each snack). Variety: Day 1 take home peanuts, Day 2 eat Oreo cookies in the laboratory and take home Tortilla chips, Day 3 eat Potato chips in the laboratory and take home chocolate chip cookies. Control: Take home Crumb cake on days 1 – 3, and eat Crumb cake in the laboratory on days 2 and 3. Outcome: Grams (weighed), converted to Kcal consumed.	There was no significant effect of variety condition on energy intake from crumb cake on days 1 and 4. Total intake for each snack on days 2 – 4 was not reported. Total intake across days was not reported.	None reported.	There was no significant interaction reported for time (day) X variety.	No sample size calculation; Control procedures included instructions to eat in their usual eating pattern before each session, to abstain from eating for 3h before each session, and participants self-reported intake prior to the session to check compliance; Pre-post assessment of hunger in each session reported; Liking assessed for each food on day 1 and 4; No information about cover story; Food intake assessed in cafeteria (social setting is a potential confound, though participants were seated on individual tables facing away from other participants to reduce influence); No additional variables controlled in main model (no significant differences found for any baseline characteristics between conditions; no significant differences in liking for foods between conditions

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						on day 1; no significant differences between conditions and days for hunger, hours since last eaten, or intake prior to test session).
Raynor (2012), US (Raynor & Osterholt, 2012)	Laboratory; Within-subjects; Random order of conditions stratified by gender, but no method given. Sample = 24 adults (10 females). Age = 26.5 yrs, SD = 8.1. BMI = 22.9 kg/m^2, SD = 3.0. Exclusions N = 4 (N = 2 did not like test foods, N = 1 did not complete all sessions, N = 1 refused to eat in one session).	Variety manipulated across courses; test meal included fruit only (serving = 200g). Variety: Given their four highest rated fruits in four separate courses (grapes, pineapple, orange, apple, peaches, cantaloupe). Control: Given their highest rated fruit in each of four courses (either grapes, pineapple, orange, apple, peaches or cantaloupe). Outcome: Grams (weighed). Kcal consumed also reported.	There was no significant effect of variety condition on weight or energy consumed.	None reported.	There was a significant interaction reported for course X variety. Intake in course 4 was significantly greater in the variety condition compared to control. Intake in courses 2, 3, and 4 was significantly lower than intake in course 1 in the control condition. Intake in course 4 (grams only) and intake in courses 3 and 4 (energy only) were significantly lower than intake in course 1 in the variety condition.	No sample size calculation; Control procedures included instructions to eat a meal bar (220kcal, highest rated for liking in screening) 2h before the session and to abstain from eating all other foods and energy-containing beverages, sessions were scheduled on separate days (but no more than one week apart), and participants self-reported intake prior to the session to check compliance; Pre-post assessment of hunger and fullness in each session reported; Pre-post assessment of pleasantness of foods in each session reported; Cover story was used, but no indication as to

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						whether this was believed by participants; No additional confounds identified; No additional variables controlled in main model (no significant differences found between sessions in time since eating, food intake prior to sessions, hunger, fullness, or liking).
Roe (2013), US (Roe et al., 2013)	Field (School); Within-subjects; Counterbalanced order of conditions using Latin square, and randomized assignment of order to classrooms using a computerized randomizer. Sample = 61 children (32 females). Female age = 4.2 yrs, SEM = 0.1. Male age = 4.6 yrs, SEM = 0.1.	Variety manipulated within a single course; test meal included fruits and vegetables offered family style (serving = 300g per bowl), and a pita bread (serving = 16g)[13]. Variety: Each of three serving bowls contained a different type of fruit or vegetable (depending on session). If fruits were served, children were offered apple, peach, and pineapple. If vegetables were served, children were	There was a significant effect of variety; children consumed more pieces of fruits and vegetables in the variety condition compared to control.	None reported.	No significant snack type (fruit vs. vegetable) X variety interaction.	No sample size calculation; Control procedures included a washout period between conditions, conducting each session at a standard time after a nap or quiet play in usual setting; No assessment of appetite reported; Assessment of liking of foods was conducted 1 week after the final session; No information about cover story (though it is reported that adult helpers were unaware of study hypotheses); Food intake assessed in groups (social setting is a potential

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	Female BMI percentile = 52.7, SEM = 4.8. Male BMI percentile = 58.5, SEM = 4.6. No exclusions.	offered cucumber, sweet pepper, and tomato. Control: Each of three serving bowls contained a single type of vegetable or fruit (depending on session). If a fruit was served, children were offered apple, peach, or pineapple. If a vegetable was served, children were offered cucumber, sweet pepper, or tomato. Outcome: Piece count (No. pieces of vegetables or fruit selected, and any leftovers were recorded by two observers).				confound, though adult helpers instructed not to influence food intake); Food intake assessed using piece count (a potential confound); Effects of age, sex-specific BMI-for-age percentile, and food liking on intake were tested as potential covariates; A random effect was included in models to account for the correlation between repeated observations for each child.
Roemmich (2010), US (Roemmich et al., 2010)	Laboratory; Within-subjects; Counterbalanced order of conditions, but no method given. Sample = 38 children (19 pairs of male	Variety manipulated within a single course; test meal included snack assortment (variety meal serving = approx. 880g, control	Significant effect of variety; children consumed greater energy and weight of food in the variety condition compared to control.	None reported.	No significant weight classification X variety interaction for intake.	No sample size calculation; Control procedures included a washout period between conditions, instructions to abstain from eating for 4h prior to the test session, instructions to avoid all

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	siblings, grouped by weight). Lean weight sibling age = 12.8 yrs, SD = 2.5. Overweight sibling age = 12.4 yrs, SD = 2.1. Lean weight sibling BMI z-score = 12.4, SD = 2.1 Overweight sibling BMI z-score = 1.6, SD = 0.4. No exclusions.	meal serving = approx. 800g). Variety: Served pizza, chicken nuggets, Doritos, iced fruit and oatmeal bites, skittles, chocolate chip cookies. Control: Served pizza only. Outcome: Grams (weighed). Kcal consumed also reported.				test foods for 24h prior to session, physical activity was monitored during the week between visits, and test sessions were scheduled during normal dinner hours; Baseline assessment of hunger in each session reported; Food liking assessed before main study (inclusion criteria specified that participants must report >50mm liking scores for 5 of 6 test foods); Cover story was used, and participant awareness was checked; Order of tasks was unclear (timing of eating behaviour questionnaires); 'Sibling' and 'family' treated as random effects in models, and presentation order of conditions was considered as a potential covariate (but not significant).
Rolls (1981), UK [Study 1]	Laboratory; Within-subjects; Counterbalanced order of conditions,	Variety manipulated across courses; test meal included an assortment of	Significant effect of variety; total food intake across courses was greater in the	Significant differences in intake for individual courses; intake declined more across	No significant interaction for time X variety. There were no significant differences	No sample size calculation; Control procedures included a washout period between

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
(Rolls, Rowe, et al., 1981)	but method unclear. Sample = 36 students (Females only). Age range = 18 – 25 yrs. BMI range = 18.4 – 26.4 kg/m^2. No exclusions.	sandwiches (serving size unknown). Variety: Given sandwiches with a different filling for each of four courses; egg, tomato, cheese, and ham. Control: Given sandwiches with the same filling for each of four courses; egg, tomato, cheese, or ham. Outcome: Piece count (number of pieces of sandwich eaten, converted to grams consumed based on average weight of sandwich).	variety condition compared to control.	courses in the control condition compared to the variety condition. In the variety condition, intake in each course (courses 2, 3, and 4) was greater than intake in the control condition.	in normalized intakes between conditions for 'obese' and 'leaner' participants.	conditions, a standardised meal time across participants, and instructions to abstain from eating and drinking between a coffee break and the test session at lunch; Pre-post assessment of hunger in each session reported; Participants ranked liking of foods in a final debriefing session, and rated pleasantness before eating (as part of a cover story); Cover story was used, and participant awareness was checked in a debrief session; Food intake assessed using piece count (a potential confound); No additional variables included in models (no significant differences in intake between subjects who had their favourite sandwich and those that had their least favourite sandwich in the control condition).
Rolls (1981), UK [Study 2]	Laboratory; Within-subjects;	Variety manipulated across courses; test	Significant effect of variety (for both grams	Significant differences in intake for individual	No significant interaction for time X	No sample size calculation; Control

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(Rolls, Rowe, et al., 1981)	Counterbalanced order of conditions, but method unclear. Sample = 24 adults (12 females). Age range: 18 – 35 yrs. BMI range: 19.9 – 24.4 kg/m^2. No exclusions.	meal included an assortment of yogurts (serving = 400-500g per course). Variety: Given a different yogurt for each of three courses; hazelnut, blackcurrant, and orange. Control: Given the same yogurt for each of three courses; hazelnut, blackcurrant, or orange. Outcome: Grams (weighed). Energy consumed also reported (unit unclear).	and energy consumed); total food intake across courses was greater in the variety condition compared to control (averaged across three control conditions with one yogurt).	courses; intake declined more in courses 2 and 3 in the control condition compared to the variety condition. In the variety condition, intake in course 3 was greater than intake in course 3 in the control condition.	variety. Intake in each condition was compared for sex, obesity index, yoghurt preference ranking and restraint score; intake was significantly greater for females in the variety condition compared to control, and intake in the variety condition was significantly greater than intake in the control condition with participants' preferred yogurt. Obesity index and restraint did not significantly influence the effect of variety on intake.	procedures included a washout period between conditions, and instructions to abstain from eating and drinking between a coffee break and the test session at lunch; Pre-post assessment of hunger in each session reported; Participants ranked liking of foods in a final debriefing session, and rated pleasantness before eating (as part of a cover story); Cover story was used, and awareness was checked in a debrief session; No additional confounds identified; No additional variables were included in models.
Rolls (1981), UK [Study 3] (Rolls, Rowe, et al., 1981)	Laboratory; Within-subjects; Counterbalanced order of conditions, but method unclear.	Variety manipulated across courses; test meal included an assortment of yogurts (serving = 400-500g per course).	No significant effect of variety for total food intake across courses.	No significant differences in intake for individual courses, and no significant differences in the rate	Intake in each condition was compared for restraint scores and obesity; no significant associations were found.	No sample size calculation; Control procedures included a washout period between conditions, and instructions to abstain from eating and drinking

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	Sample = 24 students (Females only). Age range = 18 – 20 yrs. BMI = Not reported, but all participants were within 15% of 'recommended' body weights. No exclusions.	Variety: Given a yogurt for each of three courses that differed only in flavours; cherry, raspberry, and strawberry. Control: Given the same yogurt for each of three courses; cherry, raspberry, or strawberry. Outcome: Grams (weighed).		of decline in intake between conditions.		between a coffee break and the test session at lunch; Pre-post assessment of hunger in each session reported; Participants ranked liking of foods in a final debriefing session, and rated pleasantness before eating (as part of a cover story); Cover story was used, and awareness was checked in a debrief session; No additional confounds identified; No additional variables were included in models.
Rolls (1982), UK [Study 2][14] (Rolls et al., 1982)	Laboratory; Within-subjects; Counterbalanced order of conditions, but method unclear. Sample = 24 students (12 females). Age range = 18 – 25 yrs. BMI range =18.5 – 28.9 kg/m^2.	Variety manipulated across courses; test meal included pasta with sauce (serving = 300g per course). Variety: Given a different shape of pasta for each course; spaghetti, bow tie shapes, and hoop shapes. Control: Given their most preferred shape of	Significant effect of variety for total food intake across courses; participants consumed more energy in the variety condition compared to control.	Significant differences in intake for individual courses; intake was significantly greater in the third course in the variety condition compared to control.	No significant interaction for time X variety. Normalized intakes in each condition were compared for sex, restraint scores and BMI; females and participants who were categorized as more restrained had greater intake in the variety condition compared to control.	No sample size calculation; Control procedures included a washout period between conditions, instructions to arrive in the same state of hunger on each test day, and meals given at usual time for test foods to be eaten; Baseline assessment of hunger in each session reported; Pre-post assessment of pleasantness of test foods in each session reported;

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	No exclusions.	pasta in every course (as rated during an initial assessment); spaghetti, bow tie shapes, or hoop shapes. Outcome: Eating intake (amounts of dry pasta and sauce eaten calculated from proportion of pasta to sauce served before meal), converted to energy consumed (kJ).				Cover story was used, and awareness was checked in a debrief session; No additional confounds identified; No additional variables were included in models.
Rolls (1982), UK [Study 3] (Rolls et al., 1982)	Laboratory; Within-subjects; Counterbalanced order of conditions, but method unclear. Sample = 24 students (12 females). Age range = 19 – 25 yrs. BMI range = 18.2 – 32.9 kg/m^2. No exclusions.	Variety manipulated across courses; test meal included an assortment of sandwiches (serving = 200g per course). Variety: Given sandwiches with a cream cheese filling which had a different flavours in each course; salt flavours, lemon and saccharin flavours, and curry flavours. Control: Given sandwiches with their	Significant effect of variety for total food intake across courses; participants consumed more energy in the variety condition compared to control.	Significant differences in intake for individual courses; intake was significantly greater in the second and third courses in the variety condition compared to control.	No significant interaction for time X variety. Normalized intakes in each condition was compared for sex, restraint scores, BMI, and initial liking of test foods. There was no difference in intake between conditions for participants with initial liking differences of foods of >35mm, but intake was greater in the variety condition compared to control for participants with initial	No sample size calculation; Control procedures included a washout period between conditions, instructions to arrive in the same state of hunger on each test day, and meals given at usual time for test foods to be eaten; Baseline assessment of hunger in each session reported; Pre-post assessment of pleasantness of test foods in each session; Cover story was used, and awareness was checked in a debrief session; No

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
		most preferred cream cheese filling in every course (as rated during an initial assessment); salt flavours, lemon and saccharin flavours, or curry flavours. Outcome: Eating intake (amount eaten in grams calculated from proportion of bread to filling in each piece, and number of pieces consumed), converted to energy consumed (kJ).			liking differences of foods of <35mm. No significant differences were found for sex, restraint scores, or BMI.	additional confounds identified; No additional variables were included in models.
Spiegel (1990), US[15] (Spiegel & Stellar, 1990)	Laboratory; Within-subjects; Counterbalanced order of conditions using a method of alternation. Sample = 27 adults (Females only) (Participants were grouped by weight). Underweight, Age = 24.7 yrs.	Variety manipulated across courses; test meal included an assortment of sandwiches (serving size unknown). Variety, sequential: Given bite-sized sandwiches with one of their three most preferred fillings in each of three courses;	Significant effect of variety for total food intake across courses; for all participants, intake was significantly greater in the simultaneous variety condition compared to control. Intake in the sequential variety condition was not significantly different from intake in the	Significant differences in intake for individual courses; for all participants, intake was significantly greater in the first and second courses in the simultaneous variety condition compared to control; for all participants, intake was greater in the sequential variety condition compared to	When effects were explored for each weight group separately; differences between conditions for total food intake were only significant for lean weight and overweight participants (intake was significantly greater in the simultaneous variety condition compared to control). Differences between	No sample size calculation; Control procedures included a washout period between conditions, and instructions to eat the same breakfast at the same time (or skip breakfast) on the morning of each test day, to otherwise abstain from eating until the test session, and food intake prior to the session was checked on arrival;

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	Lean weight, Age = 31.8 yrs. Overweight, Age = 31.8 yrs. Underweight, % ideal body weight = 80.1. Lean weight, % ideal body weight = 94.2. Overweight, % ideal body weight = 128.0. No exclusions.	tuna, turkey, beef, egg, ham, cheese. Variety, simultaneous: Given bite-sized sandwiches with all three of their most preferred fillings in each of three courses; tuna, turkey, beef, egg, ham, cheese. Control: Given bite-sized sandwiches with their middle-preferred filling in all three courses (as rated during an initial assessment); tuna, turkey, beef, egg, ham, or cheese. Outcome: Piece count (number of pieces of bite-sized sandwiches eaten).	simultaneous or control conditions.	the control, but only in the second course.	conditions for first and second courses were only significant for lean weight and overweight participants (intake in the first course was significantly greater in the simultaneous variety condition compared to control for both overweight and lean weight participants, and intake in the second course was significantly greater in the simultaneous variety condition compared to control for lean weight participants only).	Assessment of hunger at the beginning and end of each course reported; Pre-post assessment of liking of test foods in each session (at the start and end of the meal) reported; Cover story was used, but no awareness check was reported; Food intake assessed using piece count (a potential confound); No additional variables were included in models.
Stubbs (2001), UK[16] (Stubbs et al., 2001)	Laboratory (Resident trial); Within-subjects; Randomized order of conditions, but no method given. Sample = 12 adults	Variety manipulated across meals; choices available for breakfast (serving = 600g), lunch (serving = 400g), dinner (serving = 400g), and snacks	Significant effect of variety for total daily food intake (g and MJ); for all participants, average daily food intake was significantly greater in the high	Differences in intake for each individual meal, or for each individual meal session (i.e., breakfast, lunch,	Significant weight X variety interaction; lean participants consumed significantly more food in the high variety condition compared to the medium variety and	No sample size calculation; Control procedures included a washout period between conditions, a maintenance diet for 2d before the trial, instructions to maintain

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	(Males only) (Participants were grouped by weight). Lean, Age = 27.0 yrs, SD = 2.9. Overweight, Age = 39.7 yrs, SD = 2.9. Lean, BMI = 23.6 kg/m^2, SD = 1.1. Overweight, BMI = 28.1 kg/m^2, SD = 0.5. No exclusions.	(standard portions available for each meal, and energy per meal matched across conditions) were manipulated. Cereals were served at breakfast, and a choice of hot dishes and garnish were served at lunch and dinner. Snacks included a mix of soups, desserts, and energy-containing beverages. Tea, coffee, salt and pepper were available *ad libitum* at meals across conditions. High variety: Three choices available at breakfast, lunch, and dinner. Six choices of snacks available per day. Medium variety: Two choices available at breakfast, lunch, and dinner. Four choices of	variety condition compared to the medium variety and control conditions. Total intake across days is not reported.	dinner) are not reported.	control conditions, but there were no significant differences in intake between conditions for overweight participants.	their normal activity routine during the whole study, instructions to abstain from drinking alcohol during the study period, and all participants kept a food log to check compliance with study instructions; Hourly assessment of hunger, fullness and desire to eat on each test day reported; Assessment of pleasantness of test foods after each meal reported; No cover story was used; Participants were weighed before eating, and multiple times throughout the trial (a potential confound); 'Subject', 'run', 'day' and 'time' were included in models.

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		snacks available per day. Control: One choice available at breakfast, lunch, and dinner. Two choices of snacks available per day. Outcome: Grams (leftovers collected and weighed). Energy consumed (MJ) also reported.				
Vadiveloo (2019), US[17] (Vadiveloo et al., 2019)	Laboratory; Between-subjects; Blocked randomization to conditions using ID number. Sample = 184 adults (31.7% female). Age = 34.8 yrs, SD = 14.1. BMI = 24.4 kg/m^2, SD = 5.2.	Variety manipulated within a single course; test meal included fruits and vegetables only. Pears and peppers were served in separate bowls, and depending on condition, different shapes and/or colours of each food were presented in the same bowl. (pear serving = 224g, pepper serving = 140g). Combination variety: Two conditions (separate groups of	No significant effect of variety for intake of pears or peppers.	None reported.	No significant prime X variety, sex X variety, or usual fruit and vegetable intake X variety interactions. Subgroup analyses revealed significant effects of variety when participants were grouped by age and weight status. Participants classified as overweight (using self-reported BMI) had a greater intake of pears in the colour variety condition compared to	Target sample N = 600 reported (Cohen's d effect size = 0.31, 1−β = 0.80, α = 0.05); No control procedures reported; No assessment of appetite reported; Assessment of liking reported during questionnaire; Cover story was used, but no awareness check was reported; No additional confounds identified; Age, weight status, sex, prime, usual fruit and vegetable intake, and presentation order were

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
	Exclusions N = 20 (participants included in pre-test only).	participants) were combined to form a single condition. Participants were initially randomized to receive two shapes of pears and peppers, and to receive both two shapes and two colours of pears and peppers. Colour variety: Participants received two colours of pears and peppers (all in the same shape). Control: Participants received a single colour and shape of pears and peppers. Outcome: Ounces (weighed).			participants classified as having a lean weight or compared to the combination condition, and participants older than 36 years old had a greater intake of peppers in the colour variety condition than participants younger than 36 years old. Participants older than 36 years old also had a greater intake of peppers in the colour variety condition compared to the combination variety condition.	additional variables included in models.
Van Wymelbeke (2020), FR[18] (Van Wymelbeke et al., 2020)	Field (Nursing home); Within-subjects; Order of conditions was counterbalanced across nursing	Variety manipulated within a single course; main dish was manipulated, and served as part of a multicourse meal consisting of a starter (grated carrots or	Significant effect of variety for intake; total food intake (in g and kcal) was greater in the variety condition compared to control.	Garnish intake was significantly higher when participants were served two garnishes in the variety condition compared to control. Bread intake was significantly higher in	Significant condition X repetition interaction; Bread intake was significantly higher in the variety condition compared to control in the second replication of the study, but not the	Target sample N = 77 reported (effect considering average SD of 80 for intake in older adults with contingency for 20% dropouts, $1-\beta = 0.90$, $\alpha = 0.05$);

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
	homes, but allocation method is unclear. Sample = 89 older adults (63 females). Age = 87.5 yrs, SEM = 0.8. BMI = Not reported. Exclusions N = 7 (N = 4 participants withdrew from study, and N = 3 participants did not complete at least four test sessions).	vegetable soup depending on preference), dessert (custard), and a course of bread with cheese (serving = 810kcal per whole meal serving in the variety and control conditions). Participants who did not like cheese (N = 11) or custard (N = 6) were instead served yoghurt and apple puree. Variety: Participants served veal blanquette and two garnishes (steamed potatoes and green beans) for main course. Participants were also able to help themselves to seven condiments (butter, fresh cream, mustard, mayonnaise, tomato sauce, parsley, lemon) in addition to salt and pepper. Control: Participants served veal blanquette		the variety condition compared to control.	first. Dessert intake was also significantly higher in the variety condition in the second repetition compared to the first. Total energy intake was greater in variety conditions compared to control, but only in the second replication.	Control procedures included a washout period between conditions, and presenting the test meal at the standard lunch time in the usual setting for the nursing home; Pre-post assessment of hunger reported; Liking assessed after meal; No information about a cover story; Unclear whether participants were tested in groups (social setting is a potential confound); Condition, repetition, nursing homes, hunger, and liking were additional variables included in models.

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
		and one garnish (steamed potatoes) for main course. Participants were also able to help themselves to salt and pepper, but no additional condiments were available. Outcome: Grams (weighed). Energy consumed (kcal) also reported. Piece count (no. of spoons or units consumed) used to measure condiment intake.				
Wijnhoven (2015), NL[19] (Wijnhoven et al., 2015)	Laboratory; Within-subjects; Randomized order of conditions, but no method given. Sample = 24 older adults (Females only). Age = 84.0 yrs, SD = 8.0.	Variety manipulated within a single course; test meal with a meat or fish (150 – 170g), starch (225g), vegetable (225g), and sauce (28g) component. Variety: If participants chose to have meat, participants received three different vegetables of different	Significant effect of variety for intake in both energy and grams; total food intake averaged across meals was greater in the variety condition compared to control.	Energy intake for the starch component was significantly higher in the variety condition compared to control. Intake in grams was significantly higher for vegetables in the variety condition compared to control. Comparisons for all other components were not significant.	None reported.	Target sample N = 22 reported (effect exceeding 100kcal with contingency for 25% dropouts, $1-\beta = 0.80$, $\alpha = 0.05$); Control procedures included a standardized lunch served to participants 4h before the test meal, a standardized meal setting and time across sessions, and instructions to otherwise abstain from eating and drinking until

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
	BMI = 24.8 kg/m^2, SD = 4.9. Exclusions N = 5 (N = 1 did not show up to study, N = 4 dropped out after first session).	colours (beets, cauliflower, French beans), three different meats (chicken wrapped in bacon, meatball, breaded pork schnitzel), and three different starch components (boiled potatoes, fried duchesse potatoes, fried potato slices) in a single course. If participants chose to have fish, participants received three different vegetables of different colours (broccoli, carrots, red cabbage), three different fish (cod, tilapia, salmon), and three different starch components (boiled potatoes, fried Parisienne potatoes, fried potato slices), in a single course. Control: If participants chose to have meat, participants received				the test meal (excluding 500ml of water, tea or coffee); Pre-post assessment of hunger and fullness reported; Liking of test foods reported after eating; No information about a cover story (though it is reported that participants were not informed about and unaware of the study aim); No additional confounds identified; Testing period effects were included in models.

First author (year), Country[1]	**Design and participants**	**Form of variety, test food, and outcome measure**	**Main result for total food intake (where relevant, w/o beverages)**	**Additional results for food intake (a single or combination of components within a meal)**	**Interaction effects and/or subgroup analyses for food intake**	**Methodological considerations**
		one vegetable (French beans), one meat component (chicken wrapped in bacon), and one starch component (mashed potatoes), in a single course. If participants chose to have fish, participants received one vegetable (red cabbage), one fish component (tilapia), and one starch component (mashed potatoes), in a single course. Outcome: Grams (weighed). Energy consumed (kcal) also reported. Intake was averaged across the fish/meat test meals for each condition.				
Zeinstra (2010), NL (Zeinstra et al., 2010)	Field (Restaurant); Between-subjects; Randomized allocation to conditions by schedule days, but method of	Variety manipulated within a single course; vegetables (serving = 130g) manipulated within a main meal consisting of a starch (130g), meat (60g), and	Not reported.	There was no significant effect of variety on intake of vegetables, starchy component, meat, or dessert.	Effects of age, neophobia, general vegetable liking, restriction, pressure, monitoring, sex, and trait reactance were explored as potential moderators. Significant	Target sample N = 270 (N = 90 per condition) reported (effect considering SD of 36g for vegetable intake, difference of 15g for vegetable intake between conditions, $1-\beta = 0.80$, α

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
	randomization is unclear. Sample = 326 children (147 females). Age (across conditions) = 5.2 yrs, SD = 0.7. 'No choice' BMI = 15.5 kg/m^2, SD = 1.7. 'Premeal choice' BMI = 15.3 kg/m^2, SD = 1.7. 'Variety' BMI = 15.2 kg/m^2, SD = 1.7. Exclusions N = 23 (N = 14 were not able to schedule an appointment, N = 9 cancelled appointment due to illness or other reason).	dessert (150g) component. Variety: Two vegetables included in meal (3rd and 4th preferred vegetable out of carrots, peas, cauliflower, broccoli, red cabbage, beets, French beans, and spinach). Premeal choice: Offered a choice of one of two vegetables to be included in the meal before being served (children can choose either their 3rd or 4th preferred vegetable out of carrots, peas, cauliflower, broccoli, red cabbage, beets, French beans, and spinach). Control: Randomly assigned to receive one of two vegetables in the meal (3rd or 4th preferred vegetable out of carrots, peas,			moderator effect was reported for trait reactance; in the no-choice control condition, high-reactant children consumed significantly less vegetables than low-reactant children.	= 0.05); Control procedures included that each session was conducted at children's regular dinner time, parents asked not to feed children 1h before dinner session, and parents asked not to control or influence child's eating behaviour during dinner in the restaurant, and parents completed questionnaire about child's eating habits; No assessment of appetite reported; Pre-post assessment of liking of foods was reported; No information about cover story; Food intake assessed in social setting with parents, and parent and child intake were significantly positively correlated for all meal components excluding meat (setting is a potential confound); Excluding potential moderators, no additional variables included in main models (differences in sex, restriction, pressure, and

First author (year), Country[1]	Design and participants	Form of variety, test food, and outcome measure	Main result for total food intake (where relevant, w/o beverages)	Additional results for food intake (a single or combination of components within a meal)	Interaction effects and/or subgroup analyses for food intake	Methodological considerations
		cauliflower, broccoli, red cabbage, beetroot, French beans, and spinach). Outcome: Grams (weighed).				monitoring were checked across groups but not significant).

[1]Country where the study was conducted.

[2]Article also reported condition effects on intake for dinner; As foods provided at dinner were the same across conditions and were not manipulated for variety, information relating to dinner intake (dinner intake alone, and lunch and dinner intake combined) were not extracted for this review.

[3]Effect of variety is reported separately for males and females.

[4]Article also included a pilot study for the manipulation used in the main study, but as food liking was the outcome, information was not extracted for this review.

[5]Article also reported intake in response to participants self-serving the control meal, changing the dish name, and changing the décor in the room; Information from these conditions were not extracted from the article for this review.

[6]Given the number of foods presented in this study across courses of the test meal, for brevity, only the vegetables that were manipulated for variety are reported.

[7]Article also included Study 2; variety was manipulated at home for a duration of 4 weeks, but as intake was self-report, information from these conditions were not extracted from the article for this review.

[8]Article also included Study 1; variety was manipulated across courses (different colour of candy in each of four courses) and within a single food assortment (mixed colours of candy in each of four courses), and were compared to a no-variety control condition (same colour of candy in each of four courses. However, samples of each colour were presented to measure liking between courses 2 and 3 in each condition; as this may disrupt intake, information from this study was not extracted for review.

[9] Article reports conflicting information for participant age (different values are reported in text and tables).

[10]Article also included Study 2; the same ingredients were served separately or as a part of a composite meal (stir-fry or pasta) to manipulate the perception of variety. However, as no comparative condition was included in which variety was reduced (i.e., fewer ingredients), information from this study was not extracted for review.

[11]Effect of variety is reported separately for males and females.

[12]Article also included Study 2; participants consumed a test food in the laboratory and were subsequently asked to rate the pleasantness of either the same or a different food item; as food intake was not an outcome of interest, this study was not included for review.

[13] As the pita bread was served before the snack began (i.e., before fruits and vegetables were available to children), this was not included in results for total meal intake.

[14]Article also included Study 1; effect of variety across courses (different colour of candy in each of four courses) and within a single food assortment (mixed colours of candy in each of four courses) were compared to a no-variety control condition (same colour of candy in each of four courses) and appeared eligible for this review. However, as samples of each candy were presented and consumed between courses 2 and 3 across conditions (to measure liking), intake from courses was disrupted. For this reason, information from this study was not extracted for review.

[15]Article also included a 'hidden simultaneous' condition in which participants received a mix of their three-most preferred flavours of sandwiches for each of three courses in a picnic box (so that the whole assortment was hidden from view); information from this condition was not extracted for review.

[16]Given the number of foods presented in this study across conditions, for brevity, only the number of foods presented for each condition, and a short description of the types of foods used are reported.

[17]Article also reported intake in response to a positive, negative and control prime; information from these conditions were not extracted from the article for this review.

[18]Article also included a 'Quality' condition, in which participants received enhanced main dish and dessert recipes, and preferable cheeses/bread, without the addition of added variety; information from this condition was not extracted from the article for this review.

[19]Study included older adults with a self-reported poor appetite. However, participants did not otherwise report serious illness and/or eating disorder.

2.3.1. Included studies for review

An overview of the selection process is presented in **Figure 2**. Database searching identified 7259 articles, of which 29 papers (32 studies) were eligible for the systematic review. No new articles were identified for review in an updated database search. A hand-search identified five additional articles for review, consisting of five studies.

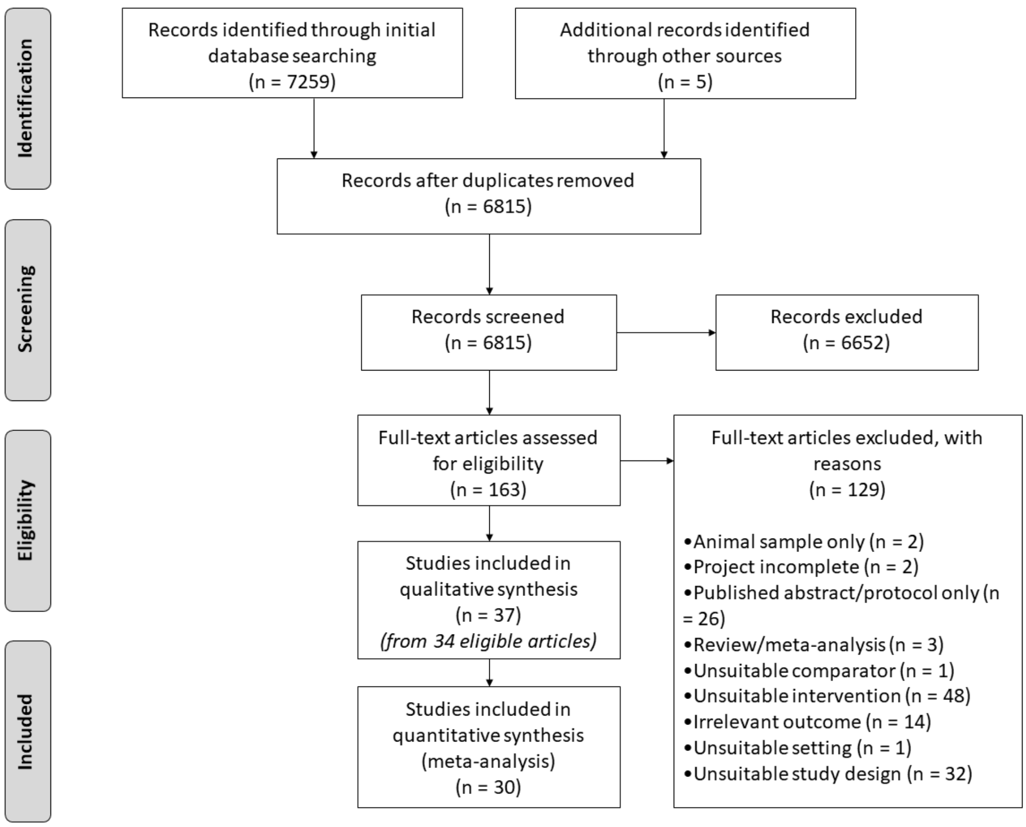


Figure 2. PRISMA diagram of the study selection process (Moher et al., 2009).

2.3.2. Study designs and samples used

Of the 37 studies included for review, nine were field studies (Appleton, 2009; Bergamaschi et al., 2016; Carstairs et al., 2018; Divert et al., 2015; Domínguez et al., 2013; Guerrieri et al., 2008; Roe et al., 2013; Van Wymelbeke et al., 2020; Zeinstra et al., 2010), and all others were conducted in the laboratory. Thirteen studies included variety as a between-subjects factor (Beatty, 1982; Domínguez et al., 2013; Epstein et al., 2013; Guerrieri et al., 2007, 2008, 2012; Kerr et al., 2019; Meiselman et al., 2000; Pliner et al., 1980; Raynor & Wing, 2006; Vadiveloo et al., 2019; Zeinstra et al., 2010), and the remainder were within-subjects.

Twelve studies were conducted in the US (Beatty, 1982; Carney et al., 2018; Epstein et al., 2013; Levitsky et al., 2012; Meengs et al., 2012; Meiselman et al., 2000; Raynor & Osterholt, 2012; Raynor & Wing, 2006; Roe et al., 2013; Roemmich et al., 2010; Spiegel & Stellar, 1990; Vadiveloo et al., 2019), twelve in the UK (Appleton, 2009, 2018; Best & Appleton, 2011; Carstairs et al., 2018; Hollis & Henry, 2007; Norton et al., 2006; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Stubbs et al., 2001), five in the Netherlands (Guerrieri et al., 2007, 2008, 2012; Wijnhoven et al., 2015; Zeinstra et al., 2010), three in France (Divert et al., 2015; Parizel et al., 2017; Van Wymelbeke et al., 2020), and a single study was conducted in Denmark (Bergamaschi et al., 2016), Spain (Domínguez et al., 2013), Australia (Kerr et al., 2019), Canada (Pliner et al., 1980), and Singapore (Mok, 2010).

Participant age varied across studies; as reported and defined in included articles, nine studies included children (Bergamaschi et al., 2016; Carney et al., 2018; Carstairs et al., 2018; Domínguez et al., 2013; Epstein et al., 2013; Guerrieri et al., 2008; Roe et al., 2013; Roemmich et al., 2010; Zeinstra et al., 2010), six included older adults (Appleton, 2009, 2018; Best & Appleton, 2011; Divert et al., 2015; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015), one included both children and adults (Kerr et al., 2019), and one included both young and older adults (Hollis & Henry, 2007). All other studies included adults from a community-based (Meengs et al., 2012; Meiselman et al., 2000; Parizel et al., 2017; Raynor & Osterholt, 2012; Rolls, Rowe, et al., 1981; Stubbs et al., 2001; Vadiveloo et al., 2019) or university-based sample (Beatty, 1982; Guerrieri et al., 2007, 2012; Levitsky et al., 2012; Mok, 2010; Norton et al., 2006; Pliner et al., 1980; Raynor & Wing, 2006; Rolls et al., 1982; Rolls, Rowe, et al., 1981).

Seven studies included only females (Guerrieri et al., 2007, 2012; Mok, 2010; Rolls, Rowe, et al., 1981; Spiegel & Stellar, 1990; Wijnhoven et al., 2015), three included only males (Pliner et al., 1980; Raynor & Wing, 2006; Roemmich et al., 2010), and all others included mixed samples, consisting of an average of 53% females.

Studies differed in terms of reporting weight status of participants; though the majority of studies reported participants' BMI (Appleton, 2018; Bergamaschi et al., 2016; Best & Appleton, 2011; Carstairs et al., 2018; Guerrieri et al., 2007, 2008, 2012; Hollis & Henry, 2007; Kerr et al., 2019; Meengs et al., 2012; Mok, 2010; Norton et al., 2006; Parizel et al., 2017; Raynor & Osterholt, 2012; Raynor & Wing, 2006; Roe et al., 2013; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Stubbs et al., 2001; Vadiveloo et al., 2019; Wijnhoven et al., 2015; Zeinstra et al., 2010), four studies reported z-scores (Carney et al., 2018; Epstein et al., 2013; Kerr et al., 2019; Roemmich et al., 2010), two studies reported separate height and weight measurements (Meiselman et al., 2000; Pliner et al., 1980), a single study reported percentage ideal body weight (Spiegel & Stellar, 1990), and six studies included no information on weight status (Appleton, 2009; Beatty, 1982; Divert et al., 2015; Domínguez et al., 2013; Levitsky et al., 2012; Van Wymelbeke et al., 2020). Of those reporting means and variance for BMI, samples had a combined mean of 24.1 kg/m^2, with a combined SD of 6.8.

2.3.3. Intervention and outcome measures

Four studies examined the short-term effects of variety across meals on food intake (Epstein et al., 2013; Meiselman et al., 2000; Raynor & Wing, 2006; Stubbs et al., 2001). Of these studies, two manipulated variety for a main meal dish across five days (Epstein et al., 2013; Meiselman et al., 2000), one manipulated variety for snacks across four days (Raynor & Wing, 2006), and one manipulated variety for breakfast, lunch, evening meals, and snacks, across three days in a residential trial (Stubbs et al., 2001). Three of these studies used a similar design; across conditions, they presented all participants with the same meal or snack on the first and last day of the study, they manipulated variety on interval days, and they measured pre-post intervention differences in intake (Epstein et al., 2013; Meiselman et al., 2000; Raynor & Wing, 2006). The remaining study (Stubbs et al., 2001) manipulated variety within each meal session for each day (e.g., foods served for breakfast differed on days one, two, and three), and they reported differences in average daily intake across conditions. All four studies used a combination of test foods in meals that varied multiple sensory characteristics (i.e., foods differed in appearance, texture, and flavour) across conditions.

The majority of studies examined the short-term effects of variety within meals on food intake. Nine studies manipulated variety across multiple courses of a meal (Hollis & Henry, 2007; Mok, 2010; Raynor & Osterholt, 2012; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Spiegel & Stellar, 1990). In these studies, the same or a different food was presented for each successive course, intake for each individual course was measured, and cumulative food intake was calculated. One study manipulated variety within a hot lunch meal (Rolls et al., 1982), and another offered participants an assortment of fruits (Raynor & Osterholt, 2012). All others presented participants with snack foods; sandwiches with different fillings (Hollis & Henry, 2007; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Spiegel & Stellar, 1990), an assortment of chocolates (Mok, 2010), and an assortment of yoghurts (Rolls, Rowe, et al., 1981). In three studies, foods varied in a single sensory characteristic (Rolls et al., 1982; Rolls, Rowe, et al., 1981). All others presented foods that varied in appearance, texture, and flavour.

Similarly, 24 studies manipulated variety within a single course of a meal (Appleton, 2009, 2018; Beatty, 1982; Bergamaschi et al., 2016; Best & Appleton, 2011; Carney et al., 2018; Carstairs et al., 2018; Divert et al., 2015; Domínguez et al., 2013; Guerrieri et al., 2008, 2012, 2007; Kerr et al., 2019; Levitsky et al., 2012; Meengs et al., 2012; Norton et al., 2006; Parizel et al., 2017; Pliner et al., 1980; Roe et al., 2013; Roemmich et al., 2010; Vadiveloo et al., 2019; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015; Zeinstra et al., 2010). In these studies, the number of different components and/ or sensory characteristics present within a single course was manipulated across conditions, and intake was measured. One study manipulated variety for every component in a multi-component meal, and offered three different meats (or fish), three different vegetables, and three different starch foods in the variety condition (Wijnhoven et al., 2015). Nine studies manipulated variety for a single component within a multi-component meal; four studies offered a selection of different vegetables (Carstairs et al., 2018; Meengs et al., 2012; Parizel et al., 2017; Zeinstra et al., 2010), two offered a selection of different vegetables/ sides and condiments (Divert et al., 2015; Van Wymelbeke et al., 2020), three offered additional condiments for a set main meal (Appleton, 2009, 2018; Best & Appleton, 2011), one offered three components instead of two components within a meal (Levitsky et al., 2012), and another offered a single vegetable with different seasonings (Carney et al., 2018). Four studies manipulated variety within a selection of fruits and/ or vegetables that were served alone, and without any other components in the meal (Bergamaschi et al., 2016; Domínguez et al., 2013; Roe et al., 2013; Vadiveloo et al., 2019).

All other studies manipulated variety within snack foods; savoury hors d'oeuvres (Pliner et al., 1980), sandwich fillings (Norton et al., 2006), ice cream (Beatty, 1982), coloured candies (Guerrieri et al., 2007), marshmallows (Guerrieri et al., 2008), and cookies (Guerrieri et al., 2012). This includes two studies that presented participants with an assortment of sweet and savoury snacks (Kerr et al., 2019; Roemmich et al., 2010). In three studies, foods varied in a single sensory characteristic (Beatty, 1982; Carney et al., 2018; Guerrieri et al., 2007). All others presented foods that varied in appearance, texture, and flavour.

To measure food intake, the majority of studies weighed servings and leftovers; ten studies reported weight consumed in grams (Beatty, 1982; Carney et al., 2018; Domínguez et al., 2013; Guerrieri et al., 2007; Hollis & Henry, 2007; Meiselman et al., 2000; Rolls, Rowe, et al., 1981; Wijnhoven et al., 2015; Zeinstra et al., 2010), one study reported weight consumed in ounces (Vadiveloo et al., 2019), three studies reported energy consumed in calories (Guerrieri et al., 2008, 2012; Raynor & Wing, 2006), three studies reported energy consumed in kilojoules (Mok, 2010; Rolls et al., 1982), fifteen studies reported weight and energy consumed (Appleton, 2009, 2018; Best & Appleton, 2011; Carstairs et al., 2018; Divert et al., 2015; Epstein et al., 2013; Kerr et al., 2019; Levitsky et al., 2012; Meengs et al., 2012; Norton et al., 2006; Parizel et al., 2017; Raynor & Osterholt, 2012; Roemmich et al., 2010; Stubbs et al., 2001; Van Wymelbeke et al., 2020), and one study reported intake as a percentage (Bergamaschi et al., 2016). Six studies used a piece count to measure intake; five studies reported the number of units consumed (Divert et al., 2015; Pliner et al., 1980; Roe et al., 2013; Spiegel & Stellar, 1990; Van Wymelbeke et al., 2020), and one study converted number of pieces to grams consumed using average unit weight (Rolls, Rowe, et al., 1981). In two studies, all or some foods were eaten outside of a monitored test session, and leftovers were returned to or collected by experimenters the following day (Raynor & Wing, 2006; Stubbs et al., 2001).

2.3.4. Other data analyses

In addition to reporting main effects of variety on total food intake, some studies also reported effects on single or multiple components within a meal, interaction effects with other factors that may influence food intake, and subgroup analyses (See **Table 2**). Additional variables in analyses included impulsivity (Guerrieri et al., 2007), response inhibition (Guerrieri et al., 2008), reward sensitivity (Guerrieri et al., 2008, 2012), trait reactance (Zeinstra et al., 2010), multiple eating behaviour traits (Mok, 2010; Norton et al., 2006; Rolls et al., 1982), choice (Domínguez et al., 2013; Parizel et al., 2017), priming effects (Vadiveloo et al., 2019), portion size (Carstairs et al., 2018), dishware size (Kerr et al., 2019), consumption of a preload (Norton et al., 2006), food liking (Rolls et al., 1982; Zeinstra et al., 2010), hunger (Guerrieri et al., 2012), neophobia (Zeinstra et al., 2010), and PROP (propylthiouracil) taster status (Carney et al., 2018). As these variables were included in only one or two studies and different measures were used, subgroup effects for these variables were not further investigated in the meta-analysis.

2.3.5. Risk of bias

Risk of bias was found to be low for the majority of studies when outcome reporting and control of confounding variables was assessed; 30 studies specified their exclusion criteria and justified data exclusions (Appleton, 2009, 2018; Best & Appleton, 2011; Carney et al., 2018; Carstairs et al., 2018; Divert et al., 2015; Epstein et al., 2013; Guerrieri et al., 2008, 2012; Hollis & Henry, 2007; Kerr et al., 2019; Levitsky et al., 2012; Meengs et al., 2012; Mok, 2010; Norton et al., 2006; Parizel et al., 2017; Raynor & Osterholt, 2012; Raynor & Wing, 2006; Roe et al., 2013; Roemmich et al., 2010; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Spiegel & Stellar, 1990; Stubbs et al., 2001; Vadiveloo et al., 2019; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015), 25 studies fully reported all pre-specified outcomes of interest in line with their reported data analysis plan (Appleton, 2009, 2018; Best & Appleton, 2011; Carney et al., 2018; Carstairs et al., 2018; Divert et al., 2015; Epstein et al., 2013; Hollis & Henry, 2007; Kerr et al., 2019; Meengs et al., 2012; Mok, 2010; Norton et al., 2006; Parizel et al., 2017; Raynor & Osterholt, 2012; Raynor & Wing, 2006; Roe et al., 2013; Roemmich et al., 2010; Rolls et al., 1982; Spiegel & Stellar, 1990; Stubbs et al., 2001; Vadiveloo et al., 2019; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015; Zeinstra et al., 2010), and no confounding variables were identified in 17 studies (Appleton, 2018; Carney et al., 2018; Epstein et al., 2013; Guerrieri et al., 2007, 2008, 2012; Hollis & Henry, 2007; Meengs et al., 2012; Norton et al., 2006; Parizel et al., 2017; Raynor & Osterholt, 2012; Raynor & Wing, 2006; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Wijnhoven et al., 2015).

However, for remaining criteria relating to the awareness of study outcomes and assignment to conditions, risk was found to be high or unclear for most studies. Only four studies reported the use of a random component to allocate participants to conditions or counterbalance condition order (studies were deemed to be 'high risk' if they counterbalanced condition order but reported a method that relied on alternation, or 'unclear' if no method was reported) (Guerrieri et al., 2008; Kerr et al., 2019; Roe et al., 2013; Vadiveloo et al., 2019). Two studies reported a method that adequately concealed condition allocation before and during enrolment (Kerr et al., 2019; Roe et al., 2013). Nine studies used a cover story and also assessed participant beliefs accordingly (Guerrieri et al., 2008, 2012; Kerr et al., 2019; Roemmich et al., 2010; Rolls et al., 1982; Rolls, Rowe, et al., 1981). Only one study reported that the experimenter who assessed food intake was blind to the study aims or conditions (Kerr et al., 2019). See **Figure 3** for an overview of results for each criterion.

In addition, three studies reported no procedures to control appetite before the test session (Domínguez et al., 2013; Guerrieri et al., 2008; Vadiveloo et al., 2019), ten studies reported no assessment of appetite on the test day (Beatty, 1982; Bergamaschi et al., 2016; Carstairs et al., 2018; Domínguez et al., 2013; Guerrieri et al., 2007; Levitsky et al., 2012; Meiselman et al., 2000; Roe et al., 2013; Vadiveloo et al., 2019; Zeinstra et al., 2010), and six studies reported no assessment of liking for test foods (Beatty, 1982; Guerrieri et al., 2007, 2008, 2012; Kerr et al., 2019; Levitsky et al., 2012). Sample sizes were often small, with 17 studies including < 30 participants per condition (Appleton, 2009; Beatty, 1982; Best & Appleton, 2011; Epstein et al., 2013; Hollis & Henry, 2007; Levitsky et al., 2012; Meiselman et al., 2000; Mok, 2010; Raynor & Osterholt, 2012; Raynor & Wing, 2006; Rolls et al., 1982; Rolls, Rowe, et al., 1981; Spiegel & Stellar, 1990; Stubbs et al., 2001; Wijnhoven et al., 2015). Six studies estimated their required sample size prior to data collection (Carstairs et al., 2018; Norton et al., 2006; Vadiveloo et al., 2019; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015; Zeinstra et al., 2010), but only four met their target sample (Norton et al., 2006; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015; Zeinstra et al., 2010).

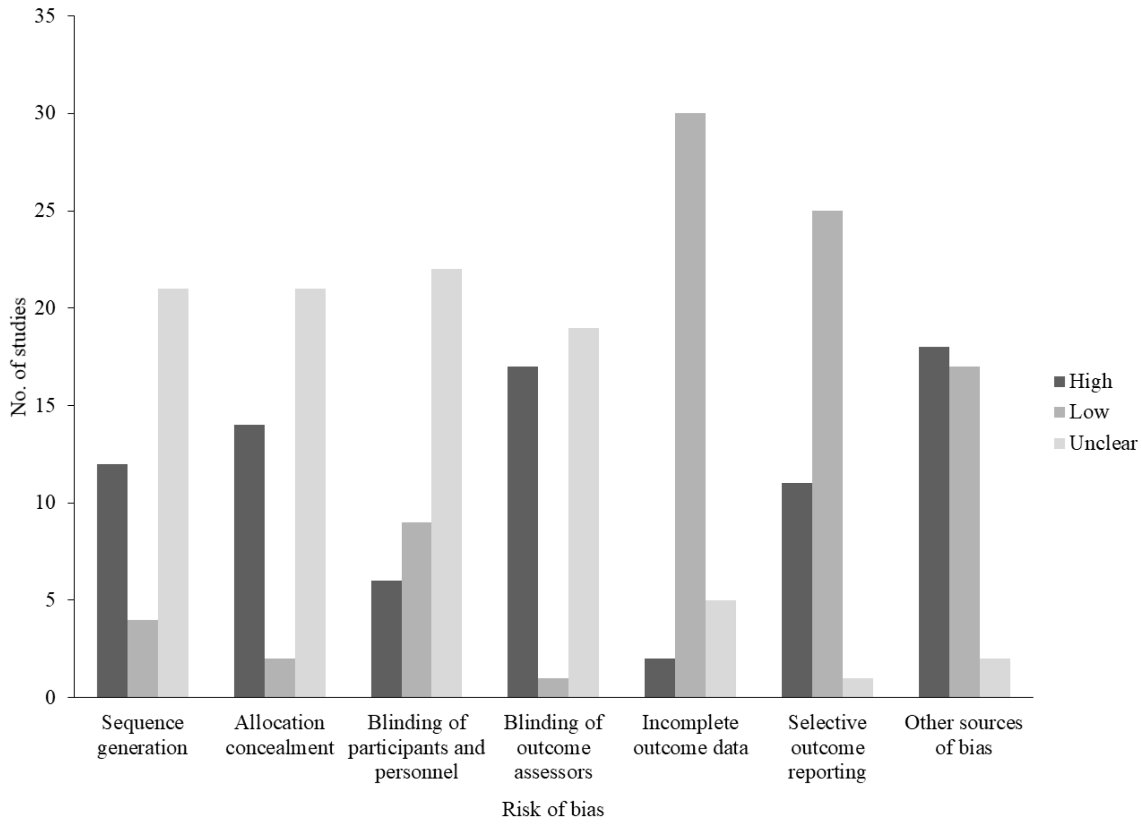


Figure 3. Risk of bias assessment for each criterion across studies (*N* = 37).

2.3.6. Overview of main results of studies

Of 37 studies included in the review, sixteen reported a significant effect where variety increased food intake (Domínguez et al., 2013; Epstein et al., 2013; Hollis & Henry, 2007; Levitsky et al., 2012; Meiselman et al., 2000; Norton et al., 2006; Pliner et al., 1980; Roe et al., 2013; Roemmich et al., 2010; Rolls, Rowe, et al., 1981; Rolls et al., 1982; Stubbs et al., 2001; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015). No significant effect was found in six studies (Carney et al., 2018; Guerrieri et al., 2007; Parizel et al., 2017; Raynor & Wing, 2006; Rolls, Rowe, et al., 1981; Zeinstra et al., 2010), and findings were mixed in fifteen studies (e.g., significance and/ or direction of effect differed depending on the unit of measurement reported for intake, individual components for which intake was assessed, or the inclusion of moderating factors in models) (Appleton, 2009, 2018; Beatty, 1982; Bergamaschi et al., 2016; Best & Appleton, 2011; Carstairs et al., 2018; Divert et al., 2015; Guerrieri et al., 2008, 2012; Kerr et al., 2019; Meengs et al., 2012; Mok, 2010; Raynor & Osterholt, 2012; Spiegel & Stellar, 1990; Vadiveloo et al., 2019).

2.3.7. Meta-analysis

Of 37 studies reviewed, data from 30 studies (consisting of 39 comparisons) were used in the meta-analysis for the main effect of variety on total meal intake. This included three studies reporting pre-post data for variety and control conditions (Epstein et al., 2013; Meiselman et al., 2000; Raynor & Wing, 2006). Data from two studies were excluded from the meta-analysis, as articles did not provide sufficient information to calculate effect size (Guerrieri et al., 2012; Pliner et al., 1980). An additional four studies were excluded as they did not report effects on total meal intake; one study reported average daily food intake but did not report intake for individual meals or meal sessions across days (Stubbs et al., 2001), and three studies reported intake for only single components within a multi-component meal (and thus, did not report effects on total meal intake) (Carstairs et al., 2018; Raynor & Osterholt, 2012; Zeinstra et al., 2010). One study was identified as an outlier and excluded from analyses; it was the only study to report separate comparisons for restrained (Hedge's g = -19.500, p < 0.001) and unrestrained eaters (Hedge's g = 28.292, p < 0.001), and effect sizes were noticeably different to all other studies included in the meta-analysis.

The meta-analysis reported a significant small-to-medium effect size of variety on total meal intake (in weight and energy) (Hedge's g = 0.405; 95% CI: 0.259, 0.552; Z = 5.413; p <

.001). Sensitivity analyses using the 'one study removed' procedure revealed no change in results, and the overall effect size remained within the confidence interval and was significant after adjusting the imputed correlation value (r = 0.2, Hedge's g = 0.398, p < .001; r = 0.9, Hedge's g = 0.402, p < .001). This strengthens evidence that the overall effect size is within the specified range, irrespective of imputed values, and favours increased intake in the presence of variety. However, there was considerable heterogeneity between comparisons (I^2 = 84%). See **Figure 4** for a forest plot.

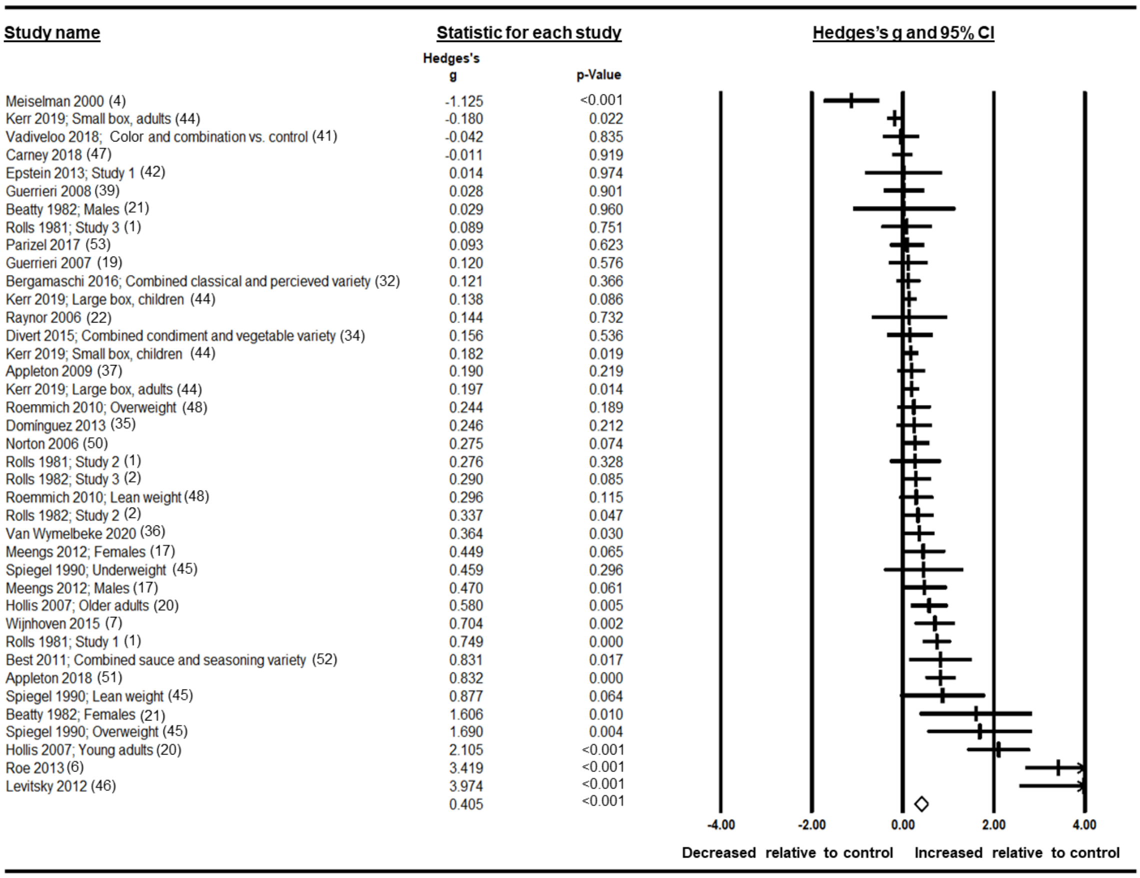


Figure 4. Forest plot displaying effect sizes for comparisons from each study included in the meta-analysis (N = 30).

2.3.8. Planned subgroup analyses

Table 3 displays effect sizes and *P*-values for planned subgroup analyses, including effects at each subgroup level. To identify sources of heterogeneity across studies and explore effects of potential moderators, differences in study manipulations and sample characteristics were assessed. There were no significant between-subgroup effects when studies were categorized by the form of variety manipulated (across meals vs. between courses vs. within a single course), the test foods used (fruits and vegetables vs. other food groups), or the number of sensory characteristics varied in the experimental condition (single vs. multiple). When investigating differences in effects for test foods, comparisons were excluded from the analysis if studies manipulated variety for both food categories (Meiselman et al., 2000; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015). Notably, when examining subgroup effects for test foods and the number of sensory characteristics manipulated, removing studies where a combination of different foods were presented within a single course (Appleton, 2009, 2018; Best & Appleton, 2011; Carney et al., 2018; Divert et al., 2015; Meengs et al., 2012; Parizel et al., 2017) did not affect results. There were also no significant between-subgroup effects when studies were categorized by participant age (children vs. adults vs. older adults), sex (male vs. female), or body weight (underweight vs. lean vs. overweight). No heterogeneity was observed within the subgroup for males or underweight, heterogeneity was low within the subgroup for lean (I^2 = 23%), moderate for studies manipulating a single sensory characteristic (I^2 = 38%), and substantial for studies manipulating variety between courses (I^2 = 73%), for older adults (I^2 = 52%) and females (I^2 = 51%). Heterogeneity within all other subgroups was considerable (I^2 > 75%).

Table 3. Effect sizes and p-values for planned subgroup analyses.

Variable	**Subgroup level (*N* comparisons)**	**Effect size [Hedges' *g* (95% CI)][1]**	***P* for total between subgroup heterogeneity [2]**	***Q***
Form of variety	Across meals (*N* = 3)	-0.363 (-1.224, 0.498)	0.062 (0.372)	5.575
	Between courses (*N* = 10)	0.651 (0.342, 0.960)***		
	Within a course (*N* = 26)	0.377 (0.215, 0.539)***		
Test foods	Fruits & vegetables (*N* = 8)	0.516 (0.069, 0.963)*	0.689 (4.134)	0.160
	Other food groups (*N* = 27)	0.419 (0.260, 0.578)***		
No. sensory components	Multiple (*N* = 32)	0.447 (0.277, 0.618)***	0.059 (0.354)	3.562
	Single (*N* = 7)	0.192 (-0.012, 0.395)		
Age	Children (*N* = 10)	0.364 (0.090, 0.639)**	0.715 (4.290)	0.672
	Adults (*N* = 22)	0.407 (0.182, 0.632)***		
	Older adults (*N* = 7)	0.501 (0.285, 0.718)***		
Sex	Male (*N* = 5)	0.291 (0.074, 0.507)**	0.101 (0.606)	2.691
	Female (*N* = 9)	0.584 (0.308, 0.860)***		
Body weight	Overweight (*N* = 2)	0.861 (-0.540, 2.263)	0.845 (5.070)	0.337
	Lean (*N* = 2)	0.424 (-0.049, 0.896)		
	Underweight (*N* = 1)	0.459 (-0.402, 1.320)		

[1] Effect size reported for each subgroup level; Asterisk indicates statistical significance for studies within each level vs. the null [*p < .05, **p < .01, ***p < .001].

[2] *P*-value reported for mixed effects analysis; Bonferroni-corrected *p* included in brackets.

2.4. Discussion

To date, this is the first systematic review and meta-analysis to formally synthesize experimental studies and quantify the size of the effect of variety on total food intake within and across meals. In line with past narrative reviews (Raynor & Epstein, 2001; Raynor & Vadiveloo, 2018; Remick et al., 2009), this work found evidence of an overall effect of variety that favoured increased meal intake. Of 37 studies included in the review, sixteen reported a significant effect where variety increased food intake (Domínguez et al., 2013; Epstein et al., 2013; Hollis & Henry, 2007; Levitsky et al., 2012; Meiselman et al., 2000; Norton et al., 2006; Pliner et al., 1980; Roe et al., 2013; Roemmich et al., 2010; Rolls, Rowe, et al., 1981; Rolls et al., 1982; Stubbs et al., 2001; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015), six reported no significant effect (Carney et al., 2018; Guerrieri et al., 2007; Parizel et al., 2017; Raynor & Wing, 2006; Rolls, Rowe, et al., 1981; Zeinstra et al., 2010), and fifteen reported mixed findings (Appleton, 2009, 2018; Beatty, 1982; Bergamaschi et al., 2016; Best & Appleton, 2011; Carstairs et al., 2018; Divert et al., 2015; Guerrieri et al., 2008, 2012; Kerr et al., 2019; Meengs et al., 2012; Mok, 2010; Raynor & Osterholt, 2012; Spiegel & Stellar, 1990; Vadiveloo et al., 2019). A meta-analysis of data from 30 studies showed that variety had a small-to-medium effect on meal intake. This overall effect appears to be robust, as sensitivity analyses showed no change in results.

As discussed in **Chapter 1**, it is generally believed that sensory-specific satiety is the mechanism by which variety influences food intake (Brondel et al., 2009; Hetherington et al., 2006; Rolls, Rolls, et al., 1981). Sensory-specific satiety has been shown to occur across age groups (Hollis & Henry, 2007; Olsen et al., 2011), though it appears to be less pronounced in older adults (Hollis & Henry, 2007; Rolls & Mcdermott, 1991). It also occurs irrespective of sex (Remick et al., 2009) and weight status (Brondel et al., 2006; Pliner et al., 1980; Snoek et al., 2004; Spiegel & Stellar, 1990), thus mirroring the effects of variety on food intake between subgroups in this meta-analysis.

It is clear that variety is a key driver of food intake across the lifespan, and may be of interest to the development of cost-effective, public health interventions to improve population wellbeing, as variety can be related to better nutrition and diet quality (Nair et al., 2016). For instance, studies included in this review that focused on children tended to explore how variety can be used to increase intake of fruits and vegetables (Bergamaschi et al., 2016; Carney et al., 2018; Carstairs et al., 2018; Domínguez et al., 2013; Roe et al., 2013; Zeinstra et al., 2010). Several studies also aimed to increase food intake in older adults in the presence of variety (Appleton, 2009, 2018; Best & Appleton, 2011; Divert et al., 2015; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015), as this age group is known to be at greater risk of undernutrition due to poor appetite (Ahmed & Haboubi, 2010; Giezenaar et al., 2016). However, results of this review suggest that interventions may be premature; only two studies exploring effects in children reported a significant increase in intake for fruits and vegetables in the presence of variety (Domínguez et al., 2013; Roe et al., 2013), whilst remaining studies reported mixed (Bergamaschi et al., 2016; Carstairs et al., 2018) or nonsignificant results (Carney et al., 2018; Zeinstra et al., 2010). For older adults, two studies reported a significant increase in food intake in the presence of variety (Van Wymelbeke et al., 2020; Wijnhoven et al., 2015), whilst remaining studies reported mixed results (Appleton, 2009, 2018; Best & Appleton, 2011; Divert et al., 2015). Further evidence is needed to identify a consistent effect of variety in these contexts.

There was considerable heterogeneity present across studies that was not explained by subgroup analyses; there were no significant differences in effect size when studies were categorized by the form of variety manipulated, the test foods used, the number of sensory characteristics varied, or key demographics of samples. However, there were clear methodological differences between studies that were identified in the review (see **Table 2**). For instance, the difference in variety between experimental and control conditions was smaller within some studies compared to others, particularly when the control condition consisted of multiple foods and sensory characteristics in and of itself. It may be that the effects of variety were undermined in such comparisons, and the question of whether there is a ceiling effect at which point further increases in variety no longer result in increased intake warrants further exploration in future research. Studies were also often designed to manipulate multiple factors in addition to variety, and different variables were controlled in models across studies. Given that studies often reported the use of small samples, it is likely that more than half of studies were at risk of being underpowered. Risk of bias was also deemed to be high or unclear for most studies when procedures for sequence generation, allocation concealment, and blinding was assessed. In order to confirm the results of this review and meta-analysis, there is a clear need to conduct well-powered, blinded, randomized-control studies that are specifically focused on variety.

Limitations of this systematic review and meta-analysis should also be acknowledged. Though efforts were made to ensure that data extraction was accurate and consistent across articles, the use of single data extraction can have a higher error rate than double data extraction (Buscemi et al., 2006). In order to synthesize studies, this work focused on the short-term main effect of variety on total meal intake at the exclusion of analyses within studies that explored additional effects of variety on food intake. For instance, it should be highlighted that some studies reported significant effects of variety on intake for individual components of a meal (Appleton, 2018; Best & Appleton, 2011; Carstairs et al., 2018; Divert et al., 2015; Levitsky et al., 2012; Van Wymelbeke et al., 2020; Wijnhoven et al., 2015), conflicting results depending on whether intake was reported in energy or weight (Appleton, 2009; Kerr et al., 2019; Meengs et al., 2012), and significant interaction or subgroup effects for variety (Appleton, 2018; Carney et al., 2018; Guerrieri et al., 2008, 2012; Hollis & Henry, 2007; Kerr et al., 2019; Meengs et al., 2012; Mok, 2010; Spiegel & Stellar, 1990; Stubbs et al., 2001; Vadiveloo et al., 2019; Van Wymelbeke et al., 2020; Zeinstra et al., 2010). It should also be acknowledged that only four studies eligible for review manipulated variety across meals, meaning effects on intake for variety when meals are repeated and eaten over a longer period remain unclear.

This systematic review and meta-analysis was also limited by the data available. Some studies were excluded from data analyses due to missing information required for inclusion in the meta-analysis. Missing data for the correlation between conditions was estimated for most studies that used a within-subjects design, and a summary effect size was computed for studies reporting multiple comparisons using the same participants to avoid issues associated with multiplicity. Sensitivity analyses suggest that these methods had a limited influence on results. However, as heterogeneity was high, publication bias could not be reliably assessed. Considering the high number of studies reporting significant results, some evidence of publication bias is likely, and findings of the meta-analysis should be interpreted with caution.

Therefore, though there was evidence to support that food intake is increased in the presence of variety, risk of bias and methods used to measure effects on food intake were a concern, particularly as subgroup analyses could not account for heterogeneity. It is recommended that further attention is given to the development of preregistered, well-powered randomised-controlled studies in eating behaviour research, and to the consideration of variety as a key driver of food intake in dietary interventions.

3. Chapter 3 – Defining 'food variety': A consumer perspective (Studies 2 and 3)

The two studies presented in this chapter have been published in the journal *BMC Public Health* (Embling et al., 2020).

3.1. Introduction

From reviewing the current literature focussed on the variety effect in **Chapter 1** and **Chapter 2**, there appears to be an overarching theoretical framework that is used to conceptualise 'variety', particularly when exploring effects as a driver of food intake. In line with this past research, variety may refer to the consumption of multiple food items in three main contexts; as part of the overall diet, in meals consumed within or across days, and in meals consumed within a single eating session (Meiselman et al., 2000; Raynor & Vadiveloo, 2018). It is also important to note that differences across food items may relate to energy or nutrient density (e.g., foods can be defined within or between food groups), in addition to sensory properties of components (Raynor & Vadiveloo, 2018).

However, despite the prominence of 'variety' and related terms in public health guidelines (Kennedy, 2004; Vadiveloo & Parekh, 2015), relatively little is known about the consumer understanding of the concept. Previous research suggests that consumers may be uncertain of specialised terms present in dietary guidelines relating to food choice, weight, and serving size recommendations, including 'variety or balance' (Brown et al., 2011). For example, in one study, individuals often mentioned phrases present in dietary guidelines when asked to discuss health campaigns (e.g., '5-a-day'), but they were uncertain about how to follow advice in their own diet (Khanom et al., 2015).

Moreover, prior research suggests that the consumer perception of variety differs to conceptualisations of variety in the literature. For example, studies have reported poor associations between the presence of components used to quantify variety within a meal – such as food groups, colours, and shapes – and participants' subjective ratings of variety (Haugaard, Brockhoff, Lähteenmäki, et al., 2016; König et al., 2018). This is despite evidence that individuals seem to have few difficulties identifying individual components of variety. For instance, in one qualitative study, US army soldiers were noted to generally interpret the word 'variety' as the number of items available for a meal category (Bell et al., 1999), and participants have been shown to correctly categorise mixed dishes into food groups (Britten et al., 2006). Individuals have even been shown to 'anticipate' the variety effect when selecting the courses of a hypothetical meal designed to constitute variety (Wilkinson et al., 2013), and refer to variety as a reason for consuming more chocolate when it consists of multiple colours (Hale & Varakin, 2016).

It is unclear why this mismatch between findings exists. Therefore, this chapter is concerned with further understanding the consumer perception of food variety, as it relates to the theoretical framework of defining variety as a driver of food intake mentioned above (i.e., including consideration of both the period of consumption and the characteristics that constitute variety). Given the novelty of this question, a mixed methods approach was used to determine 1) whether consumers in the UK were able to recognise different forms of variety, 2) how consumers explicitly defined food variety, and 3) beliefs about potential strategies to manage variety in the diet. These questions were explored using a series of focus groups in **Study 2**, and an online questionnaire in **Study 3** that would allow for a quantitative description of the occurrence of identified themes.

3.2. Study 2 – Consumer focus groups (Pilot study)

In the first study, a series of focus groups were conducted with UK consumers to pilot test the feasibility of a qualitative approach to explore the consumer understanding of variety. Using a deductive approach, a categorical framework of variety was developed in line with past studies on variety as a driver of food intake, and used to guide coding of participant responses (see below). As such, the purpose of this study was to check that use of this framework (and data collection procedure) would successfully capture similarities/ differences between the consumer understanding of variety and the conceptualisation of variety in the research literature.

3.2.1. Method

3.2.1.1. Participants

Participants (N =22) were recruited from Swansea University via email, posters, and the online staff community board. Participants were also recruited from surrounding areas via advertisements on social media. They were informed that the aim of the research was to "understand the factors that influence food choices in the supermarket". Participants were included if they lived in the UK, had self-assessed normal/ corrected-to-normal vision, and were 18 years old or older. Individuals were excluded if they had studied eating behaviour as part of a final year Undergraduate or Masters' course module (as participants are likely to be aware of literature concerning effects of food variety or related factors on food intake). They were also excluded if they had a current or historical diagnosis of eating disorders. See **Figure 5** for a participant flowchart. Participants were compensated with a £5 voucher for taking part. Written informed consent was obtained from all participants. The study was approved by the Department of Psychology Research Ethics Committee (**Appendix C**), and data collection and analysis methods were preregistered with the Open Science Framework (OSF; https://osf.io/af57e/).

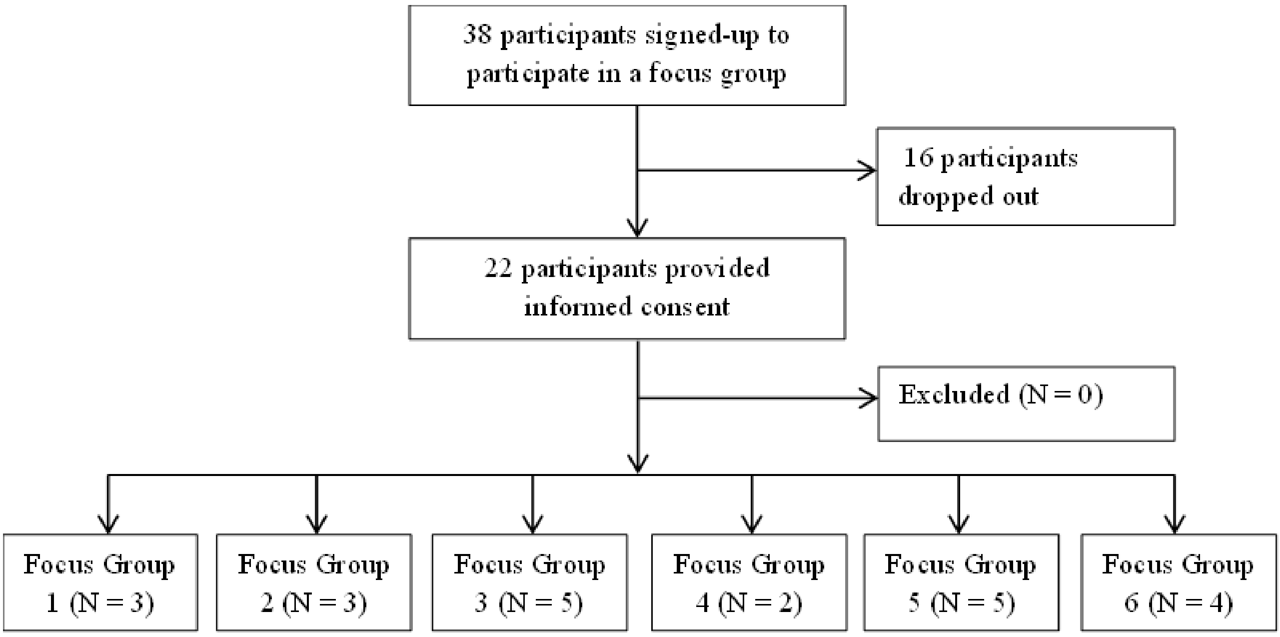


Figure 5. Flowchart of participant recruitment for focus groups.

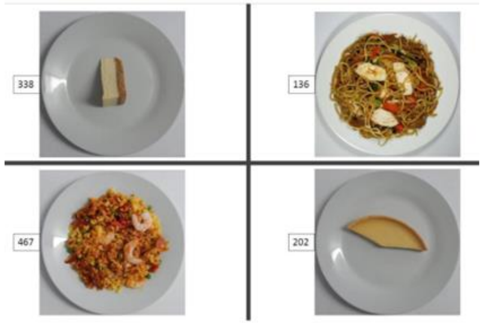
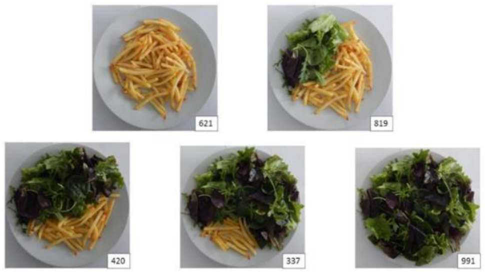
3.2.1.2. Focus group process

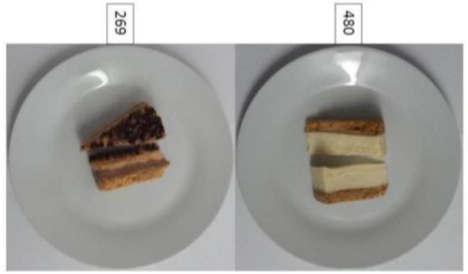
Focus groups were used to encourage open discussion about the topic among participants and increase the likelihood that perceptions and beliefs about food variety would be revealed. A series of six focus groups were conducted at Swansea University between November 2018 and February 2019. In line with Howitt (Howitt, 2013), participants were over-recruited for each session with the aim of including six participants per group. However, due to drop-outs, each group consisted of 2 – 5 participants. To ensure consistency, all focus group sessions were conducted with the same facilitator. Discussions lasted approximately 60-mins and followed a semi-structured interview guide consisting of two phases. In Phase 1, participants were not informed about the study aims (relating to variety), and were instead presented with a series of food photographs to prompt discussion of food preferences and expectations. In Phase 2, participants were informed about the study aims (relating to variety), and were directly asked to discuss their own recognition and management of variety in their diet (see below for more details).

3.2.1.3. Photographs

Participants were presented with photographs to encourage the 'spontaneous' discussion of each form of variety that was identified in the literature (see **Table 4** for details of photographs used). Where relevant, information that would allow participants to identify a specific outlet used was removed from images (e.g., supermarket logos, store signs). All foods and products shown in photographs were chosen on the basis that they would be familiar to UK consumers. Where relevant, foods were photographed on a white dinner plate against a white background from a top-down view using a high-resolution digital camera, and similar portions of foods were presented in each series of images. All photographs were edited using Microsoft Photos for Windows 10 and PhotoScape v3.7. At the end of the focus groups, participants were also shown an image of the UK government 'Eatwell Guide' (Public Health England, 2018). All photographs were approximately 210 x 297mm and printed in colour.

Table 4. Summary of topics to be explored using each series of photographs

Series [1]	Topic [2]	Photograph description	Photograph presented [3]
1	Recognition of the availability of different brands and varieties for a food item.	Supermarket aisles displaying 'crisps' and 'chocolates'	
2	Recognition of across-meal variety (when having meals in a single day), and recognition of within-meal variety (when having a first and second course)	Main meals including 'chicken chow mein' and 'paella'; desserts including 'lemon tart' and 'vanilla cheesecake'	
3	Recognition of within-meal variety (when having a combination of different foods within a single course)	Main meals with a varied proportion of the same two foods; 'whole serving of fries', 'three quarters fries, one quarter salad', 'half fries, half salad', 'three quarters salad, one quarter fries', 'whole serving of salad'	

Series [1]	**Topic** [2]	**Photograph description**	**Photograph presented** [3]
4	Recognition of within-meal variety (when having a combination of different sensory components within a single food item)	'Low variety' savoury food ('margherita pizza') and 'high variety' savoury food ('Mediterranean vegetable pizza')	
5	Recognition of within-meal variety (when having a combination of different sensory components within a single food item)	'Low variety' sweet food ('vanilla cheesecake') and 'high variety' sweet food ('chocolate, toffee & honeycomb cheesecake')	

Series [1]	**Topic** [2]	**Photograph description**	**Photograph presented** [3]
6	Recognition of variety within a single food item from an ingredient-focussed product description	Single product consisting of assorted chocolates presented with two labels [4]; 'low variety' description on packaging ('chocolates'), and 'high variety' description on packaging ('caramel chocolate buttons and milk chocolates with soft toffee, soft caramel, crisp biscuit and cereal centers')	
7	Discussion of current UK government dietary guidelines in relation to advice regarding the consumption of variety	The 'Eatwell guide' (UK dietary guidelines) [5]	

[1] Photographs were presented to participants in distinct series (i.e., participants would discuss the images in series 1 before moving on to discuss the images in series 2).

[2] Though photographs were chosen with a specific subcategory of variety in mind, it was expected that participants would naturally discuss other categories of variety that were related to the image shown.

[3] Where possible and in line with permissions, food photographs are included for each category.

[4] The same product was shown in both photographs.

[5] This was presented to participants in Phase 2 of the focus groups. N.B. Participants discussed the 'Eatwell guide' without a photograph in FG1.

3.2.1.4. Procedure

Participants were presented with an information sheet and completed a consent form. At the beginning of the discussion, participants read aloud an anonymous ID code to distinguish responses. In Phase 1 of the focus groups, participants were presented with each series of photographs in turn. They were asked to describe and compare the photographs in each series, and to justify their food preferences and expectations about their liking and the expected fullness of foods. After all food photographs had been discussed, participants were asked to directly define 'food variety'. In Phase 2 of the focus groups, participants were informed about the topic of variety by the group facilitator, specifically relating to the conceptualisation of variety in the research literature. Participants were then asked to discuss their beliefs about their own recognition and potential management of food variety in their diet. The full interview guide is available on the OSF (https://osf.io/af57e/).

After completing the focus group, participants were directed to the survey software 'Qualtrics' (https://www.qualtrics.com/). They provided demographic information including their age, gender, ethnicity, and occupation. Following Gatzemeier, Price, Wilkinson, and Lee (Gatzemeier et al., 2019), to characterise the sample, participants also completed a series of questionnaires. This included the three-factor eating questionnaire-R18 (TFEQ-R18) as a measure of general eating habits (Karlsson et al., 2000), and both the brief sensation seeking scale (BSSS; (Hoyle et al., 2002)) and the VARSEEK-scale (Van Trijp & Steenkamp, 1992) as measures of variety-seeking. Height, weight, and waist circumference were measured by the group facilitator using standardised procedures. Participants were asked to remove all outerwear and shoes before measurements were taken. Height was measured using a stadiometer and recorded to the nearest 0.5 cm, weight was measured using an electronic scale and recorded in Kg, and waist circumference was measured using a Seca ergonomic circumference measuring tape positioned midway between the lower ribs and iliac crest. At the end of the study, participants were presented with a debrief form. The study was completed in approximately 90-mins.

3.2.1.5. Qualitative coding and analysis

All discussions were audio-recorded and transcribed verbatim. In the preregistered data analysis plan for this study, it was stated that thematic analysis would be used to code the data. However, upon further reflection when developing the study protocol, one concern was that this approach alone may fail to capture whether participants' discussion of variety aligned with existing ideas about the topic from the research literature. Therefore, directed content analysis was used to code the data (Assarroudi et al., 2018). This allowed for the consideration of the consumer perspective on variety through the lens of the research literature, whilst still retaining some flexibility to code relevant data into new categories outside of this pre-existing framework where appropriate (in this case, where participant responses relevant to variety were not captured by categories of variety identified in past research).

In line with broader 'best practice' guidelines for analysing qualitative data (Braun & Clarke, 2013), transcripts were thoroughly read and all statements that were relevant to the subject matter were highlighted and given preliminary codes. Using directed content analysis, codes were then grouped according to their meanings, similarities, and differences, and sub-categorised. Broader themes were identified using an inductive approach. Though predefined categories of variety were used to identify relevant statements in Phase 2 of the focus groups (further explanation below), themes and sub-themes were created using an inductive approach in order to best represent the data. Data from Phase 1 and Phase 2 of focus groups were analysed separately to distinguish responses made when participants were aware and unaware of the aims of the study.

A formative categorisation matrix was created and agreed upon before data analysis began. Generic categories were deduced based on the different forms of food variety that were identified in the extant literature. A theoretical definition of each form of variety was developed and a set of coding rules was specified to guide the analysis and improve objectivity when coding. Following Raynor and Vadiveloo (Raynor & Vadiveloo, 2018), the focus here was on distinguishing categories of variety by period, and six distinct subcategories of variety were identified.

First, in the context of the whole diet, the availability of different varieties and brands for a single food item (Hardman et al., 2015), and the consumption of different foods across or within food groups (McCrory et al., 1999), were distinguished as subcategories of variety. Second, in the context of having variety across meals, the consumption of different foods as part of a single or multiple eating sessions, across or within days, were identified as subcategories of variety (Haws et al., 2017). For example, this could relate to having different foods for lunch (a single eating session) across multiple days of the week, or to having different foods for breakfast, lunch, and dinner (multiple eating sessions) within the same day. Finally, in the context of a single eating session, the presence of different foods across the successive courses of a meal (Rolls et al., 1982; Rolls, Rowe, et al., 1981), different food components as part of a single course (Wijnhoven et al., 2015), and a combination of different sensory characteristics within a single food item (Hale & Varakin, 2016; Rolls et al., 1982) were identified as subcategories of variety. For full definitions and coding rules for each category included in the formative categorisation matrix, see the OSF (https://osf.io/af57e/).

3.2.2. Results

3.2.2.1. Participant characteristics

Participants included 18 females and four males; for two participants, their identified gender was not assigned at birth. The majority of participants were Caucasian (*N* =20), whilst the remainder were Asian/ Asian British (*N* = 2). Participants reported being students (*N* =11), in full-time employment (*N* =5), and part-time employment (*N* =5). Employment status was unknown for one participant. Mean scores on subscales of the TFEQ-R18 were comparable to findings from previous studies in the SNAC research group laboratory at Swansea University, falling at the approximate midpoint of each subscale (Gatzemeier et al., 2019; Price et al., 2015). The mean score on the VARSEEK scale represents a medium tendency to seek a variety of foods; this was comparable to the sample mean reported by Van Trijp and Steenkamp (Van Trijp & Steenkamp, 1992), and was consistent with scores for the BSSS as a global measure of variety-seeking behaviour. See **Table 5**.

Table 5. Sample characteristics (*N* = 22)

Demographics	Range	M (SD)
Age (yrs)	18 – 64	30.7 (13.9)
BMI (kg/ m^2)	18.1 – 38.2	24.0 (4.6)
Restraint [1]	22.2 – 94.4	48.7 (17.9)
Uncontrolled eating [1]	0.0 – 70.4	44.3 (15.9)
Emotional eating [1]	11.1 – 100.0	43.9 (22.1)
BSSS [2]	13 – 40	25.9 (5.9)
VARSEEK [2]	19 – 36	29.5 (4.2)

[1] Subscale score of the TFEQ; calculated by summing coded items for the respective subscale and transforming raw scores to a 0-100 scale (((raw score − lowest possible raw score)/possible raw score range) × 100)

[2] Overall scale score; calculated by summing all coded items in the questionnaire

3.2.2.2. Phase 1 - Recognition of variety when *indirectly* discussing the topic

Predefined categories of variety were discussed by participants when they were unaware of the study aims; dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a single food. Four broader themes were also identified relating to the context in which variety was discussed using an inductive approach; participants spontaneously referenced variety in food photographs, participants justified their food choices with reference to variety, participants justified their food expectations with reference to variety, and participants defined variety in accordance with predefined categories. These themes are discussed with reference to quotes from the focus groups (labelled FG1 – 6). See **Table 6** for an example of the data coding process.

Table 6. Example of coding for themes using a categorization matrix in Phase 1.

Meaning unit	**Summarized meaning unit**	**Codes**	**Predefined category of variety**	**Theme**
"I'm just looking to see if there's sort of more variety in the brands comparing the chocolate with the crisps and... I suppose with the [popular brand name] chocolate you've got... like varieties within the same brand […] And... um, but I suppose the... sort of number of brands might be the same between the crisps and uh, and the chocolates perhaps" (FG6)	Different products available within a brand's range/Different brands available for a food item	Differences in brand availability	Brand variety	Spontaneously referring to variety
"Like I wouldn't have pasta salad for lunch and then... noodles for tea… 'Cause they would be in the same group I try to like, just have one" (FG3)	Preference for having foods from different food groups across meals	Preference for having different foods across meals	Across-meal variety	Justifying food choices with reference to variety

Meaning unit	**Summarized meaning unit**	**Codes**	**Predefined category of variety**	**Theme**
"If I had to pick one to be more filling I'd go 269 ['chocolate, toffee & honeycomb cheesecake'] just 'cause again I think you would persuade yourself that it's more filling 'cause like it's got more... um, I don't know, kinda more variety than 480 ['vanilla cheesecake]. 480 just like you'd gob down and 269 is like oh, no I'm gonna... take time to enjoy the flavours. I think you'd convince yourself maybe that [269] whatever that is like a tiny more filling but..." (FG2)	Food more filling with toppings because you take the time to enjoy the flavours	Variety in a food influences expected fullness	Variety within a food	Justifying food expectations with reference to variety
"Um... yeah, similarly like you said the main food groups like the carbs um, yeah protein's another one and... my diet's not great... so I should pay more attention to what I eat but for me variety is about balancing... it's about balance it's not about eating all carbs all the time it's about having a bit of fruit, bit of veg, bit of carbs, bit of protein so having that balance for me yeah" (FG5)	'Food variety' is having a balanced diet of foods belonging to different food groups	Defining variety across the diet	Dietary variety	Defining variety

3.2.2.2.1. Theme 1 – Spontaneously referring to variety

Independent from the discussion of food preferences and expectations, participants 'spontaneously' referred to the presence of different forms of variety when comparing food photographs. References most often related to the presence of brand variety in supermarket aisles, as participants drew attention to branding and marketing features that differed between products. For instance, participants commented on the packaging of products, relating to differences in price, colour, and portion size between brands. Differences in the organisation and availability of brands was also a common observation. Participants mentioned that there were different products available within brands, that aisles were organised according to the item brand, that popular brands were more noticeable and easily accessible on shelves, that the presentation of products on shelves differed between brands, and that a greater variety of products were available when more shelf space was dedicated to a food.

> ***FG515:*** *I'm just looking to see if there's sort of more variety in the brands comparing the chocolate with the crisps and... I suppose with the [popular brand name] chocolate you've got... like varieties within the same brand ...And... um, but I suppose the... sort of number of brands might be the same between the crisps and uh, and the chocolates perhaps (FG6)*

In contrast, relatively few references were made to other categories of variety within this context. Relating to dietary variety, some individuals highlighted that the foods displayed on shelves were 'savoury versus sweet', and categorised items into a single group (e.g., 'junk food'). Participants also briefly commented on the different ingredients and sensory characteristics that were present within foods, but only when these were emphasised on a food label.

***FG515**: You've got a lot of sort of like ingredients ...For the different components (FG6)*

***FG497:** But, whereas uh I think ooh there's caramel mixed in with that and uh… Yeah soft toffee and all the, you know the different textures of… and alternative flavours have been described there so (FG4)*

3.2.2.2.2. Theme 2 – Justifying food choices with reference to variety

Participants mentioned all six forms of variety that were identified in the literature when discussing their preferences for meals and foods; dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a food. However, the majority of participants referred to variety within meals. When choosing multiple hypothetical courses, individuals often justified their choice with reference to variety; they wanted 'a savoury followed by sweet course', they believed that having the same course twice would be "boring" or "bad etiquette", and they wanted different foods between courses.

***FG961:** So I'd probably have, normally I wouldn't eat... noodles. If I was out I wouldn't eat noodles, and I wouldn't eat fish. But I'd eat like chicken or beef or something, with* *vegetables ...That's what I'd normally go for... and then a sweet dessert so I'd probably pick... this? 'Cause it's probably more of a lemony tart thing, than cheesecake (FG3)*

Participants also wanted variety within a single course. When presented with a choice of meals, they often suggested adding different toppings or foods to a course to make it more appealing as well as more satisfying. Some participants explicitly recognised that this would add more variety to a meal and highlighted a preference for having different nutrients and sensory characteristics within a single course.

FG138: *When it's just lettuce and rocket it's the same texture, it's the same flavours, it's the same colours. Yeah, if you put some tomatoes and olives, some cucumber and celery and like red and yellow peppers, that would be good 'cause you've got a different kind of textures and you've got the flavours, and you've got the appearance (FG2)*

FG497: *Yeah, um… So- yeah, it's sort of unbalanced to just have chips. It looks very… Bland ...doesn't it... And so having the two colours together to me is more attractive (FG4)*

Participants made similar suggestions when choosing single food items. They often wanted to add different toppings or components to foods presented in photographs, reasoning that this would result in more variety and different sensory characteristics. They also believed that emphasising these characteristics on a product label would increase the appeal of a food item.

> ***FG515**: Because you've got a description there um with 955 [chocolates with 'high variety' description]... it says chocolates, but that's quite evident from the image on the packet. Whereas 103 [chocolates with 'low variety' description] it's describing caramel um inside the chocolate and soft toffee and those all you know, when you're thinking about that you can almost imagine how it's gonna taste in some way whereas if you... see chocolates you think well... what does that mean you've got, even though there's variety on the packet I think having that description... and having to read that it's more I think appealing (FG6)*

Likewise, participants wanted variety across meals; they again discussed a preference for 'savoury then sweet', they wanted different foods, and they wanted different tastes. Some participants also argued that choosing hypothetical meals was difficult because their choice often depended on the foods that they had eaten earlier in the day or on what they were planning to eat later.

> ***FG423?:** Yeah, that's what I think. If I'm planning my meals say like I'm having a smoothie for breakfast I'd have something more carb-y for like lunch... and then... it all depends that's how I kinda plan my meals see what I've had today or, yeah (FG3)*

In contrast, dietary variety was only briefly discussed, as participants commented on whether or not they had a general preference for trying new and unfamiliar foods, and discussed having preferences for specific brands.

FG633: *You just assume it's gonna be nice if you know the brand ...And if you know it's [popular brand name] ...Be like aw yeah I'll buy some [popular brand name] chocolates ...You don't think aw I'll buy the ...caramel ones, yeah (FG6)*

3.2.2.2.3. Theme 3 – Justifying food expectations with reference to variety

When justifying food expectations, participants discussed variety within foods. On the one hand, some individuals believed that having multiple components and sensory characteristics within foods would increase their feeling of fullness and satisfaction after eating. Some participants also specifically suggested that this was because a food would have greater variety.

FG423: *I don't think to eat 9, what one's that, 991 [salad leaves], that would be very satisfying would it? I think I'd feel very bland after eating it, it's not enjoyable, well maybe for some people with more things on it maybe, than leaves (FG3)*

FG138: *If I had to pick one to be more filling I'd go 269 [chocolate, toffee & honeycomb cheesecake] just 'cause again I think you would persuade yourself that it's more filling 'cause like it's got more... um, I don't know, kinda more variety than 480 [vanilla cheesecake]. 480 just like you'd [gobble] down and 269 is like oh, no I'm gonna... take [my] time to enjoy the flavours. I think you'd convince yourself maybe that [269] whatever that is like a tiny [bit] more filling (FG2)*

On the other hand, participants also suggested that they would feel less full after eating foods with a greater number of components because they would want to eat more, and they would want to eat less of foods that contained fewer components. Participants believed that emphasising variety on a food label made the food sound more filling.

> ***FG984:*** *I'm not sure. I think 'cause that is quite like plain and bland and maybe a bit dry you might get fuller quicker 'cause you're like, aww (FG1)*
>
> ***FG458:*** *Just because... you know there's like different chocolates in there which I think just kind of tricks you to believe that, there's um, that you're gonna eat more of (FG2)*

3.2.2.2.4. Theme 4 – Defining variety

When asked to directly define 'food variety', participants mentioned four of the six categories of variety that were predefined; dietary variety, brand variety, variety across courses, and variety within a single course. No specific reference was made to variety across meals or variety within a single food. In particular, it was notable that the majority of participants discussed dietary variety when defining the term. Definitions provided by participants typically related to the consumption of a range of foods belonging to different food groups as part of a balanced diet, with some participants specifically commenting on the need for foods to provide different macro- and micro-nutrients.

> ***FG905:*** *Uh I would have the macros so fat, carbs and protein, and some's got a variety in the proportions that you need. I'd say that's a variety. But also within carbs for example, you need the nutrients as well in the vitamins, and the micronutrients so, having a variety of carbs and then protein and uh... fats (FG5)*

In contrast, fewer participants referred to other forms of variety. Participants directly defined food variety as having different brands available for different foods, as having different courses in a meal (e.g., a main dish followed by a dessert), and having different foods and colours within a single course.

> ***FG732:*** *...I'd expect the chocolate aisle to be like well stocked with different brands, different varieties, different flavours, different textures (FG6)*
>
> ***FG138:*** *Um so yeah, food overall variety, but then also like... I don't know too many types of varieties so like then you've got the sweet and savoury so like what you'd have in a meal you'd have your starter, you'd have your main and dessert (FG2)*
>
> ***FG984:*** *Aw okay. Erm, I dunno first thing that came into my mind was just like... making sure you've got different colours on your plate... Like different coloured vegetables and stuff... (FG1)*

3.2.2.3. Phase 2 - Recognition of variety when *directly* discussing the topic

In phase 2 of the focus groups, participants openly discussed each of the predefined categories; dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a single food. Two broader themes relating to the context in which variety was discussed were also identified using an inductive approach; participants considered their own recognition of variety, and they expressed contrasting views when discussing strategies to manage variety. Themes are supported by quotes from the focus groups (labelled FG1 – 6). See **Table 7** for an example of the data coding process.

Table 7. Example of coding for themes using a categorization matrix in phase 2.

Meaning unit	**Summarized meaning unit**	**Codes**	**Sub-category**	**Predefined category of variety**	**Theme**
"So yeah I'd say within the meal for me so it's like the appearance for me that's the most salient. So like if I got all the colours then I know that I'm, doing good it looks good you there's a variety in the appearance of then I know I'm doing good whereas if I'm at the shop I probably just... stick with what I normally get" (FG2)	Just buy usual choices in the supermarket/different colours within a meal indicates variety	Aware of variety within a meal	Self-awareness of variety	Variety within meals	Recognising variety

Meaning unit	Summarized meaning unit	Codes	Sub-category	Predefined category of variety	Theme
"Yeah I agree with that actually. I wouldn't just have I don't know, some chicken stuffed with some cheese ...I'd like to have... like, a variety on my plate" (FG3)	Preference for different foods in a single course	Prefer to have variety	Justifying food choices with reference to variety	Variety within a single course	Recognising variety
"I think it's the effort as well isn't it, going out shopping and kind of having to find things yeah... and thinking you know, you can be quite lazy mentally and think I'll just buy this or that and sometimes it's just the easier option of... um you know not having to think about all these different things you need to buy" (FG5)	Advice requires motivation to buy a variety of foods	Accessibility/convenience of variety	Barriers to following dietary advice	Dietary variety	Discussing strategies to manage variety

3.2.2.3.1. Theme 1 – Recognising variety

Participants described their own awareness of variety across the diet and within meals. In the context of the supermarket, participants reported a greater awareness of dietary and brand variety. Participants reported that they would consider different brands and varieties available for a food item when deciding on a purchase, and that they had a greater preference for purchasing a variety of foods in the supermarket, specifically foods from different food groups.

As such, they reasoned that it is generally undemanding to distinguish foods belonging to different food groups, and to identify different foods within a food group. There were two reasons for this; the tendency for supermarket aisles to promote the categorisation of foods into dietary groups, and the inclusion of dietary variety in recommendations for healthy eating.

> ***FG348:*** *I’ll always buy a variety, like I wouldn’t... just buy like, pizzas and frozen food. And I wouldn’t, but I wouldn’t buy just like, just vegetables. Like I like myself to have just a bit of everything really. So yeah (FG1)*
>
> ***FG348:*** *Yeah, yeah. So, I think the fact that they put it into aisles in a supermarket as well. It’s like you have all your breakfast cereals and porridge and stuff in one aisle. And then... like...*
>
> > ***FG984:*** *Junk food in one aisle.*
> >
> > ***FG348:*** *Yeah.*
> >
> > ***FG984:*** *Veg in another.*
> >
> > ***FG348:*** *Yeah you have like the veg and fruit bit and then, so yeah... (FG1)*
>
> ***FG348:*** *Yeah. I think it’s, that’s just what you’re, taught I guess ...In school (FG1)*

Others reported lesser awareness of variety when purchasing foods in the supermarket. Reasons for this included a lack of choice when buying particular food items, being unaware of how variety relates to healthy eating, and having a greater preference for purchasing familiar foods rather than trying new products.

> ***FG138:*** *Yeah I feel like, being vegan especially you're kind of limited in what you can buy, um, so it's not like I'd be basically looking out for different, varieties of things 'cause yo- yeah, it's literally like... veg and cans of beans or whatever. So it's not like a, yeah huge variety (FG2)*
>
> ***FG284:*** *Yeah you don't, you still might be aware of it ...But you don't have a view on whether it's good or bad... (FG5)*
>
> ***FG138:*** *...Once I've found something I like though, often I just stick with that. So if I found that I really like, um, like one of the stir fry deals in [popular supermarket] then I'll keep going back to that one instead of like changing it up every time (FG2)*

Participants only briefly discussed an awareness of variety across-meals in relation to food preferences. Some participants preferred to make variations of recipes rather than cook the same meal, and they also noted that their children (or others in the household) may want something different after having the same dish on a weekly basis. However, others believed that convenience was the main driver of their meal choice. This meant that they often had less variety across meals due to a tendency to cook in larger quantities and store leftovers for upcoming meals.

> ***FG665:*** *Right, yeah I would. I, I'm not one of these people that eats the same thing every week. So I would change whatever I was gonna get for whatever reason if I was*

cooking something, I'll change things about it as well if I'm having some recipe then I will mix it up (FG1)

FG986: *Um well I live on my own so I'm quite... it's all about convenience for me ...It's all about... making something in the quickest way. I'll often have, if I make a big meal, I'll often have leftovers so which means I then have the same meal for a couple of days. So [variety is] not something that I actively... seek out or try to um... try to have readily in my meals (FG5)*

When discussing variety within meals, participants generally reported an awareness of variety when shopping for ingredients in addition to when cooking at home and eating. Participants described how they would plan meals as they selected ingredients in the supermarket, and how they would combine different foods and ingredients within meals when preparing foods at home. They reasoned that this was because of a preference for variety. Participants wanted to have different ingredients, colours, flavours, and textures within meals, particularly when meals would otherwise lack variety. They also reported having a greater appreciation for variety when eating out.

FG649: *...Yeah I sort of like plan meals while shopping ...Rather than ...Like when I'm home... so then it makes it easier to um, sort of plan like from the different food groups. Um, like if I'm buying like protein like a steak or chicken, I normally have um like a vegetable rice with it, or just a salad or something... so then I know, um when it comes to the meal that I'm having something from the food groups (FG3)*

> ***FG905:*** *I think though when you see something you think, aw that needs more colour ...Or that... like, ...If I'm having a chicken or something, I don't want just a chicken breast ...So, and then I think oh I'll go get some cheese because I wanted that ...That different texture, that different taste (FG5)*

> ***FG633:*** *...In a restaurant, if someone brought you food and it was really colourful then I think you'd enjoy the colours and stuff more when you were eating it whereas once you've made it [it's done] (FG6)*

In contrast, some participants believed that they were unaware of variety within a single food item, expressing that they instead viewed a food as a whole rather than the sum of its individual components. Some participants also suggested that they were unaware of variety within meals because the decision to combine foods is driven by habit.

> ***FG961:*** *Yeah, if um... so say like chilli con carne like you've got like meat, beans, peppers. I don't sit there and think... ooh yeah this is a variety I just treat it as like... one meal (FG3)*

> ***FG885:*** *Yeah I agree, you just sort of when you're when you're making all the food or whatever you think oh I want different things not just the same thing, you don't notice you're doing it that's just what you do (FG2)*

3.2.2.3.2. Theme 2 – Discussing strategies to manage variety

Participants were asked to consider strategies that increase variety when consuming 'healthy' foods, and decrease variety when consuming 'unhealthy' products, to help manage energy intake. Some participants reported already using dietary strategies focused on variety. They described how they would include a variety of healthy foods within meals, and restrict the number of different 'indulgent' food products that they would purchase.

> ***FG458:*** *...If I'm gonna eat junk food, then I, just buy like one thing. Like I'll just buy a bag of crisps I won't buy like, you know like three or four bags of crisps and a couple of different chocolates and stuff just 'cause... I know that I'll eat it all ...And like because I've got the choice as well, um I would be like... I'd go home and I'd be like I want some of that and some of that but if I've only got like one of these specific... like junk food or something then...I'm better at like... pacing myself (FG2)*

Others commented that it would be possible for them to follow dietary advice for variety. Most participants believed that strategies would help balance intake of healthy and unhealthy foods, and that following advice for variety would improve their diet without restricting what and how much they eat. Some participants also believed that following dietary strategies for variety would encourage them to purchase and consume fewer unhealthy foods, as this would reduce their enjoyment of indulgent products.

> ***FG515:*** *…Well for me, you you go for all fruit and veg and that's it, like all the healthy stuff ...Um, so by having that little treat ...Like you said cheese and that in that example, you're thinking well it is worthwhile, 'cause you are getting that balance of*

treat which is less healthy with the goodness of the nutrients from the healthy food (FG6)

FG633: *Yeah, yeah if you've got just the one boring option of the unhealthy food then you're probably less likely to have it... 'cause it just gets boring yeah (FG6)*

However, some participants believed that dietary advice for variety would not positively influence their diet. For example, they reasoned that variety would influence preference rather than health, and that strategies focused on variety may encourage greater energy intake.

FG905: *I think also, sometimes if you're introducing additional healthy foods, if you, say I've got a pizza and I go right I'm gonna have some fruit afterwards, but I wouldn't have had that fruit otherwise, you're actually increasing their overall calorie intake ...So totally including that, including the good food... can be negative (FG5)*

Most participants identified the accessibility and convenience of foods as a potential barrier to the success of following strategies focused on variety. Specifically, they recognised the following as factors that influence their ability to follow dietary guidelines; the availability of a variety of junk foods, the cost of purchasing fruits and vegetables, the limited stock of different fruits and vegetables (including frozen foods) when shopping, the convenience of purchasing pre-packaged products and fast food, the limited availability of variety when choosing healthy foods "on-the-go", and the expense of trying new foods.

FG649: *Um yeah. I think in like, in like most supermarkets there's like a more, like a complete aisle of just chocolates and then another one of biscuits. Whereas like the fruit and veg is like half, half of that. Like they need to... well I think they need to cut down like the variety in chocolate (FG3)*

FG986: *Mm I think it's the effort as well isn't it, going out shopping and kind of having to find things yeah... and thinking you know, you can be quite lazy mentally and think I'll just buy this or that and sometimes it's just the easier option of... um you know not having to think about all these different things you need to buy (FG5)*

FG905: *And you do have to have that time like you were saying earlier, have the time to... indulge in learning how to cook that ...Or try it or taste it and then have that but then if you don't like it then ...You've got to make something else anyway ...So it's about taking that risk and do you wanna pay £2 for that? Or do you wanna pay 90 pence or something for something you normally have (FG5)*

Participants also reasoned that their desire to have variety would influence their ability to follow dietary strategies. Some participants wanted to have variety when eating indulgent products, particularly when eating out. Others believed it would be difficult to increase variety for fruits and vegetables, particularly if this required trying new foods.

FG984: *I think I could [restrict variety for unhealthy foods] at home but if I'm going out for dinner, I want something nice. I'm not gonna say I'm only having bland stuff. I'm paying to go out (FG1)*

> ***FG284:*** *And you can get a huge variety of, fruit for example so like but a lot of it I don't- sometimes I tend to pick up, I've never had that so I'll try that, but nine times out of ten I don't like it (FG5)*

Participants also believed that current dietary guidelines are too vague, that it can be difficult to distinguish the healthiness of foods within food groups, and that it can be difficult to plan and prepare meals that meet current recommendations for a varied diet. When prompted to consider how to educate consumers about variety, participants believed that it was important to inform consumers about the rationale supporting dietary advice, and of specific strategies that would encourage individuals to eat a variety of foods. Suggestions included promoting a balanced diet, the benefits of having a colourful plate, strategies to improve healthy eating habits at home, and a focus on increasing variety rather than quantity of healthy foods in the overall diet.

> ***FG348:*** *...People need to think of like the reasoning behind it rather than just being told that you need to eat healthier like (FG1)*
>
> ***FG138****: Um yeah I'd go with the colours one 'cause I think most unhealthy food is literally just like... you know it's brown and [inaudible word] whatever you said, um, yeah go with the colours thing to help people like, you've got a colourful plate then it's probably... gonna be good (FG2)*

3.2.3. Interim Discussion

Firstly, the primary aim of **Study 2** was to pilot test the feasibility of the qualitative approach described, exploring the consumer understanding of food variety as it relates to the conceptualisation of food variety in previous studies. When participants were presented with photographs of different forms of variety, the discussion of the topic was consistent with categories recognised in the research literature; dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a single food. The framework used to code responses appeared to be sensitive to differences in consumer recognition of variety across contexts, and also allowed for the identification of both similarities and differences between the consumer understanding of variety in this sample and the identified conceptualisation of variety. The stimuli and questions used to prompt responding (without directly informing participants of the research aim) allowed participants to discuss themes relevant to the research topic, and statements referring to variety were captured by predefined categories, with no additional categories identified.

Despite the depth of information provided by participants in this study, it is important to highlight that there are limitations to the qualitative data discussed so far. In particular, one concern was that a focus group setting could encourage a 'collective voice' to emerge, whereby individuals construct a group consensus rather than express their individual views (Smithson, 2000). Though this can be useful for encouraging themes to emerge discursively throughout focus groups, the increased likelihood of a group consensus also means that the data cannot be interpreted in terms of the proportion of individuals who recognised different forms of variety. Therefore, in the second study, a qualitative questionnaire was used to help identify the frequency with which each category of variety was recognised.

A second concern was the representativeness of the sample used in **Study 2**. Participant drop-outs affected the final sample size, and it was notable that most participants were female, from a similar sociodemographic background, and recruited from the local area. This means that differences in the recognition of variety across contexts (specifically relating to the 'frequency' of discussion) could represent a failure to reach data saturation. To address this in **Study 3**, a significantly larger sample was recruited via an online questionnaire to increase heterogeneity.

3.3. Study 3 – Online questionnaire

3.3.1. Method

3.3.1.1. Participants

Participants (N = 240) were recruited online via Swansea University's participant subject pool, social media, survey sharing platforms such as 'Survey Circle'(https://www.surveycircle.com/en/), and the online participant recruitment platform 'Prolific' (https://www.prolific.co/). Following guidelines by Tran, Porcher, Falissard, and Ravaud (Tran et al., 2016), it was estimated that 150 responses to the online survey were required to reach data saturation, and data collection was stopped when 357 responses had been recorded to account for unusable data (e.g., where participants did not complete open-ended questions about variety, and where duplicate responses were identified for the same participant). Information provided to participants about the aim of the study and all inclusion/

exclusion criteria were the same as **Study 2**, with the addition that participants were also excluded from taking part if they had completed one of the focus groups (see **Figure 6** for a participant flowchart). Participants were compensated for their time with a payment of £2.50 via Prolific (in line with their guidelines on ethical payment of participants), course credit on the local subject pool, or in exchange for 'reward points' specified by the platform's survey ranking system on 'SurveyCircle'. No other compensation was given. Informed consent was obtained from all participants via an online form. The study was approved by the Department of Psychology Research Ethics Committee (**Appendix E**), and data collection and analysis methods were preregistered on the OSF (https://osf.io/5etd4/).

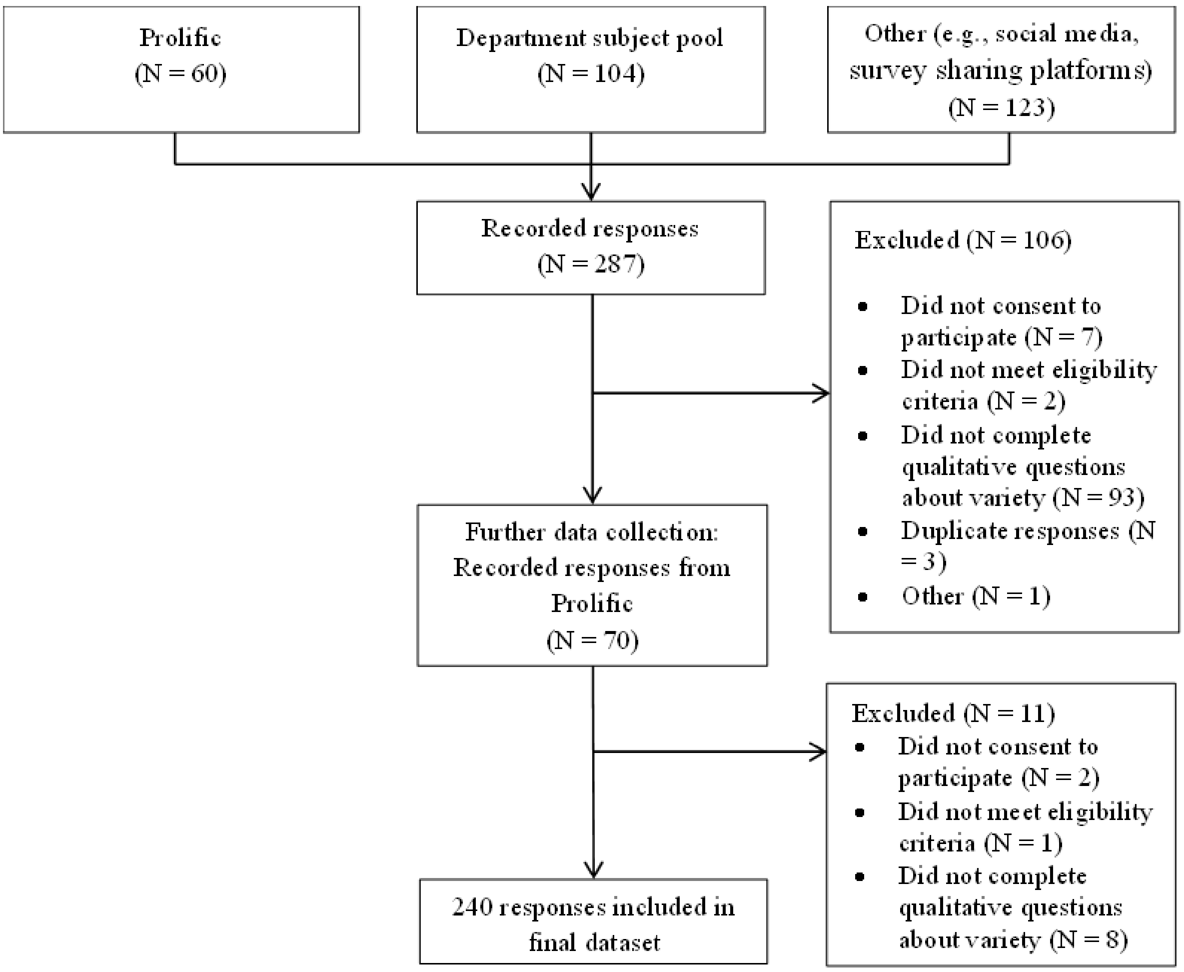


Figure 6. Flowchart of participant recruitment for online qualitative study.

3.3.1.2. Photographs

All photographs were the same as those used in **Study 2**, with the exception of the 'Eatwell Guide' (Public Health England, 2018) which was not shown to participants. For an outline of the survey and photographs presented, see the OSF (https://osf.io/89u7n).

3.3.1.3. Procedure

The procedure from **Study 2** was adapted to be suitable for an online study, with the following changes. Participants were directed to complete the study on Qualtrics. Participants did not complete any of the questions presented to participants in Phase 2 of the focus groups in order to limit the duration of the survey. Height and weight were self-reported using drop-down lists. At the end of the study, participants were also asked to "please tell us what you think the aim of this experiment to be" and provided answers in an open-text field to evaluate potential demand awareness. The survey was completed in approximately 30-mins.

3.3.1.4. Data analyses

All data were analysed using the directed content analysis approach described in **Study 2**. The number of participants that recognised each form of variety within broader themes was also recorded to allow for a quantitative description of the occurrence of themes. To enhance trustworthiness, an independent researcher coded a random sample of statements using the formative categorisation matrix developed in **Study 2** (they assigned predefined categories of variety to approximately 10% of all statements recorded). Following McAlister et al. (McAlister et al., 2017), inter-rater reliability was calculated as the number of agreed codes divided by the total number of codes assigned to statements and converted to a percentage. Disagreements based on interpretations of predefined categories were discussed at intervals and coders reassessed statements independently. Agreement was found in 81% of cases. Where changes to the codebook had been decided as a result of discussions, coding for all data was adjusted where necessary, for both qualitative and quantitative analyses.

3.3.2. Results

3.3.2.1. Participant characteristics

Participants included 138 females and 100 males; for one participant, their identified gender was not assigned at birth. Gender was unknown for two participants. The majority of participants were Caucasian (*N* = 214), whilst the remainder were Asian/Asian British (*N* = 17), Black/African/Caribbean/Black British (*N* = 3), Mixed Race (*N* = 2), or other (*N* = 2). Ethnicity was unknown for two participants. Participants reported being students (*N* = 118), in employment (*N* = 103), retired (*N* = 4), or not otherwise in employment (*N* = 8). Employment status was unknown for seven participants. Scores on subscales of the TFEQ-r18, VARSEEK, and BSSS were comparable to those reported in **Study 2**. Most participants seemed to be unaware of the study aims; when reporting their beliefs about the aim of the study, five participants made a general reference to food variety, and one participant referred to an interest in defining variety. See **Table 8**.

Table 8. Sample characteristics (N = 240)

Demographics	**Range**	**M (SD)**
Age (years)	18 – 82	28.5 (12.2)
BMI (kg/m^2)	16.3 – 40.7	24.4 (4.8)
Restraint [1]	0.0 – 88.9	39.8 (20.4)
Uncontrolled eating [1]	3.7 – 100.0	45.9 (18.8)
Emotional eating [1]	0.0 – 100.0	44.4 (26.9)
BSSS [2]	8 - 40	24.0 (6.1)
VARSEEK [2]	8 - 40	27.0 (6.1)

[1] Subscale score of the TFEQ; calculated by summing coded items for the respective subscale and transforming raw scores to a 0-100 scale (((raw score − lowest possible raw score)/possible raw score range) × 100)

[2] Overall scale score; calculated by summing all coded items in the questionnaire

3.3.2.2. Overview of results

Consistent with findings in **Study 2**, directed content analysis showed that participants referred to six predefined categories of variety identified in the literature when presented with food photographs; dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a single food. Responses were also consistent with the broader themes that were previously identified using an inductive approach, identifying the context in which variety was recognised; participants spontaneously referenced variety in food photographs, participants justified their food choices with reference to variety, participants justified their food expectations with reference to variety, and participants defined variety in accordance with our predefined categories. Consistent with the SRQR (Standards for Reporting Qualitative Research) guidelines (O'Brien et al., 2014), these themes are discussed with reference to quotes from participants (participant IDs are given in brackets), and frequencies of themes. For an example of the data coding process, see **Table 6**.

3.3.2.3. Theme 1 – Spontaneously referring to variety

Almost all participants (90%) referred to the presence of different ingredients and sensory characteristics within foods – such as different toppings, layers, flavours, colours, and textures – and emphasising these features on a product label seemingly increased the appeal of a product. References also often related to the presence of brand variety in supermarket aisles, as 68% of participants drew attention to branding and marketing features that differed between products. For instance, participants highlighted the different products and varieties of a product (relating to flavour) available within brands, and commented on differences in the organisation and packaging of products between brands relating to price, colour, shape, and portion size.

P72: *Image 435 [Mediterranean vegetable pizza] is more colourful and appetising to look at. There's variety and flavour on that pizza, in comparison to image 127[Margherita pizza] that just appears bland and unappetising.*

P58: *First of all two pictures are sweet snacks, chocolates. They have all the good brands together and stock different flavours of the same brands just as the savoury, crisps shelves. However, on photo 081[crisps aisle 2] compared to 295 [crisps aisle 1], there is not much colour for the crisps and more colour can be seen in the chocolate shelves.*

In contrast, relatively few references were made to other categories of variety. Relating to dietary variety, 16% of individuals referred to broader differences between food items (e.g., 'savoury versus sweet' or 'crunchy versus chewy'), the nutritional value of foods (e.g., high in sugar, salt, and fat), or generally categorised items into a single group (e.g., 'junk food'). Relating to variety within a single eating session, 8% of participants commented on the number of different colours, textures, foods, nutrients, and ingredients included within a single course, whilst just 0.5% of participants mentioned variety across multiple courses.

P115: *All items come out of the ground, vary in colour and texture, depending on how the chips are cooked picture 621 [fries only] may not be as healthy to eat as 991 [salad only].*

P183: *819 [three quarters fries to one quarter salad], 420 [half fries and half salad] and 337 [three quarters salad to one quarter fries] are healthier but they also only give an impression of healthiness because they are not nutritionally balanced. [...] Something else would need to be added to make the meal satisfying (i.e., you won't feel* *hungry again very shortly afterwards) and also more nutritionally sound. It is also not very appealing to the eye as it is all the one colour, and therefore does not particularly whet the appetite.*

3.3.2.4. Theme 2 – Justifying food choices with reference to variety

When asked to justify their preferences for meals and foods displayed in images, the majority of participants referred to variety within meals. When choosing multiple courses, 54% of participants justified their choice with reference to variety; they often wanted and expected to have 'a savoury followed by sweet course', a main and dessert course, different flavours across courses, or simply different foods between courses. 74% of participants also preferred variety within a single course. In relation to variety within foods, 78% referred to variety when justifying their preference for one food or another; whilst some participants preferred a combination of different sensory characteristics and components within a food, others preferred to eat 'plain' or 'simple' foods that consisted of fewer flavours, textures, and ingredients.

P128: *After eating savoury food, it is nice to change to something sweet i.e., a dessert.*

P165: *819 [three quarters fries to one quarter salad] - because it contains 2 different things, so that [there] is different textures and tastes, I would find this more appealing [than] a plate that just had either chips, or just salad*

P169: *I would prefer the food in the image 435 [Mediterranean vegetable pizza] because I like it when a food has a variety of different ingredients.*

In terms of having variety across multiple eating sessions, 36% of participants referred to variety across meals, whilst 2% referred to dietary variety. For example, participants wanted different sensory characteristics and preferred different foods across meals, though some participants referred to wanting 'similar' foods (e.g., two main course/ savoury dishes, or two sweet dishes). Some participants also justified their meal choices in relation to their current dietary needs and preferences.

> ***P100:*** *338 [vanilla cheesecake] and 202 [lemon tart] look boring, not many colours that make it look appetising, also I wouldn't want to eat the same meal twice in one day.*
>
> ***P42:*** *621 [fries only] because I like carbs but vegetables are something which I usually have to try and add in to my diet*

3.3.2.5. Theme 3 – Justifying food expectations with reference to variety

When justifying food expectations, 88% of participants mentioned variety within foods. On the one hand, individuals believed that having multiple components and sensory characteristics within foods would increase their feeling of fullness and satisfaction after eating, and that emphasising variety on a food label made the food sound more filling because it highlights different ingredients, flavours and textures. Reasons included the beliefs that foods would have added nutrients, foods would have greater variety, and it would feel like they were eating more food. On the other hand, participants also suggested that they would feel fuller after eating foods with fewer components, as the food was 'plain' and had less variety. Similar reasons were given by 23% of participants when justifying expectations for a single course.

> ***P10:*** *435 [Mediterranean vegetable pizza], because it has more flavours that way seemingly making it feel more filling, and also it most likely still has the same amount of cheese as 127 [Margherita pizza], but additionally also has toppings.*
>
> ***P73:*** *435 [Mediterranean vegetable pizza] does seem to contain more nutrients and taste. It may leave you wanting more, but overall presumably more filling.*
>
> ***P31:*** *Ironically, despite having less ingredients on the pizza, I'd expect 127 [Margherita pizza] to be more filling because it is just dough, cheese and tomato instead of a balance and mixture of many.*

3.3.2.6. Theme 4 – Defining variety

When asked to directly define 'food variety', participants mentioned all six categories of variety that were predefined; dietary variety, brand variety, variety across meals, variety between courses, variety within a single course, and variety within a single food. However, it was notable that 88% of participants defined food variety with reference to dietary variety, including 6% who referred to brand variety (relating to the context of the whole diet), though definitions typically related to the consumption of a range of foods belonging to different food groups as part of a balanced diet.

P148: *Having a wide variety of options ranging from different brands.*

P79: *A good balance of food, from fruits and vegetables of a variety of colours, to grains and carbs, dairy, meat and protein and some sugary/ high fat foods, similar to the food plate the government health guidelines used to promote.*

In contrast, relatively few participants referred to other forms of variety; 5% mentioned across-meal variety, 1% variety across multiple courses, 2% variety within a single course, 1% variety within a single food item, and 4% referred to within-meal variety with no specification regarding a sub-category. Examples of definitions relating to each form of variety are included below:

P131: *Having four or more different meals a week.*

P157: *Food variety is, when I can choose from different mains, [different] appetisers and different [desserts], not only between [desserts] and mains for example.*

P58: *I would define food variety as having lots of different food groups in a meal and lots of different flavours, smells, and textures.*

P165: *Food variety to me, means containing different ingredients, so a veggie pizza to me has a lot more variety than a cheese pizza because it has more than one item on it.*

3.4. Discussion

Across both studies, participants consistently discussed predefined categories of variety that were identified in the literature; dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a single food. They also recognised each form of variety within the same contexts; when spontaneously referring to variety in food photographs, when justifying food choices, when justifying food expectations, and when directly defining variety. The proportion of individuals recognising different forms of variety in **Study 3** also aligned with qualitative results from **Study 2**; despite referring to different forms of variety in the presence of food photographs, the majority of participants provided definitions of variety that related only to dietary variety.

Results from both **Study 2** and **Study 3** build on the findings of Hale and Varakin (Hale & Varakin, 2016), who found that snack preference was not only influenced by the presence of colour variety within a food, but that participants justified their preference with reference to variety. The research presented in this chapter demonstrates that individuals may also consider variety when choosing meals and foods that consist of multiple components, and when they vary in more than one sensory characteristic. This supports variety as a factor that consumers actively consider when choosing foods. Previous research has shown that consumed portions are planned from the outset in 92% of cases (Fay et al., 2011), and variety is one factor that can increase selected portion size *before* eating (Wilkinson et al., 2013). This research then suggests that consumers may be aware of the influence of variety on consumption when meal planning.

These results also indicate that there was a significant difference in participants' recognition of variety in the presence of food photographs compared to when asked to directly define the concept. This is consistent with prior research demonstrating that consumer ratings of variety within meals do not reflect the presence of components that are used to operationalise variety in experimental studies (Haugaard, Brockhoff, & Lähteenmäki, 2016; König & Renner, 2017). One explanation for this is that the appreciation of variety is a stimulus-driven response that requires little cognitive effort on behalf of the consumer. Wilkinson et al. (Wilkinson et al., 2013) previously demonstrated that participants expected a course to be more pleasant and selected a larger portion size if it was sensorially different to the previous course, and these decisions were made in approximately 15s. This suggests that the appreciation of variety is a habitual response, and that asking participants to 'abstractly' define variety outside of the context of making food choices may be a difficult task.

An alternative explanation is that dietary guidelines oversimplify the presence of variety in the eating environment, and this was reflected in participants' definitions of the term. Variety within food groups is often highlighted in the most recent dietary recommendations (Vadiveloo & Parekh, 2015), and this is consistent with the finding that consumers are able to accurately categorise meals and foods into food groups (Britten et al., 2006), and generally refer to variety as the 'number' of items available (Bell et al., 1999). However, little attention is given to the presence of variety within- and across-meals, the food components that constitute variety (i.e., sensory characteristics), nor the potential role of variety in encouraging greater food intake (as demonstrated in **Study 1**). A recent scientific advisory article from the American Heart Association has identified the poor level of correspondence between the research literature and dietary advice as an issue that may undermine public health efforts to promote healthy eating patterns (de Oliveira Otto et al., 2018). This research further emphasises the need for dietary guidelines to discern the nature of variety to consumers in line with the research literature.

Using a mixed-methods approach, the current research has explored the consumer understanding of the topic of food variety in greater depth for the first time. However, there are potential limitations to consider. First, it should be noted that using a directed approach to data analysis can increase the risk of bias when coding data, and the likelihood that results will be supportive of a given construct (Hovbrandt et al., 2019). It was necessary to predefine categories of variety before data collection in order to select appropriate photographs to use in this research, and probe questions were also used to facilitate the focus group discussions in **Study 2**. However, measures were taken to improve the trustworthiness of data analyses. Results from **Study 2** were replicated in **Study 3**, and an independent researcher coded a subset of the responses from **Study 3** to confirm themes.

Second, the use of food photographs may be considered a prime or demand characteristic that would make it obvious to participants that the subject of interest was actually food variety, particularly as participants were asked to compare images that displayed either 'high' or 'low' variety meals and foods. In particular, the majority of questions and photographs presented to participants were most relevant to the discussion of variety within meals, and this may have increased the frequency of discussion of within-meal variety in the presence of food photographs. Priming effects appear to be unlikely here, as participants often discussed factors unrelated to variety in both studies when justifying food preferences (e.g., general food liking, their familiarity with foods). Participant feedback in **Study 3** also supports that the majority of participants were unaware of the study aims, and it remains notable that significantly fewer participants defined variety with reference to within-meal variety.

Third, the use of food photographs also means that the perception of variety was considered in response to hypothetical food choices rather than actual consumption. This is important to consider as the awareness of sensory characteristics unrelated to visual appearance – such as texture and smell - may have been reduced by using this approach. It should be highlighted that results of this research were consistent with Hale and Varakin (Hale & Varakin, 2016), who measured participants' awareness of variety after they had consumed foods in the laboratory. Nevertheless, it would be useful for future research to explore the perception of different forms of variety, and the experience of multiple sensory characteristics, in response to eaten foods that better reflect consumption in the real world.

Despite these limitations, this research demonstrates that consumers actively consider variety within meals, across meals, and in the context of the whole diet. Results also highlight education as a potential tool to improve the consumer understanding of the concept of variety, bridging the gap between the conceptualisation of variety in the literature and the presence of different forms of variety in the eating environment to help consumers follow dietary advice and manage their own food consumption.

4. Chapter 4 – Developing an online measure of portion size selection (Studies 4 and 5)

Discussion of the online portion size selection tool presented in this chapter (in relation to **Study 4**), has been published in the journal *BMC Public Health* (Embling, Lee, et al., 2021).

4.1. Introduction

In line with the overarching aims of this thesis, a laboratory study was initially planned to explore the influence of variety within single food items on *ad libitum* food intake. This involved manipulating the sensory characteristics of an isocaloric jelly-based dessert to produce a 'high variety' food (consisting of a combination of different flavours and colours) and a 'low variety' food (consisting of a single flavour and colour). Consistent with the variety effect when presenting different food components within and across meals, it was then predicted that food intake would be greater in the presence of a 'high variety' versus 'low variety' dessert (for the preregistration of this study, see the OSF; https://osf.io/g72j3). Due to the COVID-19 pandemic and ongoing suspension of face-to-face testing, this study approach (including the manipulation of test foods in the laboratory and ad libitum food intake as an outcome measure) was no longer feasible. Therefore, to inform the development of a study testing the variety effect in an online setting (see **Chapter 5** for the updated study design), the aim of this chapter was to pilot test the validity of an online tool to assess participants' ideal portion size as an alternative measure of food intake.

As discussed in **Chapter 1**, consumer decisions around portion size are likely to occur *before* eating when planning meals (Brunstrom, 2014). 'Ideal portion size' – an individual's preferred portion of a food that is selected prior to a meal – has been identified as a strong predictor of actual food intake (Wilkinson et al., 2012), and supported as a 'proxy' measure of food intake.

However, computer-based tasks that are used to measure ideal portion size typically cannot be integrated into a web-based survey. One recent study found some evidence of agreement between a standard computer-based assessment of portion size and a 'simplified' portion selection task that could be used online (with 5 – 7 portion size images loaded into a horizontal slider and vertical Likert scale), but such tasks may be limited in terms of the variability in portion size that can be displayed to participants (Pink & Cheon, 2021). For instance, in a previous online study, participants were asked to scroll through a large selection of portion size photographs as part of a Likert-scale type measure, but functionality and the 'animated' presentation of portion sizes from a computer-based task appeared to be lost, predominantly due to a need to present smaller-scale images simultaneously rather than consecutively onscreen (Embling et al., 2019). Another recent study used a screen-share service to allow some participants to complete a computer-based task to measure ideal portion size from home (McLeod et al., 2020), but this method is not ideal when recruiting larger samples given that individuals will need access to (and be willing and able to use) specific video conferencing software on a one-to-one basis with a researcher.

Therefore, **Studies 4 and 5** had two main objectives. First, to test *convergent* validity of a novel online portion size selection task, these studies aimed to replicate well-established relationships between ideal portion size and related drivers of food intake that have been identified in past studies using a laboratory-based computer task measure of portion size selection. Second, to test *divergent* validity, this study aimed to replicate a lack of relationship between ideal portion size and relevant demographic factors that have been identified in past studies.

4.1.1. Convergent validity hypothesis

Using computer-based measures of selected portion size in the laboratory, past studies have shown that ideal portion size is consistently and significantly associated with expected satiety (Brunstrom & Shakeshaft, 2009; McLeod et al., 2020; Wilkinson et al., 2012), as well as expected satiation (Brunstrom, Collingwood, et al., 2010; Brunstrom & Rogers, 2009; Labbe et al., 2017) (See **Chapter 1**). Therefore, it was hypothesised that ideal portion size (using this online portion size selection task) would be significantly correlated with expected satiety and expected satiation.

4.1.2. Divergent validity hypothesis

Using computer-based measures of selected portion size in the laboratory, past studies have reported no significant association between ideal portion size and age in years (Embling et al., 2019; Labbe et al., 2017). This may be due to studies focussing on a relatively young and healthy adult population. For instance, these studies report a mean age of < 40 yrs old (Embling et al., 2019; Labbe et al., 2017), and research has shown that older adults (typically ≥ 50 yrs old) tend to consume smaller meals (Nieuwenhuizen et al., 2010).

In addition, no associations have been found between ideal portion size and BMI (Brunstrom, Rogers, et al., 2008; Embling et al., 2019; Labbe et al., 2017; Wilkinson et al., 2012). In this case, it is important to note that whilst larger portions have been identified as a driver of food intake (Zlatevska et al., 2014), and have been linked to overweight and obesity due to corresponding upwards trends overtime (Kral & Rolls, 2011; M. B. E. Livingstone & Pourshahidi, 2014; Rolls, 2003), ideal portion size measures are concerned with a single eating session which in and of itself may not be expected to predict BMI. This is because change in body weight occurs over a longer period of persistent positive/ negative energy balance relating to energy intake and expenditure (Colditz et al., 1990), and notably, portion size has similar effects on consumption irrespective of BMI in both adults and children in the context of a single meal (Diliberti et al., 2004; Fisher et al., 2003; Rolls et al., 2002; Spill et al., 2010). There is also some evidence to suggest that fat-free mass, rather than BMI, is positively associated with *ad libitum* food intake (Blundell et al., 2012, 2015). This means that, from a theoretical perspective, measures of ideal portion size may not be expected to relate to age or BMI. Therefore, it was hypothesised that ideal portion size would not be significantly correlated with age or BMI.

4.2. Study 4 – Methodology and initial pilot test

4.2.1. Method

4.2.1.1. Study design and procedure

Using a cross-sectional design, this online study examined associations between ideal portion size and four relevant measures (expected satiety, expected satiation, BMI, and age). Participants were directed to the study via an anonymous link to the survey software ‘Qualtrics’ (Qualtrics, Provo, UT). Judgements of foods (including ideal portion size, expected satiety, and expected satiation) were collected in response to photographs of six test foods, in three task blocks. In the first task block, participants provided ratings of liking, desire to eat, expected satiation, and familiarity for each food in turn by responding to a static photograph of a 500-kcal portion of the given food. In the second and third task blocks, participants completed ideal portion size and expected satiety tasks respectively for each food, using the novel online portion size selection tool (see below for more details). Presentation order of foods within each task block was randomised using the in-built randomiser function, and questionnaire measures were presented to participants within the survey in Qualtrics. The study was completed in approximately 20-mins. Study design, methods, data analysis procedures, and hypotheses were preregistered on the OSF before data collection had begun (https://osf.io/yq9fk/).

4.2.1.2. Participants and recruitment

Participants were recruited using the participant recruitment platform ‘Prolific’ (https://www.prolific.co/). Eligibility criteria were specified before data collection began; participants were included if they had normal or corrected-to-normal vision, and if they were 18 – 55 years old (in line with procedures reported in (Labbe et al., 2017)). Participants were excluded if they had dietary restrictions (i.e., a vegetarian or vegan diet, food allergies or intolerances), to ensure that realistic judgments could be given in response to test foods. Participants were also excluded if they were currently on a diet, or if they self-identified as having a current or historical diagnosis of eating disorders. Informed consent was obtained from all participants via an online form at the beginning of the survey. Before completing the consent form, participants were presented with an online information sheet and informed that the aim of the research was to "collect consumer beliefs about different food products". Participants were compensated for their time with a payment of £3.13 on Prolific in accordance with platform guidelines on fair pay. The study was approved by the Department of Psychology Research Ethics Committee at Swansea University (**Appendix F**).

4.2.1.3. Measures

4.2.1.3.1. Online portion size tool

4.2.1.3.1.1. Test foods

Photographs of seven test foods were presented to participants, including one food (cream and jam doughnut) that was only presented as part of a demonstration of the tool and as such was not included in data analyses (see **Table 9** for macronutrient information). All test foods were selected on the basis that they would likely be familiar to participants, and were photographed from a top-down view against a plain background using a high-resolution digital camera and tripod with lateral arm. Chicken chow mein and crisps were photographed on a white dinner plate (271-mm diameter), and granola was photographed in a shallow white bowl (204-mm diameter, 36-mm depth). All other foods were photographed on a smaller white dessert plate (230-mm diameter). In line with many of the previous research studies using ideal portion size tasks (Brunstrom, Collingwood, et al., 2010; Brunstrom & Rogers, 2009;

Brunstrom & Shakeshaft, 2009; Embling et al., 2019), each food was photographed 50 times, with each successive photograph displaying a portion that incrementally increased in size by ≈ 20 kcal. This meant that the smallest portion shown for each food was ≈ 20 kcal, and the largest ≈ 1000 kcal. Photographs were edited using Microsoft Photos for Windows 10 and PhotoScape v3.7. When uploaded to the online survey, digital dimensions for all images were 460 x 345 pixels. Food photographs used are available on the OSF (https://osf.io/yq9fk/).

Table 9. Test foods used for photographs in ideal portion size tool.

	Kcal/ 100 g	**Fat/ 100 g**	**Sugars/ 100 g**	**Salt/ 100 g**
Granola	433.5	13.3	20.5	0.0
Chicken chow mein [1]	96.0	2.5	2.4	0.6
Salted Crisps (potato chips)	476.0	21.0	1.6	1.8
Madeira sponge cake	382.0	14.6	33.0	0.6
Chocolate buttons	535.0	30.0	56.0	0.2
Skittles (fruit-flavoured candy)	404.0	4.2	89.9	0.0
Cream & jam doughnut [2]	317.4	14.4	13.2	0.4

[1] This food was 'low' energy density [< 2.5 kcal/ g (Albar et al., 2014; Rolls, 2017)].

[2] This food was only presented to participants as part of a demonstration of the portion size tool, and test responses were not included in data analyses.

4.2.1.3.1. Formatting and tool set-up in 'Qualtrics'

To create a web-based measure of portion size, JavaScript code (Sunami, 2019) posted to an opensource community board was used to adapt the slider question format in Qualtrics. This allows photographs to be loaded into a type of 'image carousel', whereby moving the slider from left to right changes the displayed image onscreen (for the full JavaScript code and source, see the OSF; https://osf.io/b4q5y). Slider size was modified to have a minimum value of '1' and a maximum value of '50' to allow a photograph to be added for each point of the scale, grid lines and labels were removed, and a custom start position was used to set the cursor at the midpoint (≈ 500-kcal portion). Participants were required to click or drag the cursor button before they could submit a response. For each test food, 50 photographs were then loaded into the slider question in successive order, from the smallest to the largest portion size. As photographs were loaded simultaneously into the slider, with each consecutive point displaying a new photograph (and incrementally smaller or larger portion), moving the cursor of the slider generated an 'animated' effect by which the portion of food appeared to grow or shrink with each interaction. This visual effect appears to be comparable to that achieved using a laboratory-based computer task to measure ideal portion size (see previous description in **Chapter 1**, (Brunstrom & Rogers, 2009)).

To use the measure, participants were instructed to click or drag the cursor to the left of the scale to decrease the portion displayed, and to click or drag the cursor to the right of the scale to increase the portion displayed. For each test food, participants were instructed to "select your ideal portion size to eat right now", or to select the portion that they would "need to eat right now in order to prevent hunger until your next meal" to measure expected satiety. The name of the presented food was included in the question. To help mitigate the potential influence of the starting portion size and encourage participants to view a range of portions before selecting a response, participants first practiced using the portion size tool with a dummy test food (cream and jam doughnut) by slowly dragging the cursor to the far left and far right anchors of the scale; they were only able to continue with the study once they had successfully completed the demonstration. The point at which participants set the cursor was automatically recorded by Qualtrics; this could be used to identify the selected photograph number, corresponding weight of food displayed (in g), and the portion size selected (in kcal) for each food. A video demonstration of this web-based tool can be viewed on the OSF (https://osf.io/yq9fk/).

4.2.1.3.2. Food ratings

To provide food ratings, participants responded to a photograph of the median portion size for each test food (≈ 500 kcal portion), using a series of 100-mm visual analogue scales with the anchors 'Not at all'– 'Extremely'. Participants were asked to provide ratings of expected satiation ('how full would you expect to feel after eating the portion of food displayed above?'), liking ('how much do you like the taste of this food?'), desire to eat ('how much would you like to eat this food right now?'), and familiarity ('how familiar is this food?'). Participants also rated their baseline hunger ('how hungry do you feel right now?') and baseline fullness ('how full do you feel right now?'). Whilst providing food ratings, participants responded to two additional questions as attention checks (on both occasions, participants were asked to 'drag the slider all the way to the left').

4.2.1.3.3. Questionnaires

Following a similar approach to past studies (Embling et al., 2020; Gatzemeier et al., 2019), the three-factor eating questionnaire-R18 (TFEQ-R18; (Karlsson et al., 2000)) was used to characterise the overall sample and assess dietary restraint, uncontrolled eating, and emotional eating traits. Responses were recorded using a 4-point Likert scale (e.g., definitely false/ mostly false/ mostly true/ definitely true), and four items were reverse-scored. For each subscale, the sum of coded items was calculated, and raw scores were converted to a 0-100 scale (((raw score − lowest possible raw score)/possible raw score range) × 100). Higher subscale scores suggest greater tendencies for dietary restraint, uncontrolled eating, and emotional eating.

Participants were also asked to provide demographic information including their age, gender, country of residence, and time since last eating. Participants self-reported their height and weight using dropdown lists to enable calculations of BMI (kg/m^2). To evaluate potential demand awareness at the end of the study, participants had an opportunity to explain their beliefs about the aim of the study using an open-text field, before viewing a debrief form.

To avoid influencing responses to foods, participants completed the TFEQ-R18 and self-reported height and weight after completing main task blocks.

4.2.1.4. Validity

To test convergent validity of the portion size selection tool, participants selected ideal portion size (in kcal) was compared to their selected portion size for expected satiety (in kcal) and rating of expected satiation (100-mm VAS) for foods. To test divergent validity of the portion size selection tool, participants selected ideal portion size (in kcal) was compared to their self-reported age (in yrs) and BMI (kg/m^2).

4.2.1.5. Sample size

Using the software program 'G*Power v.3.1.9.7', it was estimated that 42 participants were required to detect a correlation ρ of 0.50 ($1-\beta = 0.80$, $p = .01$, two-tailed), as previous research suggests that expected satiety and expected satiation are 'moderately' associated with ideal portion size ($r > 0.50$) (Brunstrom & Rogers, 2009; Brunstrom & Shakeshaft, 2009; McLeod et al., 2020; Wilkinson et al., 2012). Data collection was stopped when 56 responses had been recorded to account for unusable data (e.g., incomplete responses, multiple responses from the same participant ID). After checking inclusion and exclusion criteria, 49 responses were complete and eligible for the study.

4.2.1.6. Data analysis

For main data analyses, ideal portion size and expected satiety ratings were converted to kcal, and all ratings were collapsed across foods by calculating the mean. A Shapiro-Wilk test showed that data for age ($p < .001$), BMI ($p = .001$), ideal portion size ($p = .008$), and expected satiety ($p = .002$) were not normally distributed. As log transformation did not correct the data, an appropriate non-parametric test was used to calculate coefficients in a bivariate correlation matrix (Spearman's Rho). This was used to test the hypotheses that ideal portion size would be significantly correlated with expected satiety and expected satiation, and would not be significantly correlated with age or BMI.

No participant failed both attention checks (to warrant exclusion from the study); however, 4 participants failed a single attention check. Outliers were checked for additional food ratings (as factors that may influence ideal portion size), as well as ideal portion size and main predictors of interest (expected satiety, expected satiation, age and BMI). Outliers were removed listwise or pairwise from data analyses accordingly (1.5 x IQR). Identified outliers included a single participant that was removed from all data analyses, as they had a mean food liking score of 7.2. Identified outliers also included three participants who were removed from pairwise analyses; one participant self-reported a BMI of > 40.0 kg/m^2, and two participants had a mean ideal portion size of 634.6 kcal and 737.1 kcal respectively. This meant that data from 48 participants were included in data analyses. Significance was determined using the standard $p < .05$. Data were analysed using IBM SPSS v26.

To check that associations between ideal portion size and predictors of interest (expected satiety, expected satiation, age, BMI) were robust, non-parametric (Spearman's Rho) partial correlation coefficients were calculated to account for effects of baseline hunger and fullness, and the main analysis was repeated with individual test foods to calculate separate coefficients (following the same procedure as above). For the latter, significance was determined using the Bonferroni-corrected $p = .008$. A Bayesian non-parametric correlation matrix (Kendall's tau-b) was used to explore the strength of evidence for associations in the main analysis as support for the 'null' was also central to study hypotheses (e.g., in line with divergent validity). Bayes factors were interpreted using the descriptors 'anecdotal', 'substantial', 'strong', and 'very strong', to indicate support for alternative and null hypotheses

(Wetzels et al., 2011), and 95% Credible Intervals (CI) are reported. Bayesian analyses were conducted using the open-source software JASP v.0.11.1.0, with a default prior setting of 1.

4.2.2. Results

4.2.2.3. Participant characteristics

Participants included 24 females and 24 males. Most participants self-reported a country of residence in Europe (N = 37), five participants South America, three participants North America, and three participants South Africa. For the overall sample, mean scores on subscales of the TFEQ-R18 suggest trait levels of dietary restraint, uncontrolled eating, and emotional eating were comparable to past studies from our laboratory (Embling et al., 2020; Gatzemeier et al., 2019; Price et al., 2015). When asked to report beliefs about the aim of the study, seven participants mentioned an interest in portion size, but no participants appeared to comment on the relationship between portion size and predictor variables (expected satiety, expected satiation, age, and BMI) specifically. See **Table 10** for all other participant characteristics, and **Table 11** for descriptive statistics for food ratings.

Table 10. Sample characteristics (*N* = 48)

Demographics	Range	M (SD)
Age (years)	18.0 – 55.0	29.0 (10.7)
BMI (kg/m^2)	17.7 – 34.4	23.5 (4.4)
Baseline hunger (100mm)	0.0 – 100.0	33.0 (31.3)
Baseline fullness (100mm)	0.0 – 94.0	52.5 (28.0)
Time since eating (mins)	0.0 – 943.0	173.7 (205.7)
Restraint [1]	0.0 – 77.8	38.2 (21.5)
Uncontrolled eating [1]	3.7 – 85.2	42.0 (19.5)
Emotional eating [1]	0.0 – 100.0	43.8 (34.5)

[1] Subscale score of the TFEQ-R18, reported on a 0 – 100 scale.

Table 11. Descriptive statistics for food ratings, ideal portion size, expected satiety, and expected satiation. Mean (SD) is reported.

Variable	Collapsed across foods [1]	Granola	Chicken chow mein	Salted crisps	Madeira sponge cake	Chocolate buttons	Skittles
Food liking (100mm)	67.6 (12.3)	58.6 (31.4)	68.7 (27.9)	70.9 (26.8)	63.1 (24.7)	76.7 (24.2)	67.4 (25.8)
Food familiarity (100mm)	70.4 (17.3)	70.8 (28.2)	66.2 (29.3)	74.6 (26.9)	60.3 (31.8)	74.9 (28.9)	75.5 (30.1)
Desire to eat (100mm)	43.7 (17.2)	30.7 (30.9)	46.6 (35.9)	45.6 (31.8)	44.5 (32.9)	52.9 (34.9)	41.9 (30.7)
Expected satiation (100mm)	53.9 (17.5)	68.9 (28.2)	86.0 (13.9)	54.8 (29.5)	41.4 (27.8)	40.4 (30.0)	32.0 (29.7)
Expected satiety (kcal)	460.3 (233.7)	363.4 (205.5)	392.7 (266.9)	405.7 (251.4)	599.6 (289.8)	459.1 (271.9)	541.6 (344.2)
Ideal portion size (kcal)	281.7 (133.5)	239.8 (156.5)	316.6 (235.0)	266.1 (237.5)	462.3 (292.6)	256.1 (211.9)	250.4 (269.2)

[1] Collapsed across foods by averaging scores for individual items.

4.2.2.4. Associations between ideal portion size and measures relevant to food intake

When collapsed across foods, there was a significant positive association between ideal portion size and expected satiety ($r_s(44) = .480$, $p = .001$). There were no significant associations between ideal portion size and expected satiation ($r_s(44) = -.287$, $p = .053$), age ($r_s(44) = -.032$, $p = .835$), or BMI ($r_s(43) = -.111$, $p = .468$). However, after controlling for effects of baseline hunger and fullness, there was a significant, negative association between ideal portion size and expected satiation, whereby a larger ideal portion size was selected when expected satiation was reduced ($r_s(42) = -.310$, $p = .041$). All other results were unchanged.

Analyses with individual foods showed similar results. For all foods, there was a significant positive association between ideal portion size and expected satiety (with the exception of granola), and there were no significant associations between ideal portion size and expected satiation, age, or BMI. However, after controlling for effects of baseline hunger and fullness and correcting for multiple comparisons, only associations for salted crisps, Madeira sponge cake, and Skittles remained significant (between ideal portion size and expected satiety). See **Table 12** for correlations with individual foods.

Bayesian analyses showed that, when collapsed across foods, there was 'substantial' evidence in favour of no association between ideal portion size and age (BF_{10} = 0.196, 95% CI: -0.212, 0.168), and BMI (BF_{10} = 0.277, 95% CI: -0.277, 0.108). There was 'anecdotal' evidence in favour of a significant association between ideal portion size and expected satiation (BF_{10} = 1.591, 95% CI: -0.391, -0.010), and 'very strong' evidence in favour of a significant association between ideal portion size and expected satiety (BF_{10} = 50.172, 95% CI: 0.132, 0.511).

Bayesian analyses also showed that for all individual foods, there was 'very strong' and 'strong' evidence in favour of a significant association between ideal portion size and expected satiety (with the exception of granola), and substantial evidence in favour of no association between ideal portion size and BMI (with the exception of Skittles). Results also appeared to favour no association between ideal portion size and expected satiation, and ideal portion size and age, though there were some differences in the strength of evidence in favour of the null between foods. See **Table 13** for Bayesian analyses with individual foods.

Table 12. Correlations (r_s) between ideal portion size and predictors of food intake, for individual test foods.[1,2]

Predictor variable	**Granola**	**Chicken chow mein**	**Salted crisps**	**Madeira sponge cake**	**Chocolate buttons**	**Skittles**
Age (years)	-.317	.047	.270	-.014	-.025	-.129
	(-.313)	(.077)	(.274)	(-.013)	(.004)	(-.138)
BMI (kg/m^2)	.008	.106	.106	-.051	-.002	.169
	(.014)	(.172)	(.114)	(-.036)	(.028)	(.171)
Expected satiation (100mm)	-.004	.158	-.032	-.247	-.211	-.116
	(-.022)	(.116)	(-.030)	(-.229)	(-.224)	(-.101)
Expected satiety (kcal)	.237	.391*	.461*	.508**	.393*	.472*
	(.233)	(.321)	(.459)*	(.498)**	(.380)	(.469)*

[1] Coefficients accounting for effects of baseline hunger and fullness are given in brackets.

[2] ** Correlation is significant, $p < 0.001$; * Correlation is significant, $p < 0.008$ (Bonferroni-correction applied).

Table 13. Bayes factors (BF_{10}) for correlations between ideal portion size and predictors of food intake, for individual test foods.[1, 2, 3]

Predictor variable	Granola	Chicken chow mein	Salted crisps	Madeira sponge cake	Chocolate buttons	Skittles
Age (years)	2.00	0.20*	0.98	0.19*	0.21*	0.30*
	(-0.40, -0.02)	(-0.16, 0.21)	(-0.01, 0.36)	(-0.19, 0.19)	(-0.23, 0.15)	(-0.30, 0.12)
BMI (kg/m^2)	0.19*	0.24*	0.24*	0.20*	0.19*	0.35
	(-0.18, 0.19)	(-0.12, 0.25)	(-0.13, 0.25)	(-0.23, 0.15)	(-0.20, 0.19)	(-0.10, 0.31)
Expected satiation (100mm)	0.19*	0.35	0.19*	0.84	0.45	0.24*
	(-0.19, 0.20)	(-0.08, 0.29)	(-0.20, 0.17)	(-0.35, 0.02)	(-0.32, 0.06)	(-0.27, 0.15)
Expected satiety (kcal)	0.83	13.74**	68.14***	191.36***	10.17**	28.10**
	(-0.02, 0.35)	(0.09, 0.46)	(0.14, 0.51)	(0.17, 0.54)	(0.08, 0.46)	(0.12, 0.52)

[1] Bayes factors shown are for non-parametric correlations (Kendall's tau), that do not account for effects of baseline hunger and fullness.

[2] Bayes factor indicates *** 'very strong evidence'; ** 'strong evidence'; * 'substantial evidence'; all other factors indicate 'anecdotal' or 'no evidence'. Bayes factor > 1 indicates evidence in favour of an association (H1 over H0).

[3] 95% CI are given in brackets.

4.2.3. Interim Discussion

As predicted, ideal portion size across foods significantly correlated with expected satiety, and did not significantly correlate with age or BMI. There was also some evidence in favour of an association between ideal portion size and expected satiation, but this was weaker and less consistent compared to expected satiety. A similar pattern of results was found for individual foods, and results are generally comparable to those found in past studies using laboratory-based computer assessments of ideal portion size. First, moderate associations ($r > 0.50$) have been observed for expected satiety (Brunstrom & Shakeshaft, 2009; McLeod et al., 2020; Wilkinson et al., 2012) and expected satiation (Brunstrom & Rogers, 2009) in previous research, and given findings of a consistent association between ideal portion size and expected satiety in the present study, these results provide partial support for the convergent validity of the current measure. Second, very weak associations ($r < 0.12$) have previously been observed for age (Embling et al., 2019) and BMI (Embling et al., 2019; Wilkinson et al., 2012), and as evidence also favoured no significant associations with ideal portion size in this study, results provide support for divergent validity of the current measure.

It is important to acknowledge that the association between ideal portion size and expected satiety differed to that of expected satiation in this study. Though the relationship between expected satiety and expected satiation was not explored in this study, previous research suggests that expected satiety and expected satiation are highly correlated (Brunstrom, 2014). As such, this discrepancy may be explained by the method used to measure expected satiation. Though use of a visual analogue scale to measure expected satiation has been validated with reference to food intake (Forde et al., 2015), it has been suggested that the meaning of maximum intensity anchors (e.g., ‘not at all – extremely’) can differ across individuals, and obscure variances in scores (Bartoshuk et al., 2003, 2004). The ‘general labelled magnitude scale’ (gLMS) has been proposed as a stronger approach, as it includes intermittent labels and additional points beyond maximum descriptors to improve sensitivity of responding (e.g., ranging from ‘barely detectable’ to ‘strongest imaginable sensation of any kind’) (Bartoshuk et al., 2004). These scales have been used previously to measure satiation in both clinical and non-clinical groups (Samuels et al., 2009; Zimmerli et al., 2010). However, one concern is that the use of intermittent labels can lead to clustering effects at ‘categorical’ points of the scale, potentially undermining the continuity of the measure (J. E. Hayes et al., 2013). Removing intermittent labels is one way to combat these effects of the gLMS, whilst also maintaining sensitivity to between-group differences with the use of generalised end-anchors (J. E. Hayes et al., 2013). Therefore, **Study 5** aimed to test the association between ideal portion size (using this online tool) and expected satiation when this was measured using generalised visual analogue scales (gVAS), in addition to replicating results for associations with expected satiety, age, and BMI.

It is also important to consider how well participants are able to judge chosen test foods in photographs, especially when using this ideal portion size tool as a proxy measure of food intake. Device type was not recorded in this study, and screen size/ resolution is a factor that could inhibit functionality of the tool, particularly if participants are using a mobile device (as adherence to device guidelines can often be difficult to control). For example, previous research suggests that being able to recognise the finer granularity of foods – e.g., in terms of number of pieces – can decrease food intake, and encourage a shift towards perceiving portion sizes as larger (N. A. Lewis & Earl, 2018). Therefore, in **Study 5**, potential between-group differences in portion size were explored based on information about participants' screen resolution, browser type, and device type, to check for potential issues with consistency (in response to compliance with specified device guidelines). Likewise, differences in the usability of the portion size selection tool between groups according to participant screen resolution and device type were also checked.

4.3. Study 5 – Replication of pilot test

4.3.1. Method

4.3.1.3. Study design and procedure

As in **Study 4**, this study examined associations between ideal portion size and four relevant measures (expected satiety, expected satiation, BMI, and age), with the following changes to the procedure. In task block 1, participants were asked to provide ratings of liking, desire to eat, and familiarity for each food in turn, before providing ratings of expected satiation (see below for more details). After completing task blocks 2 and 3, participants were asked to complete the 'System usability scale' (Brook, 1986) for the online portion size selection tool before completing the TFEQ-R18. Using 'meta info' in Qualtrics, information about participants' screen resolution and browser type was automatically recorded, and participants were also asked to self-report their device type at the beginning of the study. The study was completed in approximately 20-mins. Changes made to the study protocol were preregistered on the OSF before data collection had begun (https://osf.io/yq9fk/).

4.3.1.4. Participants and recruitment

Participants were limited to current residents in the UK. Participants were instructed to complete the study on a PC/ laptop device, and using a mobile device to complete the survey was specifically listed in the exclusion criteria for the study (though participants were not screened out of completing the study based on device type). All other eligibility criteria and ethics procedures were the same as in **Study 4**, and amendments to the study protocol were approved by the Department of Psychology Research Ethics Committee at Swansea University (**Appendix G**).

4.3.1.5. Measures

Expected satiation was measured using 100-mm gVAS ('How full would you expect to feel after eating this food right now?'). Following instructions reported by Hayes and colleagues (J. E. Hayes et al., 2013), participants were first oriented to the format of the scale with the anchors 'No sensation' – 'Strongest imaginable sensation of any kind'. In order to visualise the experience that they would place at the right of the scale, participants were given examples relating to non-food experiences (e.g., 'staring at the sun', 'hearing a jet plane take off', 'severe pain'), and asked to describe their 'strongest imaginable sensation' across modalities of any kind in an open-text field. Participants then practiced rating the intensity of different sensory experiences using this scale (e.g., 'How strong is the brightness of a well-lit room?'), before providing ratings of expected satiation in response to a photograph of the median portion size for each test food (≈ 500 kcal portion). To remind participants of their strongest imaginable sensation whilst responding, the text description that participants provided of their chosen experience was displayed onscreen.

As an additional questionnaire measure, the 'System usability scale' (Brooke, 1996) was included to assess participants' experience of using the online portion size measure, consisting of 10-items relating to ease of use (e.g., 'I needed to learn a lot of things before I could get going with this *portion size selection tool*'), expected/ desired use (e.g., 'I think that I would like to use this *portion size selection tool* frequently'), and functionality (e.g., 'I found the various functions in this *portion size selection tool* were well integrated'). Responses were recorded using a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5), and scored in line with scale guidelines (Brooke, 1996). For 'positive' usability items, each item was scored as the selected value minus '1'. For 'negative' usability items, each item was scored as '5' minus the selected value. Sum of coded items was then multiplied by 2.5 to produce an overall score ranging from 0 – 100, with scores higher than 68 indicating 'above average' usability. At the end of the questionnaire, participants were also asked to indicate any additional comments they had about using the portion size selection tool in an optional open-text field (e.g., relating to technical difficulties, suggestions for improved future use). An additional attention check was included, where participants were asked to select '2' on the Likert scale.

All other measures were the same as those used in **Study 4**.

4.3.1.6. Sample size

In addition to sample size requirements for main analyses reported in **Study 4**, it was estimated that 120 participants would be required to detect a medium-large effect size for between-group differences in portion size selection/ usability, based on the assumption that screen resolution/ device type would have up to 3 categories (i.e., relating to mobile phones, tablets, and laptops/ desktop devices) ($f = .35$, $1 – \beta = .80$, $\alpha = .01$). Data collection was stopped when 124 responses had been recorded. Responses from 8 participants were removed from the dataset; participants did not provide informed consent (N = 3), response was incomplete (N = 1), response was a duplicate entry for the same participant ID (N = 1), participants did not meet eligibility criteria (N = 2), participant failed all attention checks in the survey (N = 1). This meant that 116 responses were complete and eligible for the study.

4.3.1.7. Data analysis

Tests of associations between ideal portion size and relevant measures (expected satiety, expected satiation, BMI, and age) were the same as **Study 4**, including analyses collapsed across foods (mean ratings/ portion size selected) as well as analyses for individual foods. Following the same approach, a Shapiro-Wilk test showed that data for age ($p < .001$), BMI ($p = .002$), and expected satiety ($p = .007$) were not normally distributed. As log transformation did not correct the data, an appropriate non-parametric test was used to calculate coefficients (Spearman's Rho and Kendall's tau-b). As in **Study 4**, outliers were checked and removed listwise or pairwise from data analyses where appropriate (1.5 x IQR). As in **Study 4**, significance was determined using the standard $p < .05$ for main analyses collapsed across foods, and the Bonferroni-corrected $p = .008$ was used for analyses with individual foods. Data were analysed using IBM SPSS v28, and JASP v.0.15.0.0 was used for Bayesian analyses.

Of participants included in the sample, six failed two out of three attention checks, and 11 failed a single attention check when providing food ratings. Identified outliers included two participants that were removed from all data analyses, as they had a mean food liking score of 37.3 and a mean familiarity score of 40.7, respectively. In addition, 24 participants were removed from relevant pairwise analyses. Relating to food ratings and portion size, three participants were identified as outliers as they had a mean ideal portion size of > 780.0 kcal, and two participants had a mean expected satiation score of 2.8 and 100.0, respectively. In line with the gLMS, it is important that the maximum point on the scale is unrelated to the sensory experience of interest, in order to capture relative differences in intensity between individuals (Bartoshuk et al., 2004). Therefore, participants who had described their strongest sensation in relation to food/ eating experiences, participants who changed their description across foods, and participants who did not specify a sensation, were also removed from pairwise analyses associated with expected satiation (N = 10). Participants who reported experiencing technical difficulties with the portion size selection tool for one of the foods (in open-text field responses for the usability questionnaire), whereby photographs did not change when moving the slider, were also removed from analyses relevant to those food items (N = 2). All participants who self-reported a BMI of > 40.0 kg/m^2 were removed from analyses relevant to BMI (N = 7). No outliers were removed based on age, as all participants were within the specified age range for the study. This meant that data from 114 participants were included in data analyses. However, given the number of datapoints dropped across analyses, to check that removal did not influence the overall pattern of results, tests were repeated with the full dataset as part of sensitivity analyses.

In additional exploratory analyses, independent-samples t-tests (bootstrap 1000 samples) were used to explore potential differences in ideal portion size and usability of the tool according to screen resolution/ device type. To complete the study, participants reported using a laptop/ desktop PC (N = 77), tablet device (N = 21), or mobile phone (N = 16). However, meta data indicated that 14% of participants self-reporting use of a tablet device or laptop/ desktop PC were likely mobile phone users (based on the browser, operating system, and screen resolution). To minimise overlap in screen resolution between groups, laptop/ desktop PC and tablet device users were allocated to a single group (N = 84, screen resolution range = 768x1024 – 2560x1440 px), and mobile phone device users were allocated to the comparative group (N = 30, screen resolution range = 360x747 – 428x926 px). As Levene's test was significant when portion size was included as the outcome variable ($p = .033$), test statistics were corrected for equal variance not assumed. Given the unequal sample sizes across groups, the significance of exploratory results should be treated with caution.

4.3.2. Results

4.3.2.3. Participant characteristics

Participants included 67 females and 47 males. For the overall sample, mean scores on subscales of the TFEQ-R18 suggest trait levels of dietary restraint, uncontrolled eating, and emotional eating were similar to the sample demographics recorded in **Study 4**. When asked to report beliefs about the aim of the study, participants generally mentioned an interest in eating behaviours and meal size, but only four participants included in the final dataset appeared to directly refer to associations between portion size and predictor variables (expected satiety, expected satiation, age, and BMI). See **Table 14** for participant characteristics, and **Table 15** for descriptive statistics for food ratings.

Table 14. Sample characteristics (*N* = 114).

Demographics	Range	M (SD)
Age (years)	18.0 – 54.0	31.1 (8.8)
BMI (kg/m^2)	18.3 – 39.6	26.8 (5.2)
Baseline hunger (100mm)	0.0 – 100.0	40.5 (29.1)
Baseline fullness (100mm)	0.0 – 100.0	47.2 (29.3)
Time since eating (mins)	0.0 – 1021.0	164.7 (185.1)
Restraint [1]	0.0 – 83.3	32.1 (19.4)
Uncontrolled eating [1]	11.1 – 100.0	47.3 (20.2)
Emotional eating [1]	0.0 – 100.0	52.2 (32.0)
Overall usability for portion size selection tool [2]	52.5 – 100.0	89.7 (10.2)

[1] Subscale score of the TFEQ-R18, reported on a 0 – 100 scale.

[2] Overall score of the SUS, reported on a 0 – 100 scale.

Table 15. Descriptive statistics for food ratings, ideal portion size, expected satiety, and expected satiation. Mean (SD) is reported.

Variable	Collapsed across foods [1]	Granola	Chicken chow mein	Salted crisps	Madeira sponge cake	Chocolate buttons	Skittles
Food liking (100mm)	73.9 (11.7)	58.9 (31.7)	79.4 (26.7)	75.4 (24.3)	68.8 (24.4)	85.9 (21.3)	75.0 (23.4)
Food familiarity (100mm)	84.8 (12.8)	76.8 (26.1)	83.1 (22.2)	86.9 (19.1)	77.8 (26.7)	93.8 (12.3)	90.5 (15.7)
Desire to eat (100mm)	48.0 (19.1)	29.9 (29.7)	53.4 (35.4)	49.7 (30.7)	48.9 (33.4)	59.8 (35.1)	46.6 (34.7)
Expected satiation (100mm)	48.5 (15.7)	53.7 (26.3)	75.5 (23.0)	48.2 (24.4)	45.5 (27.4)	38.4 (27.6)	29.6 (26.9)
Expected satiety (kcal)	457.5 (235.0)	357.7 (204.4)	354.7 (239.0)	422.8 (268.6)	556.4 (292.7)	494.9 (262.9)	556.9 (337.4)
Ideal portion size (kcal)	316.0 (136.0)	261.5 (201.5)	406.5 (279.6)	259.6 (212.9)	414.6 (273.4)	360.4 (247.2)	271.1 (247.2)

[1] Collapsed across foods by averaging scores for individual items.

4.3.2.4. Associations between ideal portion size and measures relevant to food intake

Results were the same as those observed in **Study 4**. When collapsed across foods, there was a significant positive association between ideal portion size and expected satiety ($r_s(107) = .348$, $p < .001$). There were no significant associations between ideal portion size and expected satiation ($r_s(96) = -.047$, $p = .645$), age ($r_s(107) = -.089$, $p = .359$), or BMI ($r_s(100) =$

-.013, p = .899). Controlling for effects of baseline hunger and fullness, and testing associations with the full sample as part of sensitivity analyses, did not change these results (see also the supplementary results on the OSF; https://osf.io/sd74c).

Analyses with individual foods showed similar results. For all foods, there was a significant positive association between ideal portion size and expected satiety (with the exception of Skittles), and there were no significant associations between ideal portion size and expected satiation, age, or BMI. However, after controlling for effects of baseline hunger and fullness and correcting for multiple comparisons, only associations for chicken chow mein, salted crisps, Madeira sponge cake, and chocolate buttons remained significant (between ideal portion size and expected satiety). See **Table 16** for correlations with individual foods.

Bayesian analyses showed that, when collapsed across foods, there was 'substantial' evidence in favour of no association between ideal portion size and expected satiation (BF_{10} = 0.135, 95% CI: -0.147, 0.113), age (BF_{10} = 0.239, 95% CI: -0.196, 0.051), and BMI (BF_{10} = 0.129, 95% CI: -0.131, 0.126). There was 'very strong' evidence in favour of a significant association between ideal portion size and expected satiety (BF_{10} = 43.274, 95% CI: 0.092, 0.339). The same pattern of results was observed for individual foods (see **Table 17**).

Table 16. Correlations (r_s) between ideal portion size and predictors of food intake, for individual test foods in Study 5.[1,2]

Predictor variable	Granola	Chicken chow mein	Salted crisps	Madeira sponge cake	Chocolate buttons	Skittles
Age (years)	-.061	.049	.016	-.095	-.074	-.152
	(-.089)	(.039)	(.010)	(-.122)	(-.076)	(-.145)
BMI (kg/m^2)	-.182	-.061	.068	-.149	.075	-.075
	(-.150)	(-.007)	(.115)	(-.112)	(.083)	(-.092)
Expected satiation (100mm)	.048	-.071	.074	.006	.143	.247
	(.131)	(-.061)	(.095)	(.059)	(.162)	(.237)
Expected satiety (kcal)	.323**	.429**	.316**	.371**	.332**	-.064
	(.244)	(.349)**	(.302)*	(.328)**	(.330)**	(-.054)

[1] Coefficients accounting for effects of baseline hunger and fullness are given in brackets.

[2] ** Correlation is significant, $p < 0.001$; * Correlation is significant, $p < 0.008$ (Bonferroni-correction applied).

Table 17. Bayes factors (BF_{10}) for correlations between ideal portion size and predictors of food intake, for individual test foods.[1, 2, 3]

Predictor variable	Granola	Chicken chow mein	Salted crisps	Madeira sponge cake	Chocolate buttons	Skittles
Age (years)	0.16*	0.14*	0.13*	0.19*	0.22*	0.58
	(-0.17, 0.08)	(-0.15, 0.10)	(-0.12, 0.13)	(-0.18, 0.06)	(-0.19, 0.05)	(-0.24, 0.01)
BMI (kg/m^2)	0.52	0.14*	0.17*	0.38	0.17*	0.15*
	(-0.24, 0.02)	(-0.15, 0.10)	(-0.08, 0.18)	(-0.22, 0.03)	(-0.08, 0.18)	(-0.17, 0.09)
Expected satiation (100mm)	0.13*	0.16*	0.18*	0.12*	0.31	2.36
	(-0.10, 0.14)	(-0.17, 0.08)	(-0.07, 0.18)	(-0.13, 0.11)	(-0.04, 0.21)	(-0.03, 0.28)
Expected satiety (kcal)	35.86***	7726.65***	28.39**	2751.77***	256.07***	0.16*
	(0.09, 0.33)	(0.17, 0.41)	(0.09, 0.33)	(0.16, 0.40)	(0.12, 0.36)	(-0.17, 0.08)

[1] Bayes factors shown are for non-parametric correlations (Kendall's tau), that do not account for effects of baseline hunger and fullness.

[2] Bayes factor indicates *** 'very strong evidence'; ** 'strong evidence'; * 'substantial evidence'; all other factors indicate 'anecdotal' or 'no evidence'. Bayes factor > 1 indicates evidence in favour of an association (H1 over H0).

[3] 95% CI are given in brackets.

4.3.2.5. Differences in portion size selection and tool usability across devices

There was no significant difference in ideal portion size selected across foods when comparing groups using mobile devices (with a lower screen resolution) versus a laptop/ desktop PC/ tablet device (MD = 28.38 kcal, SE = 32.8, $p = .385$, 95% CI: -38.1, 94.4). There was also no significant difference in usability of the tool between these groups (MD = 2.01, SE

= 2.3, p = .375, 95% CI: -6.9, 2.1). For further text comments relating to the usability of the scale, see the OSF: https://osf.io/7qsyv).

4.3.3. Discussion

Taken together, this pilot work provides preliminary evidence for the validation of a Qualtrics-based portion size selection tool to measure ideal portion size. Supporting the convergent and divergent validity of the tool, associations between ideal portion size (measured using this online tool) and relevant measures observed in **Study 4** were replicated in **Study 5**. This included consistent evidence for a significant association between ideal portion size and expected satiety across multiple food items, and evidence for a lack of association between ideal portion size and BMI, and ideal portion size and age. In **Study 5**, usability of the portion size selection tool was favourable and found to be ‘above average’ across participants, indicating that the measure is ‘undemanding’ and easy to use for participants in an online setting, without in-person guidance from a researcher. Portion size selection and usability of the tool also appeared to be relatively consistent across devices in exploratory analyses.

These results highlight the potential of using web-based survey software to develop a dynamic, photograph-based tool to measure aspects of eating relating to meal size and consumption. Compared to a previous attempt to measure ideal portion size within an online survey (Embling et al., 2019), this tool appears to have greater success in preserving key elements of laboratory-based computer tasks; 1) images are presented consecutively when participants interact with stimuli, giving rise to an ‘animated’ change in portion size, and 2) as a single photograph is displayed on screen at any time, images can be relatively large in size, allowing participants to perceive smaller changes between consecutive portions. As a 'simplified' continuous-scale measure of portion size, this tool may have particular implications for the assessment of self-reported food intake in wider research, given that it consists of fewer trials and is less effortful compared to previous tasks.

In both **Studies 4 and 5**, there was little evidence to support a significant association between ideal portion size and expected satiation, irrespective of the anchors used on visual analogue scales. In line with previous research (Brunstrom, Collingwood, et al., 2010; Brunstrom, Rogers, et al., 2008; Brunstrom & Rogers, 2009; Embling et al., 2019; McLeod et al., 2020; Wilkinson et al., 2012), the median portion size produced for each food (500-kcal) was used as the reference for participants to provide food ratings. It is notable that this was likely larger than the typical portion size consumed by participants for each food, potentially biasing the relationship between expected satiation and ideal portion size.

Results also suggest that a static measure of expected satiation (and related measures) may be less effective than dynamic measures, particularly in an online setting. For instance, studies using a psychophysical measurement of expected satiation have reported stronger associations with ideal portion size (for a discussion, see (Forde et al., 2015)). In this pilot work, changing the question used to frame the online portion size selection task seemingly allowed for the measurement of expected satiety with greater success, and there is scope to further develop the complexity of the ideal portion size tool to also allow assessment of expected satiation. For example, to implement a 'matched fullness task' (Brunstrom, Collingwood, et al., 2010; Brunstrom & Rogers, 2009), a fixed-portion for a 'standard' food may be placed to the left of a 'comparison' food within the portion size tool by combining images into a single file to load on each point of the scale (meaning two foods are simultaneously presented onscreen as opposed to a single food in this study). The image of the standard can then be kept the same at each point, whilst the image of the comparison food can be varied, allowing participants to select the portion of the comparison food that would leave them 'feeling equally full'. This then allows for measurement of expected satiation for the standard food whilst controlling for potential effects of differences across foods in terms of volume, weight, and energy density (Forde et al., 2015).

In the present work, the association between expected satiation and ideal portion size across foods also differed depending on the statistical control of hunger and fullness at baseline, particularly in **Study 4**. Given that there was little evidence of a significant association between expected satiation and ideal portion size for individual foods in both studies, and Bayesian analyses also found some substantial evidence in favour of no association, it is concluded that there was little to no evidence of an association between expected satiation and ideal portion size in this instance (see discussion of limitations for the measure of expected satiation used in this study above). However from a theoretical perspective, it is important to consider effects of baseline hunger and fullness as factors that can influence eating-related outcomes, particularly when measuring 'momentary' ratings of expected satiety/ satiation (McLeod et al., 2022). Indeed, ratings of current hunger and fullness have been significantly associated with ideal portion size in previous research (Brunstrom, Rogers, et al., 2008; Embling et al., 2019). Controlling for participant differences in appetite at baseline is also recognised to be best practice in laboratory studies measuring food intake, usually by asking participants to consume a standardised meal in the laboratory and/ or abstain from eating for a specific period before the main study (Robinson et al., 2018). As such protocols can be difficult to implement in online research, collecting ratings of current hunger and fullness as potential covariates is one way to account for these effects.

There are some limitations of these studies that should be acknowledged. Internal consistency between questionnaires and ratings of foods was not measured, as these studies were concerned with piloting single items that could be included within large-scale online surveys, that are not necessarily expected to relate to each other. Test re-test reliability was not measured, as there appears to be little evidence to support or theoretical justification for the notion that ideal portion size is a stable trait measured over time. Indeed, expectations for satiety and satiation, as identified drivers of ideal portion size, are believed to be learned and influenced by external cues in the eating environment (Forde et al., 2015). This issue of stability is particularly pertinent for online studies, as they traditionally lack constraints used to increase experimental control in laboratory studies that seek to minimise extraneous influences on ideal portion size when assessed at different times or between different groups, such as the influence of current appetite or device type. For instance, **Study 5** highlighted potential issues with compliance to device guidelines (contrasting with eligibility instructions, N = 30 were identified as mobile phone users), though conclusions about functionality and flexibility of this tool for mobile phone users specifically was limited by this study approach. However, as these pilot studies were limited to an online-only setting, future research is needed to validate this tool with direct comparisons to laboratory-based computer assessments, as well as actual food intake.

The use of this tool may also be limited by the type of food used. In this study, exploratory analyses showed that ideal portion size failed to correlate with both expected satiety and expected satiation for granola. Though there are likely to be some cultural differences, one explanation for this is that cereals are consumed as ‘breakfast foods’ in many countries (Afeiche et al., 2017; Bian & Markman, 2020; Díaz-Torrente & Quintiliano-Scarpelli, 2020; Jaeger et al., 2009, 2021; Mullan & Singh, 2010; Reeves et al., 2013; Tee et al., 2015), and regularly consuming foods during a specific mealtime (at the exclusion of other mealtimes) may increase the likelihood that individuals will select a ‘habitual’ rather than an ‘ideal’ portion size for some foods (Brunstrom & Shakeshaft, 2009). For instance, though not significantly different, McLeod et al. (McLeod et al., 2020) recently reported that the association between ideal portion size and expected satiety was weaker when ‘breakfast foods’ were presented at lunch compared to breakfast time, suggesting that ideal portions may be driven less by *current* expectations for satiety outside of the usual eating context and more by *learned* expectations associated with the usual eating context. Given that time of participation can be difficult to control in online studies, it may be of interest to consider whether potential test foods may be associated with specific meal contexts in future research.

It should also be noted that some foods are more difficult to photograph than others (e.g., the ability to distinguish encased fillings or layers in a food is often lost when photographing stimuli from a top-down view in order to show changes in portion size). For such foods, it may be unsuitable to use the tool as presented here, and researchers may need to consider additional adaptations before use (e.g., presenting images of foods from multiple angles, including a cross-section of the centre of the food item). Consideration should also be given to whether or not the experience of the food would align with expectations derived from photographs. For example, when based on appearance alone, it can be difficult for participants to perceive differences in flavour and texture that they would otherwise perceive when tasting a food. This means that highly familiar products are likely to be most appropriate for use, and this tool may need to be accompanied by additional information if more novel foods are to be used in future research (e.g., text-based sensory descriptions).

Overall, data from this pilot study support convergent and divergent validity of a web-based portion size selection tool to measure ideal portion size. Results suggest that the online portion selection tool presented in this chapter can be used to indicate ideal portion size, and that this tool may be useful as a proxy measure of food intake. Therefore, in **Chapter 5**, this portion size selection tool was used to measure the variety effect *within* foods.

5. Chapter 5 – Exploring the variety effect within foods on portion size selection: Multicomponent food items versus assortments (Study 6)

5.2. Introduction

‘Multicomponent’ foods may be considered a form of variety when using an ingredient-based approach to conceptualisation (Raynor & Vadiveloo, 2018; Wilkinson et al., 2022). Some preliminary evidence suggests that multicomponent foods can increase selected portion size. For example, as part of thesis pilot work, one study reported that participants selected larger portions in a computer-based task when cakes had a greater number of components than when cakes had comparatively fewer components (e.g., ‘iced fruit cake’ versus ‘Madeira sponge cake’) (Wilkinson, 2013). Previous research has also supported a potential variety effect when serving assortments of foods to participants and measuring food intake (Hale & Varakin, 2016), though evidence is inconsistent across these studies (Guerrieri et al., 2007, 2008, 2012; Rolls et al., 1982) (see **Chapter 1**). This may be due to methodological limitations in the current literature, as assortments have typically varied only one sensory characteristic *within* foods (e.g., colour of chocolate candies (Guerrieri et al., 2007; Rolls et al., 1982)), or otherwise may have failed to control for differences in energy density between ‘high’ and ‘low’ variety conditions (e.g., by mixing different foods together to form an assortment, versus presenting one of these foods alone).

It is also unclear whether sensory components of foods will have similar effects on portion size selection when presented as assortments versus multicomponent items. Some evidence suggests that portions may be smaller when components are ‘combined’. For example, Levitsky et al. (Levitsky et al., 2012) found that food intake was lower when multiple ingredients were presented in a cooked composite dish (a closer representation of a multicomponent food relative to food assortments) as opposed to when ingredients were presented separately as individual components. Similar findings have been found when manipulating the presentation of a salad to increase 'perceived' variety in a nudge intervention setting (i.e., mixed ingredients in a single bowl versus separate ingredients in multiple bowls) ((Kongsbak et al., 2016; Marques et al., 2020), but see (Friis et al., 2017)). However, to my knowledge, no study has directly assessed differences in consumption when variety is manipulated within multicomponent foods *and* food assortments.

Therefore, **Study 6** investigated whether multicomponent foods and assortments that contain a combination of different sensory characteristics (high variety) would encourage individuals to select larger portions than when foods/ assortments contained comparatively fewer sensory characteristics (low variety), across sweet and savoury food types. Due to the COVID-19 pandemic and ongoing suspension of face-to-face testing, this study was conducted in an online setting, with 'ideal portion size' included as the main outcome of interest (measured using the portion size selection tool described in **Chapter 4**).

First, it was predicted that there would be a significant main effect of variety, whereby participants would select larger portions when foods were 'high variety' (contain multiple components and a combination of different sensory characteristics) versus 'low variety' (contain comparatively fewer components/ sensory characteristics), supporting the variety effect.

Second, it was predicted that there would be a significant interaction between variety and food composition, whereby the size of this variety effect differs between food compositions, as a larger effect may be observed for food assortments versus multicomponent foods (it should be noted that wording of this hypothesis has improved since preregistration, but the underlying conceptualisation of this effect remains unchanged).

Third, ratings of perceived variety were expected to be significantly and positively associated with ideal portion size, reflecting the main effect of variety (when components were manipulated between conditions). As part of exploratory analyses, expected satiety was then tested as a potential mediator of this relationship, as this was significantly associated with ideal portion size in **Chapter 4**.

These effects were expected to be consistent across sweet and savoury food types.

5.3. Method

5.3.1. Participants and recruitment

Participants were invited to take part in the study via multiple online platforms, including Swansea University's participant subject pool (Sona system), 'SurveyCircle' (https://www.surveycircle.com/en/), and social media posts (e.g., 'Twitter'). Following the pilot studies conducted in **Chapter 4**, participants were included in the study if they had normal or corrected-to-normal vision, and if they were 18 – 55 years old. Participants were excluded if they had dietary restrictions, were currently on a diet, or if they self-identified as having a current or historical diagnosis of eating disorders. Informed consent was obtained from all participants via an online form at the beginning of the survey, and participants were informed that the aim of the research was to "collect consumer beliefs about different food products". Participants were compensated for their time with 3 course credits via the subject pool. Participants completed studies in exchange for 'reward points' specified by the platform's survey ranking system on 'SurveyCircle'. No compensation or reward was provided to participants completing the study via social media posts. Participants were presented with a debrief form at the end of the study. The study was approved by the Department of Psychology Research Ethics Committee at Swansea University (**Appendix H**), and preregistered on the OSF before data collection had begun (https://osf.io/x9tps/).

5.3.2. Overview of study design and procedure

Participants were directed to complete the study via an anonymous link to the survey software 'Qualtrics' (Qualtrics, Provo, UT). Using a 2 x 2 x 2 within-subjects design, this online study examined differences in portion size selection when 'variety' (high vs. low) and 'food composition' (assortment vs. multicomponent single item) were manipulated across conditions, by varying the presentation style of brownie and pizza toppings (sweet vs. savoury). In the 'high variety' conditions, participants were shown photographs of test foods consisting of three toppings (white, milk, and dark chocolate pieces for sweet items, or chicken, ham, and beef pieces for savoury items). In the 'low variety' conditions, participants were shown photographs of test foods consisting of each single topping in turn. Across these conditions, participants were presented with sweet/ savoury food assortments (with toppings presented as 'separate' components), and brownies/ pizzas (with toppings baked into the corresponding base food). For each test food, participants were asked to select their ideal portion size. This design then tested whether individuals would be more likely to select larger portions in response to variety if they were presented with food assortments, compared to if they were presented with multicomponent food items.

A similar procedure was used to that of **Study 4.** For the main portion of the study, participants responded to test foods in three task blocks. In the first task block, participants provided food ratings in response to the median portion size for each test food (500-kcal portion) for consistency across foods and conditions. In the second task block, participants selected their ideal portion size using the portion size selection tool. In the third task block, participants provided judgements of expected satiety for each food using the portion size selection tool. Presentation order of all test foods for each task was randomised using the in-built randomiser function (a total of 24 foods within each task block). The study was completed in approximately 40-mins.

5.3.3. Measures

5.3.3.3. Test foods

Photographs of 16 main test foods were included in the study. This consisted of four assortments of chocolate pieces, four brownies with chocolate pieces, four assortments of meat slices, and four pizzas with meat pieces (see **Table 18** for macronutrient information). Main test food components were selected for their potential to be presented as both assortments and multicomponent food items (i.e., they could be presented as individual items on a single plate/ bowl, and could also be mixed into another base food), and their potential to be closely matched for energy content across high and low variety conditions for each food type. For assortments, blocks of chocolate were broken into bite-size pieces (≈ 3.75g), and meats were presented in slices (≈ 17.5g). For brownies, 90g of chocolate pieces were mixed into a ready-made chocolate fudge brownie batter (*Betty Crocker, General Mills*). For pizzas, slices of meat were shredded into bite-size pieces; 45g of meat pieces and 58g of grated cheese were then added to a ready-made pizza base (*Hearty Food Co.*). Equal weights of each type of chocolate/ meat were added to items in the variety condition (i.e., 30g of each chocolate, and 15g of each meat). Brownies and pizzas were oven-baked according to package instructions and allowed to cool before plating. See **Figure 7**.

Photographs of test foods were taken using a high-resolution digital camera and tripod with lateral arm. All test foods were photographed on a white dinner plate (268-mm diameter) against a plain background from a top-down view. As described in **Chapter 4**, each food was photographed 50 times in portions that ranged from ≈ 20 kcal to ≈ 1000 kcal. These food photographs are available on the OSF (https://osf.io/x9tps/).

In addition to main test foods, eight 'dummy' test foods were presented to participants, including chicken chow mein, granola, Madeira sponge cake, salted crisps, Skittles, jam & cream doughnut, Millionaire caramel shortbread, and lemon tart. Dummy test foods were photographed in the same way as main test foods, and included in the study as distractor trials to help prevent participants from guessing the study aim (relating to manipulated components between main test foods). Responses to these test foods were not included in data analyses.

Table 18. Macronutrient composition for main test foods.

	Kcal/ 100 g	Fat/ 100 g	Sugars/ 100 g	Salt/ 100 g
Sweet foods				
Mixed chocolate pieces [1]	534.0	31.7	49.3	0.2
Milk chocolate	534.0	30.0	56.0	0.2
White chocolate	534.0	28.0	65.0	0.3
Dark chocolate	534.0	37.0	27.0	0.1
Triple chocolate brownie [1]	415.0	17.4	46.0	0.5
Milk chocolate brownie	414.3	16.8	47.9	0.5
White chocolate brownie	413.0	16.1	50.3	0.5
Dark chocolate brownie	414.1	18.8	39.5	0.5
Savoury foods				
Mixed meat slices [2, 3]	114.3	2.2	1.4	1.4
Ham [3]	114.0	2.8	3.6	1.6
Chicken [3]	114.0	1.9	0.6	1.4
Beef [3]	115.0	1.8	0.0	1.3
Meat feast pizza [2]	263.7	9.3	2.0	1.2
Ham pizza	263.5	9.3	2.2	1.2

	Kcal/ 100 g	Fat/ 100 g	Sugars/ 100 g	Salt/ 100 g
Chicken pizza	263.5	9.2	1.9	1.2
Beef pizza	263.8	9.2	1.8	1.1

[1] These foods consisted of milk chocolate, white chocolate, and dark chocolate pieces.

[2] These foods consisted of ham, chicken, and beef slices/ pieces.

[3] These foods were low energy density [< 2.5 kcal/ g (Albar et al., 2014; Rolls, 2017)].

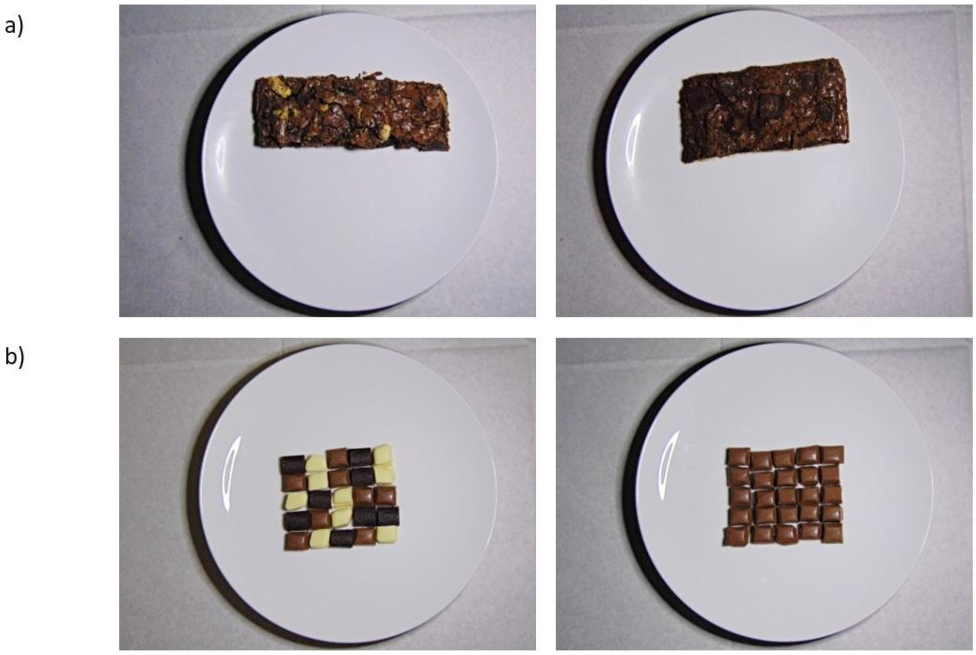


Figure 7. Brownies with chocolate pieces (a) and assortments of chocolate pieces (b), with 'high' (left) and 'low' (right) variety versions of test foods displayed (500 kcal portion).

5.3.3.4. Portion size selection

Using the online portion size selection tool and instructions described in **Chapter 4** (see also (Embling, Lee, et al., 2021)), participants were asked to select their "ideal portion size to eat right now" for each test food. To measure expected satiety, participants were asked to select the portion that they would "need to eat right now in order to prevent hunger until [their] next meal". Selected images were recorded by Qualtrics, and used to identify portion size in energy (kcal).

5.3.3.5. Food ratings

As described in **Chapter 4**, participants provided a series of ratings for each food in turn using a 100-mm VAS. This included food liking, desire to eat, familiarity, and expected satiation. To check awareness of variety within main test foods between conditions, participants were also asked to rate the level of 'variety' present within each food item, in terms of items having 'different flavours, colours, and/ or textures' ("With this definition in mind, how 'varied' is this food?"). As attention checks, participants were asked to "drag the slider all the way to the left" on two occasions whilst completing responses to main test foods.

5.3.3.6. Questionnaires

As described in **Chapter 4**, participants completed additional questionnaire and control measures. At the beginning of the study, participants provided demographics including their age, gender, and country of residence. To measure appetite, participants were also asked to report their time of last eating (in hours and minutes), and provided ratings of baseline hunger and fullness (100-mm VAS).

At the end of the study (after completing main task blocks), participants completed the TFEQ-R18 as a measure of dietary restraint, uncontrolled eating, and emotional eating traits (Karlsson et al., 2000). Participants self-reported their height and body weight using drop-down lists with pre-set metric and imperial units, to enable calculations of BMI (Kg/m^2). Demand awareness was checked by asking participants to describe their beliefs about the study aim in an open-text field.

5.3.4. Sample size

Power analyses were updated from the project preregistration to account for within-subjects effects in a linear model (see preregistration for original calculations, https://osf.io/x9tps/). Using the software program 'G*Power v.3.1.9.7', it was estimated that 114 participants were required to detect a small-to-medium effect size ($f^2 = 0.10$) for a model with 3 predictors ($1-\beta = 0.80$, $p = .05$, numerator df = 3). As a relatively conservative but practical estimate, it has been noted previously that most eating behaviour studies report effects that are “medium or smaller” (Robinson et al., 2018). Online data collection allowed for additional responses to be recorded; data collection was stopped at 284 responses to account for unusable data (e.g., low quality data, incomplete responses, multiple responses from the same participant ID), and potential underestimation of the sample size due to the exploratory nature of the study and complex study design (Kumle et al., 2021). After checking inclusion and exclusion criteria, 206 responses were complete and eligible for the study (for a complete list of exclusion reasons, see the data dictionary; https://osf.io/x9tps/).

5.3.5. Data analysis

Though it did not warrant exclusion from the study, 19 participants failed a single attention check. Outliers were checked for ideal portion size (+/- 3.0 SDs from the mean) and datapoints were removed listwise from linear mixed models (datapoint N = 42, from across 23 participants). Identified outliers for ideal portion size were removed pairwise from all other analyses, and the same pattern of results was found when conducting analyses with the full dataset. Unless otherwise stated, data for ideal portion size were collapsed across foods in control conditions by calculating the mean.

Following a similar approach in the literature (Oldham-Cooper et al., 2017), a linear mixed model was then conducted to test for differences in ideal portion size between ‘high’ and ‘low’ variety foods, whilst accounting for repeated measures across participants (an ANCOVA model was initially preregistered for this project, with a 2 x 2 design that collapsed across sweet and savoury foods). ‘Variety’ (high vs low) and ‘composition’ (assortment vs multicomponent item) were included as fixed factors, ‘participant’ was included as a random factor, and ‘ideal portion size’ was entered as the outcome. Bonferroni-corrected pairwise comparisons were used as follow-up tests for significant interactions. As data for ideal portion size were not normally distributed (zSkewness > 1.96), and data also failed to meet the assumption of homoscedasticity, bias-corrected bootstrapping approaches were used to estimate parameters (1000 samples). A bivariate correlation matrix (Spearman’s) was used to identify significant covariates to be included across models; baseline hunger, baseline fullness, time since eating, age, uncontrolled eating, emotional eating, gender, food liking, food familiarity, and desire to eat were all entered as control variables (see **Table 19**).

Exploratory analyses were conducted to check robustness of results. To test whether effects were consistent across sweet and savoury food types, a series of paired-samples t-tests (bootstrap 1000 samples) were conducted to check for differences in ideal portion size between sweet and savoury foods (collapsed across components in low variety conditions for each food type). A series of one-way ANOVAs were used to check for differences between components within low variety conditions for each food type, with the Greenhouse-Geisser correction applied to within-subjects effects (for Mauchly's test of sphericity, $p < .01$). As appropriate, food type was then included as an additional factor in models, and separate linear mixed models were conducted as follow up tests to check for differences in main results when individual foods were included in 'low' variety conditions (milk chocolate, white chocolate, dark chocolate; ham, chicken, and beef). As three additional models were explored (alternating control conditions within each food level), significance was inferred using the Bonferroni-corrected $p = .016$.

To test whether ratings of perceived variety were positively associated with ideal portion size, a series of paired-samples t-tests (bootstrap 1000 samples) were used to check for differences in 'perceived variety' across levels of variety, and correlations (Spearman's) were explored between perceived variety ratings and ideal portion size (collapsed across foods within low variety conditions). Following the approach of McLeod et al. (McLeod et al., 2020), the strength of correlations within each variety-by-food-composition condition were compared to other food ratings by converting coefficients to z-scores (via 'Fisher's r to z transformation') and using Steiger's equations 3 and 10 to test for differences (Steiger, 1980). Web-based utility software were used to perform these functions (Lee & Preacher, 2013). Expected satiety (collapsed across foods within low variety conditions) was then explored as a potential mediator of the relationship between perceived variety ratings and ideal portion size using PROCESS v3.5 (A. F. Hayes, 2018). Expected satiation was not included in models, as this factor was poorly correlated with ideal portion size (see **Table 19**). Confidence intervals were adjusted using bias-corrected bootstrap approaches (5000 samples), and HC3 was used to adjust standard errors for heteroscedasticity (A. F. Hayes & Cai, 2007). Model effects were indicated as significant if confidence intervals did not cross zero, and if the Bonferroni-corrected $p \leq .006$ (accounting for eight exploratory models).

Unless otherwise indicated, analyses were conducted using IBM SPSS v28 and results were significant if $p < .05$.

Table 19. Correlation coefficients (Spearman's r) for associations with ideal portion size (kcal) across foods. [1]

	Brownies		**Chocolate pieces**		**Pizzas**		**Meat pieces**	
Variety	**High**	**Low [2]**	**High**	**Low [2]**	**High**	**Low [2]**	**High**	**Low [2]**
Potential covariates								
Baseline hunger (100mm)	.241 ***	.250 ***	.136	.171 *	.199 **	.267 ***	.096	.130
Baseline fullness (100mm)	-.171 *	-.198 **	-.115	-.116	-.136	-.212 **	-.086	-.121
Time since eating (mins)	.131	.186 **	.075	.081	.115	.141 *	.051	.095
Age (years)	-.018	-.070	-.072	-.059	-.108	-.160 *	.007	-.009
BMI (kg/m^2)	.079	.025	.026	.106	-.031	-.013	.098	.094
Restraint [3]	-.096	-.122	-.027	-.128	-.006	-.003	-.017	-.006
Uncontrolled eating [3]	.122	.162 *	.117	.271 ***	.082	.165 *	.060	.136
Emotional eating [3]	.094	.067	.014	.152 *	-.046	.021	-.054	-.012
Gender [4]	-.109	-.133	-.084	-.135	-.170 *	-.256 ***	-.219 **	-.321 ***
Food liking (100mm)	.444 ***	.528 ***	.297 ***	.443 ***	.516 ***	.518 ***	.523 ***	.472 ***

	Brownies		Chocolate pieces		Pizzas		Meat pieces	
Variety	**High**	**Low [2]**	**High**	**Low [2]**	**High**	**Low [2]**	**High**	**Low [2]**
Food familiarity (100mm)	.281 ***	.294 ***	.035	.120	. 331 ***	.289 ***	.233 ***	.232 ***
Desire to eat (100mm)	.556 ***	.637 ***	.388 ***	.560 ***	.646 ***	.669 ***	.512 ***	.627 ***
Potential predictors								
Perceived variety (100mm)	.183 **	.194 **	.095	.098	.245 ***	.292 ***	.213 **	.146 *
Expected satiation (100mm)	.001	-.017	.066	-.014	.042	-.007	.148 *	.066
Expected satiety (kcal)	.364 ***	.494 ***	.372 ***	.345 ***	.531 ***	.548 ***	.384***	.459 ***

[1] Significance indicated as $p < .05^{*}$, $p < .01^{**}$, $p < .001^{***}$.

[2] Collapsed across foods by averaging scores for individual items in the ‘low’ variety condition. For sweet foods, this included milk chocolate, white chocolate, and dark chocolate pieces. For savoury foods, this included chicken, ham, and beef pieces.

[3] Subscale score of the TFEQ-R18, reported on a 0 – 100 scale.

[4] Gender binary coded as 1 = female, 0 = male. As a single participant identified as non-binary, this reference category is not included in data analyses.

5.4. Results

5.4.1. Participant characteristics

Participants included 154 females, 50 males, and one participant who identified their gender as non-binary. For one participant, their identified gender was not assigned at birth, and one participant preferred not to say. Gender information was unknown for one participant. Most participants self-reported a country of residence in the UK and Ireland (N = 141). Remaining participants were resident in other areas of Europe (N = 23), Asia (N = 23), US and Canada (N = 13), Oceania (N = 2), South America (N = 2), and Africa (N = 2). When asked to report beliefs about the aim of the study, 19 participants mentioned an interest in 'variety'; all other participants appeared to be unaware of the main study aim. See **Table 20** for all other participant characteristics, and **Table 21** for descriptive statistics for food ratings.

Table 20. Sample characteristics (*N* = 206)

Demographics	Range	M (SD)
Age (years)	18 – 55	24.5 (7.3)
BMI (kg/m^2)	14.8 – 47.6	23.6 (4.9)
Baseline hunger (100mm)	0 – 100	27.9 (26.9)
Baseline fullness (100mm)	0 – 100	53.6 (26.4)
Time since eating (mins)	0 – 1057	183.6 (212.1)
Restraint [1]	0 – 100	42.1 (21.4)
Uncontrolled eating [1]	3.7 - 100	45.1 (18.8)
Emotional eating [1]	0 – 100	50.3 (27.8)

[1] Subscale score of the TFEQ-R18, reported on a 0 – 100 scale.

Table 21. Descriptive statistics for food ratings, ideal portion size, expected satiety, and expected satiation for foods. Mean (SD) is reported.

	Brownies		**Chocolate pieces**		**Pizzas**		**Meat pieces**	
Variety	**High**	**Low [1]**	**High**	**Low [1]**	**High**	**Low [1]**	**High**	**Low [1]**
Liking (100mm)	74.3 (26.4)	75.1 (22.7)	72.1 (24.4)	64.8 (20.9)	60.0 (33.4)	63.0 (25.5)	47.7 (31.4)	47.0 (24.8)
Familiarity (100mm)	71.2 (27.4)	76.5 (19.8)	84.6 (18.6)	82.8 (17.5)	73.4 (26.8)	75.6 (20.0)	64.2 (31.3)	67.3 (24.3)
Desire to eat (100mm)	52.0 (34.4)	53.3 (31.6)	50.5 (30.8)	44.2 (26.7)	39.4 (34.6)	41.1 (30.3)	26.5 (29.8)	24.9 (22.8)
Perceived variety (100mm)	58.7 (28.5)	46.1 (22.5)	59.6 (25.5)	21.9 (21.2)	67.3 (23.0)	55.0 (21.8)	56.0 (25.9)	18.0 (17.7)
Expected satiation (100mm)	55.7 (27.8)	55.8 (25.6)	46.2 (29.0)	40.3 (25.2)	76.9 (22.7)	76.2 (18.7)	68.9 (27.7)	59.8 (25.4)
Expected satiety (kcal)	461.3 (273.7)	432.2 (257.5)	447.1 (301.3)	420.4 (282.8)	374.8 (267.5)	367.7 (258.1)	207.1 (184.2)	198.9 (180.2)
Ideal portion size (kcal)	328.8 (253.6)	320.6 (228.0)	240.4 (198.5)	237.8 (184.3)	282.4 (275.5)	305.3 (260.7)	83.9 (82.7)	64.0 (56.0)

[1] Collapsed across foods by averaging scores for individual items in the 'low' variety condition. For sweet foods, this included milk chocolate, white chocolate, and dark chocolate pieces. For savoury foods, this included chicken, ham, and beef pieces.

5.4.2. Checking for differences in ideal portion size between ‘sweet’ and ‘savoury’ foods for each food composition

Paired-samples t-tests showed that ideal portion size was significantly larger for sweet versus savoury food types when participants were presented with ‘high’ variety assortments (mixed chocolate pieces vs. mixed meat pieces, MD = 154.5 kcal, SE = 13.7, $p < .001$, 95% CI: 128.6, 181.2), and ‘low’ variety assortments (single chocolate pieces vs. single meat pieces, MD = 162.4 kcal, SE = 11.9, $p < .001$, 95% CI: 139.2, 185.4). There were no significant differences between sweet and savoury food types when participants were presented with multicomponent food items (p’s > .05).

5.4.3. Checking for differences in ideal portion size between ‘low’ variety control conditions for each food composition

In the ‘low’ variety conditions specifically, a series of one-way ANOVAs showed that there were significant differences in portions selected for assortments of chocolate pieces ($F (1.87, 373.23) = 51.51$, $p < .001$, partial $\eta^2 = 0.21$) assortments of meat pieces ($F (1.90, 371.26) = 12.30$, $p < .001$, partial $\eta^2 = 0.06$), and for pizzas ($F (1.86, 380.83) = 4.83$, $p = .010$, partial $\eta^2 = 0.02$). Bonferroni-corrected pairwise comparisons showed that participants selected significantly more calories when presented with milk chocolate versus dark chocolate (MD = 173.0 kcal, SE = 18.5, $p < .001$, 95% CI: 128.3, 217.6) or white chocolate pieces (MD = 44.8 kcal, SE = 15.2, $p = .011$, 95% CI: 8.1, 81.4), and significantly more calories when presented with white chocolate versus dark chocolate pieces (MD = 128.2 kcal, SE = 19.1, $p < .001$, 95%

CI: 82.0, 174.4). Participants selected significantly fewer calories when presented with ham versus beef (MD = 19.3 kcal, SE = 4.5, $p < .001$, 95% CI: 8.5, 30.1) or chicken pieces (MD = 17.6 kcal, SE = 3.8, $p < .001$, 95% CI: 8.4, 26.7). Participants selected significantly more calories when presented with chicken versus beef pieces as pizza toppings (MD = 48.1 kcal, SE = 14.0, $p = .002$, 95% CI: 14.3, 81.9). There were no significant differences between brownies (F (1.57, 322.62) = 3.09, $p = .059$, partial $\eta^2 = 0.02$), and all other pairwise comparisons were not significant ($p > .05$).

5.4.4. Effects of variety on ideal portion size across food compositions and food types

5.4.4.3. Linear mixed model with ideal portion size collapsed across ‘low’ variety foods

As there were significant differences between sweet and savoury foods within conditions (see **Section 5.4.2.**), ‘food type’ (sweet vs. savoury) was entered as an additional fixed effect in linear mixed models. Contrary to predictions, there was no significant main effect of variety on ideal portion size ($F(1, 1359.01) = .07$, $p = .797$), and variety did not significantly interact with food composition ($F(1, 1359.05) = 1.72$, $p = .190$) to influence ideal portion size. There was also no significant two-way interaction between variety and food type ($F(1, 1359.05) = .73$, $p = .394$), and no significant three-way interaction between variety, food composition, and food type ($F(1, 1359.04) = 2.85$, $p = .092$).

5.4.4.4. Linear mixed model with ideal portion size for individual foods

Low variety conditions for each food composition were alternated based on significant differences observed between components for ideal portion size (see **Section 5.3.2.**). As portions selected for meat pieces differed between food compositions, comparative order was decided based on the smallest portion selected for food assortments (ham), and the largest portion selected for pizza (chicken). Three separate models were then conducted to include the following components across food compositions; dark chocolate and ham (smallest portions), white chocolate and beef, milk chocolate and chicken (largest portions). For brevity, only significant effects and comparisons relevant to the variety effect are highlighted here ($p \leq .016$).

When dark chocolate and ham were used as components in low variety conditions, there was a significant main effect of variety ($F(1, 1378.64) = 12.30$, $p < .001$), as participants selected more calories overall when presented with high ($M = 231.3$ kcal, $SE = 10.1$) versus low ($M = 200.5$ kcal, $SE = 10.1$) variety foods. There were also significant two-way interactions between variety and food composition ($F(1, 1378.64) = 17.92$, $p < .001$), and variety and food type ($F(1, 1378.64) = 9.46$, $p = .002$). Bonferroni pairwise comparisons showed that participants selected significantly more calories for assortments (but not multicomponent foods) when variety was high versus low ($p < .001$). Participants also selected significantly more calories for sweet foods (but not savoury foods) when variety was high versus low ($p < .001$). See **Figure 8**.

When milk chocolate and chicken were entered as individual components, there was also a significant three-way interaction between variety, food composition, and food type ($F(1, 1362.91) = 10.89$, $p < .001$). However, contrary to predictions, Bonferroni pairwise comparisons showed that participants selected significantly more calories for pizza when variety was low versus high (p = .009), and no other significant differences were observed between high and low variety conditions **within** food compositions or food types. See **Figure 9**.

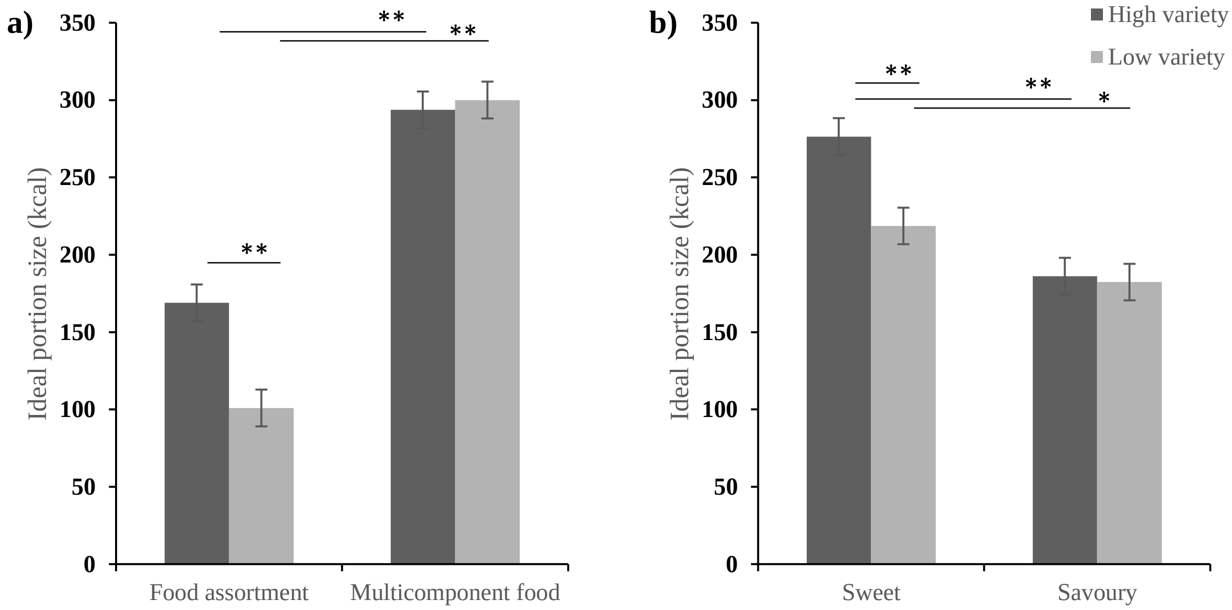


Figure 8. Estimated marginal means and SE for ideal portion size across food compositions (a) and food types (b), with ‘dark chocolate’ (sweet) and ‘ham’ (savoury) included as single components in low variety foods (* p < .005, ** p < .001).

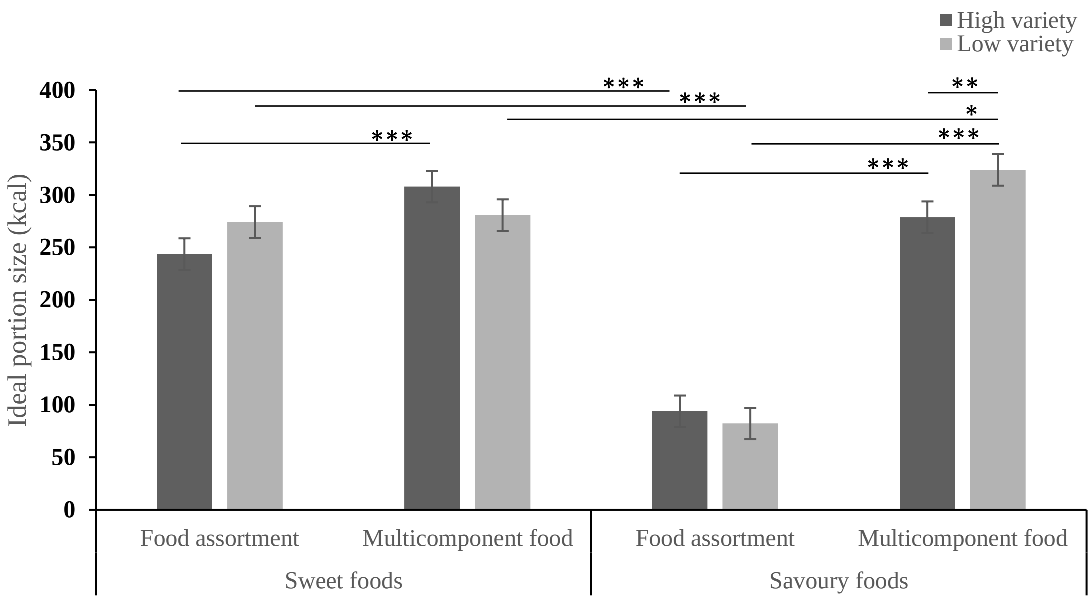


Figure 9. Estimated marginal means and SE for ideal portion size, with 'milk chocolate' (sweet) and 'chicken' (savoury) included as single components in low variety foods (* p < .05, **p < .01, *** p < .001).

5.4.5. Associations between 'perceived variety' ratings and ideal portion size

When compared to 'low' variety foods, paired-samples t-tests showed that participants gave significantly higher ratings of perceived variety to 'high' variety food compositions, including brownies (MD = 12.6 kcal, SE = 1.5, p < .001, 95% CI: 9.5, 15.4), assortments of chocolate pieces (MD = 37.7 kcal, SE = 1.8, p < .001, 95% CI: 34.3, 41.4), pizzas (MD = 12.3 kcal, SE = 1.4, p < .001, 95% CI: 9.5, 15.1), and assortments of meat pieces (MD = 38.0 kcal, SE = 1.9, p < .001, 95% CI: 34.4, 41.8).

As displayed in **Table 19**, participant ratings of variety were significantly and positively associated with ideal portion size, as a small-to-medium effect was observed across conditions (excluding assortments of chocolate pieces). However, Steiger's equations indicated that significantly larger effects were observed for desire to eat and liking relative to perceived variety, whereby stronger ratings were associated with selecting larger ideal portions across conditions ($Z \geq 2.28$, $p \leq .023$). There were no significant differences between correlation coefficients observed for ratings of variety and familiarity with ideal portion size ($Z \leq 1.15$, $p \geq .252$).

Across mediation models (see **Table 22**), perceived variety did not significantly predict ideal portion size via direct or indirect pathways, despite expected satiety being a significant and positive predictor of ideal portion size. The same pattern of results was also found after removing participants with an awareness of variety from analyses.

Table 22. Direct and indirect effects of perceived variety on ideal portion size (kcal) across conditions.[1, 2]

Food type	**Variety condition**	**Total effect (c)**				**Direct effect (c')**				**Indirect pathway**											
										Effect on mediator (*a*)				**Effect of mediator (*b*)**				**Indirect effect (*ab*)**			
		B	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**
Brownies	High	.12	.62	-1.09, 1.34	.01	.19	.57	-.92, 1.32	.02	-.29	.68	-1.62, 1.04	-.03	.21	.07	.09, .35	**.23***	-.06	.15	-.36, .26	-.01
	Low [3]	.10	.68	-1.24, 1.45	.01	.44	.62	-.80, 1.62	.04	-1.08	.79	-2.66, .49	-.09	.32	.06	.21, .44	**.36****	-.34	.26	-.87, .17	-.03
Chocolate pieces	High	-.50	.59	-1.68, .67	-.06	-.39	.54	-1.47, .68	-.05	-.50	.86	-2.23, 1.11	-.04	.22	.05	.13, .32	**.33****	-.11	.20	-.54, .26	-.01
	Low [3]	.24	.64	-1.03, 1.50	.03	.45	.59	-.69, 1.60	.05	-1.30	.95	-3.25, .50	-.10	.16	.04	.09, .25	**.25****	-.21	.17	-.58, .08	-.02
Pizzas	High	.25	.84	-1.42, 1.92	.02	.16	.73	-1.25, 1.62	.01	.31	.93	-1.48, 2.17	.03	.31	.07	.17, .46	**.31****	.10	.30	-.48, .74	.01

Food type	**Variety condition**	**Total effect (c)**				**Direct effect (c')**				**Indirect pathway**											
										Effect on mediator (*a*)				**Effect of mediator (*b*)**				**Indirect effect (*ab*)**			
		B	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**	**B**	**SE**	**95% LLCI, ULCI**	**β**
	Low [3]	1.39	.77	-.13, 2.92	.12	1.24	.72	-.25, 2.64	.10	.61	.79	-.92, 2.10	.05	.25	.07	.11, .39	**.26***	.15	.22	-.22, .64	.01
Meat pieces	High	.20	.19	-.18, .57	.06	.16	.19	-.21, .54	.05	.33	.46	-.52, 1.30	.05	.10	.19	.11, .39	**.21***	.03	.05	-.06, .14	.01
	Low [3]	-.01	.26	-.51, .50	-.00	.04	.25	-.43, .54	.01	-.70	.80	-2.31, .79	-.07	.07	.02	.02, .11	**.20***	-.05	.06	-.17, .05	-.01

[1] Each model contained perceived variety as the predictor (X), expected satiety as the mediator (M), and ideal portion size as the outcome (Y). Effects of baseline hunger, baseline fullness, time since eating, age, uncontrolled eating, emotional eating, gender, food liking, food familiarity, and desire to eat were controlled for across model pathways.

[2] Significance indicated as $p < .006^{*}$, $p < .001^{**}$ (Bonferroni-corrected for multiple comparisons).

[3] Collapsed across foods by averaging scores for individual items in the 'low' variety condition. For sweet foods, this included milk chocolate, white chocolate, and dark chocolate pieces. For savoury foods, this included chicken, ham, and beef pieces.

5.5. Discussion

Research on the effects of multicomponent foods – as this relates to portion size selection and food intake – is limited in the current literature (Wilkinson et al., 2022). Though past studies have manipulated variety within foods by exploring effects in food assortments, conflicting results have been reported (Guerrieri et al., 2007, 2008, 2012; Hale & Varakin, 2016; Rolls et al., 1982). For the first time, this study has allowed direct comparisons to be drawn between 'high' and 'low' variety foods, when considering effects for both multicomponent foods and food assortments. However, contrary to study predictions, there was little evidence to support a main effect of variety on ideal portion size, as there was no significant difference between high (three components) and low (single component) variety foods overall. There was also little evidence to support an interaction between variety and food composition, as participants tended to select similar portions **within** food compositions and food types across variety conditions (see discussion of results for analyses with individual foods below).

One explanation for the lack of a variety effect is that the manipulation of variety within food compositions was limited to similar food components in order to control for differences in energy density (e.g., different types of chocolate). In contrast, previous research by Wilkinson et al. demonstrated the anticipation of the variety effect during meal planning when participants were asked to select sweet and savoury dishes across multiple hypothetical courses (Wilkinson et al., 2013), and to select ideal portions for cakes with different levels of intensity/ complexity relating to the number of components and flavours they contained (e.g., 'Madeira sponge cake' versus 'Iced fruit cake') (Wilkinson, 2013). Though components used in this study differed in multiple sensory characteristics – and these differences appeared to be perceived by participants – portion size selection may have been driven by anticipated consumption effects for food items more generally (e.g., 'chocolate brownies'), particularly as participants reported a high level of familiarity with foods across conditions (Brunstrom, Shakeshaft, et al., 2008, 2010). Effects of variety may also be more pronounced in response to tasting foods, given that the variety effect is believed to be influenced by sensory specific satiety (and habituation) during consumption (e.g., (Rolls et al., 1982; Rolls, Rolls, et al., 1981)). As such, it would be useful for further research to systematically explore the relative number of components that may exhibit the variety effect within foods (e.g., by contrasting components from within 'same', 'similar', and 'different' food classes when brought together).

It should be noted that effects of variety differed across exploratory models that aimed to account for differences between individual test foods. When dark chocolate and ham pieces were used in control conditions, there was some support for effects of variety on portion size selection in line with hypotheses, as participants selected significantly more calories for 'high' variety foods, but only when responding to 'assortments' and 'sweet' foods. When milk chocolate and chicken pieces were included in control conditions, participants also selected larger portions when presented with pizzas in the low rather than high variety condition. Given inconsistencies between foods, these effects were likely governed by differences observed between food compositions and food types, rather than the manipulation of variety per se.

From a theoretical perspective, differences in food intake relating to food composition are believed to occur because the 'perceived' number of different foods available (i.e., variety) is increased when components are served individually (Kongsbak et al., 2016; Levitsky et al., 2012; Marques et al., 2020). As hypothesised, higher ratings of perceived variety – in this case, relating to the perception of different flavours, colours, and textures within foods – were significantly associated with selecting larger ideal portions across foods in the present study. However, perceived variety was a relatively poor predictor of ideal portion size overall after considering associations with covariate effects, including food liking and desire to eat. There was also no significant indirect effect of perceived variety on ideal portion size via expected satiety, which has previously been identified as a strong predictor of portion size selection (Brunstrom & Shakeshaft, 2009; McLeod et al., 2020; Wilkinson et al., 2012). This does not appear to be due to discrepancies between ratings of perceived variety and manipulated levels of variety across conditions, as mean ratings of perceived variety significantly increased for ‘high’ versus ‘low’ variety foods across food compositions and food types. Indeed, other studies that have attempted to manipulate ‘perceived variety’ (e.g., by differentially drawing attention to components) have failed to report effects on consumption (Embling et al., 2019; Vadiveloo et al., 2019), though a significant influence on satiation alone has been found (Redden, 2008).

5.5.1. Feasibility of exploring effects of variety within foods

As highlighted in a recent review (Wilkinson et al., 2022), it may be particularly challenging to test effects of variety within foods. First, test food components in this study were selected for their potential to be closely matched for energy density across high and low variety conditions for each food type. However, difficulties sourcing test foods meant that this was not possible for all conditions, and differences in energy density between assortments and multicomponent foods limited the direct comparisons that could be drawn between these foods. Where base foods used for multicomponent items were typically energy-dense and palatable items (brownies and pizzas), savoury components used to construct food assortments were low energy density. Wilkinson et al. (Wilkinson et al., 2022) have previously acknowledged potential barriers to testing effects of variety within foods on eating behaviour in the laboratory, as it can be difficult to construct and photograph ‘standardised’ test foods (i.e., to develop isocaloric test foods that can be manipulated across levels of variety *and* food compositions, whilst maintaining visibility of components in portions). Future studies may have more success testing interactive effects in particular if there is scope to invest in product development before conducting food trials.

Second, data collection and development of materials for this study were adapted to an online setting in response to the COVID-19 pandemic. This involved the additional challenge of identifying available foods that could be photographed successfully for a portion size selection task, whilst manipulating components within foods (i.e., considering the need to maintain product appeal and consistency between conditions, and maintain visibility of components from a top-down view). For example, though measures were taken to identify low-effort responses and potential bots (e.g., by including multiple attention checks, screening qualitative responses for comprehension, and checking feasibility of response completion time), it is notable that responses across several scales appeared to cluster around end-anchor points. For ideal portion size in particular, a potential floor effect may have occurred, as selection was significantly skewed towards the smallest portions for some foods. This may be due to the polarising nature of foods used in the study in terms of appeal (particularly for savoury foods that were more difficult to photograph), suggesting that investigation of effects with alternative food components is warranted.

There were also potential issues relating to the sensitivity of the ideal portion size tool to capture sufficient variability across responses. Pilot tests of the ideal portion size tool did not identify any significant issues relating to the convergent or divergent validity of the setup, granularity of images/ portion sizes, or task usability (**Studies 4 and 5**). However, functionality of the tool across devices (including mobile phone devices) and study settings (online versus laboratory-based measures) warrants further exploration. Indeed, the perceived granularity of foods may be particularly relevant to portion size selection when manipulating variety within foods (as this relates to the number of components presented) (N. A. Lewis & Earl, 2018). This is a factor that may differ across participants as a result of inconsistencies in image size, as well as food type (considering that components may be more difficult to perceive in photographs of multicomponent foods versus food assortments). Food ratings were also selected in response to the median portion size available for each food (in line with **Studies 4 and 5**). Though ideal portion size was the main outcome of interest in this study, it is acknowledged that this may have influenced expected satiation ratings. For further discussion, see **Chapter 4**.

Third, the feasibility of translating this study design to a laboratory setting should be acknowledged. Though similar challenges may be faced when developing test foods, a particular advantage of testing the variety effect in this setting may be the ability for participants to more easily perceive sensory differences in flavour and texture when tasting foods (relative to food photographs). In the context of exploring oral processing behaviour, this perceived sensory contrast has been achieved by adding gel-based pieces (e.g., bell pepper) to standardised sample foods (e.g., cheese) (e.g., (Aguayo-Mendoza et al., 2021). For example, the initial preregistration of this study design involved manipulating the flavours and colours of an isocaloric jelly-based dessert to measure food intake (as described in the introduction of **Chapter 4**).

5.5.2. Study conclusion

Overall, this study begins to further develop our understanding of an 'underexplored' conceptualisation of variety in the literature. Though there was little evidence to support effects of variety within foods on ideal portion size, this study provides initial pilot data to inform the development of future studies, particularly as this relates to study design (e.g., to enable simulation power analyses). Further attention should be given to the development and manipulation of standardised test foods for use in eating behaviour studies focussed on ‘composite’ foods.

6. Chapter 6 – Associations between dietary variety, portion size, and body weight: Prospective evidence from 35 449 UK Biobank participants (Study 7)

The study presented in this chapter (**Study 7**) has been submitted as an article for publication.

6.2. Introduction

In addition to effects of variety *within* foods on consumption discussed in **Chapter 5** (**Study 6)**, several studies have reported positive associations between dietary variety scores and food intake (Vadiveloo et al., 2013). Multiple reviews have highlighted energy density as a potential moderator of the effect of variety on body weight and body fatness, whereby consuming a greater variety of low energy density foods is negatively associated with body adiposity (Kennedy, 2004; McCrory et al., 2012; Raynor & Vadiveloo, 2018; Vadiveloo et al., 2013). However, results appear to differ between studies, with many reporting nonsignificant findings or effects in the opposite direction to what was predicted, and the most consistent evidence being found for dietary variety within 'non-recommended' food groups (i.e., energy-dense foods) (Vadiveloo et al., 2013).

In addition to the role of energy density, variety may impact food intake by influencing selected portion size. Experimental studies in the laboratory have demonstrated that variety increases the weight of food consumed in the context of a single meal (indicating larger portions) (see **Chapter 2,** as reported in (Embling, Pink, et al., 2021)). Variety has also been shown to increase the size of planned portions when selecting foods before eating (Haws & Redden, 2013; Wilkinson et al., 2013), and portion size itself is known to significantly increase food intake (Zlatevska et al., 2014). Consistent with these effects, dietary variety scores have been associated with increased energy intake using self-report measures (McCrory et al., 1999). However, across these literatures, no study has directly explored portion size as a specific mediating mechanism by which dietary variety may influence body weight and body fatness at a population level.

Therefore, this study aimed to further explore the relationship between dietary variety and body weight in a large cohort using secondary data from the 'UK Biobank' (https://www.ukbiobank.ac.uk/). It was predicted that higher dietary variety scores (including participants' self-evaluated rating of dietary variety) would be associated with a higher body weight (and body fatness) when energy density was high. It was also predicted that portion size would mediate this relationship, meaning higher dietary variety scores would be associated with a higher body weight (and body fatness) when individuals reported greater food intake (when energy density was high), constituting a mediated moderation effect.

6.3. Method

6.3.1. **Overview of UK Biobank procedures and ethical approval**

Prospective data from the UK Biobank were used in this study to analyse associations between dietary variety, portion size, and body weight outcomes (Project ID: 53159). The UK Biobank is a large-scale, cohort study focussed on participants between the ages of 40 – 69 years old, with a sample of >500,000 individuals living within the UK (Allen et al., 2012). During baseline assessment centre visits, written informed consent was obtained from all participants. Participants completed a series of questionnaires via a touch-screen and verbal interview, and physical measures and biological samples were collected by UK Biobank staff. Demographic information including participant sex, age (in years), age completing full-time education (in years), employment status, ethnicity, and Index of Multiple Deprivation scores (IMD), were recorded. The initial recruitment phase took place between 2006 – 2010, and occasional follow-up assessments have since been completed in-person and online. For an overview of the assessment timeline, see **Figure 10.**

UK Biobank data collection and access were conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects/ patients were approved by the Northwest Multi-centre Research Ethics Committee (MREC). Use of data for secondary data analysis were approved by the UK Biobank, and received departmental ethical approval from Swansea University's Department of Psychology Research Ethics Committee (**Appendix I**). In line with ethical procedures, participants who later withdrew their data from use by contacting the UK Biobank were removed from ongoing data analyses for this project (whilst the project was still ongoing). The data analysis plan was preregistered on the OSF prior to main analyses (https://osf.io/hfrej/).

For more information about the data collection process and access to the UK Biobank, see the study website (https://www.ukbiobank.ac.uk/).

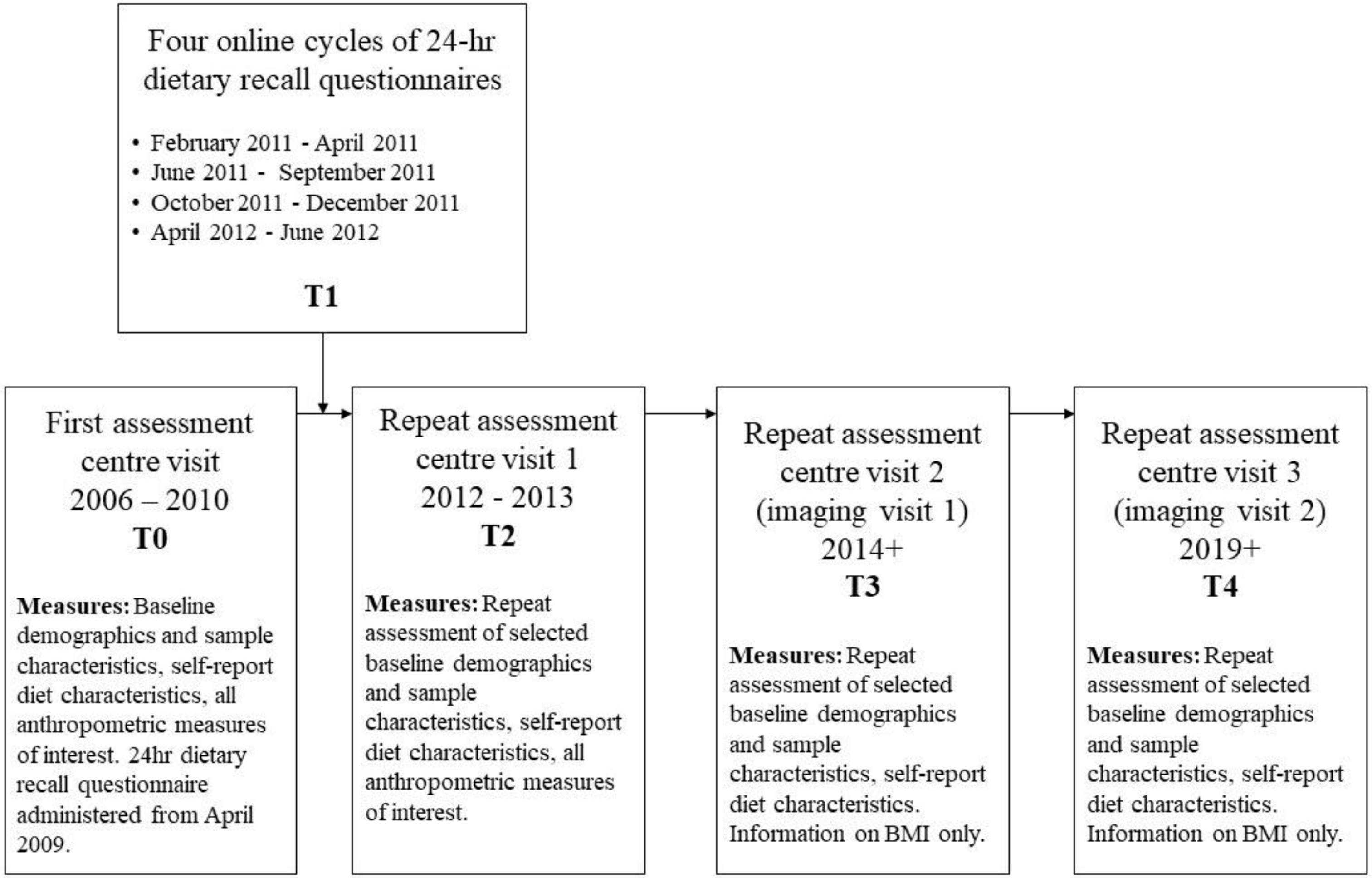


Figure 10. Overview of the data collection timeline for the UK Biobank, and measures of interest collected at each timepoint.

6.3.2. Participant eligibility for current sample

Participants were eligible for the project sample if they had both dietary recall questionnaire data and BMI recorded at baseline. Participants were included in the project sample if they had self-reported experiencing no major dietary changes in the preceding 5 years, had no recent experiences of poor appetite or overeating, were not currently pregnant (where relevant), had not been previously or currently diagnosed with cancer by a doctor, and had not reported any ongoing behavioural addictions or substance dependencies. Participants were excluded if they self-reported having a current or history of professionally diagnosed eating disorders. Participants were also excluded from the sample if their daily energy intake had been flagged by the Biobank as 'not credible' (>20 MJ/ 4780 kcal for males, >18 MJ/ 4302 kcal for females), or if their daily energy intake would otherwise be deemed implausible according to recommended energy intakes (daily energy intake < 2 MJ/ 500 kcal) (Banna et al., 2017; Rhee et al., 2015). Where information about current pregnancy, major dietary change, cancer diagnoses and data credibility had been reassessed during follow-up visits, participant data was checked and removed from the relevant timepoint if eligibility criteria (listed above) were no longer met.

6.3.3. Measures

6.3.3.3. 24-hr dietary recall questionnaires

The Oxford webQ 24-hr dietary recall questionnaire (B. Liu et al., 2011) was first administered to participants at baseline, before they were subsequently invited to complete up to four follow-up assessments via email (The UK Biobank, 2012). Participants were asked to report their consumption of >200 individual foods and beverages during the previous day. Foods and beverages were presented to participants in 21 broader categories that expanded to include individual items if relevant to the participant. For each item, participants were asked to estimate the number of servings consumed. Where possible, participants reported servings in standard ‘units’ (e.g., ‘a slice of bread’, ‘an individual pot of yoghurt’). For an item to be reported, participants must have consumed ≥ 0.25 serving (self-assessed).

Participants also provided information about their general diet and engagement in physical activity during the recall period using multiple-choice lists. Participants self-reported dietary restrictions (relating to products containing eggs, dairy, wheat, and sugar), and whether or not they followed any type of special diet (including gluten-free, lactose-free, low calorie, vegetarian, vegan). Participants self-reported time spent doing vigorous (e.g., physically demanding work, fast running/cycling), moderate (e.g., brisk walking, jogging), and light exercise (e.g., leisurely walking, housework). Participants commented on the perceived typicality of their reported servings in comparison to people they know (“How would you describe your serving size?”). As a data check at the end of the survey, participants were asked “Would you say that what you ate and drank yesterday was fairly typical for you?”.

For more information about dietary questionnaires and procedures, see the UK Biobank guidelines (The UK Biobank, 2012).

6.3.3.4. Dietary variety scores

Overall dietary variety score (DVS). For each 24-hr dietary recall questionnaire, the number of individual foods and energy-containing beverages consumed was calculated. Condiments, breakfast food condiments, and beverage condiments (see **Table 23**) were excluded from this count to avoid repetition of items (e.g., oil for cooking, milk for cereal, sugar in tea/ coffee). Scores could range from 1 – 203 items, with higher scores indicating greater dietary variety.

Dietary variety between food groups score (DVS-B). Following McCrory et al. (McCrory et al., 1999), individual foods and beverages were categorised into ten food groups (see **Table 23**). Participants were assigned a score from 1 – 10 based on the number of food groups from which they had consumed at least one item. Each food group was counted only once, irrespective of the number of additional items consumed. Higher scores indicated that items were consumed from a greater variety of food groups.

Dietary variety within food groups score (DVS-W). The percentage of individual foods/ beverages consumed from within each defined food group was determined (see **Table 23**). Scores for condiment groups were not included in data analyses (condiments, breakfast condiments, and beverage condiments), as items generally referred to broader yes/ no categories without measuring serving sizes. For each specific food group, a higher percentage indicated a greater variety of items consumed.

Self-evaluated dietary variety. As part of questionnaires completed at the baseline assessment centre visit, participants self-reported beliefs about variety in their diet ("Does your diet vary much from week to week?"), and provided answers on a 3-point scale ('never/rarely', 'sometimes', 'often').

Table 23. Foods and beverages included in the Oxford WebQ 24-hr dietary recall questionnaire, with assignment to ten food groups[1].

Food group no	Food group name	Items included
1	Breakfast foods	Cereals (including porridge, muesli, whole-wheat cereals and sweetened cereals); whole eggs, omelette, other eggs; sausage, bacon
2	Lunch and dinner entrees	Pizza; instant, canned and homemade soups; white and wholegrain pasta; sandwiches with eggs; beef, pork, lamb, poultry, ham, liver, other meat intake; crumbed or deep-fried poultry, breaded fish, battered fish; sushi, tinned tuna, oily fish, white fish, prawns, lobster/crab, other fish; vegetarian sausages/burgers, tofu, Quorn, other vegetarian alternatives
3	Sweets, snacks, and carbohydrates	Sliced bread, baguettes, baps, bread rolls, naan bread, garlic bread, crisp bread, oatcakes, other bread; white and brown rice, Cous Cous, other grains; boiled/baked potatoes, fried potatoes, mashed potatoes, sweet potatoes; Yorkshire pudding, Indian snacks; pastry, crumble, pancakes, croissants, scones, cakes, doughnuts, sponge pudding; yogurt, ice cream, milk-based pudding, other milk-based pudding, cheesecake; soya dessert, other dessert; chocolate, sweets, diet sweets, sweet biscuits, cereal bars, other sweets; salted nuts, unsalted nuts, seeds, olives, crisps, savoury biscuits, scotch egg, other savoury snacks, snack pot
4	Condiments	Butter/margarine on breads, butter/margarine added to potatoes; added salt to food, spreads/sauces consumed, use of cooking fat

Food group no	Food group name	Items included
5	Fruits	Stewed fruit, prune, dried fruit; berry, cherry, grape; grapefruit, mango, melon, orange, satsuma, peach/nectarine, plum, pineapple; apple, banana, pear; mixed fruit, other fruit
6	Vegetables	Baked beans, pulses, broad beans, green beans, peas; coleslaw, cabbage/kale, turnip/swede, butternut squash, parsnip; side salad, watercress, cucumber, celery, lettuce; garlic, onion; avocado, beetroot, broccoli, carrot, cauliflower, courgette, leek, mushroom, sweet pepper, spinach, sprouts, sweetcorn, fresh and tinned tomatoes; mixed vegetables, vegetable pieces, other vegetables
7	Energy-containing beverages	Low-calorie drinks, fizzy drinks, squash; fruit and vegetable juices, smoothies; coffees, teas, decaffeinated coffee, decaffeinated tea, hot chocolate; milk, flavoured milk; other non-alcoholic drinks; beer, cider, wine, fortified wine, and spirits
8	Other dairy products	Low fat cheeses, hard cheese, soft cheese, blue cheese, mozzarella, goat's cheese, feta; cheese spreads, cottage cheese, and other cheeses
9	Breakfast food condiments	Dried fruit added to cereals, milk added to cereals, sugar added to cereals, artificial sweetener added to cereals
10	Beverage condiments	Added milk, added sugar, added artificial sweetener

[1] In line with the approach of McCrory et al. (McCrory et al., 1999), individual foods and beverages were categorised into ten food groups.

6.3.3.5. Portion size and energy density

Total weight of food consumed was automatically generated by assigning portion sizes to individual foods and beverages, and nutritional content (including energy intake) was estimated by allocating nutrient codes from standard food composition tables (The UK Biobank, 2012). For overall intake for each dietary questionnaire (across items and food groups), these data were readily available in the dataset. Procedures that were comparable to those reported by the UK Biobank were used to calculate intake within defined food groups. For individual items, standard portion sizes were used to estimate weight consumed (Ministry of Agriculture Fisheries and Food, 1993), and standard food composition tables were used to estimate energy intake (Holland et al., 1991). Total intake of items was then calculated for each individual food group. Values > 16 Kj/ g (4 kcal/ g) indicate ‘high’ energy density (Rolls, 2017).

When considering the measurement of portion size and energy density for the recall period, the potential issue of structural multicollinearity within models was considered given that common measures would be shared between derived variables. To calculate average portion size consumed per item, total weight of food consumed (g) was initially divided by the overall DVS score (as indicated in the preregistration of data analyses). However, including this variable in the model appeared to inflate the strength of the relationship between DVS and portion size (r_s = -0.30 - -0.62). As such, total weight of food consumed (g) was used to indicate cumulative portion size. To calculate energy density (Kj/ g), total energy consumed (Kj) was divided by the total weight of food consumed (g), and there were no apparent issues with including both total weight of food consumed and energy density within the same model (r_s = -0.34 - -0.37).

6.3.3.6. Anthropometric outcome measures

Anthropometric measurements were collected from participants during assessment centre visits (for a detailed description of procedures, see (The UK Biobank, 2014)). Standing height and waist circumference were measured using a Seca 240-cm height measure and Seca 200-cm tape measure respectively, and manually recorded (in cm) by Biobank staff. Body weight (in kg), whole body fat (%) and fat free mass (in kg) were uploaded directly from a Tanita BC418MA body composition analyser. Where otherwise required, body weight was measured using standard weighing scales, and manually recorded by Biobank staff. Height and weight measurements were used to calculate BMI (kg/ m^2), and this was readily available as a data field within the dataset.

6.3.4. Data analyses

At baseline, 35 449 participants were eligible for inclusion in the study, had completed the 24-hr dietary recall questionnaire, and had BMI recorded. Of these participants, 34 974 and 34 992 had body fatness and fat-free mass measured respectively. Initial data cleaning was conducted in Python; this included identifying eligible participants for the study, removing unnecessary columns from the dataset, creating variable scores for multiple timepoints (including energy density and dietary variety scores), and reshaping data for analyses. Moderated mediation models were conducted using PROCESS v3.5.3 (A. F. Hayes, 2018), and remaining data analyses were conducted in Stata 16.0 (StataCorp, 2019). For access to data cleaning and analysis scripts, see the OSF (https://osf.io/hfrej/).

A series of bivariate correlation analyses were used to identify significant covariates to be controlled in models by directly correlating predictors with outcome variables (potential covariates included; age, sex, age completing full-time education, whether or not 24-hr recall data was self-reported to be a typical representation of the participant's diet, whether or not participants self-reported having dietary restrictions, level of physical activity reported during the recall period, and IMD score). Where relevant, categorical covariates were dummy coded to produce binary variables, and all covariates were entered at baseline (T0). If covariates were significant but had missing data, models were repeated with these variables included as part of sensitivity analyses to check for differences in effects. To explore relationships between derived variety scores and participants' perception of variety in their diet, point-biserial correlation was used to correlate DVS, DVS-B, and DVS-W scores with participants' self-evaluated rating of dietary variety at baseline (entered as 'never varies' vs. 'sometimes/ often varies'). Pairwise correlation analyses were also used to explore the relationship between DVS-W scores, cumulative portion size within groups, and energy density within groups. Across these analyses, non-parametric tests were used (Spearman's) as data were not normally distributed.

To test the hypothesised mediated moderation effect of dietary variety on body weight outcomes, a series of second-stage moderated mediation models were conducted at baseline (T0) (see **Figure 11**). Dietary variety scores were included as the predictor (X), cumulative portion size was entered as the mediator (M), and overall energy density was entered as the moderator (W) of both the direct and mediated pathways. BMI, body fat percentage, and fat-free mass were included as the outcome (Y). Pairwise correlation analyses (Spearman's) identified participant sex (r_{pb} = .185 - .842) as a significant covariate to be controlled in models. Effect of age completing full-time education (N = 21 068, r_s = -.100) was explored as part of sensitivity analyses. Across models, predictors were mean-centred, confidence intervals were adjusted using bias-corrected bootstrap approaches (5000 samples), and HC3 was used to adjust standard errors for heteroscedasticity (A. F. Hayes & Cai, 2007). See **Table 24** for correlations between model predictors.

To explore longitudinal changes in body weight outcomes, second-stage moderated mediation models conducted at baseline were repeated with dietary variety scores entered at T0, and composite scores for cumulative portion size and energy density entered at T1 (averaged across completed follow-up questionnaires). BMI was included as the outcome at T2 and T3, and body fat percentage and fat free mass at T2. Participant sex (r_{pb} = .177 - .848), age (r_s = .143), IMD score for England (r_s = .105), and time spent doing vigorous physical activity (r_{pb} = -.158), were included as significant covariates. Baseline measures of BMI, body fat percentage, and fat free mass were also controlled in the appropriate model. Effect of age completing full-time education (r_s = -.160) was again explored in sensitivity analyses. A series of Wilcoxon signed-rank tests were used to check for differences in dietary intake and body weight outcomes between timepoints. As < 50 participants had both dietary data and BMI collected at T4, this timepoint was dropped from analyses. See **Table 25** for correlations between model predictors.

Unless otherwise stated, effects were significant if confidence intervals did not cross zero, and $p < .05$. However, given the large sample size and increased risk of finding significant but 'trivial' effects across multiple models (Kaplan et al., 2014; Khalilzadeh & Tasci, 2017; Lantz, 2013), overall model and coefficient effects were considered meaningful if equivalent to a 'small effect size' (observed $R^2 \geq .02$; $r \geq .10$) (Cohen, 1992). To align with current longitudinal trends in weight gain and development of overweight (Katan & Ludwig, 2010), change in dietary intake was identified as significant if it indicated ≥13 kcal increase in daily food consumption per unit (≈ 2.7 g based on average energy conversion values (Holland et al., 1991)). Given weight change patterns reported in other samples, change in BMI was identified as significant if it increased by at least 0.10 kg/m^2 (Guo et al., 1999; Hughes et al., 2002; Kahn et al., 1997; C. E. Lewis et al., 2000; Rosell et al., 2006), and body fat if it increased by at least 0.3% (Guo et al., 1999).

As part of exploratory sensitivity checks, total energy intake for the recall period was tested as the mediator in models at baseline and follow-up (converted to kcal), and a similar pattern of results was found (for brevity, pathway coefficients are included in supplementary materials on the OSF: https://osf.io/tv4j8). To check for potential differences in energy density depending on the inclusion of beverages, estimated values for energy intake and weight of food consumed within food groups were also used to calculate energy density after removing estimated beverage scores. Overall energy density scores (Kj/ g) were lower than estimated energy density scores (without beverages) at baseline (mean difference = -3.38, SD = 1.81) and follow-up (mean difference = -3.12, SD = 1.33). However, mean scores were < 6.28 Kj/ g across measures, indicating ‘low’ energy density (Rolls, 2017).

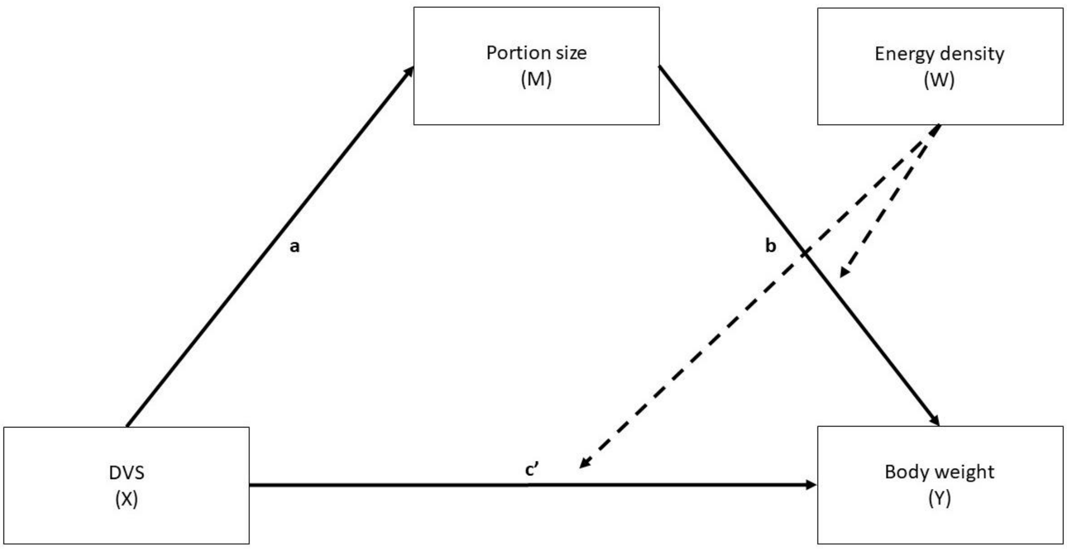


Figure 11. Overview of proposed mediated moderation model predicting body weight outcomes (Y), including dietary variety (X), cumulative portion size (M), and energy density (W) in direct and mediated pathways.

Table 24. Correlations (Spearman's) between model predictors and outcomes at baseline.[1]

Variable	**BMI (Kg/m²) (T0)**	**Whole body fat (%) (T0)**	**Fat-free mass (Kg) (T0)**	**1**	**2**	**3**	**4**
1. Portion size (g)	.013	-.111 *	.145 *	-			
2. Energy density (Kj/ g)	.030	-.122 *	.159 *	-.338 *	-		
3. Sex [2]	.185 *	-.675 *	.842 *	.109 *	.167 *	-	
4. Age completing full-time education (yrs)	-.100 *	-.077	.009	.056	-.010	-.018	-
DVS [3]	-.121 *	-.030	-.069	.504 *	.021	-.084	.129 *
DVS-B [4]	-.112 *	-.030	-.057	.251 *	.069	-.055	.061
DVS-W (%) [5]							
Breakfast foods	-.028	-.061	.037	.128 *	.081	.051	-.002
Lunch and dinner entrees	.005	-.014	.030	.175 *	.058	.008	.082
Sweets, snacks, and carbohydrates	-.036	-.049	.024	.171 *	.406 *	.007	.040

Variable	BMI (Kg/m^2) (T0)	Whole body fat (%) (T0)	Fat-free mass (Kg) (T0)	1	2	3	4
Fruits	-.121 *	.014	-.131 *	.291 *	-.174 *	-.132 *	.069
Vegetables	-.099	.035	-.122 *	.319 *	-.157 *	-.123 *	.079
Energy-containing beverages	-.014	-.073	.079	.385 *	-.041	.068	.087
Other dairy products	-.052	-.033	-.001	.076	.097	-.017	.050

[1] Significance denoted for coefficients ≥ .10, and indicated as * < .001.

[2] ‘Sex’ binary coded as 0 = female, 1 = male.

[3] Dietary variety score calculated as the count of individual foods and beverages consumed across food groups.

[4] Dietary variety score calculated as the count of food groups from which participants consumed ≥ 1 food or beverage, scored from 1 – 10.

[5] Dietary variety score calculated as the percentage of items consumed from within each food group.

Table 25. Correlations (Spearman's) between model predictors and outcomes at follow-up.[1]

Variable	**BMI (Kg/ m²) (T2)**	**BMI (Kg/ m²) (T3)**	**Whole body fat (%) (T2)**	**Fat-free mass (Kg) (T2)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Portion size (g) (T1)	.065	.044	-.089	.157**	-									
2. Energy density (Kj/ g) (T1)	.012	.008	-.132**	.188**	-.372**	-								
3. Sex [2]	.177**	.218**	-.684**	.848**	.105**	.180**	-							
4. Age completing full-time education (yrs)	-.160*	-.066	-.082	-.052	.025	-.006	-.018	-						
5. Age (yrs)	.143**	.027	.077	.004	-.000	.004	.050	-.018	-					
6. Index of Multiple Deprivation (IMD) England [6]	.070	.105**	.014	.027	-.034	.007	.013	-.140**	-.088	-				

Variable	BMI (Kg/ m^2) (T2)	BMI (Kg/ m^2) (T3)	Whole body fat (%) (T2)	Fat-free mass (Kg) (T2)	1	2	3	4	5	6	7	8	9	10
7. Vigorous physical activity [7]	-.040	-.014	-.158**	.093	.057	-.027	.082	-.053	.011	.015	-			
8. BMI (Kg/m^2) (T0)	.948**	.918**	.398**	.432**	.035	.002	.185**	-.100**	.080	.091	-.010	-		
9. Whole body fat (%) (T0)	.423**	.361**	.947**	-.485**	-.090	-.150**	-.675**	-.077	.099	.046	-.099	.458**	-	
10. Fat-free mass (Kg) (T0)	.418**	.452**	-.467**	.982**	.145**	.158**	.842**	.009	-.046	.019	.069	.468**	-.452**	-
DVS (T0) [3]	-.092	-.112**	-.027	-.067	.265**	-.041**	-.084	.129**	.105**	-.125	.002	-.121**	-.030	-.069
DVS-B (T0) [4]	-.078	-.079	-.026	-.033	.136**	.031	-.055	.061	.126**	-.120	-.010	-.112**	-.030	-.057
DVS-W (%) (T0) [5]														
Breakfast foods	-.033	-.020	-.056	.021	.080	.039	.051	-.002	.102**	-.058	.009	-.028	-.061	.037

Variable	**BMI (Kg/ m²) (T2)**	**BMI (Kg/ m²) (T3)**	**Whole body fat (%) (T2)**	**Fat-free mass (Kg) (T2)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Lunch and dinner entrees	.010	.038	.014	.007	.076	.009	.008	.082	-.043	-.054	-.030	.005	-.014	.030
Sweets, snacks, and carbohydrates	-.047	-.042	-.067	.030	.079	.189**	.007	.040	.003	-.038	-.013	-.036	-.049	.024
Fruits	-.114**	-.152**	-.032	-.099	.199**	-.158**	-.132	.069	.157**	-.095	.013	-.121**	.014	-.131**
Vegetables	-.078	-.099	.043	-.118**	.151**	-.117**	-.123**	.079	.086	-.067	-.002	-.099	.035	-.122**
Energy-containing beverages	.004	.004	-.041	.036	.187**	-.013	.068	.087	.046	-.092	.010	-.014	-.073	.079
Other dairy products	-.041	-.030	-.020	.003	.042	.036	-.017	.050	.002	-.048	-.007	-.052	-.033	-.001

[1] Significance denoted for coefficients ≥ .10, and indicated as * $p < .01$, ** $p < .001$.

[2] ‘Sex’ binary coded as 0 = female, 1 = male.

[3] Dietary variety score calculated as the count of individual foods and beverages consumed across food groups.

[4] Dietary variety score calculated as the count of food groups from which participants consumed ≥ 1 food or beverage, scored from 1 – 10.

[5] Dietary variety score calculated as the percentage of items consumed from within each food group.

[6] Higher scores indicate residential areas have greater levels of deprivation.

[7] ‘Vigorous physical activity’ binary coded as 0 = 0 – 60 minutes of activity, 1 = 1 – 6+ hours of activity.

6.4. Results

6.4.1. Cross-sectional analyses at baseline

6.4.1.3. Participant characteristics

Table 26 displays sample characteristics. Of those included in the sample, 52.3% were female. Most participants identified themselves as British (87.9%) or Irish (2.7%), or other White background (3.8%), and were either in paid employment (59.6%) or retired (32.7%). Specific dietary restrictions were reported by 16.7% of participants (no eggs, dairy, wheat, and/ or sugar), 13.6% followed a special diet (including gluten-free, lactose-free, low calorie, vegetarian, vegan or other), and 39.1% were users of vitamin supplements. Most participants reported doing between 0 – 60 minutes of vigorous (92.5%) and moderate (83.7%) physical activity, and between 0 – 5 hours of light physical activity (93.1%) in the 24-hr recall period. 83.2% reported that recall of their diet was representative of their typical eating habits, and 40.5% reported 'never/ rarely' varying their diet from week-to-week. See **Table 27** for dietary intake at baseline.

Table 26. Overview of sample characteristics at baseline (T0).[1]

Demographic	**Female (N = 18 551)**	**Male (N = 16 898)**	**Overall (N = 35 449)**
Age (yrs)	55.9 ± 8.2 (40.0 – 70.0)	56.6 ± 8.3 (40.0 – 70.0)	56.2 ± 8.3 (40.0 – 70.0)
Age completing full-time education (yrs)	17.0 ± 2.1 (0.0 – 35.0)	17.1 ± 2.5 (0.0 – 35.0)	17.0 ± 2.3 (0.0 – 35.0)
Index of Multiple Deprivation (IMD) [2, 3]			
England (N = 34 338)	15.4 ± 11.5 (1.44 – 79.3)	15.9 ± 12.1 (1.43 – 82.0)	15.7 ± 11.8 (1.43 – 82.0)
Wales (N = 299)	12.3 ± 10.2 (2.6 – 61.6)	13.2 ± 11.4 (2.6 – 57.7)	12.7 ± 10.8 (2.6 – 61.6)
BMI (Kg/m^2)	26.0 ± 4.7 (15.2 – 59.5)	27.2 ± 3.9 (14.9 – 63.4)	26.5 ± 4.4 (14.9 – 63.4)
Whole body fat (%)	35.4 ± 6.8 (9.4 – 63.1)	24.5 ± 5.7 (5.0 – 52.6)	30.2 ± 8.3 (5.0 – 63.1)
Fat-free mass (Kg)	44.0 ± 4.7 (29.5 – 78.0)	63.4 ± 7.5 (35.7 – 100.0)	53.2 ± 11.5 (29.5 – 100.0)
Waist circumference (cm)	82.1 ± 11.7 (48.0 – 157.0)	95.2 ± 10.8 (63.0 – 163.0)	88.3 ± 13.1 (48.0 – 163.0)

[1] Mean ± SD (range).

[2] Higher scores indicate residential areas have greater levels of deprivation.

[3] Statistics not reported for Scotland as IMD score was available for a single participant.

Table 27. Dietary intake at baseline (T0) and follow-up (T1).[1]

Variable	**T0**			**T1**		
	Female (N = 18 551)	Male (N = 16 898)	Overall (N = 35 449)	Female (N = 940)	Male (N = 1 056)	Overall (N = 1 996)
Energy intake (MJ/ day)	8.1 ± 2.5	9.6 ± 3.0	8.8 ± 2.8	8.3 ± 1.8	9.4 ± 2.3	8.9 ± 2.1
	(2.1 – 18.0)	(2.1 – 20.0)	(2.1 – 20.0)	(3.1 – 15.7)	(3.8 – 17.4)	(3.1 – 17.4)
Food weight consumed (kg/ day)	3.1 ± 0.8	3.4 ± 1.0	3.2 ± 0.9	3.1 ± 0.6	3.3 ± 0.8	3.2 ± 0.7
	(0.3 – 9.8)	(0.6 – 9.7)	(0.3 – 9.8)	(1.4 – 6.1)	(1.4 – 6.4)	(1.4 – 6.4)
Energy density (Kj/ g)	2.7 ± 0.8	2.9 ± 0.8	2.8 ± 0.8	2.8 ± 0.6	3.0 ± 0.7	2.9 ± 0.7
	(0.7 – 9.4)	(0.8 – 9.5)	(0.7 – 9.5)	(1.2 – 5.4)	(1.3 – 6.3)	(1.2 – 6.3)
Protein (g/ day)	76.3 ± 25.4	85.5 ± 30.2	80.7 ± 28.2	77.4 ± 19.2	84.6 ± 22.1	81.2 ± 21.1
	(7.8 – 246.7)	(4.6 – 364.1)	(4.6 – 364.1)	(25.8 – 155.1)	(21.3 – 189.3)	(21.3 – 189.3)
Carbohydrate (g/ day)	239.9 ± 83.1	273.7 ± 95.6	256.0 ± 90.9	240.0 ± 63.4	268.6 ± 73.3	255.2 ± 70.3
	(18.0 – 702.7)	(6.5 – 783.4)	(6.5 – 783.4)	(70.0 – 524.7)	(80.0 – 578.4)	(70.0 – 578.4)

Variable	**T0**			**T1**		
	Female (N = 18 551)	Male (N = 16 898)	Overall (N = 35 449)	Female (N = 940)	Male (N = 1 056)	Overall (N = 1 996)
Total fat (g/ day)	71.8 ± 30.7	82.9 ± 35.8	77.1 ± 33.7	74.2 ± 23.8	82.1 ± 28.6	78.4 ± 26.7
	(2.3 – 248.2)	(1.5 – 268.2)	(1.5 – 268.2)	(16.7 – 159.9)	(17.9 – 226.9)	(16.7 – 226.9)
Saturated fat (g/ day)	27.5 ± 12.9	32.2 ± 15.3	29.7 ± 14.3	28.4 ± 10.5	31.5 ± 12.4	30.0 ± 11.6
	(0.3 – 103.9)	(0.7 – 116.3)	(0.3 – 116.3)	(4.8 – 73.4)	(5.6 – 95.5)	(4.8 – 95.5)
Total sugars (g/ day)	116.7 ± 51.2	126.5 ± 56.0	121.4 ± 53.7	115.6 ± 39.8	124.7 ± 43.6	120.4 ± 42.1
	(3.6 – 522.4)	(0.4 – 548.3)	(0.4 – 548.3)	(25.3 – 342.9)	(29.7 – 294.3)	(25.3 – 342.9)
DVS [2]	16.9 ± 5.3	16.1 ± 5.4	16.5 ± 5.4	17.8 ± 4.4	17.1 ± 4.7	17.5 ± 4.5
	(2.0 – 46.0)	(2.0 – 53.0)	(2.0 – 53.0)	(7.5 – 36.0)	(4.0 – 36.0)	(4.0 – 36.0)
DVS-B [3]	7.9 ± 1.4	7.7 ± 1.5	7.8 ± 1.4	8.1 ± 1.1	7.9 ± 1.2	8.0 ± 1.1
	(1.0 – 10.0)	(1.0 – 10.0)	(1.0 – 10.0)	(3.0 – 10.0)	(4.0 – 10.0)	(3.0 – 10.0)
DVS-W (%) [4]						
Breakfast foods	7.9 ± 6.0	8.6 ± 6.6	8.2 ± 6.3	8.5 ± 4.9	9.2 ± 5.6	8.9 ± 5.3

Variable	**T0**			**T1**		
	Female (N = 18 551)	Male (N = 16 898)	Overall (N = 35 449)	Female (N = 940)	Male (N = 1 056)	Overall (N = 1 996)
	(0.0 – 53.8)	(0.0 – 46.2)	(0.0 – 53.8)	(0.0 – 26.9)	(0.0 – 34.6)	(0.0 – 34.6)
Lunch and dinner entrees	4.9 ± 3.1	4.9 ± 3.1	4.9 ± 3.1	5.2 ± 2.3	5.1 ± 2.5	5.2 ± 2.4
	(0.0 – 33.3)	(0.0 – 33.3)	(0.0 – 33.3)	(0.0 – 16.7)	(0.0 – 20.0)	(0.0 – 20.0)
Sweets, snacks, and carbohydrates	6.6 ± 2.8	6.7 ± 3.0	6.7 ± 2.9	7.0 ± 2.3	7.0 ± 2.5	7.0 ± 2.4
	(0.0 – 24.2)	(0.0 – 25.8)	(0.0 – 25.8)	(0.8 – 14.5)	(0.0 – 16.1)	(0.0 – 16.1)
Condiments	25.7 ± 22.3	23.6 ± 22.7	24.7 ± 22.5	27.8 ± 17.6	25.7 ± 19.1	26.7 ± 18.4
	(0.0 – 100.0)	(0.0 – 100.0)	(0.0 – 100.0)	(0.0 – 100.0)	(0.0 – 100.0)	(0.0– 100.0)
Fruits	11.6 ± 8.6	9.4 ± 8.0	10.5 ± 8.4	11.6 ± 7.5	10.2 ± 7.4	10.9 ± 7.5
	(0.0 – 73.7)	(0.0 – 73.7)	(0.0 – 73.7)	(0.0 – 47.4)	(0.0 – 59.6)	(0.0 – 59.6)
Vegetables	10.6 ± 8.8	8.6 ± 8.2	9.6 ± 8.6	10.8 ± 6.7	9.5 ± 6.7	10.1 ± 6.7
	(0.0 – 62.9)	(0.0 – 68.6)	(0.0 – 68.6)	(0.0 – 40.0)	(0.0 – 42.9)	(0.0 – 42.9)
Energy-containing beverages	10.6 ± 4.7	11.3 ± 4.8	10.9 ± 4.8	11.5 ± 4.3	11.8 ± 4.1	11.7 ± 4.2

Variable	**T0**			**T1**		
	Female (N = 18 551)	Male (N = 16 898)	Overall (N = 35 449)	Female (N = 940)	Male (N = 1 056)	Overall (N = 1 996)
	(0.0 – 37.5)	(0.0 – 43.8)	(0.0 – 43.8)	(0.0 – 28.1)	(1.6 – 28.1)	(0.0 – 28.1)
Other dairy products	4.9 ± 5.8	4.7 ± 5.9	4.8 ± 5.8	5.0 ± 4.9	4.7 ± 4.6	4.9 ± 4.7
	(0.0 – 54.5)	(0.0 – 90.9)	(0.0 – 90.9)	(0.0 – 27.3)	(0.0 – 27.3)	(0.0 – 27.3)
Breakfast food condiments	25.1 ± 22.6	26.0 ± 23.3	25.5 ± 22.9	26.3 ± 19.8	27.8 ± 20.2	27.1 ± 20.0
	(0.0 – 100.0)	(0.0 – 100.0)	(0.0 – 100.0)	(0.0 – 75.0)	(0.0 – 75.0)	(0.0 – 75.0)
Beverage condiments	15.6 ± 10.5	17.8 ± 11.6	16.7 ± 11.1	15.2 ± 9.3	16.6 ± 10.7	16.0 ± 10.1
	(0.0 – 60.0)	(0.0 – 70.0)	(0.0 – 70.0)	(0.0 – 50.0)	(0.0 – 50.0)	(0.0 – 50.0)

[1] Mean ± SD (range).

[2] Dietary variety score calculated as the count of individual foods and beverages consumed across food groups.

[3] Dietary variety score calculated as the count of food groups from which participants consumed ≥ 1 food or beverage, scored from 1 – 10.

[4] Dietary variety score calculated as the percentage of items consumed from within each food group.

6.4.1.4. Dietary variety scores as predictors of body weight outcomes

After controlling for effects of participant sex, models conducted at baseline (**Figure 12**) showed that contrary to predictions, higher DVS was a significant and negative predictor of BMI and fat-free mass. Though greater dietary variety significantly predicted increased daily food intake and the consumption of larger portions overall, cumulative portion size did not directly predict BMI, body fatness, or fat-free mass. Energy density did not significantly moderate the effect of DVS – or portion size – on BMI, body fatness, or fat-free mass. Moderated mediation effects of DVS on BMI (Index = .007, bootstrap SE = .003, bootstrap 95% CI = .001, .013) and fat-free mass (Index = .035, bootstrap SE = .005, bootstrap 95% CI = .026, .044) were significant but relatively small, as the conditional indirect effect of DVS increased at higher levels of energy density for both BMI (-1SD Effect = .037 vs. +1SD Effect = .048, bootstrap SE = .005, bootstrap 95% CI = .002, .021) and fat-free mass (-1SD Effect = .098 vs. +1SD Effect = .156, bootstrap SE = .008, bootstrap 95% CI = .042, .073). The moderated mediation effect of DVS on body fatness was not supported (Index < .001, bootstrap SE = .004, bootstrap 95% CI = -.009, .009).

A similar pattern of results was also observed when dietary variety between food groups (DVS-B) and dietary variety within each individual food group (DVS-W) were included as predictors, and participants' self-evaluated rating of variety was positively associated with body weight outcomes (see **Table 28**). Pairwise correlation analyses also showed that, for each individual food group, consuming a greater variety of items was significantly and positively associated with portion size consumed, and this in turn was positively associated with higher energy density for that particular group (with the exception of sweets, snacks, and carbohydrates) (see **Table 29**). However, the relationship between DVS and whether or not participants reported varying their diet from week-to-week was 'trivial' (N = 35 435, r_{pb} = .011).

Across baseline models, a similar pattern of results was found when 'age completing full-time education' was included as a covariate (see supplementary sensitivity analyses on the OSF: https://osf.io/tv4j8).

Table 28. DVS-B, DVS-W, and 'self-evaluated' dietary variety as predictors of portion size and body weight outcomes at baseline (T0), where X is the predictor (dietary variety) and W is the moderator (energy density).[1, 2]

Predictor	Portion size (g)	BMI (Kg/m^2)		Body fat (%)		Fat-free mass (Kg)	
		X	X * W	X	X * W	X	X * W
DVS-B	153, 3.31 (147, 159) ***	-.371, .02 (-.407, -.336) ***	-.047, .02 (-.093, -.003)	-.396, .03 (-.445, -.347) ***	-.073, .03 (-.129, -.015)	-.334, .03 (-.384, -.284) ***	-.030, .03 (-.089, .028)
Self-evaluated dietary variety	21, 9.64 (3, 41) *	.872, .05 (.783, .963) ***	.009, .06 (-.104, .131)	1.219, .07 (1.085, 1.349) ***	-.042, .09 (-.201, .120)	.646, .07 (.515, .777) ***	.004, .09 (-.161, .176)
DVS-W							
Breakfast foods	16, .77	-.028, .00	-.004, .01	-.031, .01	-.011, .01	-.034, .01	.002, .01

Predictor	**Portion size (g)**	**BMI (Kg/m^2)**		**Body fat (%)**		**Fat-free mass (Kg)**	
		X	**X * W**	**X**	**X * W**	**X**	**X * W**
	(15, 18) ***	(-.035, -.021)	(-.014, .005)	(-.041, -.020)	(-.024, .002)	(-.045, -.023)	(-.011, .016)
Lunch and dinner entrees	51, 1.58	.004, .01	.008, .01	-.002, .01	-.001, .01	.026, .01	.003, .01
	(48, 54) ***	(-.011, .019)	(-.010, .027)	(-.025, .019)	(-.025, .025)	(.005, .048)	(-.024, .030)
Sweets, snacks, and carbohydrates	52, 1.65	-.091, .01	.037, .01	-.124, .01	.034, .01	-.102, .01	.017, .02
	(48, 55) ***	(-.109, -.072)	(.015, .062)	(-.152, -.095)	(.005, .062)	(-.128, -.073) ***	(-.012, .047)
Fruits	32, .56	-.055, .00	-.001, .00	-.078, .00	-.007, .01	-.059, .00	-.001, .01
	(30, 33) ***	(-.061, -.050)	(-.009, .007)	(-.087, .-.070)	(-.018, .004)	(-.067, -.051)	(-.011, .010)
Vegetables	35, .56	-.04, .00	-.005, .00	-.041, .00	<.001, .01	-.056, .00	-.013, .01

Predictor	Portion size (g)	BMI (Kg/m²)		Body fat (%)		Fat-free mass (Kg)	
		X	**X * W**	**X**	**X * W**	**X**	**X * W**
	(33, 36) ***	(-.046, -.034)	(-.013, .002)	(-.049, -.032)	(-.011, .011)	(-.064, -.048)	(-.023, -.002)
Energy-containing beverages	71, .94	-.037, .01	-.006, .01	-.026, .01	.010, .01	-.026, .01	-.011, .01
	(69, 73) ***	(-.047, -.026)	(-.019, .008)	(-.041, -.011)	(-.009, .030)	(-.041, -.011)	(-.030, .008)
Other dairy products	12, .79	-.035, .00	-.002, .01	-.059, .01	.006, .01	.006, .01	-.001, .01
	(11, 14) ***	(-.043, -.028)	(-.012, .007)	(-.071, -.048)	(-.009, .020)	(-.005, .017)	(-.015, .013)

[1] Unstandardised beta coefficients, adjusted SE (bootstrap LLCI, ULCI).

[2] Significance is noted as *p < .05, **p < .01, *** p < .001. If p < .05 but confidence intervals contain or cross zero, p-values are not noted as significant.

Table 29. Correlations (Spearman's) between dietary variety and portion size, and energy density and portion size, within each food group at baseline (T0).[1]

DVS-W	**Portion size (g)**
Breakfast foods	0.803*
Lunch and dinner entrees	0.751*
Sweets, snacks, and carbohydrates	0.707*
Fruits	0.903*
Vegetables	0.876*
Energy-containing beverages	0.502*
Other dairy products	0.955*
Energy density (Kj/ g)	
Breakfast foods	0.234*
Lunch and dinner entrees	0.105*
Sweets, snacks, and carbohydrates	-0.183*
Fruits	0.379*
Vegetables	0.421*
Energy-containing beverages	0.219*
Other dairy products	0.888*

[1] Significance denoted for coefficients ≥ .10, and indicated as * $p < .001$.

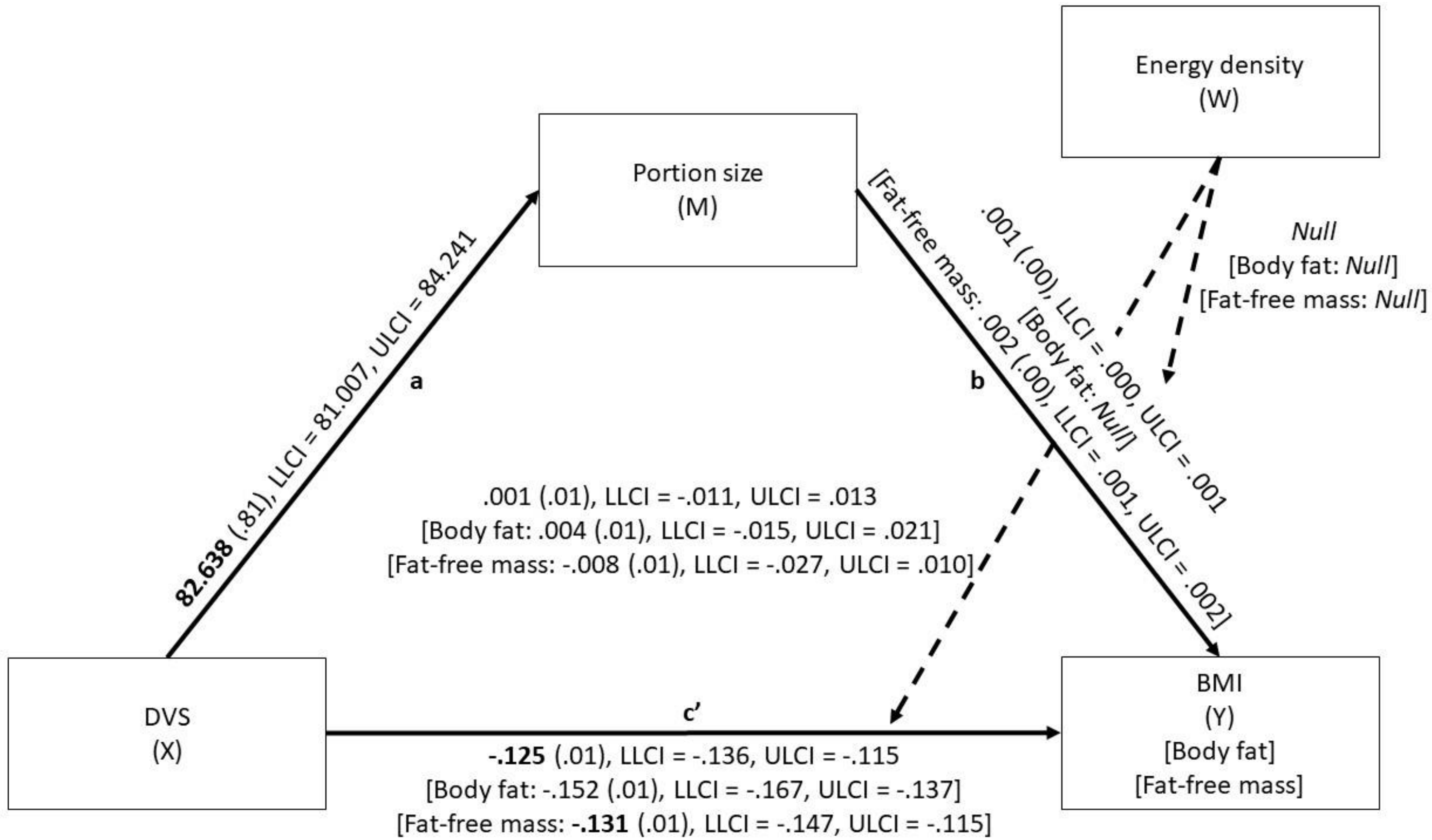


Figure 12. Baseline models of overall dietary variety (DVS) as a predictor of BMI (R^2 = .035), body fatness (R^2 = .434), and fat-free mass (R^2 = .718). Unstandardised regression coefficients (b) with adjusted standard error in brackets (SE), and Bootstrap confidence intervals are displayed (LLCI, ULCI). Pathways including the moderator are indicated with a dashed line. Where coefficients < .001, effects are indicated as ‘null’. Significant coefficients are indicated in bold (p < .001), if at least a ‘small’ effect size was observed. Where relevant, results for models with body fatness and fat-free mass are presented in brackets.

6.4.2. Longitudinal analyses at follow-up

6.4.2.3. Data availability and participant characteristics

Of 17 272 participants who had completed at least one 24-hr dietary recall questionnaire at follow-up (T1), up to 738 participants had body weight outcomes recorded at T2 (46.7% female) and 1 563 at T3 (47.3% female), meaning they were eligible for inclusion in follow-up models.

Changes in dietary intake and body weight outcomes across timepoints were small. Compared to baseline, participants were consuming a smaller cumulative portion size at T1 (T0 M = 3.3 kg, SD = 0.8 vs. T1 M = 3.2 kg, SD = 0.7; Z = 5.690, $p < .001$, r = .13), but energy density was significantly higher overall (T0 M = 2.8 Kj/ g, SD = 0.8 vs. T1 M = 2.9 Kj/ g, SD = 0.7; Z = -4.660, $p < .001$, r = .10) (see **Table 27** for dietary intake at follow-up). BMI (T0 M = 25.7 kg/ m^2, SD = 3.9 vs. T2 M = 26.0 kg/ m^2, SD = 4.1; Z = -3.639, $p < .001$, r = .13) and body fatness (T0 M = 28.6%, SD = 8.0 vs. T2 M = 29.5%, SD = 8.2; Z = -5.175, $p < .001$, r = .19) had increased at T2, whilst fat-free mass had decreased (T0 M = 53.6 kg, SD = 11.1 vs. T2 M = 52.8 kg, SD = 10.9; Z = 7.165, $p < .001$, r = .27). All other differences between timepoints for dietary intake and body weight outcomes were either not significant or trivial effects.

6.4.2.4. Time-lagged associations between dietary variety and weight-related outcomes

After controlling for effects of participant sex, age, IMD score for England, and time spent doing vigorous physical activity, time-lagged moderated mediation models (**Figure 13**) showed similar results as baseline models. DVS (T0) remained a significant and positive predictor of cumulative portion size (T1), but portion size did not significantly predict BMI (T2, T3), body fatness (T2), or fat-free mass (T2). Energy density (T1) also did not significantly interact with portion size or DVS to predict body weight outcomes at follow-up, and the moderated mediation effect of DVS on BMI (T2 Index < .001, bootstrap SE = .004, bootstrap 95% CI = -.007, .008; T3 Index < .001, bootstrap SE = .003, bootstrap 95% CI = -.006, .006), body fatness (Index = .007, bootstrap SE = .010, bootstrap 95% CI = -.012, .027), and fat-free mass (Index = -.001, bootstrap SE = .007, bootstrap 95% CI = -.014, .012) was not supported. A similar pattern of results was found when DVS-B and DVS-W were included as the predictor at T0 (see **Table 30**), and when 'age completing full-time education' was included as a covariate (see supplementary sensitivity analyses on the OSF: https://osf.io/tv4j8).

Table 30. DVS, DVS-B, and DVS-W (T0) as predictors of portion size (T1) and body weight outcomes (T2/ T3) at follow-up, where X is the predictor (dietary variety) and W is the moderator (energy density; T1).[1, 2]

Predictor	**Portion size (g) (T1)**	**BMI (Kg/m^2) (T2)**		**BMI (Kg/m^2) (T3)**		**Body fat (%) (T2)**		**Fat-free mass (Kg) (T2)**	
		X	**X * W**	**X**	**X * W**	**X**	**X * W**	**X**	**X * W**
DVS	42, 4.83 (32, 51) ***	-.001, .01 (-.017, .016)	.010, .01 (-.014, .034)	-.011, .01 (-.027, .006)	-.004, .01 (-.027, .020)	-.005, .02 (-.046, .035)	-.020, .03 (-.081, .040)	-.010, .01 (-.038, .017)	.030, .02 (-.009, .067)
DVS-B	62, 19.77 (24, 101) **	-.033, .03 (-.095, .026)	-.015, .05 (-.104, .077)	-.087, .03 (-.143, -.030)	.012, .04 (-.073, .098)	-.058, .08 (-.211, .095)	-.048, .10 (-.243, .147)	-.051, .05 (-.153, .051)	.012, .07 (-.123, .147)
DVS-W									

Predictor	**Portion size (g) (T1)**	**BMI (Kg/m²) (T2)**		**BMI (Kg/m²) (T3)**		**Body fat (%) (T2)**		**Fat-free mass (Kg) (T2)**	
		X	**X * W**	**X**	**X * W**	**X**	**X * W**	**X**	**X * W**
Breakfast foods	9, 4.06 (1, 17) *	.001, .01 (-.010, .012)	-.001, .01 (-.018, .016)	-.008, .01 (-.020, .003)	-.008, .07 (-.025, .011)	.005, .02 (-.025, .034)	-.021, .02 (-.063, .020)	-.015, .01 (-.036, .005)	.023, .02 (-.010, .051)
Lunch and dinner entrees	22, 9.13 (4, 39) *	-.008, .01 (-.032, .015)	.010, .02 (-.025, .045)	.004, .01 (-.020, .028)	.025, .02 (-.014, .061)	.028, .03 (-.031, .084)	-.046, .04 (-.125, .030)	-.022, .02 (-.066, .022)	.069, .03 (.009, .129)
Sweets, snacks, and carbohydrates	18, 8.21 (2, 34) *	.017, .02 (-.012, .045)	.031, .02 (-.007, .071)	.003, .02 (-.027, .031)	-.017, .02 (-.059, .022)	.003, .04 (-.063, .070)	.014, .04 (-.067, .099)	.031, .03 (-.022, .082)	.037, .03 (-.026, .100)
Fruits	23, 3.23	-.003, .01	.008, .01	-.013, .01	.003, .01	-.031, .01	.019, .02	.019, .01	.009, .01

Predictor	**Portion size (g) (T1)**	**BMI (Kg/m²) (T2)**		**BMI (Kg/m²) (T3)**		**Body fat (%) (T2)**		**Fat-free mass (Kg) (T2)**	
		X	**X * W**	**X**	**X * W**	**X**	**X * W**	**X**	**X * W**
	(17, 30) ***	(-.014, .008)	(-.010, .026)	(-.022, -.004)	(-.012, .017)	(-.060, -.003)	(-.022, .062)	(.001, .037)	(-.019, .036)
Vegetables	16, 3.22	-.005, .01	-.015, .01	-.002, -.01	<.001, .01	-.003, .01	-.034, .02	-.015, .01	-.008, .01
	(10, 23) ***	(-.015, .005)	(-.030, .002)	(-.011, .007)	(-.014, .014)	(-.029, .020)	(-.070, .002)	(-.032, .002)	(-.031, .015)
Energy-containing beverages	33, 5.74	.003, .01	.024, .01	.004, .01	-.013, .01	.013, .02	.038, .03	-.016, .02	.005, .02
	(22, 45) ***	(-.017, .023)	(-.002, .048)	(-.012, .020)	(-.038, .012)	(-.034, .059)	(-.020, .096)	(-.050, .017)	(-.043, .049)
Other dairy products	3, 3.756	-.012, .01	.016, .01	-.006, .01	-.002, .01	-.010, .02	.037, .02	-.014, .01	.009, .02
	(-4, 11)								

Predictor	**Portion size (g) (T1)**	**BMI (Kg/m²) (T2)**		**BMI (Kg/m²) (T3)**		**Body fat (%) (T2)**		**Fat-free mass (Kg) (T2)**	
		X	**X * W**	**X**	**X * W**	**X**	**X * W**	**X**	**X * W**
		(-.025, .001)	(-.004, .037)	(-.017, .006)	(-.019, .014)	(-.040, .019)	(-.007, .084)	(-.036, .009)	(-.026, .043)

[1] Unstandardised beta coefficients, adjusted SE (bootstrap LLCI, ULCI).

[2] Significance is noted as *p < .05, **p < .01, *** p < .001. If p < .05 but confidence intervals contain or cross zero, p-values are not noted as significant.

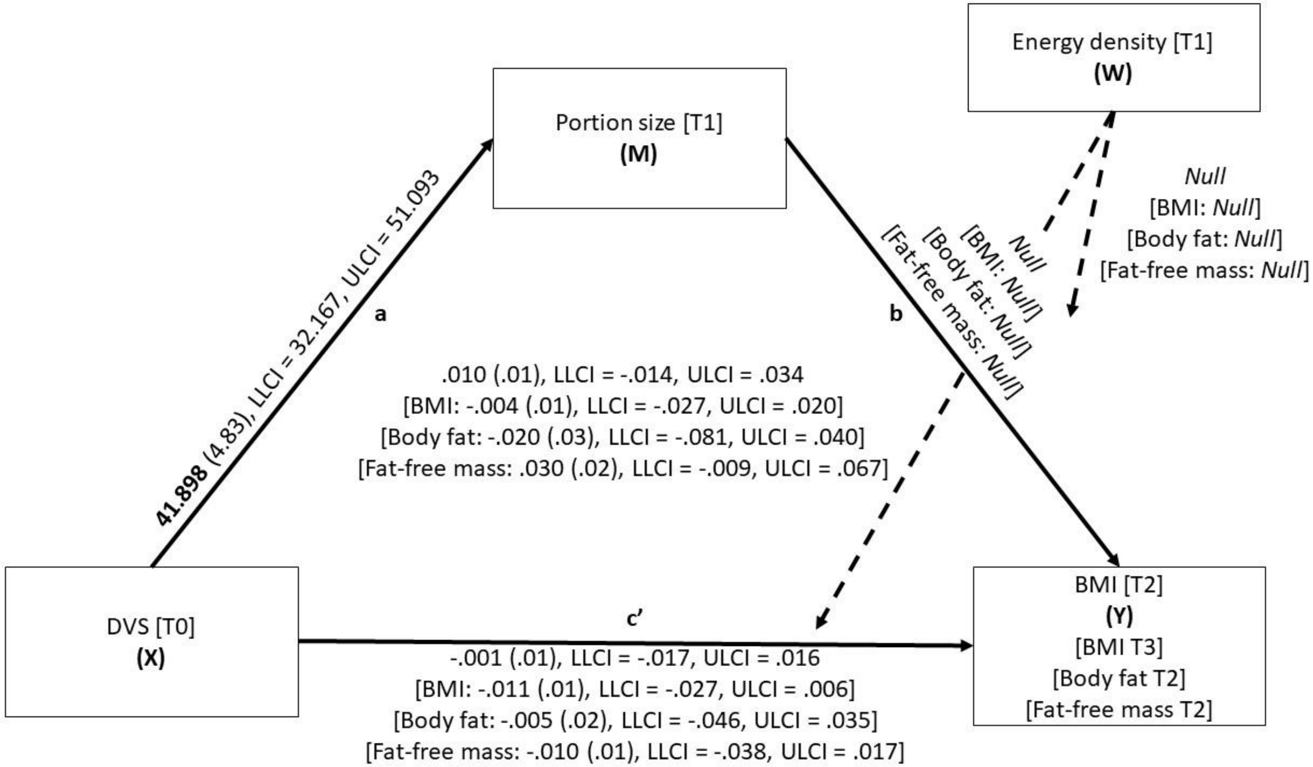


Figure 13. Time-lagged model of overall dietary variety (DVS) as a predictor of outcomes at follow-up, including BMI (T2 R^2 = .926; T3 R^2 = .872), body fatness (R^2 = .899), and fat-free mass (R^2 = .971). Unstandardised regression coefficients (b) with adjusted standard error in brackets (SE), and Bootstrap confidence intervals are displayed (LLCI, ULCI). Pathways including the moderator are indicated with a dashed line. Where coefficients < .001, effects are indicated as 'null'. Significant coefficients are indicated in bold (p < .001), if at least a 'small' effect size was observed. Where relevant, results for models with BMI (T3), body fatness (T2) and fat-free mass (T2) are presented in brackets. All models included baseline measures of body weight outcomes as predictors.

6.5. Discussion

This study sought to further explore the relationship between dietary variety and body weight outcomes, whilst considering the intermediate roles of cumulative portion size and energy density. First, as predicted, consuming a greater variety of individual foods and beverages overall, consuming items from across a greater variety of food groups, and consuming a greater variety of items from within food groups, significantly predicted increased weight of food consumed during the recall period. In a step towards triangulation, these results further corroborate findings from short-term experimental studies in the laboratory (see the findings of **Chapter 2**, as reported in (Embling, Pink, et al., 2021)), supporting variety as a driver of food intake. In order to help identify potential causal relationships and effects, replication alone is unlikely to be sufficient, and the use of multiple complementary methodologies is needed to generate inference from comparative findings (Munafò & Davey Smith, 2018). Past studies that have explored effects of dietary variety on consumption have typically focussed on cross-sectional effects at a single timepoint, in relation to energy intake (Vadiveloo et al., 2013). By adopting a time-lagged modelling approach, this study specifically highlights consistent effects of dietary variety on weight of food consumed over a longer period of time, outside of a single meal-time context, and across several potential eating sessions. Results also highlight a level of consistency between dietary variety scores in relation to food intake, as scores based on the overall count of individual items, number of food groups from which items were consumed, and percentage of items consumed within food groups, were all significantly associated with cumulative portion size.

Second, model results provide further population-level evidence to support a potentially beneficial role of variety in the consumer diet, as both overall dietary variety and dietary variety between food groups significantly predicted a lower BMI and fat-free mass at baseline. In this study sample, participants' average energy consumption was within the recommended range for males and females in the UK (NHS, 2019), and energy density overall was noticeably low (Albar et al., 2014; Rolls, 2017). Participants were also consuming foods from across a wide range of food groups (including fruits and vegetables). This is consistent with prior research that has associated dietary variety with higher diet quality (Drewnowski et al., 1997; Kennedy, 2004; Meng et al., 2018; Nair et al., 2016). Indeed, evidence suggests that moderating variety appropriately across foods – according to energy and/ or nutrient content – can be particularly helpful to consumers when utilised in interventions aiming to assist healthy eating and body weight management (Epstein et al., 2013, 2015; Raynor et al., 2006, 2012). More generally, consuming a greater volume of low energy density foods has also been shown to significantly reduce energy intake, increase satiety, and support body weight management (Rolls, 2017).

A similar effect was also found when measuring dietary variety within food groups, but this was limited to variety within sweets, snacks, and carbohydrates as a negative predictor of fat-free mass at baseline. Though this effect appears to be counterintuitive, energy density within this group was negatively associated with cumulative portion size, and it is important to note that food groups were constructed in line with previous categories of foods used for FFQ data when exploring effects of dietary variety within food groups (McCrory et al., 1999). DVS-W was included as an exploratory measure in addition to overall DVS (and energy density) in models, as previous studies have reported negative versus positive associations with body adiposity when scoring variety separately for groups of 'healthful' foods (typically fruits, vegetables, and low energy-density foods) and 'energy-dense' foods respectively (for a review, see (Vadiveloo et al., 2013)). As McCrory and colleagues highlighted a key difference in the direction of associations between vegetables and other food groups specifically (McCrory et al., 1999), this food group approach was adopted in the current study. However, 'sweets, snacks, and carbohydrates' included a comparatively greater number of items than others, potentially allowing for more scope to indicate 'variety' within a limited recall period. It is also acknowledged that the categories used for the purpose of this study were generally broad and collapsed across foods that may be further distinguished based on nutritional content, particularly where diet quality specifically is of interest (for a more recent example with UK Biobank dietary data, see (Piernas et al., 2021)).

More specifically, energy density scores appeared to have little variability across participants in this study, potentially accounting for the lack of support for the predicted moderated mediation effect of dietary variety scores on body weight outcomes (via cumulative portion size). Diets with the highest energy density values were representative of 'medium' energy density' (9 Kj/ g) according to some definitions in the literature (Rolls, 2017). This may indicate potential bias from 'underreporting', though dietary data were removed from analyses where reporting credibility was a concern. Previous research also suggests that including beverages within calculations of energy density can reduce overall estimates (Cox & Mela, 2000; Ledikwe et al., 2005; Wrieden & Barton, 2011). In this case, values were based on all foods and beverages (including water) that were consumed in line with derived dietary intake values available from the UK Biobank. Though sensitivity analyses indicated that energy density calculated from estimates of energy intake and weight consumed – when all beverages were excluded – was still low across participants, justification for removing beverage intake from analyses may be of interest in future research, particularly when energy density is high for food items alone. It is also important to acknowledge that cumulative portion size (in weight) within a single recall period would not be expected to significantly influence body weight stability, particularly if energy density was low (Rolls, 2009, 2017). Indeed, research suggests that cumulative dietary recall measures, that are collected over several days or weeks in a period, may provide more comprehensive self-report data (Raynor et al., 2019).

Considering the relationships between dietary variety and body weight outcomes discussed so far, it is interesting that participants' self-evaluated level of dietary variety was significantly and positively associated with BMI, body fatness, and fat-free mass (thus suggesting a relationship in the opposite direction to calculated dietary variety scores). Though it should be acknowledged that participants were asked to assess a different timeframe to the 24-hr recall period, participants self-reporting to 'never' vary their diet on a weekly basis may have underestimated dietary variety consumed, given that average dietary variety scores across measures were similar for both groups (smallest mean difference = .01, SE = .06; largest mean difference = 1.21, SE = .25). This data reflects findings discussed in **Chapter 3** (relating to the consumer perception and understanding of 'variety'), again highlighting a potential discrepancy between consumer evaluations of their own dietary variety, and quantitative assessments of variety that are presented in the literature (Haugaard, Brockhoff, Lähteenmäki, et al., 2016; König et al., 2018). However, caution is advised when interpreting these results, as the binary variable used to indicate self-evaluated level of dietary variety was unbalanced.

Some additional limitations of data analyses in this study should also be addressed. Though bootstrapping approaches and a robust standard error estimator were used to measure effects, and participant sex was included as a covariate across models, it is important to acknowledge that some assumption checks were violated during data analyses and that the distribution of fat-free mass was bimodal. Missing data across timepoints meant that models were cross-sectional at baseline, and only a single timepoint was included for dietary data at follow-up (averaged across available reports in a 12-month period). Dietary data was also derived from self-report 24-hr recall questionnaires, and though this specific measure has been validated within the Biobank (Galante et al., 2015; B. Liu et al., 2011), there was a lack of specificity when reporting consumed portion size for some foods (as this was defined by multiple-choice lists). Participants were instructed to use an ingredient-based approach to reporting food intake, whereby mixed meals/ dishes were disaggregated into component parts (e.g., 'Spaghetti bolognaise' was reported as 'pasta', 'beef', and 'tomato-based sauce'(The UK Biobank, 2012)). More recent evidence has highlighted that such an approach can improve sensitivity when estimating nutritional intake (Carter et al., 2016; Marconi et al., 2018), and consideration of multiple components included within mixed dishes/ foods may be particularly important when considering effects of 'sensory' dietary variety on food intake (Raynor & Vadiveloo, 2018; Wilkinson et al., 2022). However, information about specific flavours and brands consumed (e.g., for different varieties of snacks) may also be relevant to calculations of dietary variety, particularly when concerned with measuring food intake across several days (Raynor et al., 2019).

Considering the findings of this study, two key issues are acknowledged. First, it is important to consider the possibility of a bidirectional relationship between dietary patterns and body weight outcomes, whereby having a lower body weight (and body fatness) can predict healthier eating patterns. Though this was not directly explored within models presented here, bidirectionality has been discussed in relation to other predictors of body weight outcomes and food intake, such as weight stigma (Major et al., 2018), depression (Haynes et al., 2019), and social effects on eating (Robinson et al., 2013). As such, future research should further explore the direction of possible 'causality', whereby potential reciprocal predictive pathways between body weight and dietary variety are observed in cross-panel, time-lagged models of effects over a longer period with more frequent timepoints (e.g., a similar approach has been adopted to explore longitudinal associations between BMI and internalising symptoms in a cohort study (Patalay & Hardman, 2019)).

Second, results of this study further highlight potential sample bias when interpreting results. Compared to the general population, UK Biobank participants in particular have been found to be more likely to live in areas with less deprivation, have a lower average BMI, be less likely to have obesity, and have lower incidence of self-reported health conditions that may be associated with overweight and obesity, such as cardiovascular diseases, diabetes, and cancers (Fry et al., 2017). In this study, participants self-reporting health-related conditions that may otherwise influence dietary intake were also excluded to control for potential confounding effects within models. Previous research has indicated that around 40% of Biobank participants are consuming a healthy diet (Chudasama et al., 2020; Sarris et al., 2020), with fruits and vegetables (including potatoes) contributing approximately 16.5% to energy intake per capita (Piernas et al., 2021). As such, it is important to acknowledge potential limitations of generalisability for such population samples that may be susceptible to 'healthy' volunteer bias (particularly when using a subset of the sample).

Therefore, this study provides further support for dietary variety as a predictor of increased food intake. Though there was little evidence to support a moderated mediation effect of dietary variety on body weight outcomes when considering the role of cumulative portion size and energy density in this relationship, results highlight the importance of considering both positive and negative associations between dietary variety and body weight. In turn, these findings have potential implications for body weight management, but further research is needed to explore the influence of these associations over a longer consecutive period, particularly as this relates to variability in energy density across the consumer diet.

7. Chapter 7 – General Discussion

7.1. Overarching aims and objectives

This thesis aimed to further explore the effect of variety on food intake in the current 'obesogenic' food environment, considering lines of enquiry that were relevant to implications for both diet quality and overconsumption. More specifically, seven studies were conducted to address three main research questions. First, the conceptualisation of variety was explored from a researcher (**Study 1**) and consumer perspective (**Studies 2 and 3**), to synthesise findings across experimental studies that have operationalised the 'variety effect' in different eating contexts, and to compare the identified framework to the consumer recognition and definition of 'variety'. Second, the effect of variety on portion size selection (using a novel online tool developed in **Studies 4 and 5**) was examined *within* foods, specifically for multicomponent foods and food assortments (**Study 6**), as a conceptualisation of variety that has received little attention in the current literature. Finally, the longitudinal association between dietary variety and body weight was investigated using prospective data from the UK Biobank (**Study 7**), as no study had simultaneously modelled effects of 'portion size' as a mediator and 'energy density' as a moderator of this relationship, despite dietary variety having differential effects on diet quality and overconsumption across studies. This chapter presents 1) a summary of findings, 2) strengths and limitations of this thesis, 3) implications of findings and directions for future research, and 4) two key issues relevant to theory and practice for testing the variety effect.

7.2. Summary of findings

7.2.1. Conceptualisation of 'food variety' as a driver of food intake

In a recent narrative review of the literature, Raynor and Vadiveloo (Raynor & Vadiveloo, 2018) outlined an overarching conceptualisation of variety as a driver of food intake, highlighting the defining features that should be considered when measuring food variety; 1) the period of consumption, and 2) characteristic differences that constitute variety, relating to both nutritional and sensory traits of foods.

To identify potential differences in effect size between study approaches to manipulating variety (in line with this framework), **Study 1** reported findings from a systematic review and meta-analysis of experimental studies exploring the variety effect. Data extraction included information relevant to the period of consumption (variety manipulated within and across meals) and the number of components varied (i.e., foods/ sensory characteristics manipulated), both of which were considered as potential moderators of effects on food intake (among additional potential influences, such as test food type and sample demographics). Overall, variety was shown to have a small-to-medium effect across studies as variety significantly increased food intake, supporting its influence on consumption. Though subgroup analyses did not find any significant differences in effect size between study manipulations, several methodological issues were identified that may have made it difficult to draw these comparisons. For instance, the number of components included in experimental *versus* control conditions largely differed between comparisons, assessments of study quality differed across studies, and noticeably fewer studies had explored short-term effects of variety across meals.

Given the operationalisation of variety in experimental studies, **Studies 2 and 3** utilised a qualitative, mixed-methods approach to specifically explore the consumer perception of 'variety'. **Study 2** was conducted to test the feasibility of coding participant responses about variety in focus groups using a categorical framework that was developed in line with the existing literature (including dietary variety, variety across meals, variety within meals, and variety within foods) (Raynor & Vadiveloo, 2018). **Study 3** then extended use of this framework to a larger online sample, and identified the frequency (and context) with which each category of variety was recognised. Across these studies, results showed that individuals discussed different forms of variety in the presence of food photographs when justifying food choices, justifying food expectations, and defining variety, as individuals referred to dietary variety, brand variety, across-meal variety, variety between courses, variety within a single course, and variety within a single food. These results were consistent with previous research inferring a consumer awareness of variety, particularly in the context of making food choices and explaining food preferences (Bell et al., 1999; Hale & Varakin, 2016; Wilkinson et al., 2013).

However, **Study 3** also found evidence that individuals were more likely to explicitly define variety in the context of the whole diet (e.g., 'consuming foods from different food groups'), with fewer references made to other periods of consumption and components contributing to variety. This appeared to reflect the use of the term 'variety' in dietary guidelines (Vadiveloo & Parekh, 2015), that emphasise nutritional differences between foods, and pay less attention to the presence of variety within and across meals, particularly as this relates to sensory characteristics of foods. For example, when participants were specifically instructed to rate variety according to the number of 'different flavours, colours, and/ or textures' within foods in **Study 6**, these ratings closely corresponded to the number of components that had been experimentally manipulated within foods, as participants gave significantly higher ratings of variety to 'high' variety foods. In contrast, when participants were asked to more generally rate the level of variety in their diet in **Study 7**, individual perceptions of variety were less consistent with calculated scores of dietary variety. These findings indicate a potential gap between the perception of variety and the conceptualisation of variety *within* consumers, suggesting that further informational scaffolding is needed to support consumer understanding of the term, particularly as this relates to effects of variety on food intake (**Study 1**).

7.2.2. Exploring the variety effect *within* foods

Previous studies have typically focussed on manipulating variety in a single eating session, across or within courses (e.g., by changing the number of different foods presented) (**Study 1**). In **Chapter 1** of this thesis, two forms of variety that are specific to individual food items were highlighted as being relatively 'underexplored' within this literature; 1) dietary variability, relating to the availability of different brands and varieties for a product, and 2) multi-component foods, products that consist of multiple components in and of themselves.

Though investigating the effect of dietary variability on consumption was not included in the main aims of this thesis, the consumer perception of 'brand variety' was explored within the conceptual framework developed in **Studies 2 and 3**. Participants often commented on the availability of different brands and varieties (e.g., flavours) for products, though this tended to be in the context of generally referring to differences between foods or food categories (i.e., relating to 'dietary variety') rather than more specific periods of consumption. As previous research has shown that such dietary variability can influence food choice (Sevilla et al., 2019) and food intake (Hardman et al., 2015; Martin, 2016), these findings add to the assumption that dietary variability may be a form of variety that *is* apparent to the consumer and can exhibit the variety effect.

In these qualitative studies (**Studies 2 and 3**), participants also referred to variety within foods when discussing food choices, particularly as this related to wanting specific toppings and fillings within composite dishes and products. **Study 6** specifically examined effects of variety within foods on portion size selection, with a focus on multicomponent foods and food assortments. Results showed that there were no significant differences between high (three components) and low (single component) variety foods overall, and that there was little evidence to support an interaction between variety and food composition. Participants also tended to select significantly larger portions for multicomponent foods versus food assortments irrespective of variety conditions, potentially due to issues developing isocaloric test foods that were suitable for use in a photograph-based portion size selection task. Though these results did not support the variety effect in this context, previous studies that had manipulated variety within foods had typically only used food assortments (Guerrieri et al., 2007, 2008, 2012; Hale & Varakin, 2016; Rolls et al., 1982) or composite dishes (Friis et al., 2017; Kongsbak et al., 2016; Levitsky et al., 2012; Marques et al., 2020). This study extended previous findings to test effects within multicomponent foods, and provided initial pilot data to inform the development of standardised test foods and study designs that can be used to test effects of components within foods in future studies (i.e., relating to average portion size and food ratings, when considering variety and food composition as potential factors influencing food intake).

7.2.3. Modelling effects of dietary variety on body weight outcomes

Previous research exploring the effects of dietary variety on body weight outcomes have reported inconsistent results across studies (Vadiveloo et al., 2013). To further our understanding of the effects of dietary variety on body weight outcomes, **Study 7** examined associations between dietary variety scores and BMI, body fatness, and fat-free mass, whilst considering the potential role of cumulative portion size (mediator) and energy density (moderator) in determining these relationships.

Using 24-hr recall questionnaire data from the UK Biobank, cross-sectional and time-lagged models consistently showed that higher dietary variety scores – i.e., consuming a greater number of foods within and across food groups – was significantly and positively associated with the weight of food consumed during the recall period. These results provide strong population-level evidence to support associations between dietary variety and dietary intake, that further reflects findings of experimental studies on the variety effect in a mealtime context conducted in the laboratory (**Study 1**), and contributes to the triangulation of results across literatures relevant to dietary variety and effects on consumption.

There was also some evidence of a direct relationship between dietary variety scores and body weight outcomes, whereby greater dietary variety was significantly associated with having a lower BMI and fat-free mass at baseline, though there was little evidence to support a moderated mediation effect across timepoints. This was likely due to the weaker relationship observed between cumulative portion size and body weight outcomes (mediated pathway), and overall lack of variability across participants in terms of energy density (moderated pathways), highlighting a need to explore associations over a longer consecutive period and in additional population samples (e.g., using the National Diet and Nutrition Survey (Murakami & Livingstone, 2016)). Indeed, **Studies 4 and 5** also demonstrated poor associations between portion size selection and BMI when measured at a single timepoint, and previous research has reported similar effects of portion size on short-term meal intake irrespective of BMI (Diliberti et al., 2004; Fisher et al., 2003; Rolls et al., 2002; Spill et al., 2010). In the few studies that had explored body weight as a moderator of the variety effect in the meta-analysis of this literature in **Study 1**, there appeared to be no significant differences between comparisons when comparing body weight groups.

7.2.4. Broader perspective on findings: The 'variety effect' as a biopsychological influence on appetite

Taken together, results of this thesis provide novel insight into the conceptualisation of variety in the literature by 1) synthesising findings across studies that differ in their approach to measuring variety, 2) extending this framework to the consumer perception of variety, 3) using this framework to test the variety effect within foods, and 4) exploring mechanisms that are central to the variety effect as factors that may underpin associations with body weight outcomes. These findings strengthen evidence supporting the variety effect, and highlight 'variety' as an important biopsychological influence on appetite. As discussed in **Chapter 1**, variety is believed to disrupt the process of sensory specific satiety (Rolls, Rolls, et al., 1981), as the presence of different foods (and sensory characteristics) within meals increases the magnitude of sensory specific satiety effects (i.e., pleasantness experienced for 'eaten' versus 'uneaten' foods) (Rolls et al., 1984), and this subsequently increases food intake (e.g., (Brondel et al., 2009; Hendriks et al., 2019, 2021; Hetherington et al., 2006; Rolls, Rolls, et al., 1981)).

Results from **Study 1** indicated a consistent overall effect of variety within meals on food intake when using data from more than 30 studies in the literature, reflecting the relatively consistent effect of sensory specific satiety across potential moderating influences (Remick et al., 2009).

Some support for the variety effect was also reported across meals (**Study 1**) and eating sessions as part of the overall diet (**Study 7**). Typically, sensory specific satiety has been shown to have relatively short-term effects on eating behaviour (Hetherington et al., 2000, 2002; Miller et al., 2000). Of note here is that by demonstrating support for longer-term effects of variety on food intake, these results highlight the importance of considering variety as a broader driver of consumption, that may operate outside of a typical mealtime context, via a combination of mechanisms relevant to repeated exposure in addition to sensory specific satiety, such as monotony or ‘stimulus satiation’ effects (e.g. (Hetherington et al., 2002; Meiselman et al., 2000; Raynor et al., 2006)).

More specifically, previous research has emphasised the importance of considering the role of anticipatory influences on eating behaviour that are relevant to satiety and satiation (Brunstrom, 2014). In particular, Wilkinson et al. (Wilkinson et al., 2013) demonstrated that participants’ ‘expectations’ of the variety effect could influence portion size selection before eating, as courses of a hypothetical meal were rated as being more pleasant and selected in larger portions when they were characterised by greater sensory differences (e.g., a ‘savoury’ followed by ‘sweet’ food). A common theme throughout the studies presented in this thesis has related to understanding consumer expectations and perceptions of variety (**Studies 2, 3, 6, 7**). **Studies 2 and 3** specifically found evidence of a consumer appreciation of variety in the presence of food stimuli that was generally at odds with instances where consumers were directly asked to identify ‘variety’ in their diet (**Studies 2, 3, 7**). By establishing a consumer awareness of variety (in the presence of food stimuli), these findings support expectations of variety as a potential influence on food choice and consumption before eating (Keenan et al., 2015; Wilkinson et al., 2013). However, these findings also highlight consumer difficulties that may be associated with 'quantifying' variety in the diet, reflecting evidence that variety is a factor that can potentially increase 'decision complexity' and undermine associative learning for post-ingestive effects of foods that inform meal size (e.g., expected satiation) (Keenan et al., 2015; Martin, 2016). Therefore, in addition to investigating effects of variety on food intake, it is important to consider the influence of variety on expectations of satiety, satiation, and portion size selection.

7.3. Strengths and limitations of thesis approach

This thesis has provided novel insight into the manipulation and measurement of variety across literatures that are relevant to dietary health, consumer behaviour, and appetite control. Typically, studies focussed on the variety effect have adopted experimental short-term methods to investigate effects on food intake (e.g., (Rolls et al., 1982, 1984; Rolls, Rowe, et al., 1981)), with a limited number of more recent studies also exploring effects on portion size selection (e.g., (Bucher et al., 2011, 2014; Haws & Redden, 2013; Wilkinson et al., 2013)). In contrast, studies focussed on dietary variety have used mostly observational methods to examine relationships with body weight outcomes (see (Vadiveloo et al., 2013)), with a limited number of intervention trials that have manipulated dietary variety over several weeks or months (Epstein et al., 2013, 2015; Raynor et al., 2006, 2012; Stubbs et al., 2001). This research considers effects of variety from both of these perspectives, and directly explores 'the variety effect' as a factor that bridges the gap between discussions of variety in a mealtime context, and the role that dietary variety plays in influencing dietary intake and body weight outcomes overall.

This thesis also adopted a sequential ‘mixed-methods’ approach to studies across chapters by utilising different quantitative and qualitative data analyses. Such an approach can mitigate limitations of individual methods (e.g., use of Bayesian statistics to evaluate strength of evidence for null results, use of population-level data to increase sample size and improve scope for generalisability), and allow for exploration of a broader range of research questions (e.g., characterising consumer beliefs about variety using qualitative methods, versus testing for quantitative differences in portion size selection in response to variety). A clear strength of this thesis also lies in the inclusion of pilot work to test the feasibility of novel methods (**Studies 2, 4, 5**), the use of specific data quality and sensitivity checks to enhance rigour within each study’s methods, and the replication and triangulation of findings provided across these studies to provide further confirmation of results.

It is also notable that this research was conducted in line with open science practices to support reproducibility and replicability, enable reuse of data and materials, increase transparency, and allow for open access to research outputs (Ayris et al., 2018; Spellman et al., 2017). More specifically, all studies were preregistered, and articles resulting from this thesis have been published in peer-reviewed journals using open-access options (**Studies 1, 2, 3, 4**). Where applicable, generated datasets (**Studies 1, 4, 5, 6**), study materials (e.g., food photographs, survey questions, qualitative codebook; **Studies 2, 3, 4, 5, 6**), and detailed data analysis logs (**Study 7**) have also been made publicly available on the OSF.

However, the scope of this thesis was limited by the data and methods available. Though effects of variety on both actual consumption (namely **Study 1**) and portion size selection (namely **Study 6**) were investigated between studies, there remains a need to test the consistency of effects across these outcomes within each study domain (e.g., to systematically review the variety effect in relation to portion size selection, and explore effects of variety within foods on *ad libitum* food intake). At present, fewer studies appear to have focussed on the influence of variety on portion size selection, meaning current data availability may be limited for review. Nevertheless, this remains an important question to address given the use of ideal portion size as a 'proxy' measure of food intake (**Studies 4 and 5**; (Pink & Cheon, 2021; Wilkinson et al., 2012)), and the relevance of portion size selection in consumer meal planning (Brunstrom, 2014). As the study protocol for **Study 6** was also notably adapted to an online setting for data collection in response to the COVID-19 pandemic, there remains scope to expand this study to a laboratory setting where both portion size selection and food intake can be measured, particularly as the variety effect may be strongest in response to oro-sensory exposure (given effects of sensory specific satiety) (Hendriks et al., 2019).

In addition to exploring effects on consumption and body weight, it should be acknowledged that effects of variety have been explored in relation to other key outcomes, most notably diet quality (e.g., (Kennedy, 2004)) and sensory specific satiety (e.g., (Rolls, Rolls, et al., 1981)). Studies included in this thesis also tended to focus on short-term, cross-sectional effects of variety on outcomes, with the exception of time-lagged models conducted with prospective data from the UK Biobank (though these data were limited and averaged across timepoints). As such, cumulative measures of variety and food intake are needed to study the variety effect over a longer period of time (Raynor et al., 2019). Though moderating influences on the variety effect were explored across studies (**Studies 1, 6, 7**), further research is needed to develop our understanding of combined effects for variety and other drivers of food intake within and across meals, particularly as data for some potential moderators were difficult to synthesise in the extant literature (e.g., relating to individual differences in behavioural traits, such as impulsivity and responsivity to food cues (Guerrieri et al., 2007, 2008, 2012; Haws & Redden, 2013; Mok, 2010; Pliner et al., 1980; Rafieian et al., 2021)).

7.4. Implications of findings and directions for future research

From a theoretical perspective, this thesis provides novel insight into the conceptualisation of variety and the variety effect. This thesis builds on an existing theoretical framework in the literature (Raynor & Vadiveloo, 2018), to test effects of variety across periods of consumption on food intake as well as portion size selection and body weight outcomes, whilst also extending this framework to the consumer perception of variety. For the first time, this thesis has also specifically explored effects of multicomponent foods on portion size selection as a form of variety, highlighting directions for future research relating to potential comparisons between food compositions when manipulating variety.

From a public health and/ or clinical perspective, understanding the conceptualisation of variety and its effects on food intake has important implications for dietary health and body weight management. This thesis has demonstrated further evidence for variety as a driver of food intake that may increase the risk of overconsumption in a mealtime context (when energy density is high), though overall dietary variety may also have particular benefits for body weight management as demonstrated in **Study 7** (see below for further discussion on variety in dietary guidelines). This is particularly important to consider in food environments where variety has generally increased in the food supply (Foster & Lunn, 2007; Gallo, 1997; USDA Foreign Agricultural Service, 2016; Vadiveloo et al., 2021), and where dietary patterns are increasingly characterised by the consumption of highly-processed, palatable, and energy-dense foods (Johnson & Wardle, 2014; Kearney, 2010; Monteiro et al., 2019; Popkin et al., 2012). As overweight and obesity remain a significant public health concern (Wang et al., 2011), combatting these environmental influences on dietary health is a key target for public health strategies (Commission of the European Communities, 2007; Department of health and human services Centers for Disease Control and Prevention, 2009; Department of Health and Social Care, 2020). 'Variety' is one factor that may be considered in public health strategies and dietary interventions to influence food intake at different 'levels' of the eating environment (e.g., across periods of consumption, food types, and product formulations).

More specifically, it is notable that 'variety' is a key term included in dietary guidelines (Herforth et al., 2019; Kennedy, 2004; Ross, 1993; Vadiveloo & Parekh, 2015), typically as this relates to improving diet quality (Kennedy, 2004), and results of **Study 7** demonstrated that overall dietary variety may be negatively associated with body weight outcomes. However, previous research has suggested that dietary guidelines are often poorly understood by consumers and difficult to put into practice (Brown et al., 2011; Khanom et al., 2015). Results in this thesis suggest that there may be inconsistencies between the use of variety within dietary guidelines (i.e., to promote nutritional differences between foods within food groups (Vadiveloo & Parekh, 2015)), and the consumer appreciation of variety within and across meals (i.e., relating to sensory differences between and within foods that may influence food choice and food intake). This gap in the conceptualisation of variety between dietary guidelines and consumers may undermine potential benefits of including variety in dietary advice. Indeed, when asking consumers to manage their own food intake, Raynor & Vadiveloo (Raynor & Vadiveloo, 2018) identified the consumer ability to consider (and quantify) variety as an important influence on the successful implementation of such guidelines. Therefore, there remains a need to develop dietary guidelines that are comprehensive of the effects of variety from a nutritional and behavioural perspective, that are consistent with the consumer appreciation of variety, but also discern the nature of variety across periods of consumption to assist consumers with following dietary recommendations.

Many studies have also explored the variety effect in the context of developing dietary interventions to support health and body weight management, but often report results with mixed success. For instance, **Study 1** highlighted several experimental studies with children and older adults in particular that have tested effects of using variety to encourage food intake (e.g., to increase fruit and vegetable consumption for children, and combat poor appetite for older adults). However, in this 'intervention' setting, only two studies provided clear support for the variety effect in children (Domínguez et al., 2013; Roe et al., 2013), and only two studies for older adults (Van Wymelbeke et al., 2020; Wijnhoven et al., 2015). Use of cognitive strategies (e.g., priming) to manipulate the perception of variety within meals has been explored as a way to increase consumption of fruits and vegetables, but these strategies alone have not significantly influenced food intake (Friis et al., 2017; Vadiveloo et al., 2019). Additional intervention trials – that have provided individuals with instructions to manipulate intake of variety over a longer period of time – have found some support for using variety-focussed strategies to reduce energy intake (Epstein et al., 2015; Raynor et al., 2006, 2012), decrease hedonic ratings for 'restricted' foods (Raynor et al., 2006, 2012), and promote weight loss (Epstein et al., 2015). However, most of these studies have been preliminary in nature, and often focussed on manipulating variety for either 'recommended' foods (e.g., increasing variety for fruits and vegetables) or 'non-recommended' foods (e.g., restricting variety for high energy-dense, nutrient-poor foods).

As such, several gaps have been identified to better inform the development of such interventions in a treatment setting. Vadiveloo and Parekh (Vadiveloo & Parekh, 2015) previously noted that strategies adopting a 'whole diet approach' for variety – whereby variety is both increased and decreased appropriately across foods – are likely to have more consistent effects on dietary intake and body weight management (e.g., by accounting for compensatory food intake). For example, interventions may provide recipe ideas and meal kits to increase use of variety for ‘healthful foods’ within and across meals, whilst also incorporating guidelines to restrict variety for high energy-dense foods with the repetition of leftovers and limitations on choice. This has been shown to be more effective than targeting restrictions for single eating occasions in a pilot study of ‘family-based treatment’ for obesity (e.g., (Epstein et al., 2015)). Given that these interventions are likely to be consumer-led (i.e., they rely on participants following variety-focussed dietary guidelines (Raynor & Vadiveloo, 2018)), results from this thesis further emphasise the importance of disambiguating the term ‘variety’. This thesis also highlights a longer-term model of the variety effect to consider combined influences on intake and body weight outcomes (e.g., relating to portion size and energy density across foods), and identifies a need to test interventions in larger studies (e.g., considering the need for randomised-controlled trials in this literature).

This thesis has also drawn further attention to potential effects of variety when considering differences *within* foods and product ranges, that is consistent with market development patterns focussed on increasing product variability by introducing changes to product characteristics (e.g., offering consumers new flavours and textures for a specific product) (Gallo, 1997), and consumer behaviours associated with variety seeking (e.g., brand switching) (Sevilla et al., 2019). For example, an ice cream product line may introduce a ‘new’ chocolate flavour by combining different toppings and fillings. Though such products may be prolific in the current eating environment, test foods often do not fully encapsulate such differences within foods, and there is further scope for research to explore the variety effect within this domain, particularly as this relates to formulating more nutritious products that may promote better diet quality (given that multicomponent foods in particular are often more energy-dense and ultra-processed (Wilkinson et al., 2022)).

From a broader perspective, this research also led to the development of a novel approach to measuring portion size selection that can be utilised in future eating behaviour research, and this tool has some specific practical advantages. As identified for laboratory-based computer assessments of ideal portion size (Wilkinson et al., 2012), a photograph-based measure can remove barriers associated with testing effects on *ad libitum* food intake (e.g., relating to products being discontinued or becoming difficult to source, time needed to prepare foods in advance of multiple test sessions, and food waste, particularly when developing 'new' products for experimental studies). In addition, online testing is known to significantly reduce the time needed for data collection, meaning larger samples are more likely to be viable (e.g., participation is no longer restricted by a need to arrange one-to-one timeslots at a specified location, participants are free to take part at their own convenience, and multiple participants may complete the study in parallel). As paradigms consisting of many trials can often be difficult to implement for online research, the use of this tool may be considered a more accessible, alternative approach to developing such a task for testing the variety effect and other influences on portion size selection. For instance, Qualtrics has an intuitive user interface, allowing for the seamless integration of the tool into a large-scale online survey with other questions in multiple formats, and does not require users to have an advanced understanding of coding language. When assessing food intake over a longer period of time, there may also be an opportunity to include such a task in online FFQs or food diaries, to help improve sensitivity of portion size reports (as an alternative to multiple choice lists/ use of generic serving units).

Nevertheless, there are caveats of online research that need to be balanced with some of these benefits (see **Chapters 4 and 5** for further discussion). First, there is generally a trade-off between study length/ complexity and data quality online (Fan & Yan, 2010; Meade & Craig, 2012). As it can be difficult to sustain participation for longer studies, this often limits the number of tasks presented within and across sessions, and task difficulty needs to be minimised given that participants complete measures without direct clarification from a researcher. It is also often necessary to collect additional measures that increase study length to account for the loss of experimental control in this setting relative to the laboratory. For example, **Studies 4 and 5** highlighted the need to collect baseline appetite ratings, contextual information (such as time of participation, device type), and include compliance checks throughout (e.g., to identify failures to follow instructions and low effort/ potential bot responses). This means that over recruitment is typically needed to meet sample targets. Second, the ecological validity of online measures needs to be considered. This is particularly relevant for photograph-based measures of portion size selection and food ratings, where there may be an overreliance on the visual appearance of foods, and participants lose out on the additional sensory and feedback information gained from consuming test foods. Therefore, such online measures may be most useful when responding to highly familiar foods, or otherwise in conjunction with actual food intake.

7.5. Broader key issues for future directions

7.5.1. Key issue 1: Towards conceptual clarification for 'variety'

A key challenge for future research to address relates to the consistent identification and operationalisation of variety across study methodologies. In **Chapter 1** of this thesis, four overlapping concepts/ experimental paradigms relevant to the variety effect were identified, including 'monotony' and 'perceived sensory complexity' as frameworks that may be particularly difficult to distinguish from the measurement of variety. Considering the findings of this thesis, there are two main lines of enquiry that should be explored in future research relating to these conceptual ambiguities, to better define the 'boundaries' of effects (though concepts may still intersect with one another).

First, it is important to consider whether or not variety should be defined as a 'continuous' or 'categorical' factor, particularly as this relates to the manipulation of variety and monotony. Typically, experimental studies have manipulated the presence of variety within and across meals by changing the number of foods/ components consumed (**Study 1**), and dietary variety scores have been calculated by quantifying the number of individual items consumed within a given period of consumption (Drewnowski et al., 1997). This has led to the observation that the variety effect may present as a "dose-response relationship" (i.e., food intake continues to increase with greater amounts of variety) (Hendriks et al., 2019), and this is generally reflected in findings that dietary variety scores are positively associated with food intake (**Study 7**).

However, a 'monotonous' condition (i.e., consisting of a single food/ characteristic) is often used as a control condition in study comparisons, and measures of variety and monotony are sometimes treated as opposing ends of a 'dichotomous' scale (i.e., the presence of variety versus no variety) (Meiselman et al., 2000; Zandstra et al., 2000). Though the variety effect has been demonstrated with smaller sensory differences between foods (e.g., different yoghurts (Rolls, Rowe, et al., 1981)), effects have been inconsistent when exploring the manipulation of a 'single' sensory characteristic, particularly as studies have generally focussed on manipulating colour ((Guerrieri et al., 2007; Rolls et al., 1982; Vadiveloo et al., 2019); but see (Rolls et al., 1982; Rolls, Rowe, et al., 1981)). As such, it is unclear whether a certain number of components (and type of sensory characteristic) needs to differ to constitute 'variety' (Raynor & Vadiveloo, 2018). Whether or not there is a potential ceiling effect – at which point no further effects of variety are found – also warrants further attention, particularly as some studies have found little evidence of an effect when comparing 'higher' levels of variety (e.g., six versus eight snack items (Kerr et al., 2019), from three to eleven condiments (Divert et al., 2015)). Future research may explore the sensitivity of the variety effect in response to changes in the level of variety within and across meals, as this relates to the number of items as well as sensory characteristics, specifically.

Second, it should be acknowledged that exploration of the variety effect has shifted towards an ingredient-based approach (Raynor & Vadiveloo, 2018). When defining variety within multicomponent foods in line with this approach, there appears to be overlap with studies of complexity from a 'food' perspective (Wilkinson et al., 2022). In other words, similar foods (and manipulations of sensory characteristics) may be used across studies interested in variety and complexity, and some may argue that what is a test of the variety effect is actually concerned with perceived sensory complexity (or vice versa), though complexity effects are typically concerned with food preferences/ hedonic evaluations of foods rather than food intake. As this thesis established some evidence of a consumer appreciation of variety within foods, a logical next step would be to investigate effects of variety within multicomponent foods on *ad libitum* food intake in the laboratory (as mentioned previously), to help distinguish effects of sensory components within foods on consumption specifically (akin to the variety effect), though overlap between definitions of these concepts may remain difficult to disentangle (see also **Section 1.6.4.**).

It would also be useful to explore effects of variety within multicomponent foods in relation to specific mechanisms associated with the variety effect. For example, studies could explore potential differences in sensory specific satiety when manipulating the number of components included within these foods (Hetherington & Rolls, 1996). More specifically, given that oro-sensory exposure to foods has been identified as a mediating influence on effects of variety within meals in relation to sensory specific satiety effects (Hendriks et al., 2019), future research could explore how oral processing behaviours for multicomponent foods influence exposure to sensory characteristics (e.g., do consumers create 'mixed' bites across components within these foods, or do they separate out components to consume individual 'parts'?), using edographic measurements (Bellisle, 2020).

7.5.2. Key issue 2: Towards an open science 'collaborative' approach

There is a clear need to work towards developing robust and consistent methodologies to test the variety effect. Therefore, four methodological recommendations are suggested for future research as they apply specifically to the topic of food variety, though applications to the wider literature of human appetite research are acknowledged (Robinson et al., 2018).

First, differences between variety conditions should be clearly identified within reports of methods, particularly as this relates to the number of components that constitute variety (i.e., nutritional and sensory differences), and possible effects of variety in a control condition that may impact effect size (for further discussion, see *Key Issue 1* above).

Second, it would be useful to develop guidelines for best practice regarding the design of future studies on the variety effect, to increase study quality and improve the standard of reports for methods and results (e.g., relating to study power and sample size, randomisation and assignment to conditions, participant awareness of variety and study aims, the identification and control of covariates, and the measurement of appetite across conditions and groups).

Third, researchers should be encouraged to adopt open science practices in order to facilitate the future development of studies in this field, such as preregistration, open materials, and open access datasets as modelled in this thesis (Spellman et al., 2017). Such an approach has specific benefits for future research, by helping to combat 'waste' issues associated with the time, effort, and resources needed to reproduce materials across studies and research laboratories, and by potentially enabling comparisons to be drawn across more heterogenous samples (e.g., to consider possible differences in eating patterns across cultures, particularly as this relates to diet quality (Low et al., 2022)).

Finally, as variety has been studied across multiple literatures, there remains a need to consider developing collaborative, interdisciplinary networks to help address the knowledge and skills gaps that may restrict research possibilities (e.g., the need to develop specialised test foods to measure the variety effect within multicomponent foods (Wilkinson et al., 2022)).

7.6. Conclusions

Food variety is a key component of the consumer diet that has an important influence on health. This thesis highlights the importance of defining 'variety', to aid consistency within this literature when operationalising foods to measure effects on consumption, and provide guidance to consumers that better reflects the influence of variety on eating behaviour in addition to diet quality. Although questions about the conceptualisation of variety still remain, this thesis identifies a robust, small-medium effect of variety on food intake within and across meals, that appears to be consistent across prospective timepoints, and recognised by consumers when discussing dietary preferences. It also draws attention to methodological issues affecting study quality in this literature, and a need to further explore the consistency of potential longitudinal effects of variety on body weight outcomes. More specifically, future research should explore effects of variety within composite foods on actual food intake, to test the ‘boundaries’ of the variety effect on food intake, and consider interactive effects of variety in the context of the whole diet. For body weight management trials and dietary guidelines focussed on variety to be successful, it is particularly important that the difficulties examining variety (including overlapping constructs) are acknowledged.

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Appendices

Contents of appendices:

See also project pages on the OSF, for additional information and materials where specified in the main text:

Study 1 – https://osf.io/ze6cr/

Study 2 – https://osf.io/af57e/

Study 3 – https://osf.io/5etd4/

Study 4 – https://osf.io/yq9fk/

Study 5 – https://osf.io/yq9fk/

Study 6 – https://osf.io/x9tps/

Study 7 – https://osf.io/hfrej/

Appendix A. Study 1: Search strategy

Key terms included in search strategy; example provided for use in Web of Science.

(variety[Title] OR varied[Title] OR various[Title] OR “dietary diversity”[Title] OR "sensory variety"[Title] OR "food group*"[Title] OR monoton*[Title])

AND

("energy intake" OR intake[Title] OR consum*[Title] OR portion*[Title] OR serving*[Title] OR “meal size”[Title])

AND

(meal*[Title] OR snack*[Title] OR food*[Title] OR breakfast[Title] OR lunch[Title] OR dinner[Title] OR course*[Title] OR buffet[Title] OR dietary[Title])

Limits: publication date from 1980/01/01, Humans, English

Note: If possible, additional limits were included to filter by article type (e.g., exclude reviews, commentaries, meta-analyses)

Appendix B. Study 1: Risk of bias guidelines

Cochrane risk-of-bias tool guidelines[1], modified for use following the approach of Buckland and colleagues[2]

1. Sequence generation

Describe the method used to generate the allocation sequence in sufficient detail to allow an assessment of whether it should produce comparable groups.

High = no random element was used in generating the allocation sequence or the sequence is predictable. Examples include alternation; methods based on dates (of birth or admission); patient record numbers; allocation decisions made by clinicians or participants; allocation based on the availability of the intervention; or any other systematic or haphazard method.

Low = If a random component was used in the sequence generation process. Examples include computer-generated random numbers; reference to a random number table; coin tossing; shuffling cards or envelopes; throwing dice; or drawing lots. Minimization is generally implemented with a random element (at least when the scores are equal), so an allocation sequence that is generated using minimization should generally be considered to be random.

Unclear = If the only information about randomization methods is a statement that the study is randomized, or no information is given.

NB. If between-subjects, this should refer to the allocation of participants to different

[1] Retrieved from Higgins JPT, Sterne JAC, Savović J, Page MJ, Hróbjartsson A, Boutron I, Reeves BC, Eldridge S. A revised tool for assessing risk of bias in randomized trials. Cochrane Methods. *Cochrane Database of Systematic Reviews* 2016 [cited 2020 Jul 13]; 10:52. Available from: http://doi.wiley.com/10.1002/14651858.CD201601

[2] Buckland NJ, Er V, Redpath I, Beaulieu K. Priming food intake with weight control cues: Systematic review with a meta-analysis. International Journal of Behavioral Nutrition and Physical Activity. BioMed Central Ltd.; 2018

conditions. If within-subjects, this should refer to the order of conditions (i.e., the use of counterbalancing).

2. Allocation concealment

Describe the method used to conceal the allocation sequence in sufficient detail to determine whether intervention allocations could have been foreseen in advance of, during, enrolment.

High = If participants or investigators enrolling participants could possibly foresee assignments and thus introduce selection bias, such as allocation based on: using an open random allocation schedule (e.g., a list of random numbers); assignment envelopes were used without appropriate safeguards (e.g., if envelopes were unsealed or non-opaque or not sequentially numbered); alternation or rotation; date of birth; case record number; or other explicitly unconcealed procedures. Also, answer 'high' if there is reason to suspect that the enrolling investigator or the participant had knowledge of the forthcoming allocation.

Low = If the participants and investigators enrolling participants could not foresee assignment because one of the following, or an equivalent method, was used to conceal allocation: central allocation (including telephone, web-based and pharmacy-controlled randomization); sequentially numbered drug containers of identical appearance; or sequentially numbered, opaque, sealed envelopes.

Unclear = If no information about allocation concealment is given.

3. Blinding of participants and personnel

Performance bias due to knowledge of the allocated interventions by participants during the study. Assessment should be based on whether a cover story was used and believed by participants (following Buckland, Er, Redpath, & Beaulieu, 2018).

High = If no cover story is used and/or participants were aware of their allocated condition throughout the study.

Low = If a cover story is used and participants report being unaware of their allocated condition throughout the study.

Unclear = If no information is given about the use of a cover story. If a cover story is used, no information is given about whether or not this was believed by participants.

4. Blinding of outcome assessors

Based on whether the experimenter who assessed food intake was blind to the study aims or condition administered (following Buckland, Er, Redpath, & Beaulieu, 2018).

High = If the experimenter who assessed food intake was aware of the study aims or condition administered when presenting foods to participants and/or when calculating food intake (e.g., weighing leftovers).

Low = If the experimenter who assessed food intake was blind to the study aims or condition administered when presenting foods to participants and when calculating food intake (e.g., weighing leftovers).

Unclear = If no information is given about awareness of conditions, and it is unclear whether the experimenter was aware of study conditions.

5. Incomplete outcome data

Based on whether the exclusion of participants was specified in the exclusion criteria or exclusions deviated from standard procedures in the research field (following Buckland, Er, Redpath, & Beaulieu, 2018).

High = If exclusion criteria are specified but not justifiable (i.e., they are not standard practice in the field and are not otherwise justified by the researcher). Any exclusion of participants from data analyses are not justified by the researcher.

Low = If exclusion criteria are specified and clearly justified by the researcher; criteria are standard practice in the field and otherwise justified for the present study. Any exclusion of participants from data analyses are justified by the researcher.

Unclear = If exclusion criteria are not specified.

6. Selective outcome reporting

Reporting bias due to selective outcome reporting.

High = if not all of the study's pre-specified primary outcomes have been reported; one or more primary outcomes is reported using measurements, analysis methods or subsets of the data (e.g., subscales) that were not pre-specified and are not identified as exploratory analyses; one or more outcomes of interest in the review are reported incompletely so that they cannot be entered in a meta-analysis; the study report fails to include results for a key outcome that would be expected to have been reported for such a study.

Low = if the study protocol/data analysis plan is available and all of the study's pre-specified (primary and secondary) outcomes that are of interest in the review have been reported in the prespecified way, or if the study protocol is not available but it is clear that the published reports include all expected outcomes, including those that were pre-specified.

Unclear = A study protocol/data analysis plan is not included.

7. Other sources of bias

Based on risk of confounding variables influencing food intake - e.g., used piece count that is susceptible to researcher bias, absence of procedures to control for appetite between conditions; experiment conducted in a social setting outside of the laboratory (e.g., in a cafeteria); administering psychometric scales related to eating before assessing food intake. Please list confounding variables in textbox.

High = At least one confounding variable is identified, and it is not adequately controlled in the experimental procedure.

Low = No confounding variables identified, or confounding variables are adequately controlled in the experimental procedure.

Unclear = The method is lacking detail to identify whether confounding variables are present (e.g., setting is not described, method for calculating intake is not explained, order of tasks is not clear, sample characteristics not fully reported).

Appendix C. Study 2: Ethics approval

1 November 2018

Dear ROCHELLE EMBLING and Dr Laura Wilkinson,

Re: 0283 , What food choices do YOU make in the supermarket and why? II

Your application - [redacted] - has been reviewed and approved by the Department of Psychology Ethics Committee.

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted]).

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr GABRIELA JIGA-BOY (Reviewer of Application)

Associate Professor Andrew Kemp (Committee Chair)

Appendix D. Study 3: Ethics approval

4 March 2019

Dear ROCHELLE EMBLING, Dr Laura Wilkinson,

Re: 1363 , What food choices do YOU make in the supermarket and why? Online

Your application - [redacted] - has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	Other student applicant - Surname	Other student applicant - email

additional researcher or student - first name	additional researcher or student - surname	additional researcher or student - email

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

<u>To advertise your study on the departmental Participant Pool:</u> You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted]).

<u>For students:</u> Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr IRENE Reppa (Reviewer of Application)

Dr Gabriela Jiga-Boy (Committee Chair)

Appendix E. Study 4: Ethics approval

27 October 2020

Dear ROCHELLE EMBLING, , , Dr Laura Wilkinson,

Re: 4951 , Exploring consumer beliefs about different food products: A pilot study

Your application - [redacted] - has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	Other student applicant - Surname	Other student applicant - email

additional researcher or student - first name	additional researcher or student - surname	additional researcher or student - email

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted].

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr Daniel Zuj (Reviewer of Application)

Dr Gabriela Jiga-Boy (Committee Chair)

Appendix F. Study 5: Ethics approval

23 September 2021

Dear ROCHELLE EMBLING, , , Dr Laura Wilkinson,

Re: 4951 , Exploring consumer beliefs about different food products: A pilot study

Your application [redacted] - has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	**Other student applicant - Surname**	**Other student applicant - email**

additional researcher or student - first name	**additional researcher or student - surname**	**additional researcher or student - email**

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted].

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr Gabriela Jiga-Boy (Reviewer of Application)

Dr Gabriela Jiga-Boy (Committee Chair)

Appendix G. Study 6: Ethics approval

20 November 2020

Dear ROCHELLE EMBLING, , , Dr Laura Wilkinson,

Re: 4994 , Exploring consumer beliefs about different food products: Main study

Your application - [redacted] has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	**Other student applicant - Surname**	**Other student applicant - email**

additional researcher or student - first name	**additional researcher or student - surname**	**additional researcher or student - email**

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted]).

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr Menna Price (Reviewer of Application)

Dr Gabriela Jiga-Boy (Committee Chair)

Appendix H. Study 7: Ethics approval

20 January 2020

Dear ROCHELLE EMBLING, , , Dr Laura Wilkinson,

Re: 1515 , UK Biobank secondary data analysis

Your application -[redacted] - has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	Other student applicant - Surname	Other student applicant - email

additional researcher or student - first name	additional researcher or student - surname	additional researcher or student - email

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted]).

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr Daniel Zuj (Reviewer of Application)

Dr Gabriela Jiga-Boy (Committee Chair)