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CHAPTER 1

General Introduction

1.1 Introduction

In 2015, Europe was the region most severely affected by non-communicable diseases (NCDs) of the six World Health Organisation (WHO) regions (1). In the Netherlands, NCDs were estimated to account for 90% of all deaths in 2018 (2). Furthermore, the increasing obesity rates in Europe are troublesome given the relation between obesity and NCDs (3, 4). The distribution and impact of NCDs and their risk factors is highly unequally distributed and imposes a disproportionately large burden on individuals with a lower socio-economic position (SEP) and females (5). Unhealthy dietary intake is the strongest modifiable risk factor for NCDs and has been identified as a major public health problem among adults in developed countries (6). In 2019, 13.5% and 14.6% of female and male deaths worldwide could be attributed to an unhealthy diet (7), and improvement of dietary quality could prevent one in five deaths caused by NCDs (8). However, instead of shifting towards healthier dietary patterns, evidence suggests that calorie intake from unhealthy food and beverages (hereafter referred to as 'foods') has increased, and that of fibre-rich foods such as wholegrains, pulses and roots has declined over the years amongst the global population (9). Furthermore, dietary behaviours are socio-economically patterned; individuals with a lower SEP generally have an unhealthier dietary pattern than individuals with a higher SEP (10).

This doctoral thesis aims to provide insights into factors explaining socio-economic inequalities in dietary behaviours and the effectiveness of interventions that target the context in which food choices are made. In this General Introduction, I will first describe socio-economic patterns in dietary behaviours and factors affecting food choice. The next section is about environmental interventions aimed at improving healthy dietary behaviours. Finally, I will describe the research aims and outline of this thesis.

Diet taxonomy used in this thesis (adapted from Stok et al. 2017)

Food choice =	Diet-related behaviours and factors associated with selecting, obtaining, receiving and purchasing foods
Food purchases =	The purchasing of food and beverages which is precedent to dietary intake
Dietary intake =	All outcomes that break down the content of food and beverages being consumed
Dietary quality =	The quality of dietary intake, often defined as whether or not this intake adheres to dietary recommendations
Dietary pattern =	Specific combination of foods and beverages a person habitually consumes
Unhealthy foods =	Foods and beverages attributed to have a negative effect on health through unhealthy nutrients such as sugar, salt and saturated fat (e.g. sugar-sweetened beverages)
Healthy foods =	Foods and beverages attributed to have a positive effect on health through healthy nutrients such as fibre and unsaturated fats (e.g. fruits and vegetables)
Dietary behaviours =	Overall umbrella term referring to all phenomena related to food choice and dietary intake

1.2 Dietary intake and NCDs

Numerous studies have investigated the association between dietary intake and overweight, obesity, and/or diet-related NCDs such as cardiovascular disease and type 2 diabetes (11-19). These studies determined that ultra-processed foods (17), high intakes of fat and energy-rich beverages and low intakes of fibre, fruits and vegetables are all associated with overweight, obesity and diet-related NCDs (11, 16, 18, 19). Similarly, evidence suggests that following a healthy dietary pattern reduces the risk of developing NCDs (12-15). For example, high quality diets, as assessed by the Healthy Eating Index, Alternate Healthy Eating Index, and Dietary Approaches to Stop Hypertension scores are associated with an approximately 20% reduced risk of all-cause mortality, cardiovascular disease incidence or mortality, and incidence of type 2 diabetes (15).

Unfortunately, many people do not adhere to a healthy dietary pattern. For example, according to the Dutch nutrition guidelines, adults should consume at least 200 grams of fruit and 250 grams of vegetables per day (20). However, the Dutch adult population consumes 116g/day of fruit and 145g/day of vegetables on average, and only around 15% of adults consume the recommended amounts of fruit and vegetables (20). Overall, the percentage of adults that follow the Dutch nutrition guidelines varies between 3% to 57% depending on the food group (20). While the proportion of adults who adhere to the Dutch nutrition guidelines has increased over the years, still only a small proportion of adults adhere to the recommended dietary pattern (20).

Therefore, improvements are still necessary in order to decrease the prevalence of overweight/obesity and diet-related NCDs.

1.3 Socio-economic inequalities

Numerous studies have shown that adults with a lower SEP have an unhealthier diet compared to adults with a higher SEP (11, 21-23). When stratifying the percentage of adults who adhere to the Dutch fruit and vegetable guidelines by educational level, only 8% of adults with a lower education level (a proxy of SEP) adhere to these guidelines compared to 24% of adults with a higher education level (20). This unhealthier diet puts adults with a lower SEP at an increased risk of developing overweight/obesity and diet-related NCDs (24). For example, evidence from a Dutch prospective cohort study showed that adults with the lowest educational level had a 2-fold higher risk of developing coronary heart disease compared to adults with the highest educational level and that dietary factors explained 30% of this association (25).

The burden of overweight, obesity and NCDs can be reduced by tackling socio-economic inequalities in diet and health. For example, the results from a recent study on health inequalities in England suggests that one in three premature deaths were attributable to socio-economic inequality (26). In other words, reducing socio-economic inequalities could actually enhance health at the population level (27, 28). Besides reducing the burden of obesity and NCDs, tackling socio-economic inequalities is important as these inequalities can be considered unjust; the poorer health of individuals with a low SEP are largely attributable to societal and environmental processes which are beyond an individual's control (10).

Several theories have been used to conceptualise and explain socio-economic inequalities in health. The Black report, published in 1980, marked a milestone in understanding how social conditions shape health inequalities (29). In 2010, the World Health Organization published a conceptual framework for action on social determinants of health (30). This report described three perspectives on explaining health inequalities which are not mutually exclusive. The social selection perspective implies that health determines SEP and not vice versa. However, evidence suggests that social selection cannot be regarded as the predominant explanation for health inequalities (31). The life course perspective recognizes that social determinants of health operate at every level of development ranging from early childhood to adulthood (30). According to the social causation perspective, socio-economic conditions affect health largely through diverse material, psychosocial, and behavioural risk factors.

The perspectives used to explain health inequalities can also be applied to dietary inequalities. For example, given that material and psychosocial factors can influence dietary behaviours, it can be postulated that these factors explain socio-economic inequalities in dietary behaviours. In this thesis, I will use the social causation perspective as a framework for explaining socio-economic inequalities in dietary behaviours.

1.4 Determinants of food choice

The social causation perspective and social ecological models have something in common; they both theorize that, besides personal factors, environmental factors are important in determining health behaviours. Social ecological models emphasize that besides individual and interpersonal factors, more upstream factors such as healthy food availability play an important role on health behaviours (32). Factors on the individual level that may influence food choices include genetics and personal characteristics such as food choice motives, SEP, age, sex, knowledge, cooking skills and self-efficacy (33-37). Interpersonal factors associated with food choice are for example social influence and social contacts (38, 39).

Upstream factors can be found in the food environment, and according to the ANGELO (analysis grid for environments linked to obesity) framework there are micro-environmental and macro-environmental settings (40). Micro-environments are settings that people use for specific purposes (e.g. supermarkets) and where people interact directly with objects and stimuli in those environments (41). In contrast, macro-environments shape the characteristics of micro-environments and the relationship between them (e.g. the amount of food retailers within a neighbourhood). The ANGELO framework also distinguishes between four types of environments, namely the physical, economic, political and sociocultural environment (40). Factors within the physical food environment are related to the availability and accessibility of food and food providers, while price and affordability are factors associated with the economic food environment. Factors within the political food environment include rules and regulations, and factors within the sociocultural food environment relate to social and cultural preferences (42).

Currently, the food environment predominately offers convenient and cheap ready to-eat foods of low nutritional value (i.e. unhealthy foods) which are easily available and heavily marketed (43). A good illustration for the scale at which these foods of low nutritional value are offered can be found in supermarket environments. According to a recent report on the environment of Dutch supermarket chains in the Netherlands, the supermarket lay-out mostly promotes unhealthy foods; 82% of foods in advertising flyers are unhealthy and over 59% of the supermarket assortment can be considered unhealthy even after excluding the unhealthy food group confectionery (44). Given that the current food environment heavily promotes unhealthy foods, addressing factors within this environment is vital when wanting to improve the dietary quality of the general population, and particularly those with a low SEP.

1.5 Food environment interventions

A multitude of intervention strategies aimed at increasing healthy dietary behaviours have been investigated to date. Such interventions range from directly changing behaviours by targeting individuals through health promotion, education, advice and counselling all the way to adapting the environment in which health behaviours take place. Interventions directly aimed at changing behaviours generally target a small population of high-risk individuals while environmental or more upstream interventions tend to target a much broader population (45). Given the high prevalence of obesity worldwide, upstream approaches may be more appropriate for the prevention/reduction of obesity.

Several reviews have synthesized the evidence on upstream approaches aimed at improving healthy dietary behaviours (46-50). Examples of these approaches include increasing the number of food outlets that offer fresh produce, making healthy foods more attractive through product placement and promotion strategies, decreasing portion size and discounting healthy foods. The included studies within these reviews can broadly be classified into three intervention strategies: nudging strategies/marketing approaches, pricing strategies and strategies aimed at changing the availability of foods (51). Both nudging and pricing strategies are found within the physical and economic micro-environment.

In this thesis, I will focus on nudging and pricing strategies as upstream approaches to increase healthier dietary intake. While interventions/policies aimed at increasing healthy dietary behaviours should target multiple environments, I will focus on the implementation of these strategies within supermarkets. Supermarkets form an important setting as a large proportion of the available healthy foods can be purchased here. Also, in the Netherlands, 70% of daily foods are purchased in supermarkets (44).

1.6 Pricing strategies

Taxing unhealthy products can address the negative externalities that occur when the consumption of a product does not include the external costs on third parties. These external costs are a cause of market failure, and throughout history taxing schemes have been utilized to address this market failures (i.e. in the case of tobacco and alcohol products) (52). Market failures transpire when the individual incentives for rational behaviour (e.g. the consumption of alcoholic beverages) do not lead to rational outcomes for the population (e.g. the increased health care costs due to alcohol-related accidents). More recently, evidence has shown that consuming too much sugar can lead to weight gain, which in turn increases the risk of developing NCDs (53, 54). Therefore, next to taxing tobacco and alcohol, it may also be necessary to tax foods high in sugar. This tax revenue can be used to pay for the health care costs incurred and could also be used to subsidize healthy foods. Evidence also shows that besides generating income, taxes can effectively discourage the consumption of these unhealthy products.

The price of food is an important driver of food choice (55), therefore many studies have investigated the effectiveness of pricing strategies on food purchases, consumption and weight status as a means to improve population health (43, 46, 56-64). Pricing strategies include increasing the prices of unhealthy foods or nutrients and/or decreasing the prices of healthy foods. These studies can be roughly categorized as evidence from interventional/experimental studies and modelling studies. Evidence from experimental studies, namely Randomized Control Trials (RCTs), in virtual supermarkets and real-world retail settings such as supermarkets and cafeterias found that pricing strategies influence the purchases and consumption of targeted foods in the intended direction (56, 61, 64). For example, a systematic review including both RCTs as well as nonrandomized interventions in various real-world settings (e.g. vending machines and restaurants) found that a 10% decrease in price increased the consumption of targeted healthy foods by 12%, and a 10% increase in price decreased consumption of targeted unhealthy foods by 6% in (56). A large RCT conducted in a virtual supermarket found that a saturated fat tax, sugar tax and salt tax significantly increased the proportion of healthy foods purchased by 1-2%, while a SSB tax and fruit and vegetable subsidy did not result in significant changes of food purchases (65). Virtual supermarkets are becoming increasingly popular to study the effects of pricing strategies on food purchases given the ease of implementing RCTs within this setting. Besides RCT evidence, evidence from natural experimental studies in regions/countries that have already implemented health-related taxes or subsidies can also be evaluated. The most common health-related pricing strategy implemented in the real-world are SSB taxes, which to date have been implemented in over 40 countries (66). Similar to the results found in the RCT studies, a recent systematic review investigating the impact of SSB taxes on purchases and dietary intake found that the equivalent of a 10% SSB tax was associated with an average decline in beverage purchases of 10% (58).

Modelling studies use data from observational or experimental studies to simulate how reactive the demand for a food (group) is to price changes using price elasticities. A systematic review of modelling studies found that the mean price elasticity estimates range from -0.27 to -0.81, with higher price elasticities found for food consumed away from home, soft drinks and juices (57). A price elasticity of -0.81 indicates that when the price of the food group increases by 10%, then the demand for the food group decreases by 8.1% on average. Thus, larger price elasticities lead to larger changes in demand. However, contrary to the evidence from experimental studies, evidence from modelling studies suggest that the percentage change in demand is smaller than the percentage change in price as most price elasticities on food groups are below 1.0 (57). Besides the effect pricing strategies have on targeted foods, compensatory purchasing may also take place. For example, individuals faced with an SSB tax may purchase less sugary beverages (own-price elasticity), but purchase more beverages high in fat (cross-price elasticity). Evidence on cross-price elasticities is scarce, with most modelling studies investigating cross-price elasticities between food groups (e.g. what is the influence of an SSB tax on discretionary foods) (67).

The combined effect of pricing strategies on targeted and non-targeted foods determines the overall effectiveness of pricing strategies on food purchases, consumption and health outcomes (Figure 1). Ideally, evidence on the relation between pricing strategies and health outcomes comes from robust research methodologies (i.e. experimental studies). However, pricing strategies are difficult to undertake in the real world and RCTs are generally too short to determine long-term health effects (68). Modelling studies offer a solution by estimating the impact of price changes on health outcomes through causal diagrams and policy-oriented computer models that use a collection of mathematical equations to quantify the relationship between pricing strategies and health outcomes (68). Most modelling studies to date have investigated the effect of SSB taxes on weight outcomes (62, 69, 70). The results from these studies are less straightforward than the evidence for dietary behaviours, with some reviews suggesting that SSB taxes do not have an effect on weight-related outcomes (62, 69, 70). Nevertheless, it is unrealistic to expect that one single intervention strategy can reduce multifactorial diseases such as obesity and cardiovascular disease. Therefore, multiple strategies should be utilized to try and combat obesity and diet-related NCDs.

Despite the strong evidence showing that pricing strategies effectively improve healthy dietary behaviours, dissidents of SSB taxes believe that such taxes are regressive (71). Individuals with a lower SEP tend to consume more SSBs and therefore spend a greater percentage of their income on the SSB tax (72). However, adults with a lower SEP are likely more price sensitive than adults with a higher SEP due to their limited food budget. In turn, people who are more price sensitive may react more strongly to price changes. The current evidence on the possible differential effects by SEP in the relation between pricing strategies and dietary behaviours is equivocal (24, 73-75), with most studies finding no differential effects by SEP (73, 74). A recent modelling study found that a targeted 50% fruit and vegetable subsidy combined with a national SSB tax could be used to reduce the tax regressivity among adults with a lower SEP (76). A systematic review on differential responses to price changes concluded that there may be other personal characteristics – such as impulsivity and body weight - for which the differential effect of pricing strategies may be important to consider in order to avoid increasing health inequalities (75).

In conclusion, the current evidence suggests that pricing strategies can contribute to the promotion of healthy dietary behaviours. Nevertheless, some gaps in the literature remain which warrant further investigation. This includes evidence on cross-price elasticities, whether pricing strategies are equally effective for all, and what the effect is of utilizing a combination of strategies on dietary behaviours, all of which will be addressed in this thesis.

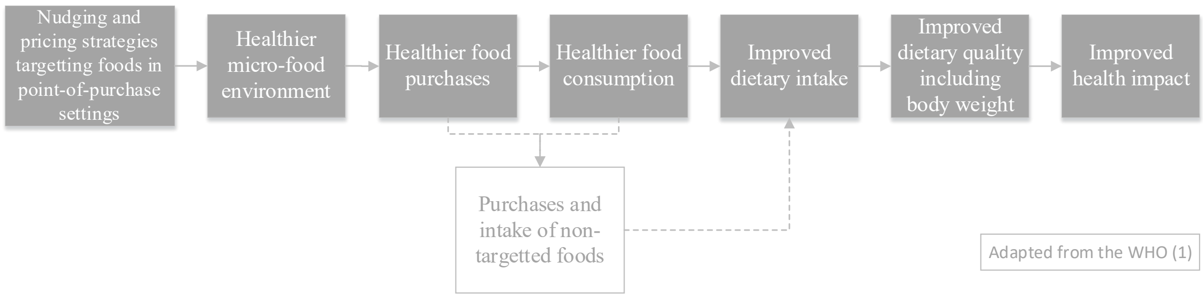

Figure 1. Pathway through which it is hypothesized that nudging and pricing strategies influence health and disease

1.7 Nudging strategies

According to Thaler and Sunstein, the term 'nudge' can be defined as: '*Any aspect of the choice architecture that alters people's behaviour in a predictable way, without forbidding any options or significantly changing their economic incentives*' (77). In other words, nudging strategies use the choice architecture to modify peoples' behaviour without restricting choice. Nudges can entail similar interventions as food marketing strategies, yet are only directed at healthy foods. Food marketing strategies include using trendy messages, novel displays, colourful floor decals, compelling store arrangements and other environmental triggers (78). Given the similarities between nudging and food marketing strategies, it can be argued that these nudging strategies can be implemented relatively easily within the current structure of retail food environments. However, whether these nudging strategies should be implemented, mostly depends on their effectiveness in influencing healthy food behaviours.

In this thesis, I classify nudges using the TIPPME (typology of interventions in proximal physical micro-environments) typology developed by Hollands et al. (41). Six nudging types are identified; availability, position, functionality, presentation, size and information. Most nudging studies conducted in the retail food environment investigated the effect of the availability, position and information nudges (79-82). A systematic review investigating the effect of altering the availability and proximity of foods found that these types of nudges change the food purchasing and consumption behaviour in the intended direction (79). The summary effect sizes suggest that nudges could decrease the amount of energy purchased and consumed by between 17% and 36% on an average snack occasion (79). However, the risk of bias for the majority of included studies was assessed as high, mostly arising from the randomisation process. Comparable results were found in other systematic reviews; position (81, 82) and information nudges (80, 81) have modest tendencies towards beneficial effects on dietary behaviours, but most studies included were of weak to moderate quality (81, 82). Currently, information nudges are gaining popularity as several governments have implemented a policy mandating front-of-package nutrition labels. These information nudges – contrary to the other five nudging types – call upon individuals' conscious thought processes instead of their unconscious/automatic processes. A systematic review on different food labelling schemes found that they may play a significant role in facilitating consumers to select healthier food products (80). Conversely, the findings show a less clear picture in terms of whether food labelling schemes affect calorie choice or consumption (80).

Several gaps in the nudging literature remain. First, more high-quality research with larger and more representative samples are needed (78). Second, more research on the long-term effectiveness of nudges is needed as most studies had an intervention duration of less than 6 months (81). It is possible that the novelty of nudging interventions wears off, thereby decreasing its effectiveness over time. Third, most studies to date have been conducted in laboratory settings assessing behaviour in relation to single or very limited ranges of snack foods (79). The effect of nudges across a full range of products, preferably in real-world settings, needs to be assessed. Fourth, more research on other nudging types should be conducted (e.g. presentation-type nudges). Fifth, more research on the differential effects of nudges should be conducted in order to assess which individuals are more susceptible to nudges (78, 82). Nudges that work well for one group of people (e.g. impulsive individuals or individuals with a high education) may not work well for other groups of people (e.g. non-impulsive individuals and individuals with a low education).

In this thesis, I will address some of the aforementioned research gaps by focussing on the effectiveness of presentation and information nudges in virtual and real-world supermarket environments among a relatively large and representative study sample. Additionally, I will investigate the susceptibility to presentation-type nudges according to personal characteristics such as impulsivity and food choice motives. Multiple scholars find that nudging strategies should complement, rather than substitute for, more forceful policies such as health-related taxes (78). Therefore, in this thesis, I will additionally focus on the combined effects of nudging and pricing strategies.

1.8 Aims and outline of this thesis

This doctoral thesis is part of the larger Supreme Nudge project which aims to develop, implement and evaluate strategies for adults with a low SEP to improve dietary behaviours and physical activity levels and, ultimately, cardiometabolic health (83). This doctoral thesis consists of two aims; the first aim was to gain insight into factors that explain socio-economic inequalities in dietary quality. The second aim was to investigate the effectiveness of nudging and pricing strategies on food purchases and the possible differential effectiveness of these strategies across food groups and individuals with different personal characteristics. The findings from this doctoral thesis can be used to inform organisations interested in using nudging and pricing strategies as a means to improve public health by increasing healthy dietary behaviours.

With regards to the first aim, Chapter 2 describes the cost and affordability of healthy and current diets for households with a low, medium and high educational level. Chapter 3 describes the extent to which dietary cost explain socio-economic inequalities in dietary quality and Chapter 4 describes the extent to which other material and psychosocial resources may explain these socio-economic inequalities.

Regarding the aim to investigate the effectiveness of nudging and pricing strategies on healthy food purchases and their equity, in Chapter 5, the effectiveness of on-shelf sugar labelling implemented by a supermarket chain on beverage sales is evaluated. Chapter 6 describes how successful different recruitment strategies are for adults with a low and high SEP participating in a virtual supermarket study. Chapters 7 and 8 describe the effect of nudging and several pricing strategies on healthy food purchases in this virtual supermarket and possible differential effects of nudging and pricing strategies according to socio-economic indicators and personal characteristics. Using the same data as Chapters 6 through 8, Chapter 9 describes the differential effectiveness of nudging and pricing strategies on healthy food purchases within several food groups. Chapter 10 describes the effectiveness of food taxes on healthy food purchases using cross-price elasticities estimated from data of the Price ExaM study (a virtual supermarket study conducted in New Zealand).

Chapter 11 provides a summary and synthesis of the main findings presented in this doctoral thesis and the results described in Chapters 2 through 10 are put in a broader perspective and in the current societal context. Also, future directions for research, practice and policy are provided. Lastly, in the appendix, a summary of the findings (in Dutch and English), a list of publications and my PhD portfolio can be found. The appendix also includes the most read section of any thesis, the acknowledgements.

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CHAPTER 2

The cost of healthy versus current diets in the Netherlands

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2.1 Abstract

Purpose The higher cost of healthy diets could hamper individuals from following dietary recommendations, especially those with a limited food budget. While the cost differential between current and healthy diets has been previously investigated, these studies did not account for the variation in dietary patterns. The current study aimed to describe the cost and affordability of healthy and current diets for households with a low, medium and high educational level in the Netherlands.

Methods The lowest available prices of commonly consumed foods were collected across local food shops and supermarkets in Amsterdam, the Netherlands. Data from the Dutch National Food Consumption Survey was used to construct commonly consumed food lists separately for an average Dutch household and for households with a low, medium and high educational level. The distribution of the cost of two-weekly healthy and current household diets were modelled using the DIETCOST program which accounts for variations in healthy and current diets.

Results None of the modelled two-weekly household current diets in our sample adhered to the Dutch dietary recommendations due to high intakes of sodium and low intakes of fibre and fruit. The average cost of the current household diet was €210.64/fortnight (SD 8.86) and the healthy household diet was on average €50.21 (24%) more expensive. For households with a low, medium and high educational level, healthy diets were on average 10% (€17.41), 26% (€49.97) and 36% (€71.55) more expensive compared to current diets, respectively. All healthy diets were deemed to be affordable in terms of requiring around 20% of the average disposable income.

Conclusion Although healthy diets were found to be affordable in terms of disposable income, healthy diets were on average substantially more expensive than current diets. Levelling the prices of healthier versus unhealthier foods, for example through removing taxes on fruit and vegetables or implementing a health-related tax on sugar sweetened beverages, is therefore an important strategy in improving population diets.

2.2 Introduction

Although unhealthy diets are an important risk factor of non-communicable diseases (NCDs) such as diabetes, cancer and cardiovascular diseases (1), population diets in general do not adhere to recommended dietary guidelines for healthy eating. For example, the Dutch guidelines state that adults should consume at least 200 grams of fruit and 250 grams of vegetables per day, which is achieved by only 13% and 16% of adults (2). Furthermore, when stratifying the percentage of adults who adhere to the fruit and vegetable guidelines by educational level, only 10% and 8% of adults with a lower educational level adhere to these guidelines compared to 17% and 24% of adults with a higher educational level (2). This finding is in line with previous research showing that individuals with a lower socio-economic position (SEP) generally adhere less often to dietary guidelines compared to individuals with a higher SEP (3-5).

Most evidence to date suggests that healthier dietary patterns are more costly than less healthy dietary patterns (6, 7). For example, findings in a previous review suggest that healthy diets are approximately \$1.50/day more expensive than current diets (6). Several methods have been used to assess the cost differential between healthier and less healthy dietary patterns, including comparing healthier and less healthy food baskets and comparing categories of food-based dietary patterns (e.g. the Dutch Healthy Diet Index or the Healthy Eating Index) (6). However, current attempts to model the cost of healthy and current diets have important limitations, mostly because they do not take into account the variation in dietary patterns or food prices, or only measure the cost of a healthy diet while not providing insight into the cost of current diets. Therefore, the International Network for Food and Obesity/NCDs Research, Monitoring and Action Support (INFORMAS) developed a program (DIETCOST) allowing researchers to model the cost differential between healthy and current household diets while taking into account the variations in two-weekly household meal plans and prices. Previous research using the DIETCOST program in New Zealand found that the average cost of healthy diets was around 4% (or \$1.93/day) more expensive than current diets and that 25% of healthy diets were cheaper than the average cost of the current diet (8).

As population dietary patterns, dietary guidelines and the price of food vary from country to country, it is important to investigate the cost differential between current and healthy diets in multiple settings. For example, white meat is comparatively cheap in Australasia compared to Europe (9), and in Australia basic healthy foods are exempt from Goods and Services Taxes (10), while in the Netherlands the tax has recently been increased from 6% to 9% (11). This difference in price can in turn partly explain the finding from an Australian study suggesting that – contrary to most studies (6) – healthy diets are actually less expensive than current diets (10). According to the Dutch National Institute for Family Finance Information, currently, the minimum cost of a healthy food basket in the Netherlands for a four-person household is €15.91/day (12). However, it is unclear what the cost differential is between healthy and current diets. Previous Dutch studies showed that higher dietary cost was associated with better dietary quality (13) and that higher energy dense diets were associated with lower diet costs (14). We therefore expect that healthier diets in the Netherlands are more expensive than less healthy/current diets.

Besides evaluating the cost differential between healthy and current diets in different contexts, it may also be important to investigate the cost differential for different subpopulations. A review of the literature on diet quality and its socio-economic gradient found that the higher cost of healthy diets poses an especially important barrier for a healthy lifestyle for individuals in economically and socially deprived households (3). If populations were to follow the dietary guidelines, this may lead to increased expenditure, with the lowest SEP households being most vulnerable as they spend a greater proportion of their total expenditure on food (even though they likely spend less per person on food) (15). Indeed, a recent Australian study found that both healthy and current diets were considered least affordable for the most disadvantaged household (10).

The current study aimed to describe the cost and affordability of healthy and current diets for an average household as well as for households with a low, medium and high educational level (as a proxy for SEP) in the Netherlands using the DIETCOST program.

2.3 Methods

This modelling study used the DIETCOST program to model the costs of current and healthy household diets using a list of commonly consumed foods including a set of minimum and maximum quantity constraints. The reference household for which the costs were calculated comprised of a 45-year-old man, a 45-year-old women, a 14-year-old boy and a 7-year-old girl to allow for comparability with previous studies. This modelling study was based on population-level data and averages, which did not require the involvement of members of the public in the study conception, design, data analysis or reporting.

2.3.1 DIETCOST program

A comprehensive description of the manual for the DIETCOST program can be found elsewhere (16). The DIETCOST program was developed with the aim to model the distribution of the cost of healthy and current diets. Unlike other traditional approaches that calculate the cost of healthy and current diets through developing one healthy and one current meal plan, and collecting the prices of the food items within these two meal plans, the DIETCOST program allows for taking into account variations in healthy and current diets by varying the serving size of food items within the healthy and current dietary baskets. The program runs on input files including data on a list of foods commonly consumed by the population under study, nutrient targets and minimum/maximum constraints for healthy and current diets, healthy and current diet baskets, food composition data and food price data. These inputs are further described below.

2.3.2 List of commonly consumed foods

In accordance with the DIETCOST program manual, we constructed a commonly consumed foods list (16). This list for the Dutch population was derived from the Dutch National Food Consumption Survey (DNFCS), which is a survey that is conducted every four years by the Dutch Ministry of Public Health, Welfare and Sports. This survey consists of two 24-hour dietary recalls on two random non-consecutive days. For children aged 1 to 8 years, the 24-hour recall was combined with a food diary, both completed by the child’s caretaker one day before the interview. Also, socio-demographic information was collected via questionnaires. We used the most recent DNFCS which was collected between 2012 and 2016. DNFCS 2012-2016 study participants are representative for the Dutch population regarding their age, gender, region, degree of urbanisation and educational level (17). Educational level was measured by participants' highest completed educational level or, in case of participants aged under 19, that of the head of household. For this study, educational level was categorised into low (primary education, lower vocational education, advanced elementary education), medium (intermediate vocational education, higher secondary education) and high (higher vocational education and university) education. The response rate of the DNFCS 2012-2016 was approximately 65% (n=4313). More information on the collection of data and participant characteristics can be found elsewhere (17).

The DNFCS 2012-2016 included 1854 food items and distinguishes 18 food groups based on the GloboDiet grouping (17). All food items have a unique code that describes the food composition of that particular item. This Dutch Food Composition code (NEVO) was used to link nutrient information and whether the food is included in the Dutch dietary guidelines. From this list, data on commonly consumed foods, the distribution in which they are consumed (i.e. high, medium and low frequency (16)), whether a food item is considered healthy or less healthy, which population group consumes the food and whether children, adults or both consume the commonly consumed foods were extracted. Provided that no guidance about the construction of the commonly consumed food list was available, we decided to calculate the mean frequency food items were consumed by each of the four household members, resulting in 13 items for girls, boys and women, and 15 items for men. This number was then used as a cut-off for the selection of commonly consumed foods. We chose not to calculate this cut-off separately for each food group as using the cut-off across the entire diet gives a better representation of the average Dutch diet. If the food item was consumed more than the mean intake (i.e. the cut-off) only for children or only for adults, this food was considered a commonly consumed food for either children or adults. Commonly consumed foods were found across a range of food groups, except for the food groups legumes, nuts and fish. Therefore, we selected additional healthy and less healthy foods within these food groups that were consumed just below the mean threshold. Overall, n=200 food items were determined to be commonly consumed foods, of which n=17 were consumed exclusively by children and n=21 exclusively by adults.

DNFCS data was then also used to construct a list of food items commonly consumed by individuals with a low, medium and high education with education level-specific cut-offs deriving to three separate datasets. For all three education categories, additional healthy food items needed to be included in the commonly consumed food list in the categories fruit, vegetables, grains, dairy and protein foods given the small amount of commonly consumed healthy food items within these categories. The food items included for the average household did not vary much from the food items included in the low, medium and high educated households. The largest difference included the number of food items for the different households (in other words the level of variety); in total, 103, 137 and 149 food items were included in the commonly consumed food list of households with a low, medium and high education, respectively.

2.3.3 Nutrient composition

Next to a list of commonly consumed foods, information on the nutrient composition for each commonly consumed food was required. According to the DIETCOST manual, information on energy kJ/100g, fat g/100g, carbohydrates g/100g, sugars g/100g, fibre g/100g, protein g/100g and sodium mg/100g is required, which was extracted from the NEVO database (18).

2.3.4 Nutrient targets and constraints

We set nutrient targets including a minimum and maximum (constraints) amounts of consumption for food groups and macronutrients in the dataset file required for the DIETCOST program. This input is used to construct a variety of meal plans of which the nutrient composition and food group consumption of each meal plan falls within a set of (realistic) constraints. The DIETCOST program uses these constraints to then develop a number of realistic meal plans. The nutrient targets and constraints differed for healthy and current diets.

Input for the nutrition targets and constraints of current diets separately for the four household members were derived from a previously published report analysing the diet of the Dutch using the DNFCS 20212-2016 data (17). Constraints for the macronutrients fat, saturated fat, carbohydrates, total sugars, fibre, protein and sodium were collected, including the number of servings for the food groups fruit, starchy vegetables, vegetables, dairy, grains and proteins (16). The nutrient constraints were then calculated by taking the average intake in grams of macronutrients and food groups ± 30%, except for energy (which was equal to the mean intake ± 5%). For example, 4 to 8 year old girls consume on average 14.7 grams of fibre per day for which the nutrient constraints were set at 10.3 and 19.1. The nutrition targets for individuals with a low, medium and high education were derived from the Dutch National Institute for Public Health and the Environment website (19). Unlike the report, the website reports the DNFCS 2012-2016 results stratified by age, sex and educational level, but only by two age categories (children and adults).

Information on the nutrient targets and constraints for a healthy diet were based on the Dutch dietary guidelines (20). These guidelines provide recommendations for the average Dutch population on the ideal minimum and/or maximum intake of food groups and nutrients stratified by sex and age. More information on the dietary guidelines can be found elsewhere (20). While the nutrient targets were completely based on the Dutch dietary guidelines, the nutrient constraints were based on a combination of the Dutch dietary guidelines and the World Health Organization population nutrient intake goals as an ideal range for macronutrients is not reported in the Dutch dietary guidelines (21). The nutrient targets/constraints for a healthy diet are equal for the overall population and for household members with a low, medium and high education.

2.3.5 Healthy and current food baskets

Based on the commonly consumed food list for the average population as well as for households with a low, medium and high education, four current and four healthy food baskets were constructed for each of the groups. These baskets contain food items and their corresponding weekly serving size constraints. Serving sizes were identified on the website of the National Institute for Health and Environment (22). For example, a bowl of yoghurt is approximately

150 grams, and the minimum serving of yoghurt is 75 grams (i.e. half a portion per week) and the maximum serving is 2100 grams (i.e. 14 servings of yoghurt per week). According to the DIETCOST manual, more servings should be given to the most commonly consumed food items; e.g. while yoghurt had a maximum weekly serving of 14 bowls, low fat yoghurt had a maximum serving of 7 bowls.

Both current as well as healthy food baskets contained food items in the food groups fruit, vegetables, starchy vegetables, grains, dairy, protein foods, fats and oils, sauces (i.e. sauces, dressings, spreads and sugars), discretionary foods, beverages, takeaway and alcohol. The minimum serving size for each food item included in healthy and current diet baskets is 0.5, except for food items within the food group discretionary foods in the healthy diet basket where it was zero. Thus, not all foods of the commonly consumed list were included in the two food baskets. Furthermore, a few less healthy food items were included in the healthy food basket as the Dutch dietary guidelines state that a maximum of 15% of energy can come from foods outside the Dutch dietary guidelines (e.g. candy or bacon) (20). As the discretionary food group is the only food group in the healthy diet basket that does not require at least a 0.5 serving per food item, most less healthy food items from the categories sauces and proteins were included in the category discretionary foods.

2.3.6 Food prices

A Dutch food price database was used to link food prices to the commonly consumed food items. A detailed description of the database can be found elsewhere (23). Briefly, prices were collected in the summer of 2017. Researchers collected the retail prices for 902 food items commonly included in Dutch food frequency questionnaires. The lowest non-promotion price was included in the price database. Data was collected in two Dutch supermarket chains located in Amsterdam, the Netherlands; a high segment supermarket called the Albert Heijn and a discount supermarket named Lidl. Prices were also collected from local food shops such as bakeries and butchers in Amsterdam. All prices in the food price database were adjusted for preparation and waste and were expressed in Euros (€) per 100 g edible portion. Prices of takeaway foods were not collected.

The food items within the price database were then linked to the commonly consumed food items in the Dutch food consumption survey. Of the n=200 commonly consumed food items for the general population, n=114 food items were directly linked using the NEVO code and n=86 food items were indirectly linked. An indirect link included finding a comparable product with a known price and linking it to the product within the food consumption survey. For example, we used the price of wholemeal bread with NEVO code 246 and linked it to the food item coarse wholemeal bread with NEVO code 2782.

2.3.7 Affordability

According to the INFORMAS framework's 'optimal' approach to assess the cost, price differential and affordability of healthy diets (24), healthy diets are considered unaffordable if it costs more than 30% of household income. According to the Dutch Central Bureau of Statistics, the average standardized net household income for the Dutch population in 2016 was €33.500/year (i.e. €1196/fortnight) (25). For the different educational levels this fortnightly income was €1046, €1107 and €1386 per fortnight for households with a low, medium and high education, respectively.

2.3.8 Analyses

Information on the DIETCOST program interface is reported elsewhere (8, 16). Briefly, the program user interface allows users to specify daily targets for the food groups and macronutrients for all household members for current and healthy diets separately (based on the nutrient constraints). The program algorithm uses a random number generator to specify the starting meal plan and starting values in grams for each common food item. When a meal plan meets all targets and constraints, it is added to the results; i.e. the list of meal plans. All meal plans are independent from each other. For each individual household member, the current and healthy diet scenarios were run 500,000 times and subsequently again with increments of 500,000 to arrive at an accurate estimate of the average cost of healthy and current household diets (i.e. less than €1 difference between runs) (8).

As the number of possible combinations of meal plans is too large to construct, a selection of combined two-weekly meal plans for healthy and current diets were made using a bootstrapping method. Bootstrapping was used to select a random number (n=1000 through n=10000) of combined two-weekly meal plans (seed set at 1234). The range and distribution of the cost of the fortnightly household meal plans and the contributions of each food group to the cost of the diets was calculated. Bootstrapping and descriptive statistics were conducted in RStudio version 4.0.3.

2.4 Results

On average, current meal plans required less iterations compared to healthy meal plans in order to produce a stable average cost, and in most cases 1 million iterations was sufficient for current meal plans. With regard to healthy meal plans, for some household members less than 20 healthy meal plans could be constructed (Table 1).

None of the modelled current diets for either of the four types of households meet the dietary recommendations (Table 2 and Supplementary Table 1). This was largely due to the fact that no household member met the maximum sodium intake guidelines and most household members (excluding girls) did not meet the minimum intakes for fibre and fruit.

2.4.1 Cost and affordability of current and healthy diets

For all four households (the average Dutch household and households with a low, medium and high educational level) the average cost of healthy diets was higher than the average cost of current diets (Table 1). For the average household, the average cost of healthy diets was €261/fortnight (SD 16.62), which was €50.21 (24%) more costly than the average cost of current Dutch household diets. The lowest cost for healthy and current diets was found for the household with a low education and the highest cost for healthy and current diets was found for the household with a high education. The average cost of healthy and current diets for the household with a low education was €200.65/fortnight (SD 15.72) and €183.24/fortnight (SD 12.51) (i.e. a cost differential of €17.41/fortnight). The average cost of healthy diets for the household with a high education was €68.75/fortnight higher than the average cost for the household with a low education. The difference between the cost of healthy and current diets was 10% for the household with a low education, 26% for the household with a medium education and 36% for the household with a high education. The distribution of the two-weekly costs of healthy and current household diets for all four households can be found in Figure 1.

For all four households, healthy diets were found to be affordable in terms of being below the 30% threshold of household income. Namely, healthy diets cost the average Dutch household approximately 22% of their disposable income (€260/€1196). For households with a low, medium and high education, this was 18%, 22% and 19%. In fact, according to Table 1 and Figure 1, none of the healthy household diets would be considered unaffordable as the most expensive diet does not reach the 30% threshold. Given the lower cost of current diets, these can be considered more affordable than healthy diets.

Table 1. Average (SD) cost in the Netherlands and energy density of two-weekly household healthy and current diets

	Average household		Low educated household		Medium educated household		High educated household	
	Healthy diets	Current diets	Healthy diets	Current diets	Healthy diets	Current diets	Healthy diets	Current diets
N iterations	1M-4M	1M-1.5M	1M-4M	500.000-1M	2M-3M	1M	1M-5M	1M
N commonly consumed foods included	108	135	72	71	81	95	90	98
N individual meal plans for girls, boys, women and men	13+228+16+170	214+112+276+57	52+48+79+124	275+381+181239	47+70+49+49	157+215+289+253	13+30+46+53	188+230+208+205
N bootstrap household meal plans	5000	5000	5000	5000	5000	5000	5000	5000
Average cost in € (SD)	260.85 (16.62)	210.64 (8.86)	200.65 (15.72)	183.24 (12.51)	240.31 (15.65)	190.34 (9.51)	269.40 (16.42)	197.85 (10.28)
Range of cost in €	214.90 – 321.08	179.79 – 245.12	153.59 – 272.67	148.43 – 229.73	182.10 – 300.57	158.56 – 224.93	214.53 – 319.87	165.24 – 244.47
Average Energy in mJ	438.2	505.7	437.8	471.6	426.9	469.2	429.1	462.3
Range of Energy in mJ	415.5 – 450.3	493.1 – 526.6	414.4 – 446.7	459.4 – 495.5	405.8 – 444.7	458.3 – 495.7	409.8 – 445.9	446.4 – 486.6

Abbreviations; M = million, SD = Standard Deviation

Table 2. Proportion of current diets meeting the guidelines for a healthy diet by each household member for the average household (individual meals for the current diet n=214 girls, n=112 boys, n=276 women and n=57 men)

Nutrient/food group	Healthy diet guideline	N girls (%)	N boys (%)	N women (%)	N men (%)
Fat in % energy	20-35	210 (98%)	105 (94%)	185 (67%)	49 (86%)
Saturated fat in % energy	0-10	89 (41%)	9 (8%)	0 (0%)	4 (7%)
Protein in % energy	15-25	17 (8%)	44 (39%)	152 (55%)	43 (75%)
Carbohydrates in % energy	45-65	295 (100%)	110 (99%)	269 (97%)	56 (99%)
Fibre in grams	18 + 36 + 30 + 35 (minimum)	15 (7%)	0 (0%)	0 (0%)	0 (0%)
Sodium in milligrams	962 + 2015 + 1493 + 1914 (maximum)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Red meat in grams	25 + 50 + 50 + 50 (maximum)	214 (100%)	112 (100%)	276 (100%)	36 (63%)
Dairy in servings	2 + 3 + 2 + 2 (minimum)	214 (100%)	112 (100%)	276 (100%)	57 (100%)
Vegetables in servings	1 + 2 + 2 + 2 (minimum)	214 (100%)	0 (0%)	202 (73%)	37 (65%)
Fruit in servings	2 (minimum)	158 (74%)	0 (0%)	0 (0%)	0 (0%)
All healthy diet guidelines		0 (0%)	0 (0%)	0 (0%)	0 (0%)

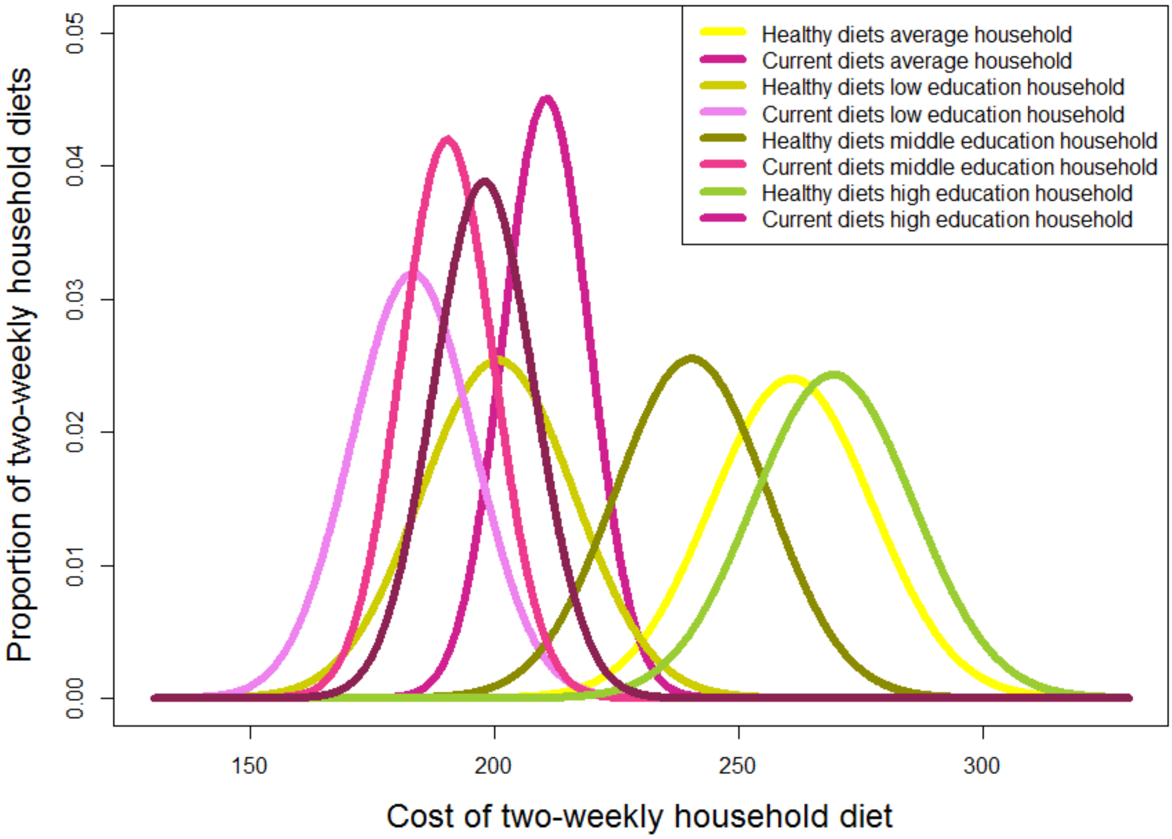

Figure 1. Distribution of the two-weekly cost of healthy and current household diets for the average Dutch population and for households with a low, medium and high education separately

2.4.2 Cost of food groups

Figure 2 displays the contribution of food groups to the average cost of two-weekly healthy and current diets for the four households (in Supplementary Table 2 the numeric values are found for all four households). All households would have to spend a greater amount of money on protein foods, fruits and vegetables, and spend less money on discretionary foods and beverages if they were to follow the dietary recommendations. The amount spent on starchy vegetables, dairy, sauces, and fats and oils would remain approximately the same.

Figure 3 displays the relative contribution of food groups to the overall cost of healthy and current diets for the average household. Protein foods, fruits and vegetables have the largest overall contribution to the cost of a healthy diet; 27%, 21% and 18% of the cost of food can be contributed to protein foods, fruits and vegetables, respectively. The highest contributors to the cost of current diets are protein foods (20%), dairy (19%) and beverages (18%).

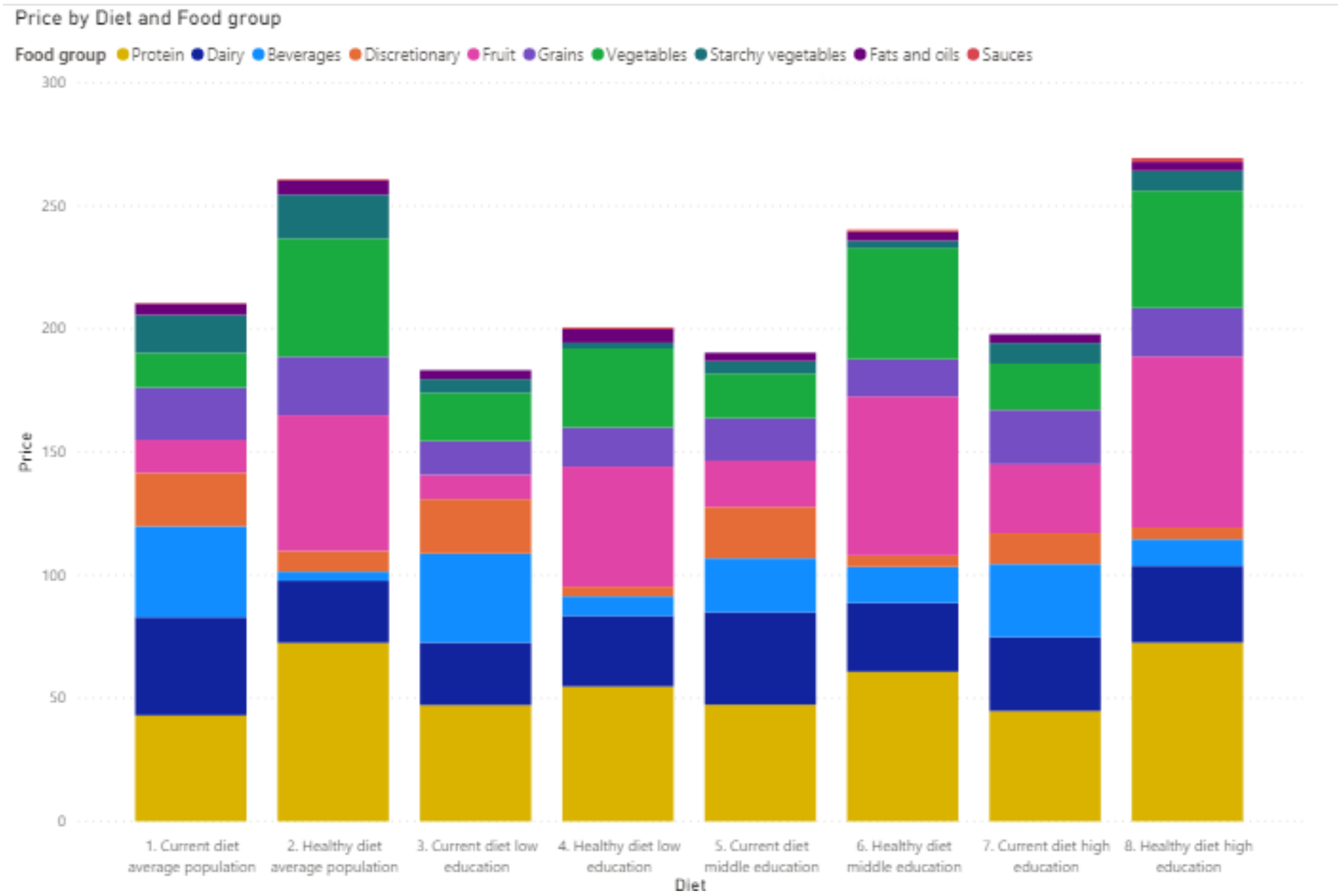

Figure 2. Contribution of food groups to the average cost of two-weekly current and healthy diets for the different households

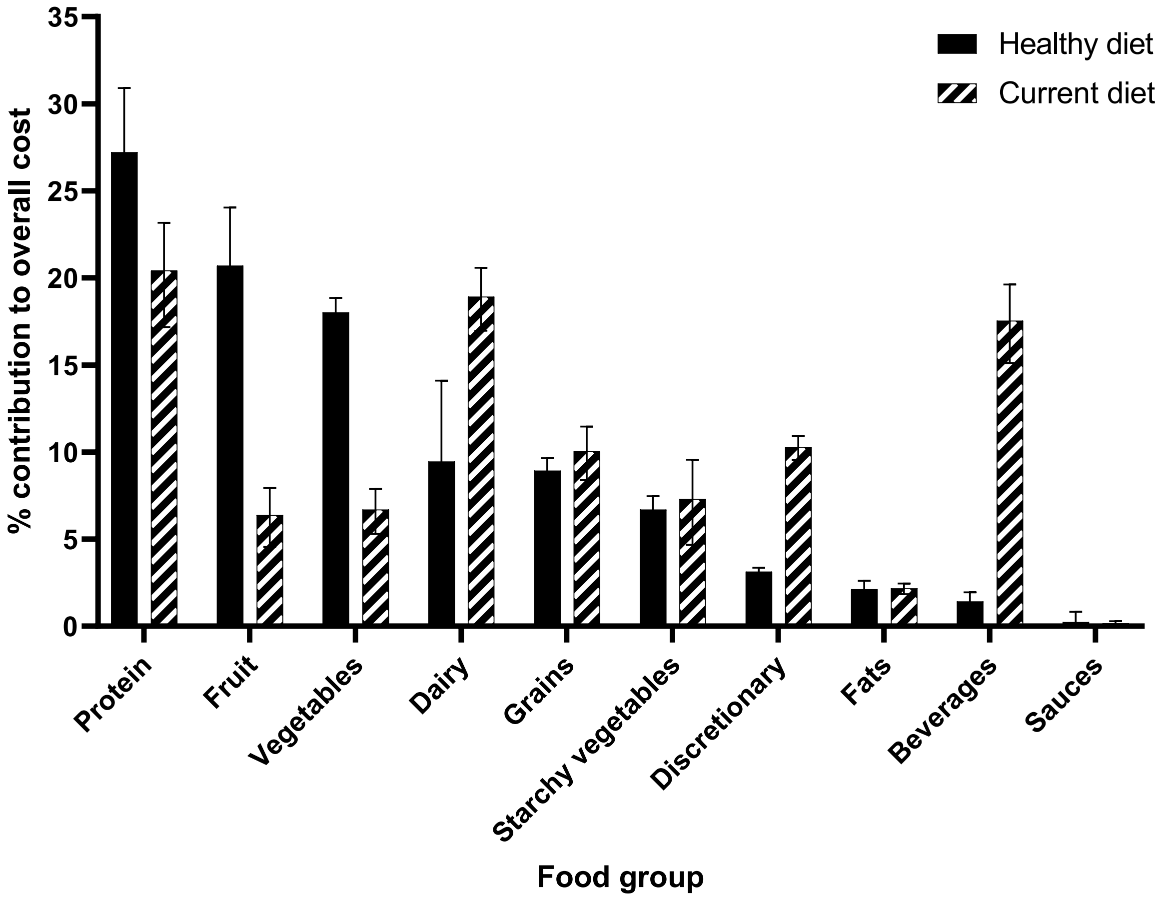

Figure 3. Percentage contribution of food groups to the overall cost of current and healthy diets of the average Dutch household with estimated 95% confidence interval

2.5 Discussion

This study used the DIETCOST tool developed by Vandevijvere et al. (8) to model the cost of healthy and current Dutch household diets stratified for low, medium and high education. For all four households, the cost of healthy diets is higher than the cost of current diets. For the general Dutch population, healthy diets were on average €50/fortnight (i.e. €3.59/day or 24%) more expensive than current diets. Healthy and current diets for the household with a low education were least costly, while those for the household with a high education were most costly. Furthermore, the difference between healthy and current diets increased by increasing educational level. For all four households, the increased cost of healthy diets was explained by the increased expenditure on protein foods, fruits and vegetables whereas households would have to spend less, i.e. save money, on discretionary foods and beverages.

The finding that an average Dutch household would spend on average €260.85/fortnight (€18.63/day) on a healthy diet is somewhat higher compared to previous estimations from the Dutch National Institute for Family Finance Information showing that the minimum cost of food for a four-person Dutch household is €222.74/fortnight (€15.91/day) (12). Apart from this cost estimate of healthy diets, no calculations for the cost of the current diet were available, so we could not compare our results to previous findings in the Netherlands. Our findings are in line with previous studies showing that healthy diets are more expensive than current diets. A systematic review investigating the prices of healthier versus less healthy dietary patterns found that healthier food-based diet patterns were $20.72/fortnight (or €1.21/day) more expensive than unhealthier diet patterns (6). Also, a Danish study found that the healthy New Nordic diet was 16% more expensive than the current Danish diet (26). This Danish study also found that the expenditure for fruits and vegetables showed the largest increase. Lastly, the previous DIETCOST study found that for the New Zealand population, healthy diets were on average $27/fortnight (i.e. €16/fortnight or 4%) more expensive than current diets (8). The observed cost differential of 24%, however, seems to be larger in the Netherlands compared to other countries. For example, compared to the previous New Zealand study, we found a more than a threefold larger difference between healthy and current diets. This high cost differential may be explained by the fact that the price of food in the Netherlands is relatively low compared to other countries; according to Eurostat, the prices of food and non-alcoholic beverages in the Netherlands is lower compared to other West-European countries such as Denmark (27). The relatively cheap price of food combined with the finding by the Dutch Central Bureau of Statistics suggesting that the price of healthier foods increasing more than that of unhealthier foods (21% compared to 15%) (28), may explain the current study results. These contextual factors highlight the importance of conducting country-specific studies on the differential cost and affordability of healthy and current diets.

We further observed that the household with a low education had the lowest dietary costs and that the cost differential between healthy and current diets increased by increasing educational level. While we observed an increasing cost differential by increasing educational level (from 10% to 36%), the previous Danish study found that the cost differential between current and healthy diets remained relatively the same for the lowest income class compared to the highest income class (16% difference compared to 15% difference, respectively) (26). The increasing difference between healthy and current diets by educational level may be explained by the relatively expensive commonly consumed food items in the grains, dairy and protein categories. Households with a higher education can lower their cost when switching to a healthier diet by also switching to food items they currently do not commonly consume (e.g. from salmon to lean fish). Nevertheless, despite the increasing cost differential found in the current study, healthy diets were approximately equally affordable across the different households (costing around 20% of their household income). This findings does not imply that for the Dutch, the cost of food is not important; studies show that the relatively high price of healthy foods compared to unhealthy foods can still be an important barrier to adopting healthy diets, especially for individuals with a low SEP (4, 29, 30).

Strengths of the study include the use of the DIETCOST program allowing researchers to generate multiple shopping lists for two-weekly meal plans that meet the targets and constraints for both current and healthy diets (8). Unlike studies to date that have compared the cost of one healthy and one current diet, DIETCOST allows for the cost of many fortnightly household diets to be generated. Additionally, common foods, nutrient and food group targets for households with different educational levels allowed for the modelling for these specific populations. A limitation is that the cost of healthy and current diets does not reflect the actual expenditure as price data regarding the cheapest available product was used instead of the price of the actual consumed product. This conservative approach of only using the lowest available price has likely led to an underestimation in the cost differences between households with a low, medium and high education. Given their limited food budget, individuals with a low SEP may be more likely to purchase the cheapest version of a food item compared to individuals with a higher SEP (e.g. home-brand versus name-brand food items and food items on promotion) (31). Another limitation is the use of educational level as a proxy for SEP as income is likely more related to dietary expenditure compared to educational level. Unfortunately, income data for all participants of the DNFCS 2012-2016 was not available.

Future research should consider the actual food expenditure, including details on buying promotional items, going to different supermarkets etc. by SEP. Furthermore, comprehensive monitoring of the price of food and beverages can inform policy action. For example, as evidence suggests that the price of healthier foods increased more than that of unhealthier foods (28), the cost difference between healthy and current diets may have actually increased since the data collection of the current study. Since the cost differential of healthy versus current diets for the household with a low education is only around 10% (compared to for example the 36% found for the high educated household), it would be of interest to investigate which other factors hamper households with a lower SEP to adopt healthier diets. Such factors may include both diet-related factors such as cooking skills and nutrition knowledge as well as more upstream factors related to social causes (e.g. inadequate and temporary housing, discrimination and stigma) (32).

With regards to policy action aiming to increase healthy dietary behaviours, it is important that the price difference between healthy and current diets is reduced by subsidizing healthy foods (e.g. fruits and vegetables) and taxing unhealthy foods (e.g. sugar sweetened beverages). Indeed, a plethora of evidence suggests that such pricing strategies can effectively influence food purchases in the intended direction (33-36). For example, evidence from real-world sugar-sweetened beverage (SSB) tax evaluations show that the equivalent of a 10% SSB tax was associated with an average decline in beverage purchases and dietary intake of 10% (35), and combining such SSB taxes with fruit and vegetable subsidies could mitigate the income regressivity of SSB taxes (i.e. that SSB taxes fall disproportionately on households with a low SEP who typically spend a larger share of their income on SSBs) (37). Evidence from the Netherlands also suggests that pricing strategies can increase healthy food purchases (38, 39), including for both populations with a low and high SEP (40). Besides taking policy action specifically aimed at improving dietary behaviours, policy action can also be implemented to reflect the true price of food. Currently, food retail prices do not take into account the negative externalities of food production and consumption. While the abovementioned fruit and vegetables subsidies and SSB taxes would account for the negative health externalities of unhealthy food *consumption*, governments may also want to consider accounting for the negative externalities food *production* has on water, soil, nature and climate (41).

2.5.1 Conclusion

Although healthy diets were found to be affordable in terms of disposable income, healthy diets were on average 24% more expensive than current diets in the Netherlands. This increased cost was mainly due to the higher required expenditure on protein foods, fruits and vegetables. Both the cost of and cost differential between healthy and current diets was lowest for the household with a low education and highest for the household with a high education. Levelling the prices of healthier versus unhealthier foods is an important strategy in improving population diets. Such pricing strategies include fruit and vegetable subsidies and SSB taxes.

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SUPPLEMENTARY MATERIAL CHAPTER 2

The cost of healthy versus current diets in the Netherlands

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Supplementary Table 1. Proportion of current diets meeting the guidelines for a healthy diet by each household member from an average Dutch household and households with a low, medium and high educational level

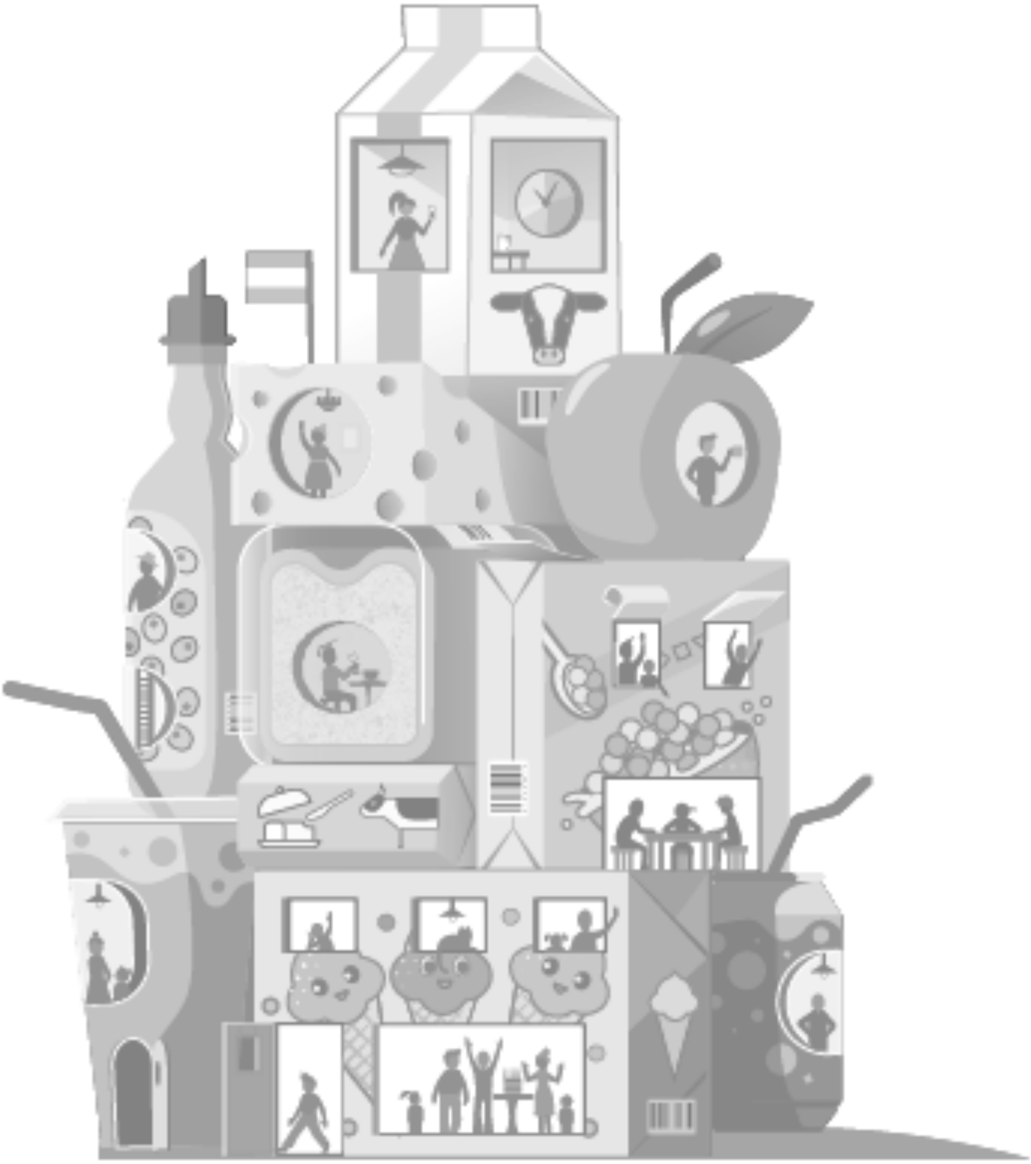
		Girl			Boy			Woman			Man		
		Educational level			Educational level			Educational level			Educational level		
Nutrient/food group	Healthy diet guideline	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Fat in % energy	20-35	270 (98%)	124 (79%)	188 (100%)	368 (97%)	213 (99%)	229 (100%)	131 (72%)	244 (84%)	173 (83%)	198 (85%)	188 (74%)	154 (75%)
Saturated fat in % energy	0-10	118 (43%)	48 (31%)	55 (29%)	129 (34%)	45 (21%)	66 (29%)	34 (19%)	25 (9%)	18 (9%)	69 (29%)	18 (7%)	15 (7%)
Protein in % energy	15-25	57 (21%)	48 (31%)	17 (9%)	85 (22%)	85 (40%)	13 (6%)	67 (37%)	179 (62%)	36 (17%)	92 (39%)	195 (77%)	65 (32%)
Carbohydrates in % energy	45-65	275 (100%)	157 (100%)	188 (100%)	381 (100%)	215 (100%)	228 (100%)	171 (94%)	275 (95%)	199 (96%)	228 (97%)	215 (85%)	192 (94%)
Fibre in grams	18 + 36 + 30 + 35 (min)	37 (13%)	10 (6%)	27 (14%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Sodium in milligrams	962 + 2015 + 1493 + 1914 (max)	0 (0%)	0 (0%)	0 (0%)	50 (13%)	19 (9%)	141 (61%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Red meat in grams	25 + 50 + 50 + 50 (max)	0 (0%)	0 (0%)	79 (42%)	280 (73%)	126 (59%)	230 (100%)	84 (46%)	289 (100%)	208 (100%)	22 (9%)	32 (13%)	205 (100%)
Dairy in servings	2 + 3 + 2 + 2 (min)	195 (71%)	132 (84%)	138 (73%)	125 (33%)	128 (59%)	48 (21%)	164 (91%)	274 (95%)	180 (87%)	234 (100%)	253 (100%)	205 (100%)
Vegetables in servings	1 + 2 + 2 + 2 (min)	275 (100%)	157 (100%)	188 (100%)	0 (0%)	0 (0%)	0 (0%)	106 (59%)	185 (64%)	193 (93%)	77 (33%)	209 (83%)	193 (94%)
Fruit in servings	2 (min)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	31 (15%)	0 (0%)	0 (0%)	0 (0%)
All healthy diet guidelines		0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

The order of healthy diet guidelines with multiple values is girl, boy, woman and man

Abbreviations: min; minimum, max; maximum

Supplementary Table 2. Average household cost by food groups

	Average household		Low education		Medium education		High education	
Food group	Healthy diets	Current diets	Healthy diets	Current diets	Healthy diets	Current diets	Healthy diets	Current diets
Fruit	55.15 (8.35)	13.45 (2.38)	48.77 (7.28)	9.88 (1.09)	64.69 (9.21)	18.79 (3.51)	69.46 (9.33)	28.00 (5.13)
Vegetables	47.97 (8.89)	14.11 (1.98)	32.12 (8.20)	19.66 (4.66)	45.31 (9.02)	18.13 (3.39)	47.60 (8.28)	18.82 (4.09)
Starchy vegetables	17.83 (4.56)	15.41 (3.26)	2.38 (0.77)	5.51 (0.58)	2.85 (0.88)	5.07 (0.46)	8.11 (2.28)	8.39 (2.24)
Grains	23.77 (2.41)	21.19 (2.53)	15.87 (1.60)	13.69 (1.49)	15.06 (1.71)	17.25 (2.33)	19.67 (2.40)	22.06 (2.67)
Dairy	25.20 (2.74)	39.86 (3.60)	28.73 (3.50)	25.38 (2.63)	27.94 (2.82)	37.58 (4.72)	31.18 (3.10)	30.04 (3.23)
Protein	72.51 (8.86)	43.02 (5.01)	54.76 (10.59)	47.21 (9.21)	60.78 (8.47)	47.37 (6.37)	72.60 (9.37)	44.80 (5.62)
Fats and oils	5.66 (0.59)	4.59 (0.52)	5.42 (0.58)	3.61 (0.48)	3.56 (0.52)	3.38 (0.38)	3.60 (0.50)	3.52 (0.47)
Discretionary foods	8.35 (1.13)	21.68 (1.64)	3.92 (0.83)	22.13 (2.01)	4.58 (0.92)	20.84 (1.80)	4.82 (1.14)	12.54 (0.81)
Sauces	0.62 (0.29)	0.34 (0.17)	0.75 (0.35)	0.00 (0.00)	0.89 (0.39)	0.00 (0.00)	1.57 (0.55)	0.00 (0.00)
Beverages	3.78 (0.97)	36.97 (3.96)	7.94 (1.28)	36.17 (6.12)	14.65 (2.86)	21.93 (3.96)	10.80 (2.81)	29.69 (3.96)
Total	266.32 (18.09)	210.64 (8.86)	200.65 (15.72)	183.24 (12.51)	240.31 (15.65)	190.34 (9.51)	269.40 (16.42)	197.85 (10.28)



CHAPTER 3

To what extent do dietary costs explain socio-economic differences in dietary behaviour?

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To what extent do dietary costs explain socio-economic differences in dietary behaviour?

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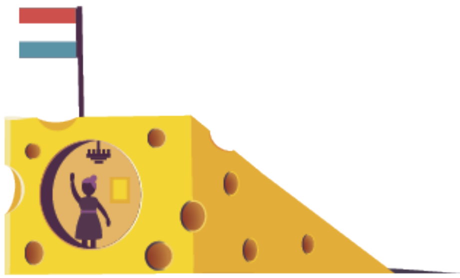

3.1 Abstract

Background Low socio-economic position is associated with consumption of lower quality diets, which may be partly explained by the cost of healthier diets. Therefore, we aimed to investigate the mediating role of dietary costs in the association between educational level and diet quality.

Methods We used cross-sectional data from Dutch older adults (N= 9,399) in the EPIC-NL cohort. Participants provided information about their own and their partners' highest attained educational level (as proxy for socio-economic position). Dietary behaviour was assessed using a food frequency questionnaire from which we derived two diet-quality scores, including the Dutch Healthy Diet index 2015 (DHD15-index) and the Dietary Approaches to Stop Hypertension (DASH) diet. Dietary cost estimates were based on food price data from food stores, and linked to reported consumption of food items. Multiple regression analyses and bootstrapping were used examine the mediating role of dietary cost in the association between educational level and diet quality.

Results Mean age of participants was 70 (SD: 10) years and 77% were women. Dietary costs significantly mediated the association between educational level and diet quality, except for high versus medium individual educational level and the DHD15-index. Depending on the dietary and educational indicator, dietary costs explained between 2% and 7% of the association between educational level and diet quality. Furthermore, associations were found to be modified by sex and age. For the DHD15-index, mediation effects were only present in females and adults older than 65 years, and for the DASH diet mediation effects were only present in females and strongest amongst adults older than 65 years compared to adults younger than 65 years.

Conclusion Dietary costs seems to play a modest role in explaining educational differences in diet quality in an older Dutch population. Further research is needed to investigate which other factors may explain SEP differences in diet quality.

3.2 Introduction

The role of diet in the development of non-communicable chronic diseases (NCDs) is well established (1, 2). Individuals with a lower socio-economic position (SEP) have an increased risk of developing diet-related chronic diseases (3, 4), which is partly explained by socio-economic differences in diet (5). Indeed, studies demonstrated that individuals with a low SEP on average have unhealthier dietary behaviours and adhere less often to dietary guidelines compared to individuals with a higher SEP (6, 7).

The cost of eating a healthy diet may play an important role in explaining socio-economic differences in diet quality (7-9). Price is an important factor in food choice, which is especially the case for individuals with a lower SEP (10). Similarly, for individuals with a lower SEP, the perceived cost of healthy foods such as fruit, vegetables and fish is an important barrier for meeting dietary guidelines (11, 12). In addition, a meta-analysis showed that, on average, healthier dietary patterns were more costly than less healthy dietary patterns (13). This suggests that both perceived and actual food prices, potentially in combination with limited individual food budgets, may indeed constrain individuals with a lower SEP in consuming a high-quality diet.

A large body of literature has investigated the relationship between SEP and dietary behaviours, while few have studied the mechanisms by which SEP influences dietary outcomes. Gaining a better understanding of the explanatory role of dietary behaviours in the association between educational level and diet quality would help to establish the potential contribution of price interventions and policies on socio-economic differences in diet and consequently health. There is already limited evidence from two United States (US) and one European study showing that dietary costs partly explain socio-economic differences in diet quality (14-16). However the study conducted in England used purchasing data instead of dietary intake data and it is unknown whether the results from the US studies prevail in European countries such as the Netherlands. Food price levels and socio-economic differences in health may differ between the US and Europe (17). Even within European countries, the magnitude of inequalities in health associated with SEP differ (3). Therefore, the current study aimed to investigate the mediating role of dietary costs in the association between educational level and diet quality in an older Dutch population.

3.3 Methods

3.3.1 Study population

The flowchart of the study population is visualized in Figure 1. This cross-sectional study used data from the European Prospective Investigation into Cancer and Nutrition cohort in the Netherlands (EPIC-NL) (18). EPIC-NL consists of two Dutch cohorts, namely the Prospect cohort and MORGEN cohort. Participants from the Prospect cohort were females aged 50-70 years recruited from the national breast cancer screening program in Utrecht and its surroundings, while participants from the MORGEN cohort were aged 20-59 years, and selected from random samples of the Dutch population in three large cities in the Netherlands (18). At baseline (1993-1997), participants filled in questionnaires and underwent a physical examination. The participants have been followed since for changes in risk factors and occurrence of chronic diseases.

In 2015, respondents to the 2011 questionnaire on electromagnetic radiation (EMR) (18) who were still alive, living in the Netherlands and who gave informed consent to be re-contacted (n=13,421) were invited to fill out a Food Frequency Questionnaire (FFQ). Participants from the Doetinchem cohort did not receive the EMR questionnaire. Therefore, participants who at that time already participated in the 6th round of the Doetinchem cohort study (n=1,528) were invited to fill in the FFQ. The response rate to the FFQ from 2015 was 62.9% (n=9,399). For the current study, participants were excluded if they had implausible energy intake levels according to the lower or upper 0.5% ratio of reported energy intake over estimated energy requirement (n= 93) (19). Ultimately, data from a total of 9,306 participants was used for analysis in the current study.

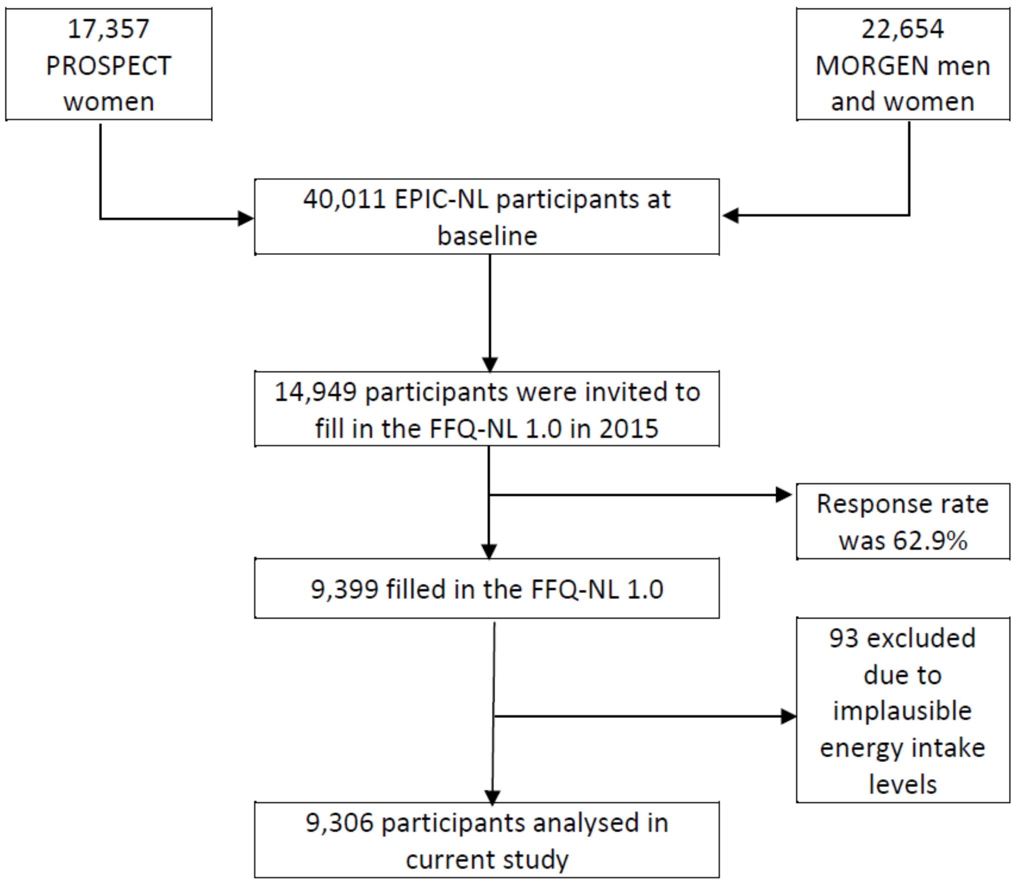

Figure 1. Flowchart of the study population

3.3.2 Dietary assessment

Dietary intake was assessed in 2015 using the validated FFQ-NL 1.0 (20). The FFQ-NL 1.0 contained questions regarding the consumption and preparation methods of 160 food items during the prior year. Intake for each food item was reported in frequencies ranging from “never” to “7 days a week”. The servings were specified in terms of household measures or units of common portions such as one egg and one slice of bread. Using the 2011 computerized Dutch food composition table, dietary intake data yielded dietary energy intake (MJ and kcal) and the average daily intake of 43 macro- and micronutrients (20). This FFQ was validated against on average 2.7 (range 1-5) telephone-based 24 hour recalls as well as biomarkers in 24-hour urine and blood samples. Correlation coefficients based on estimates of the FFQ and 24 hour recalls ranged between 0.18 for fats, oils and sauces and 0.99 for soy and vegetarian products (20).

3.3.3 Adherence to dietary guideline measures

Using the dietary intake data, adherence to the Dutch Dietary Guidelines was assessed with the Healthy Diet index 2015 (DHD15-index). The DHD15-index is developed for the Dutch population and is based on absolute intakes of selected foods. To allow comparison with international literature, adherence to the Dietary Approaches to Stop Hypertension (DASH) diet was also assessed, and represents a relative measure of dietary quality (21).

The DHD15-index was calculated as described by Looman et al. (22). Briefly, The Health Council of the Netherlands released updated Dutch Food-based dietary guidelines in 2015, in which all evidence on nutrients, foods, and dietary patterns in relation to the most important chronic diseases and related risk-factors was integrated. To measure adherence to these guidelines, the DHD15-index was constructed. The index consists of 15 components (vegetables, fruits, whole grains, legumes, nuts, dairy, fish, tea, fats and oils, coffee, red meat, processed meat, sweetened beverages and fruit juices, alcohol and salt) which were assigned a score based on absolute intake of the specific food group. For all components a minimum of 0 points and a maximum of 10 points could be allocated, resulting in a total score ranging from 0 to 150 points, with higher score indicating better adherence to the guidelines. In EPIC-NL, data regarding filtered coffee was not available and estimates of salt intake were not included given the complexity of measuring intake using FFQs. Also, as previous studies excluded alcohol beverages because of their disproportionate influence on dietary costs due to their high price (23, 24), this component was excluded from the DHD15-index in the main analyses, thus the DHD15-index ranged from 0 to 120. Supplementary Table 1 includes the components of the DHD15-index and their minimum and maximum score values.

The DASH diet was originally developed as an intervention to prevent hypertension (25). The DASH diet focuses on 8 components: high intake of fruits, vegetables, nuts and legumes, low-fat dairy products and whole grains, and low intake of sodium, sugary sweetened beverages, and red and processed meats (21). The components of the DASH diet as proposed by Fung et al. were used to calculate adherence to the DASH diet (21). For each component, participants were classified into quintiles according to their intake ranking. For components where a high intake is desired, participants in quintile 1 received one point and participants in quintile 5 received five points. For components where a low intake is desired, scoring was reversed (i.e. quintile 1 equals 5 points and quintile 5 equals 1 point). Participants in the quintiles between the lowest and highest quintiles received a score of 2, 3 or 4. Then, component scores were summed to obtain an overall DASH adherence score for each individual participant ranging from 7 to 35 (as previously mentioned, the sodium component was not calculated in this study).

A higher score indicated better adherence to the DASH diet. Supplementary Table 2 includes the components of the DASH diet and the mean intake for the lowest and highest quintiles.

3.3.4 Dietary cost measure

Individual dietary costs were derived using established methods (8, 14, 15). A Dutch food price database was used to link food prices to individual food consumption as measured with the FFQ. A detailed description of the construction of this food price database can be found elsewhere (26). Briefly, the food price database was developed in the summer of 2017 and covered 902 prices of foods based on a commonly used FFQ in Dutch cohorts (27). This database included the retail prices of the lowest, non-promotional prices collected from two Dutch supermarket chains (i.e. a high segment supermarket Albert Heijn and a discount supermarket Lidl) in Amsterdam, the Netherlands. All prices in the food price database were adjusted for preparation and waste and were expressed in Euros (€) per 100 grams edible portion (28). Approximately 47% of all food products (n= 649) underlying the FFQ-NL 1.0 could directly be linked to the retail prices in our database. For 581 products, we linked the price of a comparable product to the consumed foods. For example, we used the price for Roosvicee syrup for both regular and multivitamine Roosvicee syrup. A few products (n=78) that were assessed during the dietary intake assessment in 2015 were no longer sold when collecting the retail food prices in 2017. Furthermore, for a small number of foods (n= 27), no comparable product with a known price could be found in the database. Thus, the lowest available, non-promotional prices for these products were newly collected from two supermarket chains holding the largest market shares in the Netherlands (i.e. Albert Heijn and Jumbo). Once the dataset was complete, dietary costs were calculated by combining data from the food price database with the FFQ-NL 1.0 intake data. Each composite food item in the FFQ (total of 160 items) consists of a number of individual food items, weighted according to their relative contribution to the intake of that food in the Netherlands. We used the same weighting factor to calculate the cost of each composite FFQ food item. The variable obtained for each participant was the average monetary value of their habitual diet (reported dietary intake in the last year) in euros per day. Additional information regarding the food price database and the linking to FFQ data can be found in Supplementary file 1.

3.3.5 Educational level measures

Based on the highest level of completed school education reported at baseline (1993-1997), three educational groups were constructed (low, medium and high) for participants and (if applicable) their partner. Those who completed primary education or intermediate vocational education were classified as having a low educational level, those who completed higher secondary education were classified as having a medium educational level and those who completed higher vocational education or university were classified as having a high educational level. Because educational level may vary for different birth cohorts and given the high proportion of older women whose own educational level may not reflect their SEP accurately (29), their partner's educational level was used in addition to construct a household education level variable as a second indicator of SEP. Thus, two educational level variables were used for analyses: highest obtained individual educational level and highest household educational level (the highest attained educational level for either the participant or the partner of the participant). If a participant did not have a partner, then their own educational level was used as the highest attained educational level for the household.

3.3.6 Covariates

Self-reported data on age and sex were obtained using the baseline questionnaire. Additionally, energy intake was derived from the dietary intake data obtained from the FFQ-NL 1.0. Study recruitment area (Amsterdam, Doetinchem, Utrecht and Maastricht) was also used as covariate. Because the association between SEP and diet quality differed for males versus females and adults from varying age groups in earlier studies, effect modification by age and sex was investigated (12, 30).

3.3.7 Statistical analyses

Descriptive statistics were computed for all variables, using percentages and means with standard deviations. Item-nonresponse ranged from 0% (age, sex, study centre, DHD15-index and DASH score) to 0.33% (individual educational level). Complete case analysis was used for all analyses. Using the Hayes SPSS-macro PROCESS (31), the mediating role of dietary cost in the association between individual and household educational level and adherence to the diet quality measures (i.e. the DHD15-index and DASH diet) were assessed using multiple linear regression analyses. Figure 2 illustrates the mediating role of dietary cost in the association between individual and household educational level and diet quality. Instead of running all regression analyses separately, the package PROCESS allowed for an easier and faster estimation of the paths by running these simultaneously. Total effects were estimated by assessing the associations between individual and household educational level and the diet quality measures separately (c-path). Also, the association between the educational level variables and the potential mediator dietary cost was assessed (a-path). Furthermore, the associations between dietary cost and the diet quality measures adjusted for the educational level variables (b-path) and between the educational level measures and the diet quality measures adjusted for dietary cost (c'-path) were assessed. All analyses were adjusted for the covariates age, sex, study centre and energy intake. Modification by age and sex was assessed using interaction terms age and both educational level measures and sex and both educational level measures on the c-path, a-path, b-path and c'-path. If one of the interaction terms was significant in at least one of the paths, associations were stratified by that effect modifier. In order to assess whether dietary cost indeed mediated the association between individual and household educational levels and the DHD15-index and the DASH score, the indirect effect and the corresponding 95% confidence interval were assessed. The indirect effects were calculated by multiplying the regression coefficient of the a-path with the regression coefficient of the b-path, which is equal to subtracting the regression coefficient of the c'-path from the regression coefficient of the c-path. The bootstrapped 95% confidence intervals around the indirect effects were based on 5,000 bootstrap resamples. Statistical significance of the indirect effects was defined by the inclusion or exclusion of the value zero in the upper and lower bound of the bias corrected 95% bootstrap confidence intervals. As recommended by Hayes (31), the proportion mediated (a*b divided by a*b + c') was calculated, but only if *1)* significant mediation was found, *2)* the total (c path) and indirect (a-path * b-path) effect had the same direction and *3)* if the indirect effect was smaller than the total effect. Sensitivity analysis was conducted by excluding participants (n=529 for individual educational level and n=531 for household educational level) below the age of 30 at the time of the baseline questionnaire (i.e. between 1993 and 1997), since their educational attainment may have changed between baseline and follow-up. In addition, sensitivity analyses were conducted including the alcohol component of the DHD15-index. All analyses were conducted with SPSS 25.0, and an α-level of 0.05 was used to test for statistical significance.

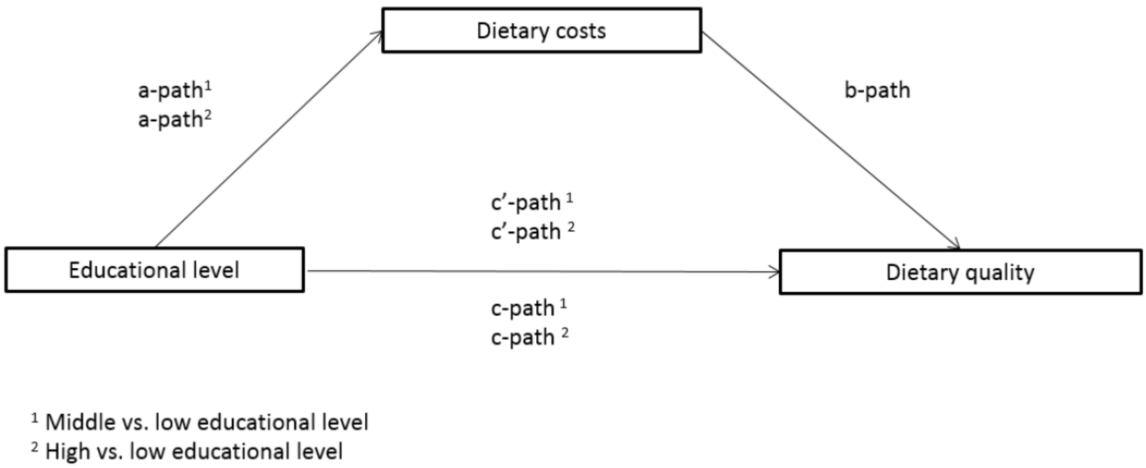

Figure 2. Pathways through which dietary cost may mediate the association between educational level and dietary quality. The c-paths are the associations between individual and household educational level and the dietary quality measures separately. The a-path is the association between the educational level variables and the potential mediator dietary cost. The b-paths and c'-paths are the associations between dietary cost and the dietary quality measures adjusted for the educational level variables (b-path) and between the educational level measures and the dietary quality measures adjusted for dietary cost (c'-path).

3.4 Results

Participant characteristics by individual and household educational level are presented in Table 1. Mean age of all participants was 69.6 (SD 10.0) years old and the majority of participants were female (77.4%). Regarding individual educational level, 58.6% had a low educational level, 10.8% had a medium educational level and 30.6% had a high educational level. When taking the household educational level measure, the percentage of participants that was categorized as highly educated increased to 42.6%, whilst the percentage of participants that was categorized as low educated decreased to 46.5%. Mean energy intake was lowest for participants with a low individual and household educational level. Mean dietary cost (€ per day), the DHD15-index and the DASH score increased with increasing individual and household educational levels.

Table 1. Sociodemographic characteristics by individual and household educational level of the EPIC-NL study population

Sociodemographic characteristics	Low education level (N= 5,435)	Medium education level (N= 1,002)	High education level (N= 2,838)	Low household education level (N= 4,316)	Medium household education level (N= 1,012)	High household education level (N= 3,954)	Total (N= 9,306)
Mean age in years (SD)	71.6 (8.8)	64.6 (13.2)	67.3 (9.9)	71.6 (8.8)	65.1 (13.1)	68.4 (9.9)	69.6 (10.0)
Sex (% female)	47.3	8.3	21.8	36.7	7.8	32.8	77.4
Mean energy intake in kcal/day (SD)	1,850 (652)	1,999 (646)	2,023 (630)	1,847 (662)	2,017 (693)	1,973 (616)	1,919 (650)
Study centre (in %)							
Amsterdam	6.6	2.9	8.7	5.6	2.6	10.0	18.1
Doetinchem	7.2	1.0	2.4	6.2	1.2	3.2	10.5
Maastricht	11.4	2.9	6.8	9.4	3.0	8.7	21.1
Utrecht	33.4	4.2	12.7	25.4	4.2	20.7	50.3
Mean dietary cost in €/day (SD)	4.9 (1.7)	5.4 (1.6)	5.5 (1.6)	4.8 (1.7)	5.3 (1.7)	5.4 (1.6)	5.1 (1.7)
DHD15-index (SD)[a]	63.2 (15.5)	67.2 (15.9)	72.0 (15.2)	62.2 (15.5)	65.3 (15.7)	70.9 (15.4)	66.2 (16.0)
DASH score (SD)[b]	20.1 (4.3)	21.2 (4.3)	22.5 (4.2)	20.0 (4.3)	20.8 (4.3)	22.1 (4.3)	21.0 (4.4)

Abbreviations: SD; Standard deviation

[a] DHD15 index without the alcohol component ranging from 11.43 to 109.78

[b] DASH score ranging from 8 to 35

3.4.1 Effects of educational level on dietary cost (a-path) and dietary cost on dietary quality (b-path)

Mostly, higher individual and household educational levels were statistically significantly associated with higher dietary costs (Supplementary Table 3; a-path). In turn, higher dietary cost was statistically significantly associated with higher DHD15-index and DASH scores (Supplementary Table 3; b-path). For individual educational level, a €1 increase in daily dietary costs was associated with a 0.74-point higher DHD15-index and a 0.29-point higher DASH score. These results are similar for household educational levels for both diet quality measures.

3.4.2 Effect of educational level on dietary quality (c-path)

Higher individual and household educational levels were statistically significantly associated with higher DHD15-index and DASH scores (Table 2; total effect). Participants with an individual medium educational level scored 3.96 (95%CI 2.93; 5.00) and participants with a high educational level scored 9.07 (95%CI 8.37; 9.77) points higher on the DHD15-index compared to participants with a lower educational level. Participants with an individual high educational level scored 5.10 (95%CI 4.01; 6.19) points higher on the DHD15-index compared to participants with a medium educational level. For the DASH diet, participants with an individual medium educational level scored 1.00 (95%CI 0.71; 1.29) and participants with an individual high educational level scored 2.25 (95%CI 2.06; 2.45) points higher on the DASH diet compared to participants with a low educational level. Participants with an individual high educational level scored 1.25 (95%CI 095; 1.56) points higher on the DASH diet compared to participants with a medium educational level. These results were similar for household educational level for both diet quality measures.

3.4.3 Mediating role of dietary cost

The association between individual and household educational level and both diet quality measures persisted after controlling for the mediator dietary cost (Table 2; direct effect). For example, household medium and high educational levels were associated with a 0.93 (95%CI 0.64; 1.22) and 2.17 (95%CI 1.98; 2.37) higher DASH score compared to household low educational level, respectively. The difference between individual medium and high educational level on the DASH diet after adjusting for dietary cost was 1.24 (95%CI 0.94; 1.54).

Regarding the pathway towards the DHD15-index (Table 2; indirect effect), dietary cost statistically significantly mediated the association between medium and high individual educational levels and the DHD15-index. These effects accounted for 4.5% and 2.2% of the difference in the DHD15-index score between medium and high versus low individual educational levels, respectively (Supplementary Table 3; proportion mediated). No mediating role of dietary cost in the association between high versus medium individual educational level and the DHD15-index was found. For household educational level, the association between medium and high household educational levels with dietary cost statistically significantly mediated the association with the DHD15-index (Table 2; indirect effect). These effects accounted for between 1.7% and 4.1% of the difference in the DHD15-index score depending on the educational level, with the lowest proportion mediated found when comparing high to medium household educational levels (Table 2; proportion mediated). Overall, the results regarding the associations between both individual and household educational level with the DASH score as the diet quality indicator were comparable to the results found with the DHD15-index.

Table 2. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score

Independent variable	Mediator	Dependent variable	Total effect (c-path) β	Total effect (c-path) 95%CI	Direct effect (c'-path) β	Direct effect (c'-path) 95%CI	Indirect effect β	Indirect effect Bootstrap 95%CI	Proportion mediated
	Dietary cost (€/d)	DHD15- index	Individual educational level[a]						
Medium vs. low			3.96*	2.93; 5.00	3.78*	2.75; 4.82	0.18*	0.10; 0.28	4.5
High vs. low			9.07*	8.37; 9.77	8.86*	8.16; 9.57	0.20*	0.11; 0.30	2.2
High vs. medium			5.10*	4.01; 6.19	5.07*	4.00; 6.16	0.02	-0.03; 0.09	N/A
			Household educational level[b]						
Medium vs. low			2.96*	1.91; 4.01	2.84*	1.79; 3.89	0.12*	0.05; 0.21	4.1
High vs. low			8.25*	7.59; 8.90	8.04*	7.37; 8.70	0.21*	0.11; 0.32	2.5
High vs. medium			5.20*	4.15; 6.24	5.28*	4.24; 6.33	0.09*	0.03; 0.16	1.7
		DASH diet	Individual educational level[a]						
Medium vs. low			1.00*	0.71; 1.29	0.93*	0.64; 1.22	0.07*	0.04; 0.10	7.0
High vs. low			2.25*	2.06; 2.45	2.17*	1.98; 2.37	0.08*	0.05; 0.11	3.6
High vs. medium			1.25*	0.95; 1.56	1.24*	0.94; 1.54	0.01	-0.01; 0.03	N/A
			Household educational level[b]						
Medium vs. low			0.75*	0.46; 1.05	0.71*	0.41; 1.00	0.05*	0.03; 0.08	6.6
High vs. low			2.02*	1.84; 2.21	1.94*	1.76; 2.12	0.08*	0.05; 0.11	4.0
High vs. medium			1.27*	0.98; 1.56	1.23*	0.94; 1.52	0.03*	0.01; 0.06	2.4

Abbreviations: B; beta regression coefficient, CI; confidence interval , N/A; Not Applicable

[a] Sample size for analyses with individual educational level is 9,275

[b] Sample size for analyses with household educational level is 9,282

* *P*<0•05

All analyses were adjusted for age, sex, study centre and energy intake

Proportion mediated was not calculated for non-significant indirect effects

3.4.4 Modification by age and sex

Both sex and age were identified as modifiers in the educational level – dietary cost – diet quality pathway. Tables 3 and 4 include the results regarding the indirect effects by strata of age and sex. Full results of the mediation analyses separate for participants younger than 65 years and older than 65 years, and for males and females, can be found in the Supplementary Tables 4 through 7, respectively.

For the diet quality measure the DHD15-index, sub-group analyses showed significant mediating effect by dietary cost in participants older than 65 years. For participants younger than 65 years, dietary cost did not play a statistically significant role in explaining educational differences in diet quality (Table 3). For the DASH diet, stronger mediating effects were found for participants older than 65 years compared to participants younger than 65 years (Table 3). Within both dietary quality measures, sub-group analyses showed that dietary cost explained between 3% and 12% of the differences between educational level and dietary quality for females, while no mediation effect was found for males (Table 4).

Table 3. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for participants within varying age groups

Independent variable	Mediator	Dependent variable	≤ 65 years[a]			> 65 years[b]		
			Indirect effect		Proportion mediated	Indirect effect		Proportion mediated
			β	Bootstrap 95%CI		β	Bootstrap 95%CI	
	Dietary cost (€/d)	DHD15- index	Individual educational level					
Medium vs. low			0.07	-0.03; 0.20	N/A	0.25*	0.13; 0.40	6.9
High vs. low			0.07	-0.03; 0.20	N/A	0.27*	0.15; 0.41	3.3
High vs. Medium			0.01	-0.05; 0.07	N/A	0.02	-0.07; 0.11	N/A
			Household educational level					
Medium vs. low			0.04	-0.04; 0.15	N/A	0.18*	0.08; 0.30	6.3
High vs. low			0.07	-0.07; 0.22	N/A	0.27*	0.15; 0.40	3.7
High vs. Medium			0.03	-0.03; 0.13	N/A	0.09*	0.02; 0.19	2.1
		DASH diet	Individual educational level					
Medium vs. low			0.04*	0.01; 0.08	3.2	0.09*	0.06; 0.14	10.5
High vs. low			0.04*	0.01; 0.08	1.5	0.10*	0.07; 0.14	5.0
High vs. Medium			0.00	-0.03; 0.03	N/A	0.01	-0.02; 0.04	N/A
			Household educational level					
Medium vs. low			0.02	-0.00; 0.06	N/A	0.07*	0.03; 0.10	10.0
High vs. low			0.05*	0.01; 0.09	1.9	0.10*	0.06; 0.14	5.8
High vs. Medium			0.02	-0.00; 0.06	N/A	0.03*	0.01; 0.07	2.9

Abbreviations: B; beta regression, CI; confidence interval, N/A; Not Applicable
[a] N=2,413 and N=2,418 for individual and household educational level, respectively
[b] N=6,862 and N=6,864 for individual and household educational level, respectively
* P<0•05
All analyses were adjusted for energy intake, study centre and sex
Proportion mediated was not calculated for non-significant indirect effects

Table 4. Results regarding the mediating role of dietary cost in the association between individual educational and household educational level and the DHD15-index and DASH score for females and males separately

Independent variable	Mediator	Dependent variable	Females[a] Indirect effect β	Females[a] Indirect effect Bootstrap 95%CI	Females[a] Proportion mediated	Males[b] Indirect effect β	Males[b] Indirect effect Bootstrap 95%CI	Males[b] Proportion mediated
	Dietary cost (€/d)	DHD15- index	Individual educational level					
Medium vs. low			0.27*	0.15; 0.40	6.8	-0.02	-0.18; 0.10	N/A
High vs. low			0.28*	0.18; 0.40	3.3	-0.03	-0.21; 0.14	N/A
High vs. Medium			0.01	-0.07; 0.10	N/A	-0.01	-0.08; 0.06	N/A
			Household educational level					
Medium vs. low			0.19*	0.10; 0.31	7.1	-0.02	-0.14; 0.08	N/A
High vs. low			0.29*	0.18; 0.42	3.8	-0.04	-0.24; 0.15	N/A
High vs. Medium			0.10*	0.02; 0.19	2.0	-0.02	-0.14; 0.09	N/A
		DASH diet	Individual educational level					
Medium vs. low			0.10*	0.06; 0.15	11.0	0.00	-0.04; 0.04	N/A
High vs. low			0.11*	0.07; 0.14	5.4	0.00	-0.05; 0.05	N/A
High vs. Medium			0.01	-0.03; 0.04	N/A	0.00	-0.02; 0.02	N/A
			Household educational level					
Medium vs. low			0.08*	0.04; 0.11	11.7	0.00	-0.03; 0.03	N/A
High vs. low			0.11*	0.08; 0.15	5.8	0.00	-0.05; 0.05	N/A
High vs. Medium			0.04*	0.01; 0.07	3.4	0.00	-0.03; 0.04	N/A

Abbreviations: B; beta regression coefficient, CI; confidence intervals, N/A; Not Applicable

[a] N=7,175 and N=7,182 for individual and household educational level, respectively

[b] N=2,100 for both individual and household educational level

* *P*<0•05

All analyses were adjusted for age, study centre and energy intake

Proportion mediated was not calculated for non-significant indirect effects

3.4.5 Sensitivity analyses

Sensitivity analyses excluding participants below the age of 30 years at baseline show similar results compared to the main analyses with all participants (Supplementary Table 8). Dietary cost accounted for 2% to 8% of the individual and household educational level differences in diet quality scores. This is similar to the results found in the entire sample, where the proportion mediated ranged from 2% to 7%.

The results for the DHD15-index including the alcohol component can be found in Supplementary Table 9. Contrary to the results without the alcohol component, dietary cost was negatively associated with the DHD15-index including the alcohol component. For example, for individuals with a medium compared to lower educational level, a €1 increase in daily dietary costs was associated with a 0.78-point lower DHD15 score. Contrary to the results excluding the alcohol component from the DHD15-index, a statistically significant negative mediating effect of dietary cost in the association between educational level and the DHD15-index was found.

3.5 Discussion

This study used a large cohort of older Dutch adults to investigate to what extent dietary costs explain educational differences in diet quality. We observed a modest association of individual and household educational level with diet quality as measured by adherence to the 2015 Dutch nutrition guidelines and adherence to the DASH diet. A small part of this association was explained by dietary costs, such that mediation effects were mostly only present in females and adults older than 65 years compared to males and adults younger than 65 years.

In line with previous findings (6, 30, 32), we observed that higher educational levels were associated with healthier dietary behaviours. We hypothesized that educational differences in diet quality would be partly explained by dietary costs, because high quality diets (e.g. diets containing plenty of fruits and vegetables and less red meats) tend to be more costly than lower quality diets (13, 33). Indeed, a €1 increase in daily dietary costs was associated with a 0.29-point higher DASH score, which is comparable to the results of a previous study (34). Dietary cost explained between 2% and 7% of the association between educational level and diet quality measures. The somewhat larger explanatory role of dietary cost in the association between educational level and diet quality for females (proportion mediated between 2% and 12%) and adults older than 65 (proportion mediated between 3% and 11%) may be explained by differences in competing factors such as perceived quality, price, taste, habits, intentions to eat healthily and family preferences for females versus males and older adults versus younger adults (35). For example, a study among European adults showed that while price was among the top four important factors influencing food choices for females, this was not the case for males (35). As noted in two previous studies (23, 24), the in- or exclusion of the alcohol component in the DHD15-index had a significant impact on the association between dietary costs and diet quality.

Compared to previous studies (14-16), this study found relatively small mediation effects by dietary cost in the association between educational level and diet quality measures for which the explanation may be two-fold. Firstly, the type of socio-economic indicator may play a role. Socio-economic indicators including income, educational level and occupation are not interchangeable, as they assess different aspects of SEP (36). Educational level is thought to better reflect knowledge-related assets, while income may reflect material circumstances such as grocery shopping budget better (37). While income and education were not differentially associated with daily dietary costs in a population from the United Kingdom(8), this may differ from country to country. A study by Aggarwal et al. found larger mediation effects with the SEP indicator income, e.g. 76% of the association between income and energy density and 36% of the association between income and the mean adequacy ratio (i.e. a truncated index of the percent of daily recommended intakes for key nutrients) could be explained by dietary cost (14). In contrast, a study by Waterlander et al. found that level of income was not associated with food expenses (38). This leads us to the second explanation, namely that in the Netherlands, dietary costs may play a smaller role in the association between SEP and dietary quality due to the relatively low cost of food compared to other countries and other consumer goods. According to European Union (EU), the prices of food and non-alcohol beverages in the Netherlands is around the EU average, which is lower compared to other West-European countries (39).

The limited explanatory power of dietary cost also warrants discussion about other potential factors that explain SEP inequalities in diet quality. Socio-economic inequalities are traditionally explained through three mechanisms; the material explanation, the behavioural explanation and the psychosocial explanation (40). While several studies have examined these explanatory mechanisms separately, it would be of interest to study the relative contribution of dietary costs compared to other explanatory factors (41). Other explanatory factors may include access to healthy foods, other aspects of the food environment and psychosocial resources such as knowledge of healthy eating, cooking skills, food literacy or social support. Thus, before developing new interventions, future studies should focus on providing insights into the most relevant causes and mechanisms that underlie socio-economic differences in diet quality. It is only then that interventions can be adequately designed and tailored to the needs and capacities of the target population. Some interventions to date that have increased dietary quality without increasing socio-economic inequalities include subsidies on healthy foods (42) and sugar sweetened beverage taxes (43).

The results of this study should be interpreted within the context of its strengths and limitations. A first strength is the use of a detailed food price database that could be linked to individual food intake using established techniques. Second, we used a diet quality indicator that was relevant for the study population (DHD15) and a diet quality indicator that is widely used in the international literature (DASH). The first limitation is the use of data from an older Dutch population, limiting the generalizability of the results. However, given that data was collected across different regions in the Netherlands, the generalizability of the results can be increased to the entire older Dutch population. Second, mediation analyses were based on cross sectional data, and therefore we cannot make inferences about causality (14). For example, it is possible that higher educational level leads to more dietary knowledge, in turn leading to a healthier diet, and that this healthier diet leads to higher dietary costs, and vice versa (16). Third, the dietary cost measure (as derived from reported dietary intake with a fixed food price database) is not suitable for estimating actual expenditure, since price data regarding the cheapest available product, instead of the actual consumed product, was collected. However, our current measure of dietary costs is found to be moderately associated with actual food expenditure, and able to rank individuals on the basis of the monetary value of their diets (44). Furthermore, our conservative approach of only using the lowest available prices is more likely to have led to an underestimation than to an overestimation of the mediating role of dietary cost in the educational level and diet quality pathway (16). Fourth, the dietary cost measure data was collected two years after the dietary intake data. Within these two years, the prices of foods may have increased due to inflation. However, given that this type of time-varying bias would not systematically misclassify people of different dietary or social characteristics, the ranking of individuals has likely not changed in the period of 2015 to 2017. Fifth, while the validity of the FFQ used in this study has been documented, the limitations of FFQs are well-known (45). One such limitation includes the fact that dietary intake may be under- or overreported. Underreporting may especially be the case for participants with a lower education (46). However, what effect this may have on the results is currently unknown and beyond the scope of this paper. Sixth, unfortunately data on other important SEP proxies such as income was not collected, potentially resulting in an underestimation of the mediating role of dietary cost in the relation between SEP and dietary quality.

3.5.1 Conclusion

Dietary costs seems to play a modest role in explaining educational differences in diet quality in an older Dutch population, such that mediation effects were mostly only present in females and adults older than 65 years compared to males and adults younger than 65 years. The results of this study suggest that further research is needed to investigate which other factors may explain SEP differences in diet quality. A multi-factorial approach is needed to tackle socio-economic differences in diet, not only focusing on the cost of food, but also other factors such as food knowledge and access to healthy foods.

3.6 References

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SUPPLEMENTARY MATERIAL CHAPTER 3

To what extent do dietary costs explain socio-economic differences in dietary behaviour?

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Supplementary File 1. Methodology used to derive the lowest available food prices for participants of the HELIUS study.

A more detailed description of this methodology is available in the methodology report. This can be downloaded from this website.

Briefly, food retailers that represented a wide range of available food products within Amsterdam, the Netherlands were identified by the Foodprice research team (JD Mackenbach, SC Dijkstra and M Nicolaou). The discount supermarket chain Lidl and the full-service supermarket chain Albert Heijn were used to collect most food price data. Also, food price data were collected from local (ethnic) shops such as a Turkish butcher and greengrocers. In total, prices were collected in 20 shops during July and August of 2017 (to prevent variation in food prices due to seasonality) and to be able to obtain the lowest price available in Amsterdam. Excel-sheets were used to collect the food price data. Items to be collected for the food price database were selected from four HELIUS Food Frequency Questionnaires (FFQs). Ultimately, the food price database consisted of 1,247 unique foods. Each individual food product underlying the HELIUS FFQ-items were translated to a specific food item in purchasable form. For example, ‘potatoes without peel’ was translated into ‘potatoes’. Additionally, food items that essentially represented the same products were combined (e.g. different types of concentrated cordials). Ultimately, the prices for 902 products were collected for the food price database. Foods were sorted according to food group to facilitate speedy data collection. Data were collected on food price (€), unit (in KG or L), name of the product, date at which this price was collected and any remarks with regard to the product. For products in tin or glass jars, the net weight of the product as unit was used. When collecting the data, photos from each separate food items were collected if possible. If multiple options were available, the cheapest products were chosen. For packaged foods, the median package size was used. When items were on sale, the sale price was ignored and the everyday price was recorded. If a product was not available, a close match was used a substitute. After collecting food price data in the selected shops, data on food prices was combined into a single excel sheet with colours indicating the source of the price information. Prices per 100 grams were calculated based on the price and the unit of the product. The Dutch ”Maten Gewichten en Codenummers 2003”(1) was used to calculate the edible portion per food. This report also included information on the weights of average non-packaged foods, such as zucchinis, and information on waste and gain/loss during preparation. The food prices of these 902 purchasable food items were then linked to the 1289 FFQ-NL 1.0 food items from the EPIC-NL study. Forty-seven percent of all food items (n= 649) underlying the FFQ-NL 1.0 could directly be linked to the retail prices in the food price database. A few products (n=78) that were assessed during the dietary intake assessment in 2015 were no longer available when collecting the retail food prices in 2017. Furthermore, for a small number of food items (n= 27), no comparable product with a known price could be found (e.g. kaki fruit, fennel and caviar) in the database. Thus, the lowest available, non-promotional prices for these products were newly collected from two supermarket chains holding the largest market shares in the Netherlands (i.e. Albert Heijn and Jumbo). For the remaining 581 food items, we linked the missing price to a comparable product within the database. For example, the price of chocolate covered waffles was given the price for waffles from the food price database. A weighting system was used to calculate the price in €/100 gr edible portion for each weighted food item within the FFQ-NL 1.0. For example, the price for the food item pizza consisted of 80.7% ‘frozen pizza’ and 19.4% ‘mini pizzas’. Once the dataset was complete (i.e. when every item within the FFQ-NL 1.0 had a price), dietary costs were calculated by combining data from the food price database to the FFQ-NL 1.0 nutrient composition database. This nutrient composition database was used to calculate the nutrient intake of each individual based on their intake of each food product in the FFQ. The food price variable obtained from the steps above included the monetary value of each participants’ diet (reported dietary intake in the last week/month) in euros per day.

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Supplementary Table 1. DHD15-index components as used in the current study with the corresponding Dutch dietary guidelines and the minimum and maximum score values per component, adapted from Looman et al.

Component	Food items in DHD15-index components	Dutch dietary guideline 2015	Minimum score of 0 points	Maximum score of 10 points
Vegetables	All vegetables except for potatoes and legumes	Consume at least 200 grams of vegetables everyday	0 grams a day	≥ 200 grams a day
Fruit	All fruits	Consume at least 200 grams of fruits everyday	0 grams a day	≥ 200 grams a day
Wholegrains[a]	High-fibre bread	1. Consume at least 90 grams of wholegrain products everyday 2. Substitute refined cereal products by wholegrain products	0 grams a day Ratio of whole grains to refined grains ≤ 0.7	≥ 90 grams a day Ratio of whole grains to refined grains ≥ 11
Legumes	Beans and peas	Consume legumes every week	0 grams a day	≥ 10 grams a week
Nuts	Nuts, seeds and seeds	Consume at least 15 grams of unsalted nuts everyday	0 grams a day	≥ 15 grams a day
Dairy	Milk, yoghurt, custard, pudding, whipped cream, milk-based ice cream	Consume some dairy produce everyday	0 grams a day or ≥ 750 grams a day	300 - 450 grams a day
Fish	Lean fishes such as prawns and codfish, fatty fish such as salmon and anchovies	Consume one serving of fish every week, preferably oily fish	0 grams a day	≥ 15 grams a day
Tea	Green or black tea	Consume three cups of green or black tea everyday	0 grams a day	≥ 450 grams a day
Fats and oils	Butter, hard margarines, cooking fats, soft margarines, liquid cooking fats and plant oils	Replace butter, hard margarines, and cooking fats by soft margarines, liquid cooking fats, and vegetable oils	No consumption of soft margarines, liquid cooking fats and vegetable oils OR Ratio of liquid cooking fats to solid cooking fats ≤ 0.6	No consumption of butter, hard margarines and cooking fats OR Ratio of liquid cooking fats to solid cooking fats ≥ 13
Red meat	Beef, pork, lamb, horse, offal meats, hot dogs, hamburger and bacon	Restrict the consumption of red meat	≥ 100 grams a day	≤ 45 grams a day
Processed meat	Sausages and deli meats	Restrict the consumption of processed meat	≥ 50 grams a day	0 grams a day

Sweetened beverages and fruit juices	Carbonated sweetened beverages, noncarbonated sweetened beverages and fruit juices	Restrict the consumption of processed meat	≥ 250 grams a day	0 grams a day
Alcohol[b]	Beer, wine, sherry, port, vermouth and strong alcoholic drinks	If alcohol is consumed, intake should be limited to one Dutch unit (i.e. 10 grams of ethanol) everyday	Women: ≥ 20 grams of ethanol a day Men: ≥ 30 grams of ethanol a day	≤ 10 grams of ethanol a day

N/A; Not applicable

[a] This component comprises two sub-components (1 and 2). Each sub-component has a maximum score of 5 points

[b] This component was only added in the DHD15-index with alcohol component found in Additional table 3

Filtered or unfiltered coffee and salt intake was not assessed in the FFQ-NL 1.0

A continuous score with a minimum score of 0 and a maximum score of 10 is possible for each DHD15-index component. For example, a person with a mean intake of 55 grams of vegetables a day received a score of 2.75 for the vegetables component

Supplementary Table 2. DASH diet components with the corresponding foods for each component and the mean intake for the lowest and highest quintiles, adapted from Fung et al.

Components	**Food items in DASH components**	**Quintile 1, mean grams per day**	**Quintile 5, mean grams per day**
Vegetables	All vegetables except for potatoes and legumes	26.34	249.22
Fruit	All fruits (not including fruit juices)	20.37	344.27
Wholegrains	Whole grain bread	0.50	159.38
Dairy	Low fat dairy products including skim milk and skim-milk cheese	26.70	564.27
Nuts and legumes	Nuts, seeds, seeds, peanut butter, beans and peas	1.80	83.23
Red and processed meats	Beef, pork, lamb, horse, organ meats, hot dogs, hamburger, bacon sausages and deli meats	175.72	14.76
Sweetened beverages	Carbonated and noncarbonated sweetened beverages	201.93	0.00

For the DASH diet score, quintiles were calculated according to intake ranking. The component score for fruits, vegetables, nuts and legumes, low-fat dairy products, and whole grains ranged from 1 point (quintile 1) to 5 points (quintile 5) is assigned 1 point. Low intakes for red and processed meats and sweetened beverages were desired. Therefore, the lowest quintile was given a score of 5 points and the highest quintile, 1 point.

Supplementary Table 3. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for participants ≤ 65 years of age.

Educational level	Dietary cost	Dietary quality	Effect of educational level on dietary cost (a-path)	Effect of dietary cost on dietary quality (b-path)	Direct effect (c'-path) β	Direct effect (c'-path) 95%CI	Total effect (c-path) β	Total effect (c-path) 95%CI	Indirect effect (a-path x b-path)	Bootstrap 95%CI	Proportion mediated $\frac{AB}{(C' + AB)}$
	Dietary cost (€/d)	DHD15- index	Individual educational level (N= 2,413)								
Medium vs. low			0.18*	0.37	5.07*	3.36; 6.79	5.14*	3.43; 6.85	0.07	-0.03; 0.20	N/A
High vs. low			0.20*		10.89*	9.53; 12.26	10.97*	9.60; 12.33	0.07	-0.03; 0.20	N/A
			Household educational level (N= 2,418)								
Medium vs. low			0.14*	0.27	4.27*	2.47; 6.07	4.31*	2.51; 6.10	0.04	-0.04; 0.15	N/A
High vs. low			0.27*		10.59*	9.20; 11.98	10.66*	9.28; 12.05	0.07	-0.07; 0.22	N/A
		DASH diet	Individual educational level (N= 2,413)								
Medium vs. low			0.18*	0.20*	1.21*	0.73; 1.68	1.25*	0.77; 1.72	0.04*	0.01; 0.08	3.2
High vs. low			0.20*		2.64*	2.26; 3.02	2.68*	2.30; 3.06	0.04*	0.01; 0.08	1.5
			Household educational level (N= 2,418)								
Medium vs. low			0.14*	0.17*	1.01*	0.51; 1.51	1.03*	0.54; 1.53	0.02*	0.00; 0.06	1.9
High vs. low			0.27*		2.61*	2.23; 3.00	2.66*	2.27; 3.04	0.05*	0.01; 0.09	1.9

Abbreviations: B; beta regression coefficient, CI; confidence interval, N/A; Not Applicable

* *P*<0•05

All analyses were adjusted for sex, study centre and energy intake

Supplementary Table 4. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for participants between 65 and 75 years of age.

Educational level	**Dietary cost**	**Dietary quality**	**Effect of educational level on dietary cost (a-path)**	**Effect of dietary cost on dietary quality (b-path)**	**Direct effect (c'-path)**		**Total effect (c-path)**		**Indirect effect (a-path x b-path)**	**Bootstrap 95%CI**	**Proportion mediated**
					β	**95%CI**	**β**	**95%CI**			$\frac{AB}{(C'+AB)}$
	Dietary cost (€/d)	DHD15- index	Individual educational level (N= 3,997)								
Medium vs. low			0.30*	0.82*	3.33*	1.63; 5.03	3.58*	1.88; 5.27	0.25*	0.08; 0.44	7.0
High vs. low			0.30*		7.92*	6.88; 8.96	8.17*	7.14; 9.20	0.25*	0.08; 0.42	3.1
			Household educational level (N= 3,997)								
Medium vs. low			0.30*	0.74*	2.99*	1.25; 4.73	3.21*	1.47; 4.94	0.22*	0.06; 0.41	6.9
High vs. low			0.34*		7.32*	6.34; 8.30	7.57*	6.60; 8.54	0.25*	0.08; 0.45	3.3
		DASH diet	Individual educational level (N= 3,997)								
Medium vs. low			0.30*	0.30*	0.71*	0.24; 1.18	0.80*	0.33; 1.27	0.09*	0.04; 0.15	10.1
High vs. low			0.30*		2.01*	1.72; 2.29	2.10*	1.82; 2.38	0.09*	0.05; 0.14	4.1
			Household educational level (N= 3,997)								
Medium vs. low			0.30*	0.28*	0.81*	0.33; 1.29	0.89*	0.41; 1.37	0.08*	0.04; 0.14	8.3
High vs. low			0.34*		1.82*	1.55; 2.09	1.92*	1.65; 2.18	0.10*	0.05; 0.15	5.2

Abbreviations: B; beta regression coefficient, CI; confidence interval

* *P*<0•05

All analyses were adjusted for sex, study centre and energy intake

Supplementary Table 5. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for participants ≥ 75 years of age.

Educational level	Dietary cost	Dietary quality	Effect of educational level on dietary cost (a-path)	Effect of dietary cost on dietary quality (b-path)	Direct effect (c'-path)		Total effect (c-path)		Indirect effect (a-path x b-path)	Bootstrap 95%CI	Proportion mediated
					β	95%CI	β	95%CI			$\frac{AB}{(C' + AB)}$
	Dietary cost (€/d)	DHD15- index	Individual educational level (N= 2,865)								
Medium vs. low			0.25*	0.76*	3.26*	1.24; 5.27	3.45*	1.43; 5.46	0.19*	0.03; 0.41	5.5
High vs. low			0.28*		7.1*4	5.80; 8.48	7.36*	6.02; 8.69	0.21*	0.04; 0.42	2.9
			Household educational level (N= 2,867)								
Medium vs. low			0.09	0.82*	2.23*	0.28; 4.18	2.30*	0.35; 4.25	0.07	-0.03; 0.21	N/A
High vs. low			0.24*		6.04*	4.87; 7.22	6.24*	5.07; 7.41	0.19*	0.05; 0.36	3.1
		DASH diet	Individual educational level (N= 2,865)								
Medium vs. low			0.25*	0.33*	0.83*	0.27; 1.39	0.91*	0.35; 1.48	0.08*	0.03; 0.15	8.8
High vs. low			0.28*		1.6*2	1.24; 1.99	1.71*	1.34; 2.08	0.09*	0.04; 0.15	5.3
			Household educational level (N= 2,867)								
Medium vs. low			0.09*	0.34*	0.41	-0.14; 0.95	0.44	-0.11; 0.98	0.03	-0.01; 0.08	N/A
High vs. low			0.24*		1.28*	0.95; 1.61	1.36*	1.04; 1.69	0.08*	0.04; 0.13	5.9

Abbreviations: B; beta regression coefficient, CI; confidence interval, N/A; Not Applicable
* *P*<0•05
All analyses were adjusted for sex, study centre and energy intake

Supplementary Table 6. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for females.

Educational level	Dietary cost	Dietary quality	Effect of educational level on dietary cost (a-path)	Effect of dietary cost on dietary quality (b-path)	Direct effect (c'-path) β	Direct effect (c'-path) 95%CI	Total effect (c-path) β	Total effect (c-path) 95%CI	Indirect effect (a-path x b-path)	Bootstrap 95%CI	Proportion mediated $\frac{AB}{(C'+AB)}$
	Dietary cost (€/d)	DHD15- index	Individual educational level (N= 7,175)								
Medium vs. low			0.25*	1.07*	3.72*	2.56; 4.88	3.99*	2.83; 5.15	0.27*	0.15; 0.40	6.8
High vs. low			0.26*		8.17*	7.37; 8.97	8.45*	7.65; 9.25	0.28*	0.18; 0.40	3.3
			Household educational level (N= 7,182)								
Medium vs. low			0.19*	1.02*	2.47*	1.27; 3.68	2.67*	1.46; 3.87	0.19*	0.10; 0.31	7.1
High vs. low			0.29*		7.28*	6.54; 8.02	7.57*	6.84; 8.30	0.29*	0.18; 0.42	3.8
		DASH diet	Individual educational level (N= 7,175)								
Medium vs. low			0.25*	0.40*	0.81*	0.49; 1.14	0.91*	0.59; 1.24	0.10*	0.06; 0.14	11.0
High vs. low			0.26*		1.93*	1.71; 2.16	2.04*	1.82; 2.26	0.11*	0.07; 0.14	5.4
			Household educational level (N= 7,182)								
Medium vs. low			0.19*	0.39*	0.53*	0.20; 0.87	0.61*	0.27; 0.94	0.07*	0.04; 0.11	11.7
High vs. low			0.29*		1.67*	1.47; 1.88	1.79*	1.58; 1.99	0.11*	0.08; 0.15	5.8

Abbreviations: B; beta regression coefficient, CI; confidence interval

* *P*<0•05

All analyses were adjusted for age, study centre and energy intake

Supplementary Table 7. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for males.

Educational level	**Dietary cost**	**Dietary quality**	**Effect of educational level on dietary cost (a-path)**	**Effect of dietary cost on dietary quality (b-path)**	**Direct effect (c'-path)**		**Total effect (c-path)**		**Indirect effect (a-path x b-path)**	**Bootstrap 95%CI**
					β	**95%CI**	**β**	**95%CI**		
	Dietary cost (€/d)	DHD15- index	Individual educational level (N= 2,100)							
Medium vs. low			0.22*	-0.11	3.67*	1.42; 5.92	3.65*	1.40; 5.89	-0.02	-0.18; 0.10
High vs. low			0.29*		10.31*	8.85; 11.77	10.28*	8.83; 11.73	-0.03	-0.21; 0.14
			Household educational level (N= 2,100)							
Medium vs. low			0.15	-0.13	3.90*	1.74; 6.06	3.88*	1.72; 6.04	-0.02	-0.14; 0.08
High vs. low			0.31*		9.88*	8.40; 11.36	9.84*	8.37; 11.31	-0.04	-0.24; 0.15
		DASH diet	Individual educational level (N= 2,100)							
Medium vs. low			0.22*	0.01	1.19*	0.58; 1.81	1.20*	0.59; 1.81	0.00	-0.04; 0.04
High vs. low			0.29*		2.72*	2.32; 3.12	2.72*	2.33; 3.12	0.00	-0.05; 0.05
			Household educational level(N= 2,100)							
Medium vs. low			0.15	0.01	1.14*	0.55; 1.73	1.14*	0.55; 1.73	0.00	-0.03; 0.03
High vs. low			0.31*		2.59*	2.18; 2.99	2.59*	2.19; 2.99	0.00	-0.05; 0.05

Abbreviations: B; beta regression coefficient, CI; confidence interval

* *P*<0•05

All analyses were adjusted for age, study centre and energy intake

Proportion mediated was not calculated due to the fact that the indirect and total effects are not in the same direction and the indirect effects are not significant

Supplementary Table 8. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index and DASH score for participants older than 30 years at baseline

Educational level	Dietary cost	Dietary quality	Effect of educational level on dietary cost (a-path)	Effect of dietary cost on dietary quality (b-path)	Direct effect (c'-path) β	Direct effect (c'-path) 95%CI	Total effect (c-path) β	Total effect (c-path) 95%CI	Indirect effect (a-path x b-path)	Bootstrap 95%CI
Individual educational level (N= 8,746)										
Medium vs. low	Dietary cost (€/d)	DHD15- index	0.29*	1.26*	2.53*	1.41; 3.64	2.90*	1.78; 4.01	0.37*	0.24; 0.51
High vs. low			0.27*		7.22*	6.50; 7.94	7.56*	6.84; 8.27	0.34*	0.24; 0.45
Household educational level (N= 8,751)										
Medium vs. low			0.21*	1.22*	2.24*	1.11; 3.36	2.49*	1.36; 3.62	0.25*	0.14; 038
High vs. low			0.29*		6.58*	5.91; 7.26	6.94*	6.26; 7.61	0.35*	0.25; 0.47
Individual educational level (N= 8,746)										
Medium vs. low		DASH diet	0.29*	0.25*	0.86*	0.55; 1.17	0.93*	0.63; 1.24	0.07*	0.04; 0.11
High vs. low			0.27*		2.15*	1.95; 2.35	2.22*	2.02; 2.41	0.07*	0.04; 0.10
Household educational level (N= 8,751)										
Medium vs. low			0.21*	0.24*	0.66*	0.35; 0.98	0.71*	0.40; 1.03	0.05*	0.03; 0.08
High vs. low			0.29*		1.91*	1.72; 2.10	1.98*	1.79; 2.17	0.07*	0.04; 0.10

Abbreviations: B; beta regression coefficient, CI; confidence interval
* *P*<0•05
All analyses were adjusted for age, study centre and energy intake

Supplementary Table 9. Results regarding the mediating role of dietary cost in the association between individual and household educational level and the DHD15-index with alcohol component

Educational level	Dietary cost	Dietary quality	Effect of educational level on dietary cost (a-path)	Effect of dietary cost on dietary quality (b-path)	Direct effect (c'-path)		Total effect (c-path)		Indirect effect (a-path x b-path)	Bootstrap 95%CI
					B	95%CI	B	95%CI		
	Dietary cost (€/d)	DHD15- index with alcohol	Individual educational level (N= 9,275)							
Medium vs. low			0.25*	-0.12	1.69*	0.60; 2.78	1.66*	0.58; 2.75	-0.03	-0.12; 0.05
High vs. low			0.28*		6.43*	5.69; 7.17	6.40*	5.66; 7.13	-0.03	-0.13; 0.06
			Household educational level (N= 9,282)							
Medium vs. low			0.18*	-0.16	1.66*	0.55; 2.76	1.63*	0.52; 2.73	-0.03	-0.09; 0.03
High vs. low			0.30*		5.84*	5.14; 6.54	5.79*	5.10; 6.48	-0.05	-0.15; 0.05

Abbreviations: B; beta regression coefficient, CI; confidence interval

* *P*<0•05

All analyses were adjusted for age, study centre and energy intake

CHAPTER 4

The role of material and psychosocial resources in explaining socio-economic inequalities in diet: A structural equation modelling approach

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4.1 Abstract

We examined to what extent material and psychosocial resources explain socio-economic inequalities in diet quality. Cross-sectional survey data from 1461 Dutch adults (42.5 (SD 13.7) years on average and 64% female) on socio-demographics, dietary quality, psychosocial factors and perceptions of and objective healthiness of the food environment were used in a structural equation model to examine mediating pathways. Indicators for socio-economic position (SEP) were income, educational, and occupational level and the 2015 Dutch Healthy Diet (DHD15) index assessed dietary quality. Material resources included food expenditure, perceptions of healthy food accessibility and healthfulness of the food retail environment. Psychosocial resources were cooking skills, resilience to unhealthy food environments, insensitivity to food cues and healthy eating habits. Higher SEP was associated with better dietary quality; $B_{education}$ 8.5 (95%CI 6.7; 10.3), B_{income} 5.8 (95%CI 3.7; 7.8) and $B_{occupation}$ 7.5 (95%CI 5.5; 9.4). Material resources did not mediate the association between SEP and dietary quality and neither did the psychosocial resources insensitivity to food cues and eating habits. Cooking skills mediated between 13.3% and 19.0% and resilience to unhealthy food environments mediated between 5.9% and 8.6% of the relation between SEP and the DHD15-index. In conclusion, individual-level factors such as cooking skills can only explain a small proportion of the SEP inequalities in diet quality. On top of other psychosocial and material resources not included in this study, it is likely that structural factors outside the individual, such as financial, work and living circumstances also play an important role.

4.2 Introduction

An unhealthy diet is an important modifiable risk factor for non-communicable diseases (NCDs) (1). Individuals with lower socio-economic position (SEP) tend to have lower quality diets (2). A theoretical explanation for socio-economic inequalities in health includes material, psychosocial and behavioural pathways (3). Given that material and psychosocial factors influence behavioural factors like diet quality (3), it can be hypothesized that material and psychosocial factors (partly) explain socio-economic inequalities in dietary behaviours. Material resources that may facilitate adherence to a healthier diet include sufficient food budgets, access to healthful food stores and owning cooking equipment. Psychosocial resources derived from a higher SEP may comprise food preparation skills, social support, and resilience to unhealthy temptations in the food environment.

The explanatory power of material and psychosocial resources may depend on the SEP indicator under study and the extent to which material and psychosocial factors interact. While education, income and occupation all represent the general concept of SEP, they also provide specific resources unique to the indicator, which may translate into differential associations with dietary outcomes (4). As such, the explanatory power of material resources such as food budget may be stronger when income is used as an indicator of SEP. However, taking into account only one explanatory factor could potentially overestimate single pathways, which does not improve our understanding of their contribution in relation to other factors (5). As evidence suggests that material resources may be able to compensate the lack of psychosocial resources (6, 7), it is especially important to explore the relative contribution of material and psychosocial resources in dietary inequalities.

To the best of our knowledge, no previous studies have examined the simultaneous mediating role of psychosocial and material resources in socio-economic inequalities in diet. Some studies have shown that psychosocial resources such as better cooking skills, resilience to unhealthy food environments, sensitivity to food cues and healthy eating habits (i.e. habitual eating behaviours that one has developed over time (8)) are related to dietary behaviours or obesity (9-12). There is also evidence that some of these psychosocial factors are differentially distributed among SEP groups (13, 14). A number of studies explored the role of (subjective and objective) food cost or affordability as material explanations for socio-economic inequalities in dietary behaviours (15-19), but few studies focused on access to healthy food retail as a material resource (20, 21).

In this study we aimed to examine the individual and combined mediating role of material and psychosocial resources in the association between SEP and dietary quality, separately for three SEP indicators. While we hypothesize that all SEP indicators are connected to material and psychosocial resources, we expect that income is most strongly related to material resources and educational level and occupation more strongly to psychosocial resources (22).

4.3 Methods

4.3.1 Study population

This study used survey data from the cross-sectional 'Eet & Leef' study on eating and lifestyle behaviours among adults from the general population (18-65 years) living in urban areas in the Netherlands. Participants were recruited through a stepwise recruitment approach. First, postal invitations were sent to ~21,500 randomly selected home addresses in the twenty largest cities of the Netherlands. Also, Facebook and Instagram campaigns were used. In addition, several males with a lower education who participated in previous studies received an invitation to participate in the current study via e-mail. Inclusion criteria were: understanding the Dutch language, having access to a computer with internet and having an email-address.

In total, 2533 participants registered for the study of whom 2434 were eligible to participate and invited to complete three parts of a survey. Overall, 1491 participants completed the study. Questions covered different domains regarding the determinants of food choices, of which the current study used data on socio-demographic and socio-economic characteristics, dietary quality, psychosocial resources and perceptions and use of the food environment. The study design and procedures were approved by the Medical Ethics Review Committee of VU University Medical Centre (no. 2019.307) and all participants gave written informed consent.

4.3.2 Outcome

Dietary intake data as assessed by the Dutch Healthy Diet Food Frequency Questionnaire (DHD-FFQ) was used to calculate adherence to the Dutch Health Diet index 2015 (DHD15-index) (23). The DHD-FFQ is a short screener questionnaire which was validated against a 180-item FFQ combined with a 24 hour urinary sodium excretion value (24). This validation showed that the DHD15-index derived from the DHD-FFQ was acceptable in ranking individuals but relatively poor in the absolute individual assessment of diet quality. Energy intake was also estimated. The DHD15-index was calculated as described by Looman et al. (25), resulting in a total score ranging from 0 to 150 points, with higher scores indicating better adherence to the guidelines. Participants were excluded if they had implausible energy intake levels (26) (n= 31). This resulted in an analytical sample of 1461 participants.

4.3.3 Determinant

Participants' answered questions about their educational level, occupation and net household income. *Education* was assessed using the question 'What is your highest educational attainment?' and consisted of seven options varying from having not completed any formal education to university degree. Due to the distribution of the data and to facilitate comparison between the three indicators, educational level was categorized into low/medium educational level and high educational level. Low/medium educational level included those who completed no education, primary education, secondary education or intermediate vocational education. High educational level included those who completed higher professional education (College/University).

Occupation was assessed using the question 'What is your profession/has been your profession?'. The open-ended answers to this question were classified into four categories according to the International Standard Classification of Occupations 2008 (ISCO-08) (27). Because less than 50 participants could be categorized in the first category, occupation was dichotomized by combining the first two skill levels (low/medium occupation) and the last two skill levels (high occupation). Low/medium occupations include those involving the performance of simple and routine physical or manual tasks or tasks such as operating machinery. High occupations include those involving the performance of complex technical and practical skills or those that require complex problem-solving, decision-making and creativity (27).

Net household income was assessed with the question 'What is your net household income (after tax deduction) per month?' and consisted of 5 answering options ranging from '€0-1200' to 'more than €4000' per month. *Household equivalent income* was calculated by multiplying overall household income with weighting factors according to household members using the OECD-modified scale (28). The monthly household equivalent income was dichotomised into low/medium (≤€1733) and high (>€1733) income based on the median individual income in the Netherlands (29).

4.3.4 Mediators

The survey included several questionnaires assessing constructs that could potentially mediate the association between SEP and dietary quality. A selection of constructs was made based on: 1) whether these factors were resources supporting healthy eating and 2) the psychometric properties of the questionnaires. Only questionnaires with acceptable psychometric properties within this study sample were selected. The structural validity was measured using either exploratory factor analysis (EFA) or confirmatory factor analysis (CFA), and the internal consistency was assessed using the Cronbach's alpha (≥0.7 was regarded as acceptable). More information regarding the psychometric properties of the potential mediators can be found in the Supplementary file.

Material resources included the average weekly food budget, perceptions of healthy food accessibility and the objectively-measured healthy food retail environment around the home. Psychosocial resources were those relating to individual differences and social relationships that potentially have beneficial effects on dietary intake, including cooking skills, resilience to unhealthy food environments in general, insensitivity to food cues and several eating habits.

4.3.4.1 Material resources

Perceived access to healthy food was assessed using the 9-item Perceived Food Environment questionnaire on a 5-point Likert scale(30), with a higher score indicating better perceived access to healthy foods in their neighbourhood.

Objective access to a healthy food retail environment was assessed through objective data on the presence of healthy and unhealthy food retailers within a 10 minute walk from the participants' home address according to an 800-meter Euclidean buffer. Using commercial food environment data from Locatus (31), the percentage of healthier food retailers of the total amount of food retailers was calculated using the modified Retail Food Environment Index (mRFEI). The classification by Timmermans et al. was used to classify food-retailers as healthy or unhealthy (32). The food retail environment of participants with no food retailers around their home was considered as healthy.

Food budget was assessed by asking participants what their average weekly expenses on groceries were (6 answering options, ranging from 0-25€ to >200€). The weekly *household equivalent food budget* was calculated by using the upper end of the six answering options (250€ for the last answering option) and weighting these according to the number of household members using the OECD-modified scale(28).

4.3.4.2 Psychosocial resources

Cooking skills were assessed using six questions (on a 5-point Likert scale) on the subscale 'food preparation skills' from the Food Literacy Questionnaire (33). A higher score indicated that participants had better cooking skills.

Resilience to unhealthy food environments was measured using a single item question on a 5-point Likert scale; 'Do you eat healthy, even when the food environment makes this difficult?'. A higher score indicated more resilience to unhealthy food environments.

Sensitivity to food cues was assessed using the 11-item Power of Food Scale questionnaire(34). The items in the questionnaire were reversed in order for a higher score to indicate less sensitivity to food cues (protective effect).

Eating behaviours were assessed using the 18 item Three-Factor Eating Questionnaire(9). This questionnaire assessed cognitive restraint, uncontrolled eating and emotional eating on a 4-point Likert scale. Restrained eaters exert cognitive effort to control their food intake, uncontrolled eaters tend to overeat with the feeling of being out of control and emotional eaters tend to eat in response to negative emotions (9, 35). The factors uncontrolled and emotional eating were recoded and renamed to 'controlled eating' and 'indifferent eating' in order to reflect a resource for healthy eating.

4.3.5 Covariates

Information regarding participants' age, sex, partner (yes/no), number of children in the household, height and weight, and energy intake were assessed through questionnaires. Body Mass Index (BMI) was calculated as self-reported weight in kilograms divided by the square height in meters.

4.3.6 Statistical analyses

Descriptive statistics were computed for all variables using frequencies and percentages for categorical variables, means with standard deviations for normally distributed continuous variables, and median with interquartile range (IQR) for skewed continuous variables. Item-nonresponse was found for the variables education (1%), income (8%), occupation (7%) and mRFEI (3%).

Structural Equation Modelling (SEM) in STATA v14.1 was used to investigate the mediating role of food-related material and psychosocial resources in the association between SEP indicators and dietary intake. Complete case analyses were conducted and the Maximum Likelihood (ML) approach was used. Supplementary Figure 1 displays the proposed mediation model. EFA did not support the measurement models for material resources and psychosocial resources as latent variables. As such, all material and psychosocial resources were treated as individual mediating variables in the structural models (Figure 1). We first investigated single mediation models, with the association between a SEP indicator and dietary intake (c-path; total effect), the association between a SEP indicator and a mediator (a-path), the association between a mediator and dietary intake (b-path) and the association between a SEP indicator and dietary intake adjusted for a mediator (c'-path; indirect effect). Then, parallel mediation analysis including all material and psychosocial resources was performed. The proportion mediated was calculated (indirect effect / total effect), but only if *1)* significant mediation was found, *2)* the total (c path) and indirect (a-path * b-path) effect had the same direction and *3)* if the indirect effect was smaller than the total effect. For all mediation models, a bootstrapped 95% confidence interval (1000 bootstrap resamples and seed number 1234) around the indirect effect was calculated. Age, sex, partner, children in the household, BMI and energy intake were included as covariates. Significance was set when the 95% confidence intervals did not include zero. We report the model fit for the single and parallel mediation models. Goodness of fit of the models was defined based on the comparative fit index (CFI), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMSR) and a $\chi 2$ test. An RMSEA value of < 0.05 indicates good fit, <0.08 indicates acceptable fit and 0.08-0.10 indicates neither a good nor a bad fit. A good fit for CFI relates to a value greater than 0.95, while a value greater than 0.90 indicates a satisfactory fit. A good fit for SRMR is a value smaller than 0.05, and a value between 0.05 and 0.10 is an acceptable fit (36).

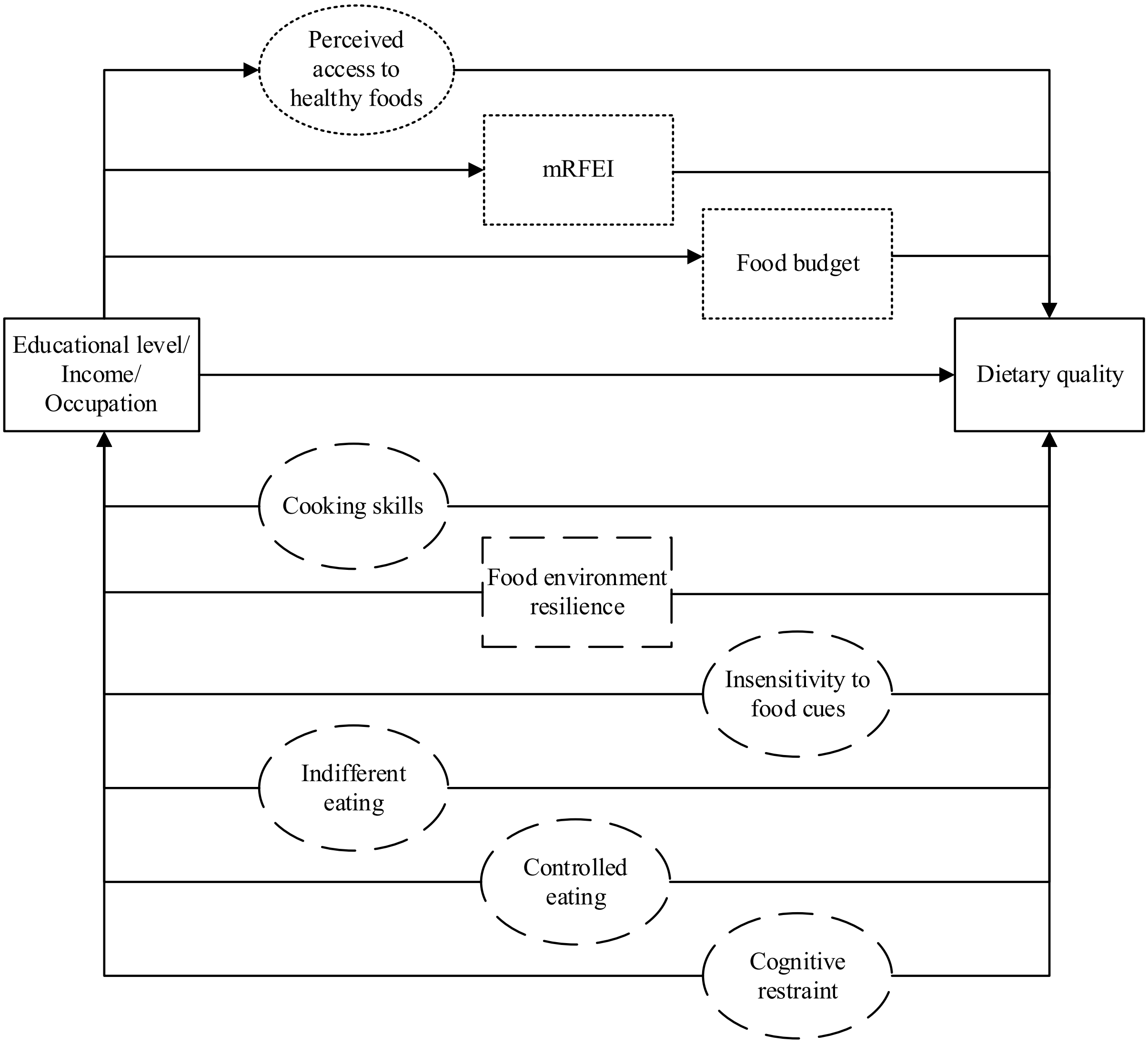

Figure. 1 Final parallel mediation models in SEM. Circles represent latent variables and rectangles represent measured variables. Dotted rectangles/circles represent material resources and dashed squares/circles represent psychosocial resources

4.4 Results

4.4.1 Descriptives

The mean age of participants was 42.5 (SD 13.7) years and the majority of participants were female (64.1%) (Table 1). In total, 42.6%, 31.5% and 34.3% of participants were considered to have a low/medium level of education, household equivalent income or occupation, respectively. Participants with a high SEP had higher mean DHD15-index scores compared to participants with a low/medium SEP.

Regarding the material resources, the median perceived access to healthy foods was 4.0 (IQR 0.8) and 30 percent of the retail food environment around participants' home were considered healthy (Table 1). These resources were approximately equally distributed among participants with a low and high SEP. The mean household equivalent food budget for the overall population was €80.5 (SD 35.0) per week, with higher food budgets for participants with a high SEP.

Regarding psychosocial resources, participants had a median score of 4.0 (IQR 1.2) on the cooking skills questionnaire and a mean score of between 2.3 and 3.4 on the questionnaires related to resilience to unhealthy food environments resilience, insensitivity to food cues and eating habits, with hardly any differences between participants with a low/medium and high SEP.

Table 1. Characteristics of the study population by educational level, occupation and household equivalent income

	Low/med education N=617	High education N=832	Low/med income N=424	High income N=924	Low/med occupation N=468	High occupation N=897	Total N=1,461
Socio-demographics							
Mean age in years (SD)	44.2 (14.7)	41.3 (12.7)	41.3 (15.1)	43.0 (12.7)	43.2 (14.3)	42.9 (12.9)	42.5 (13.7)
Sex (% female)	62.9	64.9	67.5	61.5	63.9	63.9	64.1
Mean BMI (SD)	25.9 (5.1)	24.0 (4.1)	25.3 (5.5)	24.6 (4.2)	26.0 (5.1)	24.3 (4.3)	24.8 (4.6)
Partner (% yes)	61.4	71.4	55.7	71.5	62.4	71.1	66.9
No children in household (in %)	73.6	74.9	74.5	74.5	73.1	73.8	74.5
Mean energy intake (SD)	1526.1 (560.9)	1517.0 (472.3)	1567.1 (587.2)	1518.0 (479.8)	1531.1 (558.6)	1517.2 (476.7)	1521.1 (512.7)
Material resources							
Median perceived access to healthy foods; IQR	4.0; 0.8	4.0; 0.9	4.0; 1.0	4.0; 1.0	4.0; 0.8	4.0; 1.0	4.0; 0.8
Mean mRFEI % (SD)	34.9 (19.0)	32.8 (20.2)	33.1 (17.2)	33.7 (20.5)	35.4 (19.3)	32.9 (20.1)	33.7 (19.7)
Mean household equivalent food budget (SD)	74.6 (33.1)	85.1 (35.6)	62.4 (29.2)	90.2 (34.0)	73.7 (33.1)	85.7 (34.8)	80.5 (35.0)
Psychosocial resources							
Median cooking skills; IQR	3.8; 1.0	4.2; 1.0	4.0; 1.0	4.2; 1.0	3.8; 1.0	4.2; 1.0	4.0; 1.2
Mean resilience to unhealthy food environment (SD)	3.3 (0.9)	3.5 (0.9)	3.2 (1.0)	3.4 (0.8)	3.2 (1.0)	3.5 (0.8)	3.4 (0.9)
Mean insensitivity to food cues (SD)	2.8 (0.7)	2.9 (0.7)	2.8 (0.7)	2.9 (0.7)	2.8 (0.7)	2.9 (0.7)	2.8 (0.7)
Mean indifferent eating (SD)	2.9 (0.8)	2.9 (0.8)	2.8 (0.9)	2.9 (0.8)	2.9 (0.8)	2.9 (0.8)	2.9 (0.8)
Mean controlled eating (SD)	2.9 (0.6)	3.0 (0.5)	2.9 (0.6)	3.0 (0.5)	2.9 (0.6)	3.0 (0.5)	2.9 (0.6)
Mean cognitive restraint (SD)	2.3 (0.6)	2.3 (0.6)	2.2 (0.6)	2.4 (0.6)	2.3 (0.6)	2.3 (0.6)	2.3 (0.6)
Dietary intake							
Mean DHD15-index (SD)	91.1 (18.5)	100.2 (17.3)	91.3 (18.6)	98.3 (17.8)	91.0 (18.4)	99.4 (17.6)	96.3 (18.3)

Abbreviations: BMI; Body Mass Index (kg/m^2), SD; Standard Deviation, IQR; Interquartile Range

4.4.2 Model fit

The parallel mediation models (model in Figure 1) including all nine resources for the three SEP indicators was acceptable for the model fit indices RMSEA and SRMR (RMSEA = 0.06 and SRMR = 0.10), but not the CFI (CFI = 0.86). To improve the goodness of fit, parallel mediation models only including significant mediators were performed as a sensitivity analysis. All goodness of fit statistics for the single and parallel mediation models are presented in Supplementary Table 1.

4.4.3 SEP inequalities in dietary quality

Participants with a high education scored 8.5 (95%CI 6.7;10.3) points higher on the DHD15-index compared to participants with a low/medium education. For the SEP proxies income and occupation this difference was 5.8 (95%CI 3.7; 7.8) and 7.5 (95%CI 5.5; 9.3), respectively (Table 2; total effect).

4.4.4 Mediation by material and psychosocial resources

No mediation by material resources was found in the relation between SEP and the DHD15-index (Supplementary Table 2). Similarly, the psychosocial resources insensitivity to food cues and the three eating habit factors did not mediate the association between SEP and the DHD15-index, while cooking skills and food environment resilience did mediate this association. The same results are found in the parallel mediation models in Table 2.

The indirect effect of SEP on the DHD15-index via cooking skills corrected for all other material and psychosocial resources varied between 1.0 ($95\%CI_{occupation}$ 0.4; 1.6) and 1.1 (e.g. $95\%CI_{education}$ 0.6; 1.7) (Table 2). The indirect effect of SEP on the DHD15-index via food environment resilience corrected for all other material and psychosocial resources was 0.5 (e.g. $95\%CI_{occupation}$ 0.1; 0.8). The proportion mediated for cooking skills varied between 13.3% and 19% and the proportion mediated for food environment resilience varied between 5.9% and 8.6% (Table 2; proportion mediated). The strongest mediation effects were found for the SEP indicator household equivalent income. The total indirect effect of SEP on the DHD15-index via all nine resources varied between 1.5 ($95\%CI_{income}$ 0.3; 2.6) and 1.6 ($95\%CI_{education}$ 0.7; 2.4 and $95\%CI_{occupation}$ 0.6; 2.4), resulting in a proportion mediated of between 18.8% and 25.9%. These results are similar for the parallel mediation models only including significant mediators with acceptable model fit indices (Supplementary Table 3).

Table 2. Results of the parallel mediation models regarding the role of material and psychosocial resources in the association between the three SEP indicators and the DHD15-index

Independent variables	**Mediators**	**Dependent variable**	**Total effect (c-path)**		**Direct effect (c'-path)**		**Indirect effect (a-path x b-path)**		**Proportion mediated**
			β	**95%CI**	**β**	**95%CI**	**β**	**Bootstrap 95%CI**	
Educational level	Cooking skills	DHD15-index	**8.5**	**6.7; 10.3**	**6.9**	**5.1; 8.7**	**1.1**	**0.6; 1.7**	14.1%
	Environment resilience						**0.5**	**0.2; 0.9**	5.9%
	Insensitivity to food cues						0.0	-0.1; 0.2	N/A
	Indifferent eating						-0.2	-0.4; 0.1	N/A
	Controlled eating						0.0	-0.2; 0.3	N/A
	Cognitive restraint						-0.0	-0.1; 0.1	N/A
	Food budget						0.0	-0.3; 0.3	N/A
	mRFEI						-0.1	-0.2; 0.1	N/A
	Access to healthy foods						-0.0	-0.1; 0.1	N/A
Income	Cooking skills		**5.8**	**3.7; 7.8**	**4.3**	**2.2; 6.4**	**1.1**	**0.5; 1.7**	19.0%
	Environment resilience						**0.5**	**0.1; 0.9**	8.6%
	Insensitivity to food cues						0.1	-0.1; 0.3	N/A
	Indifferent eating						-0.1	-0.3; 0.1	N/A
	Controlled eating						0.1	-0.2; 0.4	N/A
	Cognitive restraint						-0.1	-0.2; 0.1	N/A
	Food budget						-0.0	-0.8; 0.7	N/A
	mRFEI						0.0	-0.1; 0.1	N/A
	Access to healthy foods						-0.1	-0.2; 0.1	N/A
Occupation	Cooking skills		**7.5**	**5.5; 9.4**	**6.0**	**4.1; 7.9**	**1.0**	**0.4; 1.6**	13.3%
	Environment resilience						**0.5**	**0.1; 0.8**	6.7%
	Insensitivity to food cues						0.1	-0.1; 0.2	N/A
	Indifferent eating						-0.2	-0.5; 0.1	N/A
	Controlled eating						0.1	-0.2; 0.4	N/A
	Cognitive restraint						0.0	-0.1; 0.1	N/A
	Food budget						0.0	-0.3; 0.4	N/A
	mRFEI						-0.1	-0.2; 0.1	N/A
	Access to healthy foods						0.0	-0.1; 0.1	N/A

Abbreviations: β; unstandardized beta regression coefficient, CI; Confidence Interval, DHD15-index; Dutch Health Diet index 2015

4.5 Discussion

We investigated the mediating role of material and psychosocial resources in the association between SEP and dietary quality. None of the studied material resources and only two psychosocial resources mediated the association between SEP and dietary quality. Together, cooking skills and food environment resilience together accounted for approximately 20% of the association between SEP and dietary quality, which highlights the need to look for more systemic factors that could explain socio-economic inequalities in diet.

As shown in previous studies (37, 38), individuals with a higher SEP had better quality diets. Only the psychosocial resources cooking skills and resilience to the unhealthy food environment partly explained SEP inequalities in dietary quality. We believe this is because skills and knowledge-based resources are more strongly related to SEP than cognition-based resources such as food cue reactivity (21, 39-41). Furthermore, the present study findings suggest that the three socio-economic indicators included in this study have similar associations with dietary quality through material and psychosocial resources. It is possible that socio-economic indicators on a different level – e.g. childhood SEP or neighbourhood SEP – show more disparate effects on dietary behaviours (42).

Whereas there is consistent evidence that the cost of food (15-19) and some evidence that the objectively measured accessibility to healthy foods (21) partly explain dietary inequalities, we found no evidence for a mediating role of these material resources in the association between SEP and diet quality. This may be due to the Dutch context; the Netherlands is highly urbanized and has relatively good geographic access to food (43). In addition, foods are relatively affordable compared to other European countries (44). As such, food-related material resources may be accountable for less of the socio-economic dietary disparities in the Netherlands than in other contexts. Indeed, in a previous study we showed that the cost of food only explained approximately 5% of the association between SEP and dietary quality in the Netherlands (15). This is much lower than studies conducted in the United Kingdom and the United States where the proportion mediated ranged from 31% to 76% (16, 19).

While food prices, nutrition knowledge, cooking skills and unhealthy food environment resilience may help explain socio-economic inequalities in dietary behaviours, most of the association between SEP and diet quality still remains unexplained. This could be attributed to the fact that the mediating factors under study are individual-level factors. It is likely that broader factors, other than those directly relating to dietary behaviour, play an important role. The SEP/behaviour relationship is complex and most likely requires considerations of broader system factors such as the community, environment and public policy. Langellier et al. illustrate the utility of complex systems methods for unravelling wider underlying mechanisms that shape population dietary patterns as well understanding decision support for diet and nutrition policy and model validation (45). Here it is important to recognize that relations between factors are generally not linear and static, but are in fact dynamic and respond to feedback. For example, Hammond et al., suggest how social influence interacts with other mechanisms such as social capital and social stress generated by social relations, to influence diet (46).

This notion should also be taken into account in the design of preventative interventions. While interventions aimed at individual factors (e.g. providing cooking lessons) tend to have some effect (47), they may actually increase socio-economic inequalities due to their dependence on individual “agency”. Furthermore, these types of interventions are often not sustainable or scalable. In contrast, it takes no individual agency to benefit from population-level approaches such as a sugar sweetened beverage tax (48). These population-level interventions may also have a more lasting effect on behaviour change compared to individual-level interventions because they can become incorporated into structures, systems, policies, and sociocultural norms (49). However, it may be necessary to address the root causes of social inequalities in order to close the gap between the dietary quality of those with the highest versus the lowest socio-economic positions.

Strengths of the study include the relatively large sample recruited from different areas throughout the Netherlands. Another strength is the incorporation of multiple potential mediators and assessing their exploratory role simultaneously. However, a limitation of the study is that only a selective set of variables were available to represent material and psychosocial resources. Another limitation is that the present findings are based on cross-sectional data, limiting interpretations about the directions of the mediating pathways. Furthermore, we used self-reported food frequency questionnaire data, which can lead to under- or overreported dietary intake. The last limitation is that individuals with a lower SEP had a lower response to the study even though the cumulative response rate of 59% was similar to those in other mail surveys (20, 40). Caution is needed when generalizing the results to those with the lowest SEP.

4.5.1 Conclusion

In conclusion, individual-level factors such as cooking skills and resilience to the unhealthy food environment can only explain a small proportion of the SEP inequalities in diet quality. Material resources and the psychosocial resources insensitivity to food cues and eating habits do not seem to explain SEP inequalities in dietary quality in the Dutch context. However, the explanatory mechanisms of social inequalities in diet may have to be sought in the wider financial, work and living circumstances that differ between socio-economic groups.

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SUPPLEMENTARY MATERIAL CHAPTER 4

The role of material and psychosocial resources in explaining socio-economic inequalities in diet: A structural equation modelling approach

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Supplementary File 1

Psychometric properties of the potential mediators

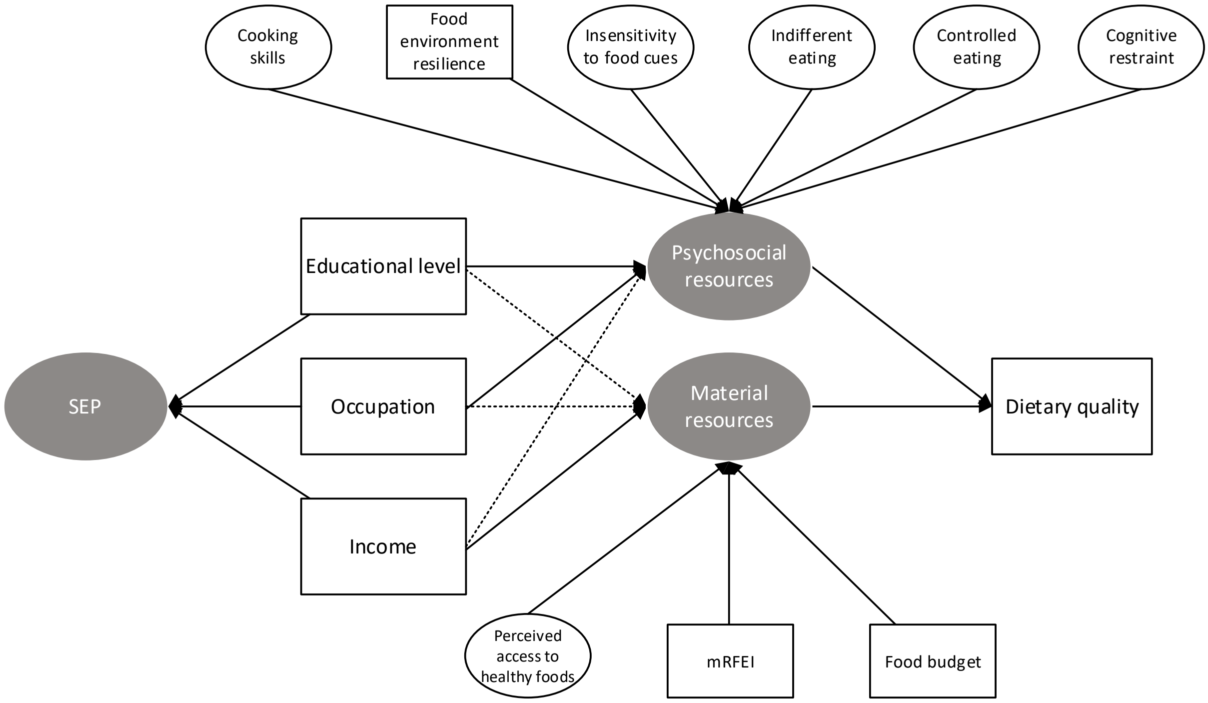
Perceptions of healthy food access was assessed using the Perceived Food Environment questionnaire (31). This questionnaire consisted of six questions relating to the accessibility of healthy foods and three questions relating to the limited accessibility of unhealthy foods measured on a 5-point Likert scale (31). CFA in the current study sample did not confirm the proposed factor structure of nine items loading onto two factors. Based on the results of an EFA, two items on the accessibility of healthy foods were removed. Furthermore, only the internal consistency of the four items relating to the accessibility of healthy foods were acceptable (Cronbach's alpha of 0.84).

Food-related psychosocial resources

Cooking skills were assessed using six questions (on a 5-point Likert scale) on the subscale 'food preparation skills' from the Food Literacy Questionnaire (34). CFA did not confirm the six items loading onto one factor. Based on EFA results, one item was removed. The internal consistency was acceptable (Cronbach's alpha 0.77).

Sensitivity to food cues was assessed using the 11-item Power of Food Scale questionnaire (35). CFA analysis in the full sample did not confirm that the 11 items loaded onto one factor. Based on the EFA results, two items were removed and the remaining items loaded onto one factor. The internal consistency of the 9-item Power of Food Scale was acceptable (Cronbach's alpha 0.88). The items were reversed in order for a higher score to indicate a higher insensitivity to food cues.

Eating behaviours were assessed using the 18 item Three-Factor Eating Questionnaire (10). This questionnaire assessed cognitive restraint, uncontrolled eating and emotional eating on a 4-point Likert scale. Restrained eaters exert cognitive effort to control their food intake, uncontrolled eaters tend to overeat with the feeling of being out of control and emotional eaters tend to eat in response to negative emotions (10, 36). CFA in the full study sample could not confirm the proposed factor structure of 18 items loading onto three factors. Based on the EFA results, four items were removed and the remaining items loaded onto three factors. The internal consistency of the items belonging to the factors uncontrolled eating (Cronbach's alpha 0.86; 6 items), emotional eating (Cronbach's alpha 0.93; 3 items) and cognitive restraint (Cronbach's alpha 0.82; 5 items) were acceptable. The factors uncontrolled and emotional eating were recoded and renamed to 'controlled eating' and 'indifferent eating' in order to reflect a resource towards healthy eating.



Supplementary Figure 1. Hypothesized pathways connecting SEP indicators with dietary quality. Circles represent latent variables and rectangles represent measured variables. White circles and squares are variables actually included in the SEM.

Supplementary Table 1. Model fit indices for the single and parallel mediation models

Independent variable	Mediator	Outcome	χ2	p-value χ2	RMSEA	CFI	SRMR
Education	Perceived access to healthy foods	DHD15-index	115.97	0.00	0.05	0.97	0.02
	Cooking skills		149.52	0.00	0.05	0.95	0.02
	Insensitivity to food cues		729.48	0.00	0.07	0.90	0.04
	Indifferent eating		28.51	0.01	0.02	1.00	0.01
	Controlled eating		449.12	0.00	0.08	0.91	0.03
	Cognitive restraint		334.98	0.00	0.08	0.91	0.04
	Cooking skills and food environment resilience		278.6	0.00	0.06	0.91	0.05
	All potential mediators		4149.8	0.00	0.06	0.86	0.10
Income	Perceived access to healthy foods		98.95	0.00	0.05	0.98	0.02
	Cooking skills		120.33	0.00	0.04	0.96	0.02
	Insensitivity to food cues		718.29	0.00	0.07	0.89	0.04
	Indifferent eating		31.21	0.01	0.03	1.00	0.01
	Controlled eating		427.68	0.00	0.08	0.90	0.03
	Cognitive restraint		330.19	0.00	0.08	0.91	0.04
	Cooking skills and food environment resilience		243.1	0.00	0.06	0.92	0.04
	All potential mediators		3951.6	0.00	0.06	0.86	0.10
Occupation	Perceived access to healthy foods		120.42	0.00	0.05	0.97	0.02
	Cooking skills		118.86	0.00	0.04	0.96	0.02
	Insensitivity to food cues		694.78	0.00	0.07	0.89	0.04
	Indifferent eating		29.48	0.01	0.03	1.0	0.01
	Controlled eating		412.51	0.00	0.07	0.91	0.03
	Cognitive restraint		350.5	0.00	0.08	0.90	0.04
	Cooking skills and food environment resilience		240.2	0.00	0.06	0.92	0.04
	All potential mediators		3941.0	0.00	0.06	0.86	0.10

The model fit indices for the single mediation models including measured factors (i.e. mRFEI, food budget and food environment resilience) are not displayed because these models had zero degrees of freedom and therefore represented a saturated model with perfect goodness of fit (i.e. RMSEA = 0.00, CFI = 1.00 and SRMR = 0.00).

Supplementary Table 2a. Results of the single mediation models regarding the role of material and psychosocial resources in the association between educational level and the DHD15-index

Independent variables	Mediators	Dependent variable	SEP on resources (a-path)		Resources on diet quality (b-path)		Total effect (c-path)		Direct effect (c'-path)		Indirect effect (c-path – c'-path)		PM
			β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	Bootstrap 95%CI	$\frac{AB}{(C' + AB)}$
Educational level	Access to healthy foods	DHD15-index	0.0	-0.0; 0.1	0.0	-0.0; 0.0	**8.6**	**6.8; 10.4**	**8.5**	**6.7; 10.3**	0.0	-0.0; 0.0	N/A
	mRFEI		**-0.1**	**-0.1; -0.0**	0.0	-0.0; 0.1			**8.6**	**6.8; 10.4**	-0.0	-0.1; 0.1	N/A
	Food budget		**0.2**	**0.1; 0.2**	0.0	-0.0; 0.1			**8.4**	**6.6; 10.2**	0.2	-0.2; 0.5	N/A
	Cooking skills		**0.2**	**0.1; 0.2**	**0.2**	**0.2; 0.3**			**7.1**	**5.3; 8.9**	**1.4**	**0.7; 2.1**	16.3%
	Food environment resilience		**0.1**	**0.0; 0.1**	**0.2**	**0.2; 0.3**			**7.8**	**6.0; 9.6**	**0.7**	**0.2; 1.2**	8.2%
	Insensitivity to food cues		-0.0	-0.1; 0.0	0.0	-0.0; 0.1			**8.6**	**6.8; 10.4**	0.0	-0.0; 0.0	N/A
	Indifferent eating		0.0	-0.1; 0.1	-0.0	-0.1; 0.0			**8.6**	**6.8; 10.4**	-0.0	-0.0; 0.0	N/A
	Controlled eating		**0.1**	**0.0; 0.1**	-0.1	-0.1; 0.0			**8.7**	**6.9; 10.5**	-0.1	-0.3; 0.0	N/A
	Cognitive restraint		0.0	-0.1; 0.1	**0.1**	**0.1; 0.2**			**8.5**	**6.8; 10.3**	0.0	-0.3; 0.3	N/A

Models were adjusted for age, sex, partner, BMI, number of children in the household and energy intake

Abbreviations: B; standardised beta regression coefficient, CI; confidence interval, N/A; Not Applicable, PM; Proportion mediated

Bold values indicate significance as the 95% confidence interval does not include zero

Supplementary Table 2b. Results of the single mediation models regarding the role of material and psychosocial resources in the association between income and the DHD15-index

Independent variables	**Mediators**	**Dependent variable**	**SEP on resources (a-path)**		**Resources on diet quality (b-path)**		**Total effect (c-path)**		**Direct effect (c'-path)**		**Indirect effect (c-path – c'-path)**		**PM**
			β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	Bootstrap 95%CI	$\frac{AB}{(C' + AB}$
	Access to healthy foods		**0.1**	**0.0; 0.1**	0.0	-0.0; 0.0			**5.7**	**3.7; 7.8**	0.0	-0.1; 0.2	N/A
	mRFEI		0.0	-0.0; 0.1	0.0	-0.0; 0.1			**5.7**	**3.6; 7.7**	0.0	-0.0; 0.0	N/A
	Food budget		**0.4**	**0.3; 0.4**	0.0	-0.0; 0.1			**5.5**	**3.4; 7.7**	0.2	-0.6; 0.9	N/A
	Cooking skills		**0.1**	**0.1; 0.2**	**0.2**	**0.2; 0.3**			**4.7**	**2.7; 6.6**	**1.1**	**0.4; 1.8**	19.0%
Income	Food environment resilience	DHD15-index	**0.1**	**0.0; 0.1**	**0.2**	**0.2; 0.3**	**5.8**	**3.8; 7.8**	**5.0**	**3.1; 7.0**	**0.8**	**0.3; 1.3**	13.8%
	Insensitivity to food cues		-0.0	-0.1; 0.0	0.0	-0.0; 0.1			**5.8**	**3.8; 7.8**	-0.1	-0.2; 0.1	N/A
	Indifferent eating		0.0	-0.0; 0.1	-0.0	-0.1; 0.0			**5.8**	**3.8; 7.8**	-0.0	-0.0; 0.0	N/A
	Controlled eating		0.0	-0.0; 0.1	-0.1	-0.1; 0.0			**5.8**	**3.8; 7.8**	-0.1	-0.2; 0.1	N/A
	Cognitive restraint		0.0	-0.0; 0.1	**0.1**	**0.1; 0.2**			**5.7**	**3.7; 7.7**	0.1	-0.2; 0.4	N/A

Models were adjusted for age, sex, partner, BMI, number of children in the household and energy intake
Abbreviations: B; standardised beta regression coefficient, CI; confidence interval, N/A; Not Applicable, PM; Proportion mediated
Bold values indicate significance as the 95% confidence interval does not include zero

Supplementary Table 2c. Results of the single mediation models regarding the role of material and psychosocial resources in the association between occupation and the DHD15-index

Independent variables	**Mediators**	**Dependent variable**	**SEP on resources (a-path)**		**Resources on diet quality (b-path)**		**Total effect (c-path)**		**Direct effect (c'-path)**		**Indirect effect (c-path – c'-path)**		**PM**
			β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	Bootstrap 95%CI	$\frac{AB}{(C' + AB}$
	Access to healthy foods		-0.0	-0.1; 0.0	0.0	-0.0; 0.1			**7.4**	**5.5; 9.5**	-0.0	-0.1; 0.0	N/A
	mRFEI		**-0.1**	**-0.1; -0.0**	0.0	-0.0; 0.1			**7.5**	**5.6; 9.4**	-0.0	-0.2; 0.1	N/A
	Food budget		**0.2**	**0.1; 0.2**	0.0	-0.0; 0.1			**7.3**	**5.4; 9.3**	0.2	-0.1; 0.5	N/A
	Cooking skills		**0.1**	**0.1;0.2**	**0.2**	**0.2; 0.3**			**6.2**	**4.3; 8.1**	**1.2**	**0.6; 1.8**	16.2%
Occupation	Food environment resilience	DHD15-index	**0.1**	**0.0; 0.1**	**0.2**	**0.2; 0.3**	**7.4**	**5.5; 9.3**	**6.7**	**4.8; 8.6**	**0.7**	**0.3; 1.2**	9.5%
	Insensitivity to food cues		-0.0	-0.1; 0.0	0.0	-0.0; 0.1			**7.5**	**5.5; 9.4**	-0.1	-0.2; 0.1	N/A
	Indifferent eating		-0.0	-0.1; 0.0	-0.0	-0.1; 0.0			**7.4**	**5.5; 9.3**	0.0	-0.1; 0.1	N/A
	Controlled eating		**0.1**	**0.0; 0.1**	**-0.1**	**-0.1; -0.0**			**7.6**	**5.7; 9.5**	-0.2	-0.4; 0.0	N/A
	Cognitive restraint		0.0	-0.0; 0.1	**0.1**	**0.1; 0.2**			**7.3**	**5.4; 9.2**	0.1	-0.2; 0.4	N/A

Models were adjusted for age, sex, partner, BMI, number of children in the household and energy intake
Abbreviations: B; standardised beta regression coefficient, CI; confidence interval, N/A; Not Applicable, PM; Proportion mediated
Bold values indicate significance as the 95% confidence interval does not include zero

Supplementary Table 3. The combined mediating role of psychosocial mediators in the association between the three SEP indicators and the DHD15-index

Independent variables	**Mediators**	**Dependent variable**	**SEP on psychosocial resources (a-path)**		**Psychosocial resources on diet quality (b-path)**		**Total effect (c-path)**		**Direct effect (c'-path)**		**Indirect effect (c-path – c'-path)**		**Proportion mediated**
			β	**95%CI**	**β**	**95%CI**	**β**	**95%CI**	**β**	**95%CI**	**β**	**Bootstrap 95%CI**	$\frac{AB}{(C' + AB)}$
Educational level	Cooking skills	DHD15-index	**0.2**	**0.1; 0.2**	**0.2**	**0.1; 0.2**	**8.6**	**6.8; 10.3**	**6.9**	**5.1; 8.7**	**1.1**	**0.5; 1.6**	12.8%
	Food environment resilience		**0.1**	**0.0; 0.1**	**0.2**	**0.1; 0.2**					**0.6**	**0.2; 1.0**	7.0%
Income	Cooking skills		**0.1**	**0.1; 0.2**	**0.2**	**0.1; 0.2**	**5.8**	**3.8; 7.8**	**4.3**	**2.4; 6.3**	**0.9**	**0.3; 1.4**	15.5%
	Food environment resilience		**0.1**	**0.0; 0.1**	**0.2**	**0.1; 0.2**					**0.6**	**0.2; 1.0**	10.3%
Occupation	Cooking skills		**0.1**	**0.1; 0.2**	**0.2**	**0.1; 0.2**	**7.4**	**5.5; 9.3**	**5.9**	**4.0; 7.8**	**0.9**	**0.4; 1.5**	12.2%
	Food environment resilience		**0.1**	**0.0; 0.1**	**0.2**	**0.1; 0.2**					**0.6**	**0.2; 1.0**	8.1%

Models were adjusted for age, sex, partner, BMI, number of children in the household and energy intake
Abbreviations: B; standardised beta regression coefficient, CI; confidence interval, N/A; Not Applicable
Bold values indicate significance as the 95% confidence interval does not include zero

CHAPTER 5

The effect of on-shelf sugar labelling on beverage sales in the supermarket: a comparative interrupted time series analysis of a natural experiment

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5.1 Abstract

Background: Nutrition labels show potential in increasing healthy food and beverage purchases, but their effectiveness seems to depend on the type of label, the targeted food category and the setting, and evidence on their impact in real-world settings is limited. The aim of this study was to evaluate the effectiveness of an industry-designed on-shelf sugar label on the sales of beverages with no, low, medium and high sugar content implemented within a real-world supermarket.

Methods: In week 17 of 2019, on-shelf sugar labels were implemented by a Dutch supermarket chain. Non-alcoholic beverages were classified using a traffic-light labelling system and included the beverage categories "green" for sugar free (<1.25g/250ml), "blue" for low sugar (1.25–6.24g/250ml), "yellow" for medium sugar (6.25–13.5g/250ml) and "amber" for high sugar (>13.5g/250ml). Store-level data on beverage sales and revenue from 41 randomly selected supermarkets for 13 weeks pre-implementation and 21 weeks post-implementation were used for analysis. In total, 30 stores implemented the on-shelf sugar labels by week 17, and the 11 stores that had not were used as comparisons. Outcome measures were differences in the number of beverages sold in the four label categories and the total revenue from beverage sales in implementation stores relative to comparison stores. Analyses were conducted using a multiple-group Interrupted Time Series Approach. Results of individual store data were combined using random effect meta-analyses.

Results: At the end of the intervention period, the changes in sales of beverages with green (B 3.4, 95%CI -0.3; 7.0), blue (B 0.0, 95%CI -0.6; 0.7), yellow (B 1.3, 95%CI -0.9; 3.5), and amber (B 0.9, 95%CI -5.5; 7.3) labels were not significantly different between intervention and comparison stores. The changes in total revenues for beverages at the end of the intervention period were also not significantly different between intervention and comparison stores.

Conclusion: The implementation of an on-shelf sugar labelling system did not significantly decrease unhealthy beverage sales or significantly increase healthier beverage sales. Nutrition labelling initiatives combined with complementary strategies, such as pricing strategies or other healthy food nudging approaches, should be considered to promote healthier beverage purchases.

5.2 Introduction

Unhealthy dietary behaviour such as a high intakes of sugars, saturated fats, and salt is associated with an increased risk of chronic diseases (1-3). The World Health Organization has endorsed the need to create a supportive food environment by introducing interpretive and consumer friendly front-of-package (FOP) and/or on-shelf nutrition labels as a priority policy issue (4). Recent systematic reviews concluded that FOP or on-shelf nutrition labels can be effective in increasing healthier product purchases or consumption (5-10).

The effectiveness of nutrition labels may vary according to the content of the label and the setting in which the label is applied. Content-wise, there are roughly two types of FOP or on-shelf nutrition labels: nutrient-specific and summary systems (11). Nutrient-specific labels display one nutrient (e.g. single Traffic Light label) or a few key nutrients such as the percentage Guideline Daily Amounts (%GDA) or Multiple Traffic Lights (MTL). Summary systems use an algorithm to provide an overall nutritional score, which can be divided into summary icons that are either present or absent (e.g. the Keyhole symbol on healthy products) or summary icons displaying a graphic rating or numerical score such as the Health Star rating or Guiding Stars (11).

A systematic review comparing the effectiveness of various nutrition labels found that nutrient-specific labels are more effective in helping consumers to identify healthier products than summary systems (11). Yet, a more recent review concluded that the results did not permit a verdict regarding whether nutrient-specific labels outperform summary labels (10). The author did, however, conclude that the designs for labels that appear to be most successful are MTL labels, warning labels, and the Nutri-Score due to their easy to understand designs, and in the case of MTL and Nutri-Score the additional use of colour (10). Other studies also conclude that labels incorporating text with colour to indicate levels of nutrients (e.g. MTL) are more effective than labels only displaying numeric information (e.g. %GDA) (11, 12). These reviews did not distinguish between the placement (i.e. FOP or on-shelf labels) or between single nutrient and multiple nutrient labels (e.g. Traffic Light versus MTL) (10-12).

Another factor influencing the effectiveness of nutrition labels seems to be the setting in which they are assessed. Although studies have shown that nutrient-specific labels and summary systems are effective in increasing healthier purchases (5, 6), evidence suggests that real-world effect sizes are around 17 times smaller than those found in laboratory settings (13). This difference may be explained by the fact that labels in real-world settings are generally less noticeable compared to laboratory settings, as they do not stand out much between the abundance of visual and auditory stimuli in real-world settings.

Nutrition labelling studies conducted in real-world settings include settings such as restaurants, sport-canteens, supermarkets, vending machines, and coffee shops (6, 7). However, even these real-world settings may not be comparable due to the differences in terms of stocking, pricing and promotion of products. Nevertheless, a review investigating the real-world effectiveness of nutrient-specific labels and summary systems concluded that there was mixed evidence regarding the impact of nutrition labels on consumer purchases and highlighted a lack of studies that objectively measured food purchasing (12).

Supermarkets are an important real-world setting given that most foods are purchased here (14). Two randomized control trials (RCTs) found that nutrient-specific and summary system labels delivered via a smartphone application were somewhat effective (15, 16), mainly in participants who used the labelling intervention more often than average users (16). While RCTs deliver important evidence based on their high internal validity, RCTs may not accurately mimic real world conditions (17). Therefore, evidence from natural experiments are also needed as these results are more generalizable. Six studies using data from experiments in supermarket settings showed mixed evidence regarding the effect of nutrient-specific FOP labels (18-20) and the on-shelf Guiding Star summary scheme (21-23) on food sales or purchases. These studies used various types of labelling implemented across various food categories – potentially explaining the mixed results. Furthermore, only one study included a control condition (23). High quality evidence on the effects of nutrition labelling on food purchases is thus scarce (10).

Many countries have mandatory nutrition facts panels on the backside of pre-packaged food products. Some countries additionally have mandatory FOP nutrition labels on pre-packaged food products (e.g. Chile and Finland) and other countries have voluntary industry-designed nutrition labels such as the Facts Up Front label in the United States and the supermarket color-coded on-shelf sugar labels across supermarket chains in the Netherlands (5, 18). This study evaluated the effectiveness of such an industry-designed color-coded on-shelf sugar label (a type of nutrient-specific label) on the number of non-alcoholic beverage sales and revenue using a natural experimental design including comparison stores. As the effectiveness of nutrition labels seems to depend on the type of label (11, 12), the targeted food category (23) and the setting (13), this study contributes to a growing literature base investigating the impact of single nutrient-specific on-shelf nutrition label interventions in real-world supermarkets.

5.3 Methods

This natural experimental study used sales data from a Dutch supermarket chain that implemented on-shelf sugar labels in their stores in 2019. Using a random number generator, we retrospectively selected fifty stores. We categorized stores that successfully implemented the on-shelf sugar labels as intervention stores and used the remaining stores as comparisons in an interrupted time series analysis. We hypothesized that the on-shelf sugar labels increased the sales of sugar free and low sugar beverages, while decreasing the sales of high sugar beverages.

5.3.1 The on-shelf sugar labels

All non-alcoholic beverages such as sodas, energy drinks, juices and water were labelled using a nutrient-specific traffic-light labelling system. Milk-based drinks were excluded. The graphical lay-out of the labelling system was designed following the corporate identity of the supermarket chain. The content of traffic-light labelling system was designed by the supermarket chain based on the Nutri-Score label (24), the Evolved Nutrition Label (developed by several companies from the food industry), and input from their costumer panel. The categories consisted of “green” for sugar free beverages (<1.25g/250ml), “blue” for low sugar beverages (1.25–6.24g/250ml), “yellow” for medium sugar beverages (6.25–13.5g/250ml) and “amber” for high sugar beverages (>13.5g/250ml). Categorization of green and blue beverages was based on the legal rules for nutrition claims as defined by the European Commission (25).

The categorization of yellow and amber beverages was based on the Evolved Nutrition Label, combined with the Nutri-Score guidelines (24). The on-shelf sugar labels were displayed next to an individual price tag (Figure 1). Such placement of on-shelf labels next to the price tag is commonly used by the supermarket chains to highlight additional information on a specific product (e.g. to highlight store brand products). The on-shelf sugar labels displayed, besides the traffic-light colours, also the range in numerical sugar content (in grams per 250ml portions) with an additional image of the number of sugar cubes. In addition, the shelf included a small poster explaining the meaning of the on-shelf sugar labels (Supplementary Figure 1; including English translation). Supplementary Figure 2 displays a photograph of the on-shelf sugar labels implemented in store.

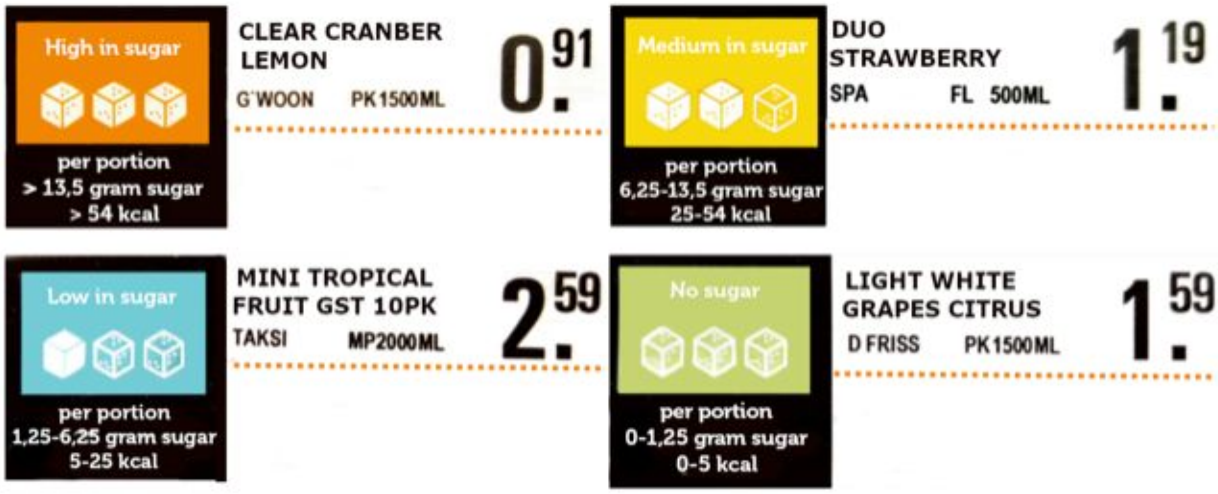

Figure 1. Examples of the on-shelf sugar labels placed next to the product descriptions and price tags in Euros (translated from Dutch to English)

5.3.2 Store selection

The supermarket chain headquarters notified all their stores to implement the on-shelf sugar labels in week 17 of 2019. The supermarket chain has three types of stores in the Netherlands: regular supermarkets, compact stores and city stores. Compact stores are small regular supermarkets, whereas city stores are small supermarkets with a different pricing line and a larger focus on convenience products. The researchers randomly selected 50 out of the possible ~300 stores to be included in the study. Weekly sales data were obtained from January 2019 to August 2019 for the four beverages categories (i.e. green, blue, yellow, and amber), resulting in data from 14 weeks before implementation and 20 weeks after the implementation of the sugar shelf labels. Literature has indicated to include a minimum number of 3 to 10 time-points in order to have enough power (26).

Due to temporary closure for store renovations, five of the selected stores did not include sales data for the entire study period and were therefore excluded from analysis. In week 20 to 22, the supermarket chain evaluated the implementation fidelity of the on-shelf sugar labels by asking the store managers to report back on whether the labels had been implemented. Of the 45 remaining stores, 29 stores had implemented the on-shelf sugar labels by week 20 to 22. We contacted the 16 remaining stores in January 2020 to check whether the on-shelf sugar labels had been implemented by then. One store indicated to have implemented the on-shelf sugar labels before the summer of 2019 and was included as intervention store. Out of the remaining stores, 10 had not implemented the on-shelf sugar labels as of January 2020, and one store had implemented the labels in the fall of 2019. These 11 stores were included as comparison stores. The last four stores indicated to have implemented the on-shelf sugar labels, but were unsure of the exact time period and were thus excluded from the analyses.

Ultimately, we included the 30 stores that implemented the on-shelf sugar labels shortly after week 17 and had data for all time-points as intervention stores, and included the 11 stores that did not implement the on-shelf sugar labels during the study period and had data for all time-points as comparison stores.

5.3.3 Outcome measures

Weekly sales data were extracted for the four beverage categories. The primary outcomes were changes in the number of non-alcoholic green, blue, yellow, and amber beverages sold (excluding products on sale), and changes in the total revenue of beverage sales. Secondary outcomes were changes in the revenue of beverages for each of the four beverage groups (excluding products on sale) and total sugar content of beverages sold. These outcomes were chosen as they capture the direct impact of targeted beverages on beverage purchases, the indirect effect on other beverage purchases, the impact on excess sugar intake from beverage purchases and the impact on beverage revenue (27). Additionally, outcomes based on both volume (i.e. sales-by-quantity) and revenue give more confidence regarding the effect estimate of on-shelf sugar labels.

Whereas outcomes involving the volume of beverages sold is of interest from a public health perspective, it can mask or pronounce effects if for example the average pack size bought changes over time. On the other hand, using revenue as an outcome avoids this challenge but may introduce problems if the price or relative price of beverages compared to other items changes over the study period. By examining patterns for both outcomes and checking for consistency, we can be more confident that there is a genuine underlying effect (28).

5.3.4 Statistical analysis

For the main analyses we used a comparative interrupted time-series (CITS) analysis as it is considered the most suitable approach to evaluate natural experimental data where researchers have no control over the design and delivery of the intervention (29-31). Given that 11 stores had not implemented the sugar shelf-labels during the study period, we were able to include those as comparison stores (32). Compared to single-group interrupted time series analyses (ITSA), the addition of a comparison group allows for a more reliable estimation of the impact of the intervention (33).

In the single-group ITSA models, the trend in beverage sales within the pre-implementation period is carried on in the post- implementation period as the counterfactual of what is expected to happen if the on-shelf sugar labels were never implemented (34). Estimates of both the change in ‘level’ and ‘trend’ of the observed versus counterfactual regression lines are calculated. The level change is the difference in intercepts between the regression lines estimated from observations before and after the interruption, whereas the trend change is the difference in slopes. In CITS models, the counterfactual not only includes information on what would have been expected to happen had the intervention not occurred from both the pre-implementation data in the intervention case, but it also includes the difference in post-implementation slopes between the intervention and comparison stores (34). The counterfactual is compared to a similar regression line calculated from the observation of what did happen following the implementation of the on-shelf sugar labels.

Using the package 'ITSA' in STATA 14.0 (35), changes in non-alcoholic beverage sales associated with the implementation of the sugar shelf-labels as an immediate change in the number of beverages sold were modelled. The step change was defined as a categorical variable equal to zero before implementation (week 18) and one after implementation of the on-shelf sugar labels, leading to 14 weekly pre-implementation time-points and 21 weekly post-implementation time-points. This approach assumes an immediate and stable effect of the intervention.

We used the STATA package ITSAMATCH to match comparison stores based on the pre-intervention level and trend of beverage sales in the intervention stores (36). Comparison stores were matched for each intervention store for each individual outcome measure. A suitable comparison store is one with a similar pre-implementation curve, but not necessarily at a similar level (34). If ITSAMATCH did not find a suitable comparison store, we selected comparison stores with similar characteristics and assessed whether these were suitable comparisons based on the similarity of pre-implementation curves (p-value curve > 0.20) (36). Suitable comparison stores were matched to intervention stores within all analyses based on pre-intervention level and trend of beverage sales, with the exception of two stores for the volume sales changes in green beverages where no suitable comparison store with similar sales patterns was found. Therefore, those two stores were excluded from the analyses, resulting in 28 instead of 30 stores analysed for this outcome.

Separate analyses for each intervention store were conducted as we expected the supermarkets to have different customer bases, to have implemented the on-shelf sugar labels at different time points, and because different comparison stores were appropriate for different intervention stores (34). Then, a meta-analytical approach was used to obtain an overall estimate of the effect, to explore the consistency of the effect size across individual supermarkets, and to identify whether outcomes varied when stratified by store characteristics (27). In case of substantial heterogeneity ($I^2 > 50\%$), subgroup analyses were conducted by store type (i.e. regular, compact, or city store), the region where the store is located and store area level deprivation.

All models were adjusted for temperature-driven variability in the consumption of beverages by including a variable representing the average of the highest measured weekly daytime temperature over the study period to adjust for changes in beverage sales by season. Although adjustment was not necessary for the CITS models, we did so to facilitate direct comparison with the ITSA model. The models were fitted assuming an autoregressive correlation with varying lags (depending on the stores and outcomes), using the Newey-West estimation method. A random-effects meta-analysis approach was then used to obtain a pooled effect estimate.

5.3.4.1 Sensitivity analysis

We carried out sensitivity analyses to examine the model assumptions. Firstly, all analyses conducted for the primary outcomes were repeated, but using a single-group ITSA design, i.e. excluding the comparison stores. Conducting both multiple- and single-group ITSA provides additional insights into possible history bias or changes in the comparison group but not the treatment group (33). Secondly, the robustness of the timing of the effect was investigated by assuming the date of implementation to be in week 22 instead of 18 to allow for delayed implementation effects. Finally, all analyses conducted for the primary outcome were repeated including non-alcoholic beverages that were on sale during the study period.

5.4 Results

Eighty percent of the included stores were regular supermarkets and approximately 50% of stores were located in socially deprived areas (Supplementary Table 1). Compact and city stores were relatively more often included as comparison stores compared to the intervention stores (35% versus 15%). After the implementation of the on-shelf sugar labels, the mean weekly sales of all four beverage categories increased in almost all intervention and comparison stores (Table 1). Also, the mean weekly revenue on all beverage sales increased in all stores. Amber beverages had the highest number of sales.

Table 1. Mean weekly number of beverages sold and total beverage revenue before and after the implementation of on-shelf sugar labels for all supermarkets

Super-market	Weekly mean (SD) sales of amber sugar beverages		Weekly mean (SD) sales of yellow sugar beverages		Weekly mean (SD) sales of blue sugar beverages		Weekly mean (SD) sales of green free beverages		Weekly mean (SD) revenue from all beverages in €	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Intervention stores										
1	1203 (189)	1440 (220)	269 (51)	357 (63)	93 (17)	107 (20)	785 (119)	1032 (245)	2779 (420)	3453 (597)
2	1774 (205)	1942 (220)	495 (79)	650 (105)	141 (24)	158 (26)	983 (129)	1222 (235)	4720 (577)	5562 (719)
3	2765 (297)	2940 (330)	654 (103)	776 (152)	235 (34)	231 (38)	1160 (145)	1396 (255)	5630 (704)	6268 (887)
4	1599 (212)	1745 (311)	339 (70)	365 (65)	119 (36)	149 (45)	462 (82)	607 (151)	2334 (311)	2754 (535)
5	867 (184)	1052 (161)	242 (42)	309 (63)	109 (24)	126 (26)	430 (47)	569 (133)	2432 (355)	3000 (505)
6	940 (111)	1036 (115)	247 (39)	306 (54)	81 (8)	89 (18)	654 (103)	829 (164)	2526 (330)	2977 (443)
7	2203 (294)	2693 (731)	545 (114)	809 (290)	90 (18)	114 (22)	1187 (232)	1759 (627)	5000 (653)	6264 (1572)
8	2398 (267)	2694 (333)	673 (112)	815 (134)	485 (106)	550 (161)	946 (117)	1232 (196)	5729 (599)	6786 (989)
9	1285 (137)	1531 (152)	374 (39)	466 (72)	117 (12)	142 (24)	897 (105)	1057 (154)	3949 (444)	4572 (514)
10	1773 (225)	1879 (219)	547 (70)	689 (137)	248 (49)	264 (51)	760 (133)	935 (151)	3892 (504)	4399(569)
11	2434 (278)	2588 (389)	664 (78)	802 (181)	427 (62)	452 (70)	1315 (175)	1595 (295)	6839 (786)	7762 (1176)
12	901 (75)	1061 (120)	301 (44)	400 (63)	101 (20)	103 (22)	648 (64)	864 (153)	2290 (185)	2892 (384)
13	2823 (202)	2721 (497)	566 (81)	692 (173)	254 (28)	269 (55)	954 (70)	1099 (257)	4723 (315)	5126 (922)
14	1050 (157)	1185 (183)	342 (46)	459 (86)	134 (15)	168 (40)	612 (94)	825 (190)	3020 (463)	3756 (653)
15	3179 (305)	3049 (250)	667 (111)	706 (105)	187 (31)	193 (34)	1293 (156)	1434 (206)	5370 (595)	5457 (562)
16	682 (113)	884 (165)	190 (45)	267 (62)	114 (25)	143 (28)	308 (50)	470 (111)	1759 (335)	2451 (442)
17	688 (104)	768 (98)	240 (51)	310 (42)	78 (16)	80 (18)	432 (75)	568 (110)	1836 (303)	2280 (329)
18	2956 (204)	3181 (337)	686 (82)	807 (150)	232 (22)	284 (37)	1089 (142)	1370 (243)	5387 (414)	6274 (803)
19	598 (65)	670 (115)	155 (44)	225 (71)	19 (5)	30 (10)	426 (51)	618 (155)	1695 (195)	2070 (393)

20	2870 (227)	3358 (444)	696 (92)	957 (189)	293 (40)	329 (50)	1215 (183)	1578 (294)	5290 (534)	6563 (980)
21	2202 (215)	2652 (365)	425 (115)	669 (176)	55 (14)	74 (23)	827 (195)	1357 (442)	4418 (658)	5955 (1256)
22	738 (70)	857 (146)	244 (37)	334 (87)	92 (17)	92 (20)	461 (67)	581 (117)	2092 (194)	2472 (469)
23	1497 (191)	1645 (232)	364 (69)	459 (93)	237 (40)	231 (49)	734 (71)	885 (188)	3975 (385)	4410 (627)
24	1423 (300)	1975 (429)	446 (91)	802 (262)	224 (59)	336 (96)	806 (214)	1396 (422)	4117 (931)	6224 (1493)
25	870 (128)	1053 (145)	248 (85)	321 (88)	118 (17)	151 (29)	536 (121)	755 (185)	2523 (428)	3287 (581)
26	510 (79)	583 (109)	154 (35)	207 (59)	36 (7)	54 (14)	325 (73)	501 (144)	1596 (272)	2031 (437)
27	880 (126)	1012 (159)	370 (47)	443 (95)	111 (16)	130 (29)	479 (52)	638 (159)	2487 (319)	2985 (513)
28	1848 (210)	1906 (304)	352 (41)	475 (90)	122 (15)	135 (30)	887 (86)	1069 (223)	3800 (343)	4304 (666)
29	1063 (160)	1455 (307)	259 (64)	435 (140)	239 (67)	322 (100)	519 (108)	913 (340)	3046 (468)	4521 (1143)
30	620 (79)	785 (122)	166 (46)	244 (74)	48 (12)	57 (15)	418 (132)	539 (155)	1806 (307)	2417 (472)
Control stores										
31	1200 (131)	1411 (190)	351 (44)	491 (100)	163 (23)	166 (39)	604 (71)	770 (184)	2862 (242)	3364 (499)
32	1284 (156)	1734 (361)	232 (42)	323 (98)	23 (7)	99 (43)	527 (114)	862 (254)	2844 (271)	3919 (884)
33	1191 (128)	1216 (255)	271 (51)	346 (104)	81 (19)	100 (33)	501 (63)	685 (168)	2219 (272)	2589 (597)
34	1066 (94)	1184 (165)	291 (77)	349 (74)	122 (22)	134 (34)	455 (93)	629 (166)	2455 (283)	2857 (511)
35	2640 (192)	2630 (278)	444 (90)	496 (59)	129 (18)	139 (22)	782 (91)	1012 (203)	4510 (406)	4805 (560)
36	1473 (163)	1739 (294)	390 (83)	572 (153)	177 (37)	225 (60)	655 (103)	911 (255)	3577 (458)	4608 (945)
37	446 (43)	429 (71)	105 (21)	116 (27)	35 (8)	34 (10)	207 (25)	250 (75)	989 (61)	1054 (196)
38	2161 (222)	2277 (292)	639 (84)	742 (138)	214 (37)	220 (44)	1583 (216)	1851 (306)	5899 (700)	6497 (912)
39	1227 (183)	1438 (176)	368 (50)	449 (97)	212 (56)	275 (77)	573 (99)	772 (179)	3266 (466)	4147 (606)
40	1747 (245)	1927 (315)	425 (86)	514 (93)	213 (56)	242 (62)	684 (85)	998 (349)	4098 (581)	5057 (760)
41	357 (52)	421 (124)	96 (18)	112 (39)	48 (10)	54 (12)	95 (14)	143 (57)	778 (92)	1011 (326)

Abbreviations: SD; Standard Deviation , Pre; Pre-implementation, Post; Post-implementation

5.4.1 Main findings

After the implementation of on-shelf sugar labels, amber beverage sales slightly increased by 0.9 (95%CI -5.5; 7.3), yellow beverage sales slightly increased by 1.3 (95%CI -0.9; 3.5) and green beverage sales slightly increased by 3.4 (95%CI -0.3; 7.0) units per week following the implementation compared to the counterfactual (i.e. the comparison stores) (**Figure 2**). These point estimates suggest a slight increase in amber, yellow and green beverage sales, however, the lower limit of the 95% confidence intervals suggest that the effects may also be negative. Implementation of on-shelf sugar labels did not change the sales of blue beverages (B 0.0, 95%CI -0.6; 0.7). Total beverage revenue only increased by 0.8 (95%CI -12.3; 14.0) Euros per week following the implementation compared to the counterfactual.

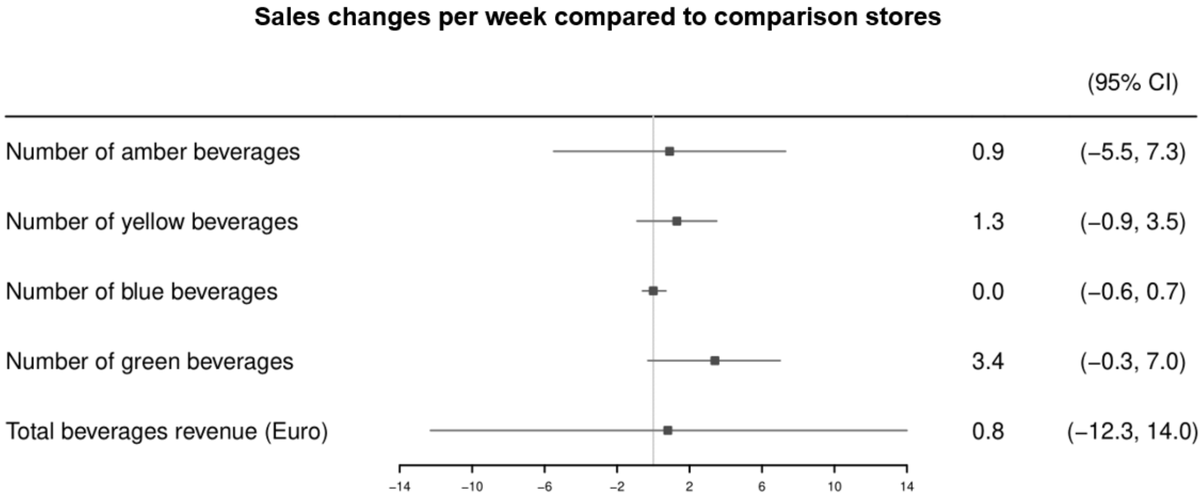

Figure 2. Pooled changes in beverage sales and total beverage revenue compared to comparison stores

Changes in beverage sales and total revenue on store-level can be found in Supplementary Figures 3 and 4. Only for one individual intervention store, a statistically significant increase of 18.8 (95%CI 5.4; 32.1) units of green beverage sales per week following the implementation compared to the counterfactual was found. No other statistically significant changes on store-level were found for the primary outcome measures. Given the low heterogeneity between stores, subgroup analyses were not conducted.

Regarding the secondary outcomes, the amount of sugar purchased slightly increased by 2.4 (95%CI -3.5; 8.3) units per week from beverage sales following the implementation compared to the counterfactual (Supplementary Figure 5). Meta-analysed results showed that the revenue on green beverages increased statistically significantly by 4.1 (95%CI 0.1; 8.0) Euros (or US$ 4.9) per week following the implementation compared to the counterfactual (Supplementary Figure 6d). No noteworthy changes in the revenue of the other three beverage categories were found (Supplementary Figures 6a, 6b and 6c).

5.4.2 Sensitivity analyses

Analyses where the pre-implementation trend was used as the counterfactual without including comparison stores indicated that the green, blue and yellow beverage sales increased by 9.2 (95%CI 6.6; 11.7), 0.7 (95%CI 0.2; 1.1) and 4.8 (95%CI 2.8; 6.9) units per week following the implementation compared to the pre-implementation trend, respectively (Supplementary Figure 7). The total revenue from all beverages sold increased by 25.3 (95%CI 16.0; 34.6) Euros (or US$ 30.1) per week following the implementation compared to the pre-implementation trend (Supplementary Figure 7). Only the sales of amber beverages did not change significantly.

Regarding the robustness of the timing of the effect, changing the timing of the on-shelf sugar labels to week 22 instead of week 18 did not affect the results (Supplementary Figure 8). Results were similar when including the sales data of beverages on sale (Supplementary Figure 9).

5.5 Discussion

This study used supermarket sales data to investigate the effect of an industry-designed on-shelf nutrient-specific labelling system on beverage sales and revenue. Our results indicate that the implementation of on-shelf sugar labels does not significantly change the beverage sales between intervention and comparison stores in all four beverage categories (i.e. green, blue, yellow, and amber) nor on total beverage sales revenue.

Real-world effects of nutrition labelling in the supermarket were examined previously (15, 16, 18-23), but a comparison of study findings is not straight forward. The methodological designs (natural experiment or randomized controlled trial), analytic approaches (CITS, ITSA, or between group comparison), the placement of the nutrition labels (FOP, on-shelf or via a mobile app), the type of labels (nutrient-specific or summary system), and the food categories on which the labels are implemented all vary across studies.

Hobin et al. (2017), a study most comparable to the current study, investigated the effect of nutrition labelling on beverage sales using CITS analysis. This study found, contrary to our results, a statistically significant decrease of 2.6% in unhealthy beverage sales compared to the control stores (23). Similar to our results, the healthier beverages sales did not significantly change. The somewhat different results between the aforementioned study and the current study may be explained by the fact that the study by Hobin et al. (2017) used an on-shelf summary system (Guiding Stars) (23), while the current study evaluated an on-shelf nutrient-specific label. Other real-world studies investigating the effect of nutrition labelling in the supermarket did not include a control condition (20-22), and/or investigated other food categories (19-21), or used nutritional warning labels (18).

In line with our findings, Sacks et al. (2009) showed no beneficial effects on the healthiness of sold products after the implementation of a FOP nutrient-specific system on ready-to-eat meals and sandwiches (20). Cawley et al. (2015) examined the effect of an on-shelf summary system (Guiding Stars) in the supermarket. Although the unhealthy beverages decreased by 27%, similar results were observed for the beverage sales with any number of stars. Likewise, Sutherland et al. (2010) showed that the Guiding Stars system significantly decreased the sales of zero-star products (21). However, given that neither studies included comparison stores, the sale changes may have been driven by overall changes over the study period. Especially in the case of Cawley et al. (2015), where a decrease of beverage sales was found in all beverage categories (22).

As demonstrated by our study, the absence of comparison data can largely affect the outcomes. When we excluded the comparison stores and only compared the post-implementation trend with the pre-implementation trend for intervention stores as the counterfactual, our sensitivity analyses showed statistically significant, albeit small, increases of green, blue and yellow beverage sales after the implementation of on-shelf sugar labels. Comparing our ITSA results with the CITS results shows that including comparison stores is necessary in order to account for possible trends in beverage sales not attributable to the implementation of the on-shelf sugar labels. However, given that this study used a natural experimental design and not an RCT, the comparison stores used in this study were not randomly selected. Also, issues with implementation fidelity might attenuate the observed results. RCTs would be needed to allow for random intervention allocation, and for monitoring implementation fidelity, while the data from this natural experiment may more accurately reflect effect sizes after the implementation of nutrition labelling under normal circumstances (e.g. when not under supervision by researchers). Two previous studies investigated implementation of nutrition labels via a smartphone application after scanning product barcodes (15, 16). One of these studies observed that among consumers who frequently used the application to receive the nutrition labelling (summary system) healthier beverage sales significantly increased (16). The other study found that the nutritional value of purchased foods was healthier after the implementation of one out of the five of the tested nutrition labels (i.e. a nutrition information panel including a recommendation or warning) (15).

Based on the current evidence it seems that nutrition labelling alone would not be sufficient to increase healthier product sales and/or decrease unhealthy product sales. Implementing multiple strategies targeted at discouraging unhealthy and/or encouraging healthier product sales are likely needed. Besides governmental guidelines on a mandatory, consistent, and easily interpretable labelling systems – which can inform consumers on healthier choices and stimulate product reformulation in the industry (37) – a supplementary strategy could include taxing of amber and yellow beverages to discourage purchases and should also stimulate product reformulation (38-40). The tax revenue could in turn be used to encourage healthy products by subsidizing these. Furthermore, nutrition labelling initiatives can be considered information nudges (41). Other nudging strategies can additionally be used to promote green and blue beverages purchases. Nudges are various environmental changes that promote healthier choices without removing the unhealthier choices (42). Examples of nudges are placing healthy beverages at eye-level and enhancing their visibility using attractive promotion materials, vivid product descriptions, or increasing healthy beverage availability (41, 43). A recent study indeed showed that combining multiple strategies within the supermarket setting is important, as nudges alone did not increase healthy food purchases, while combining pricing strategies (i.e. taxing unhealthy products and subsidizing healthy products) with nudges had the largest impact on healthier purchasing behaviours (44). Nutrition labelling initiatives combined with complementary strategies should therefore be implemented and evaluated across multiple food groups within the supermarket to promote a shift towards a healthy dietary pattern (45). Moreover, research is needed on the potential long-term effectiveness of these strategies and their potential to improve population health.

This study has several strengths. We analysed the effect of on-shelf nutrient-specific labelling on beverage purchases using real-world supermarket sales data including comparison stores. Therefore, this study generated evidence relevant for real world implementation. Moreover, we used relevant business outcomes in order to investigate the sustainability of this retail-led health intervention. We analysed our data with a CITS approach which is the recommended approach to analyse these types of natural experiments (46, 47). With the inclusion of comparison stores we accounted for possible time-varying confounders (33). Also, we had access to 34 time-points whereas literature indicates as a rule of thumb that the minimum number of time points required for this type of analysis lies between 3 to 10 (26). Furthermore, pooling of overall effects using a meta-analysis approach increased statistical power of the analysis and improved overall interpretation of the findings. Lastly, the results can be generalizable to other supermarkets in the Netherlands using color-coded on-shelf sugar labels on non-alcoholic beverages given the inclusion of a large and diverse selection of supermarket stores.

Despite these strengths, some limitations need to be considered. Natural experiments do not allow for regulation of the intervention development, allocation and implementation by researchers. Indeed, comparison stores were self-selected and probably had reasons for not implementing the on-shelf sugar labels which remain unknown to the researchers. This could for example explain why there were more compact stores in the comparison group compared to the intervention group. Moreover, due to the nature of this study, we could not study consumer awareness of the labels and did not have access to detailed information on implementation fidelity and could therefore not account for that in the analyses. Similar to other studies (20, 22, 23), we modelled changes in beverage sales associated with the implementation of the sugar shelf-labels as an immediate step change in the number of beverages sold. This approach assumes an immediate and stable effect of the on-shelf labels directly after implementation, whereas in practice the effectiveness of labels may increase gradually over time. However, since our sensitivity analysis of changing the timing of the implementation of the on-shelf sugar labels did not show different the results, we have no indications for a gradual increase of effectiveness over time.

5.5.1 Conclusion

This study provides important evidence from a natural experiment in a real-world supermarket setting regarding the effectiveness of an industry-designed on-shelf sugar label on beverage sales and revenue. The implementation of an on-shelf sugar labelling system did not significantly decrease unhealthy beverage sales and also did not significantly increase sales of beverages labelled as healthier. Nutrition labelling initiatives combined with complementary strategies, such as pricing strategies or other healthy food nudging approaches, should be considered to promote healthier beverage purchases.

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SUPPLEMENTARY MATERIAL CHAPTER 5

The effect of on-shelf sugar labelling on beverage sales in the supermarket: a comparative interrupted time series analysis of a natural experiment

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Supplementary Table 1. Supermarket characteristics

Supermarket number	Store size (m^2)	Type of store[a]	Area deprivation[b]
Intervention stores			
Supermarket 1	870	Regular	Low
Supermarket 2	1164	Regular	Low
Supermarket 3	1359	Regular	High
Supermarket 4	505	Regular	High
Supermarket 5	956	Regular	Low
Supermarket 6	838	Regular	Low
Supermarket 7	443	Regular	Low
Supermarket 8	1128	Regular	High
Supermarket 9	1263	Regular	High
Supermarket 10	1144	Regular	High
Supermarket 11	1521	Regular	High
Supermarket 12	1235	Regular	Low
Supermarket 13	896	Regular	High
Supermarket 14	1109	Regular	High
Supermarket 15	740	Regular	High
Supermarket 16	757	Regular	Low
Supermarket 17	801	Regular	Low
Supermarket 18	811	Regular	High
Supermarket 19	Missing	City store	Low
Supermarket 20	Missing	Regular	High
Supermarket 21	524	City store	Low
Supermarket 22	Missing	Regular	Low
Supermarket 23	Missing	Regular	High
Supermarket 24	1023	Regular	High
Supermarket 25	760	Regular	Low
Supermarket 26	624	Compact	Low
Supermarket 27	792	Regular	Low
Supermarket 28	838	Regular	Low
Supermarket 29	754	Regular	Low
Supermarket 30	619	Compact	Low
Comparison stores			
Supermarket 31	1036	Regular	High
Supermarket 32	Missing	City store	High
Supermarket 33	Missing	Regular	High
Supermarket 34	Missing	Regular	Low
Supermarket 35	169	Compact	High
Supermarket 36	1093	Regular	High
Supermarket 37	273	Compact	Low
Supermarket 38	1131	Regular	Low
Supermarket 39	1010	Regular	Low
Supermarket 40	916	Regular	Low
Supermarket 41	427	Compact	High

[a]Regular: Regular supermarket, Compact: small regular supermarket, City Store: small city supermarket with different pricing line
[b]High or low area deprivation level as compared to the national average

’Beverages decision aid’

‘Easy and quick insight into the sugar content of your beverages.’

‘No sugar’

‘These products contain per serving*:’

‘0-1.25 gram sugar’

‘Low in sugar’

‘These products contain per serving*:’

‘1.25-6.25 gram sugar’

‘Medium in sugar’

‘These products contain per serving*:’

‘6.25-13.5 gram sugar’

‘High in sugar’

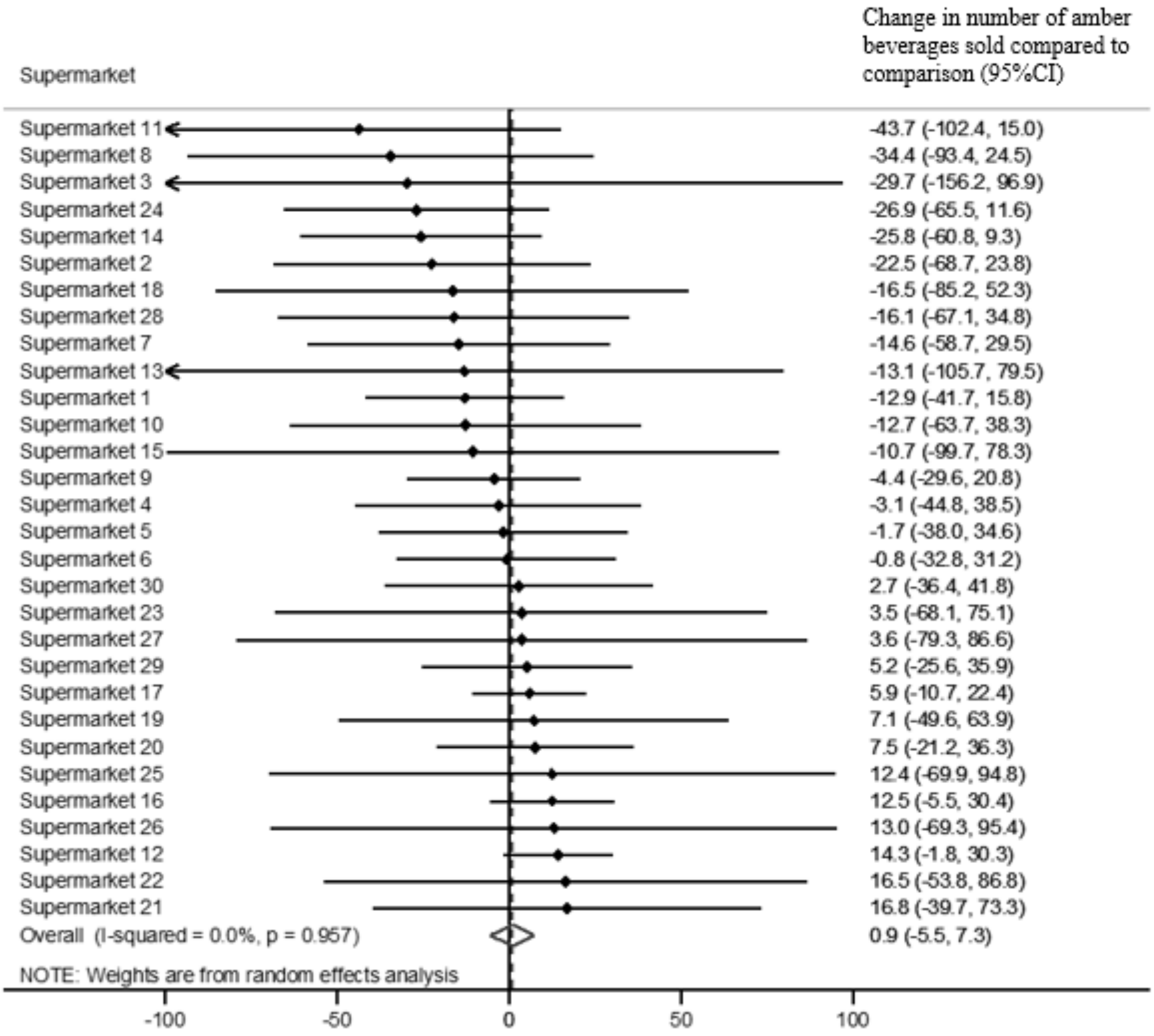
‘These products contain per serving*:’

‘>13.5 gram sugar’

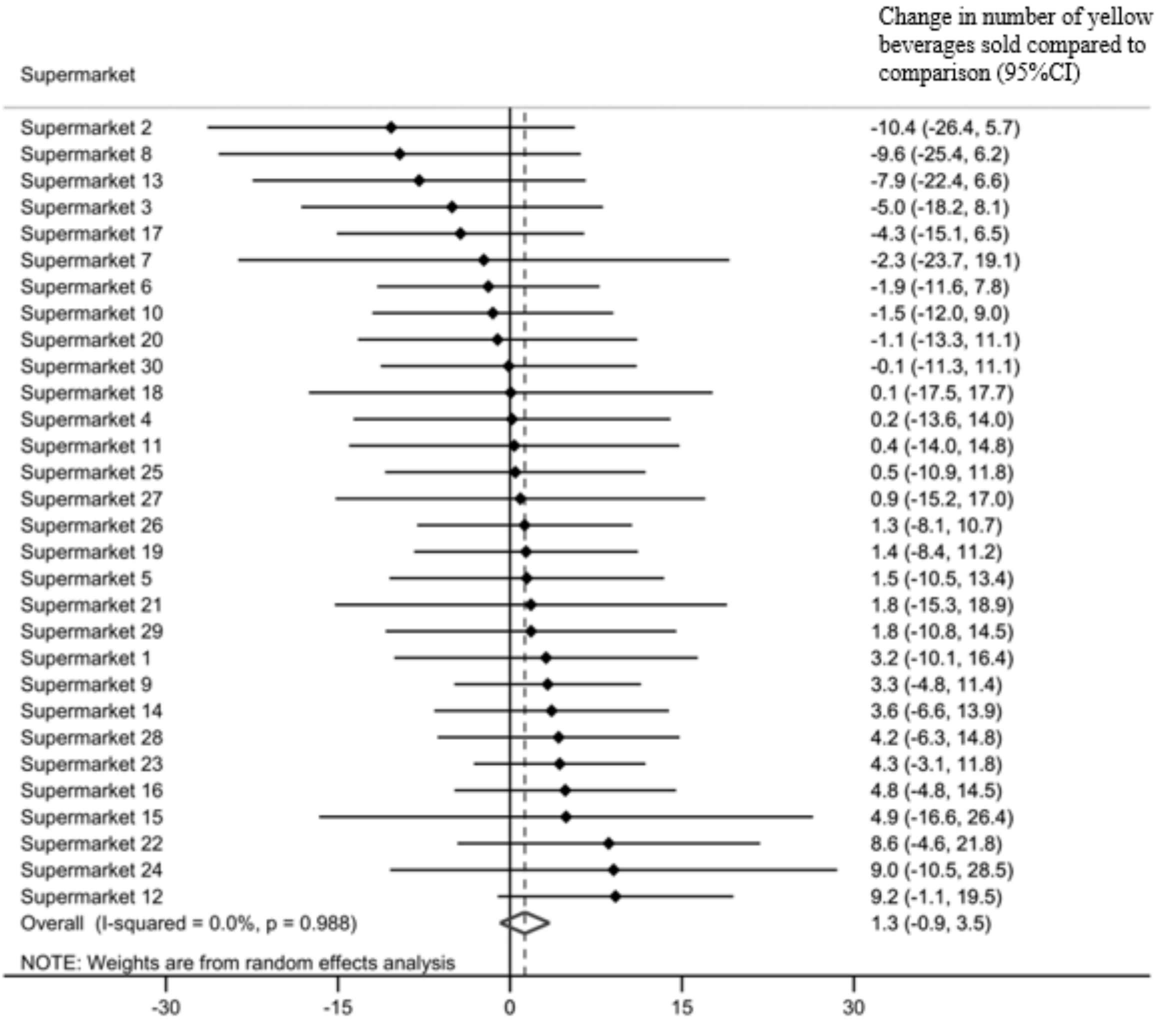
‘* This discicion aid is based on serving sizes of 250 ml’

Supplementary Figure 1. In-store poster explaining the on-shelf sugar labelling colours in Dutch, including English translation

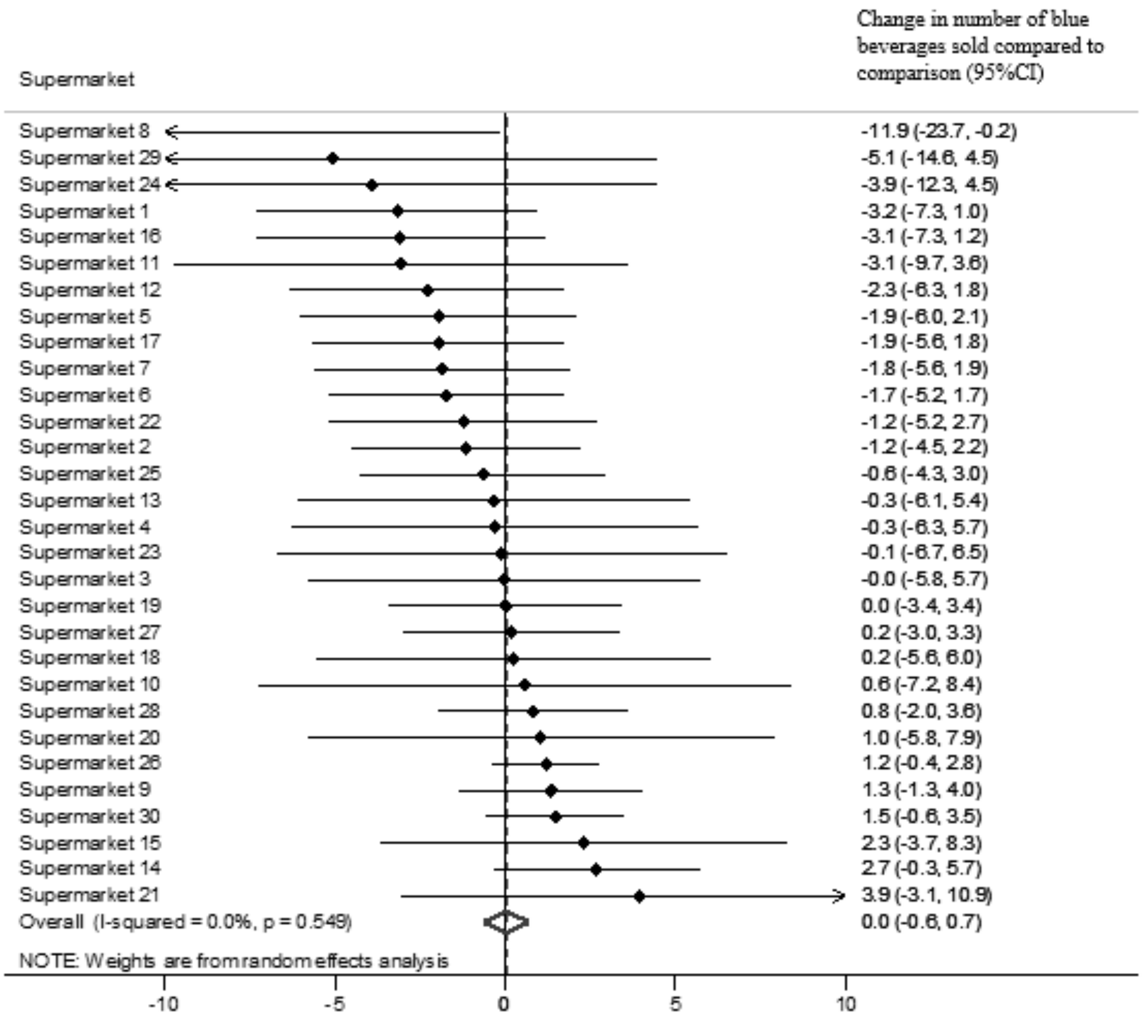
Supplementary Figure 2. Photograph of the on-shelf sugar labels implemented in store



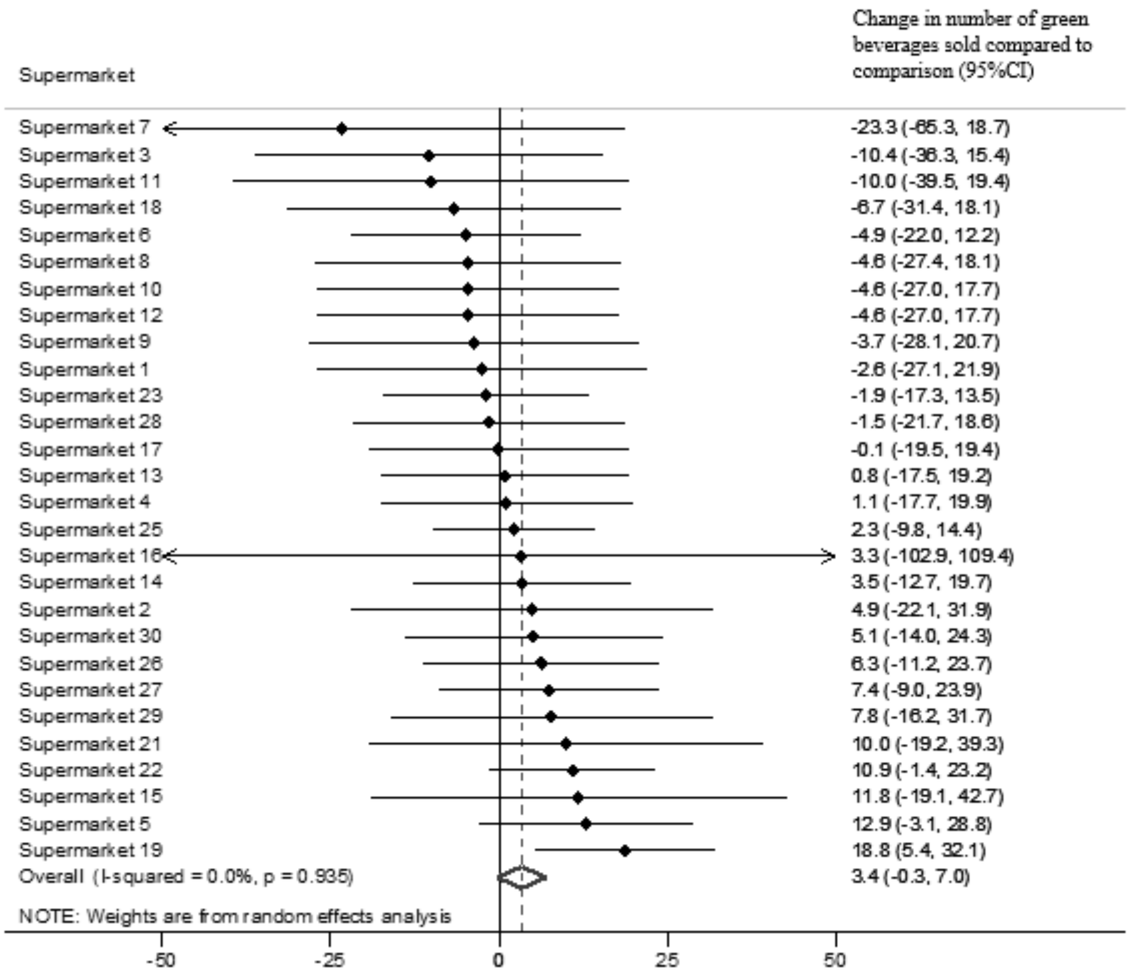
Supplementary Figure 3a. Change in sales of amber beverages compared to comparison stores



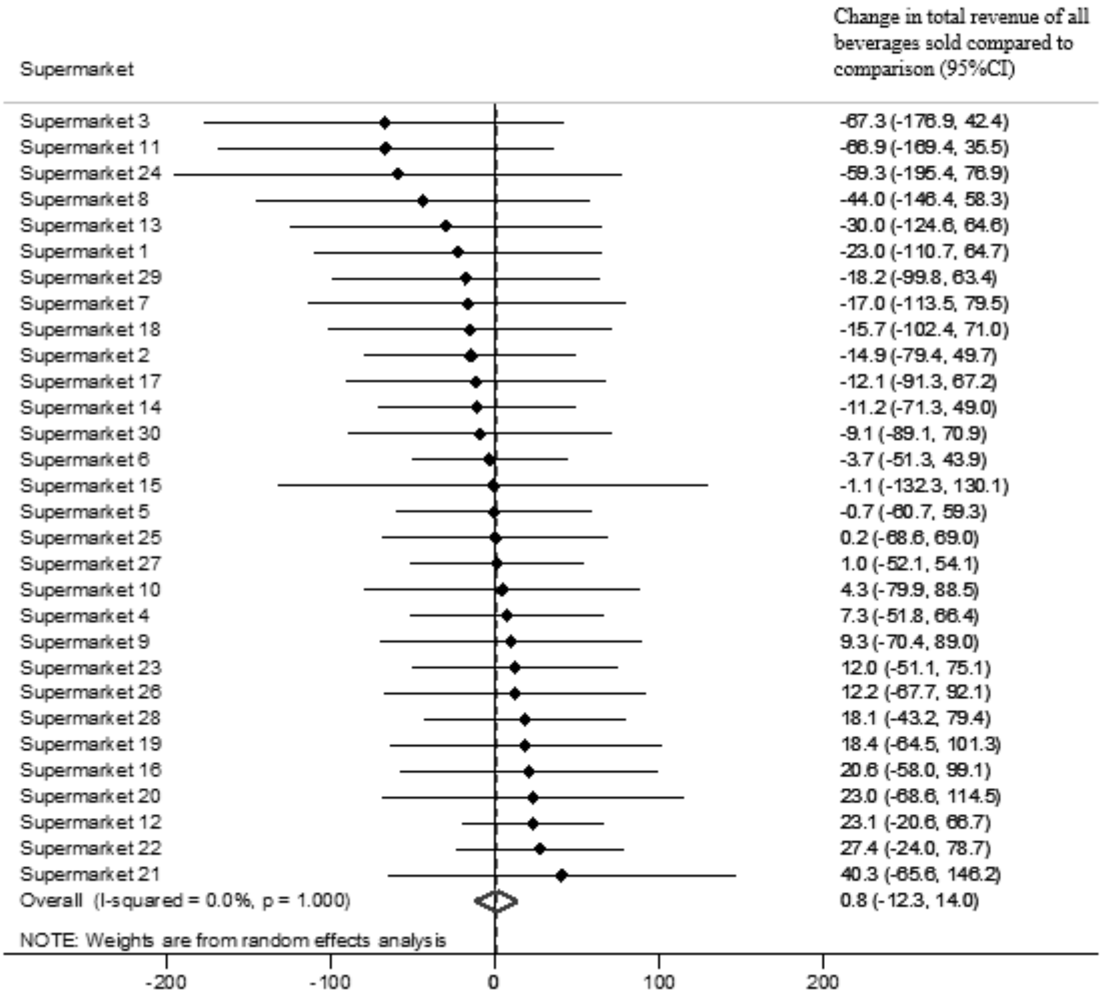
Supplementary Figure 3b. Change in sales of yellow beverages compared to comparison stores



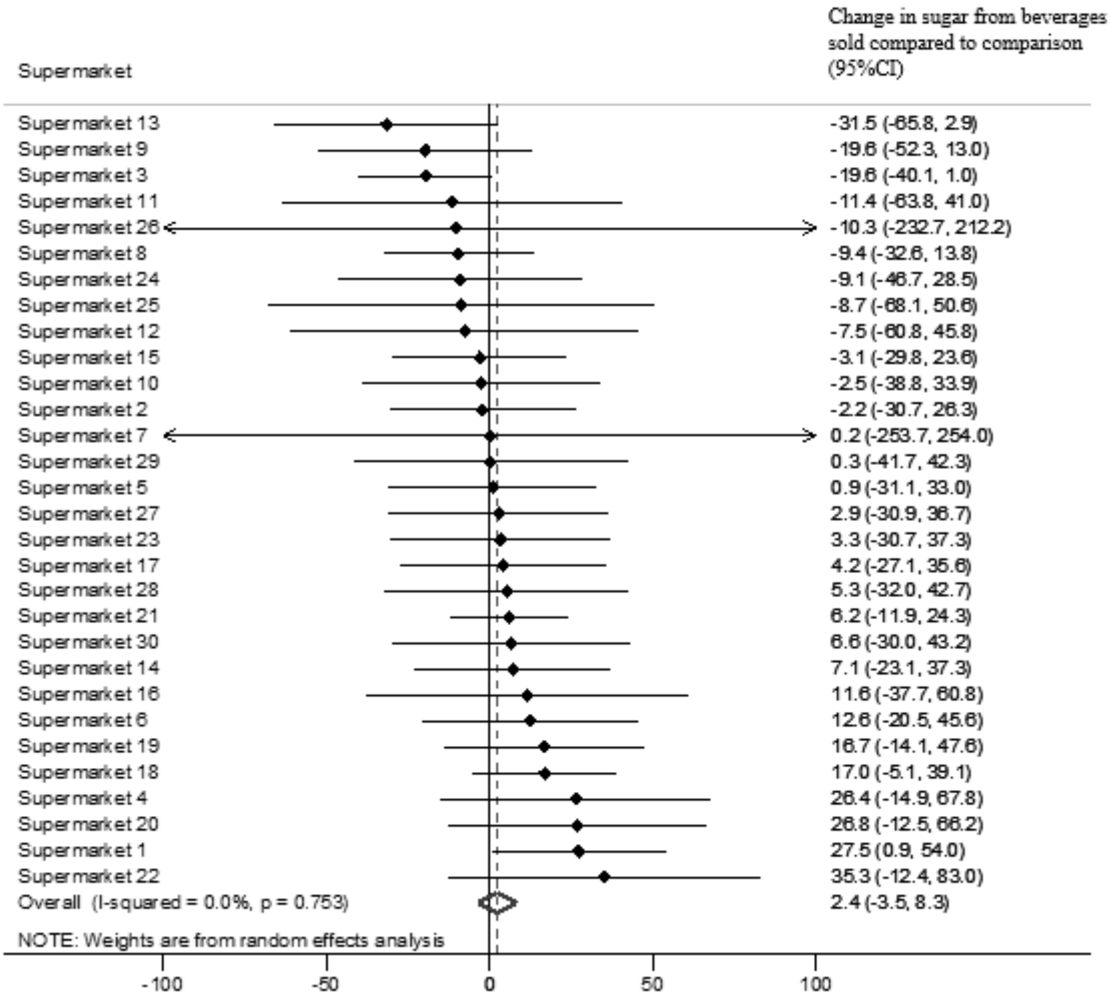
Supplementary Figure 3c. Change in sales of blue beverages compared to comparison stores



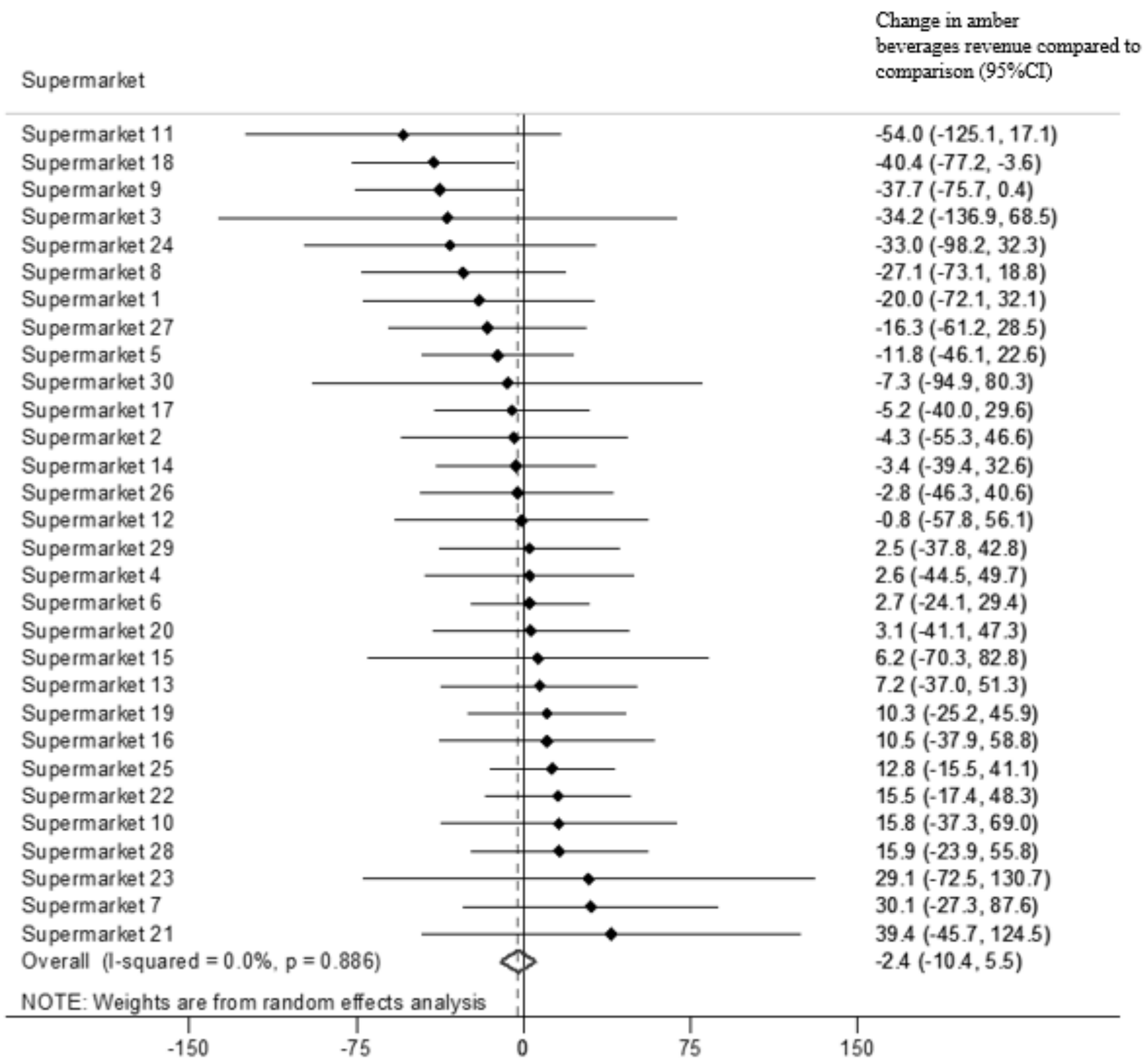
Supplementary Figure 3d. Change in sales of green beverages compared to comparison stores



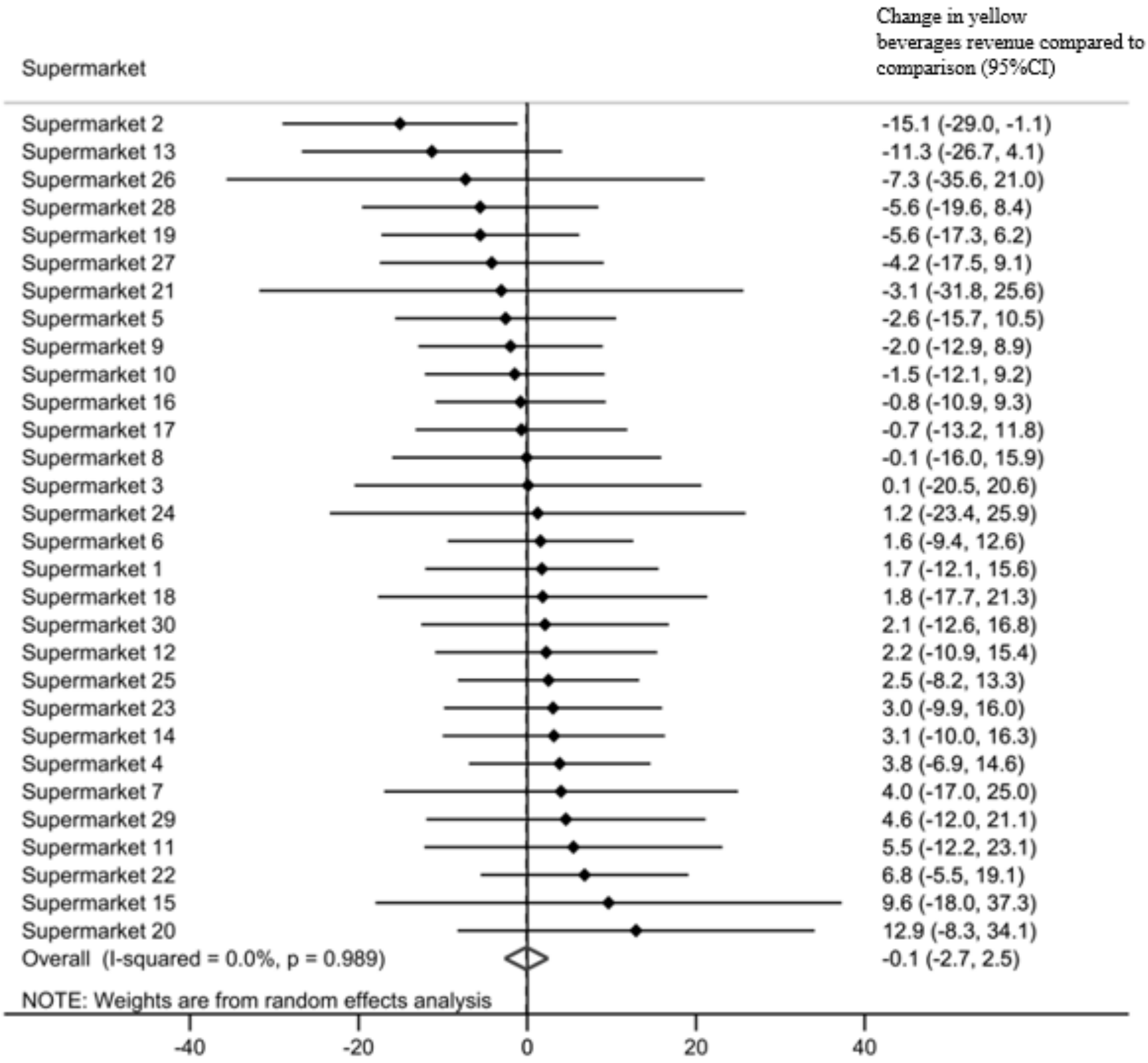
Supplementary Figure 4. Change in beverage revenue compared to comparison stores



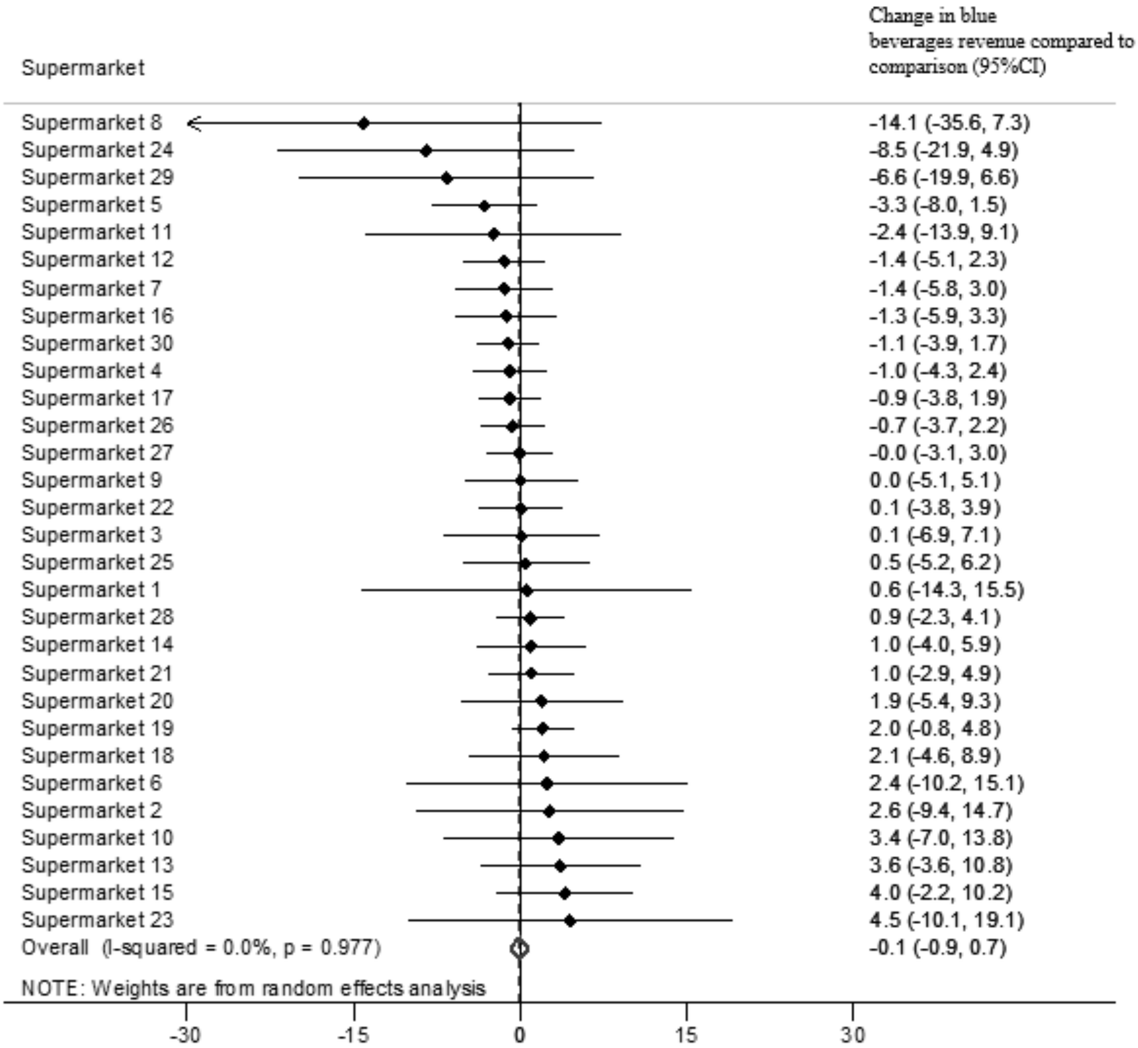
Supplementary Figure 5. Change in total sugar from beverages sold compared to comparison stores



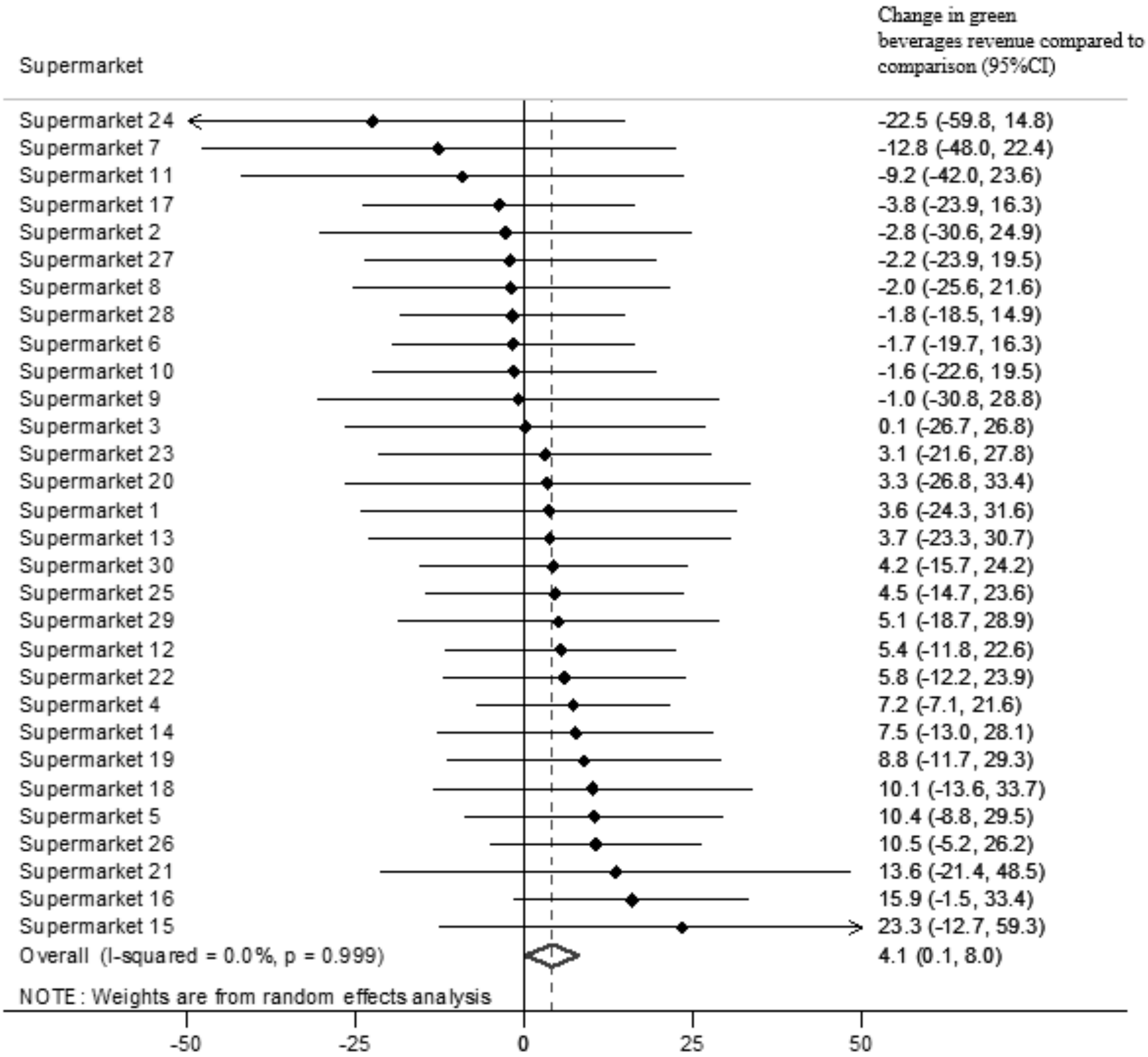
Supplementary Figure 6a. Change in revenue after implementation of on-shelf sugar labels of amber beverages compared to comparison stores



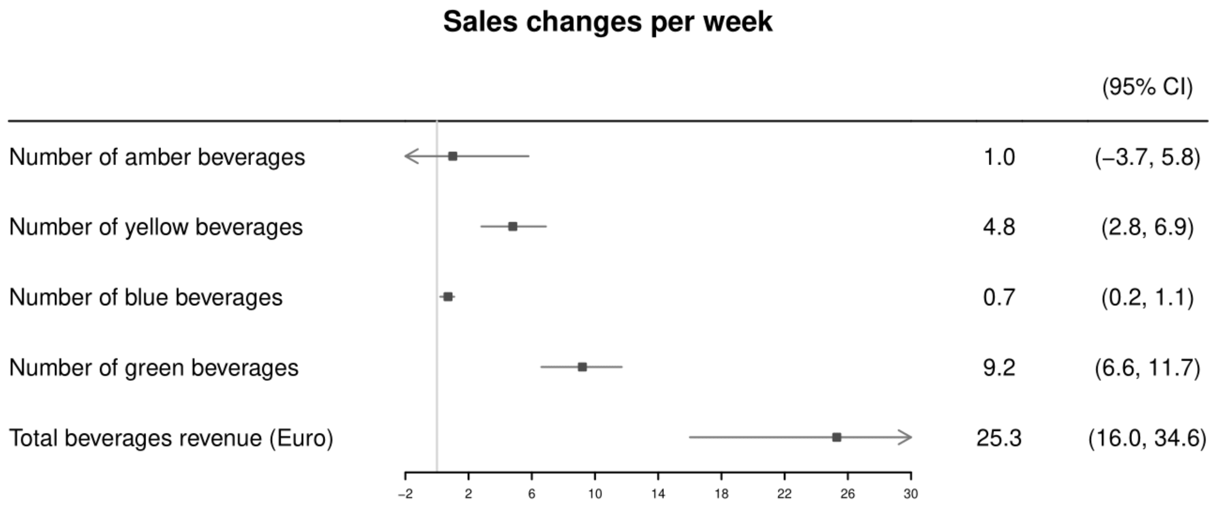
Supplementary Figure 6b. Change in revenue after implementation of on-shelf sugar labels of yellow beverages compared to comparison stores



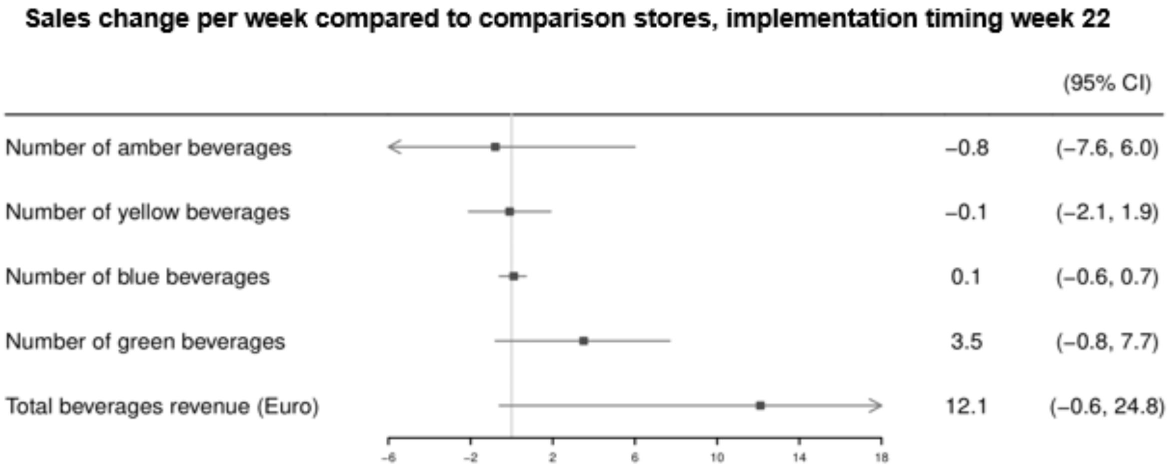
Supplementary Figure 6c. Change in revenue after implementation of on-shelf sugar labels of blue beverages compared to comparison stores



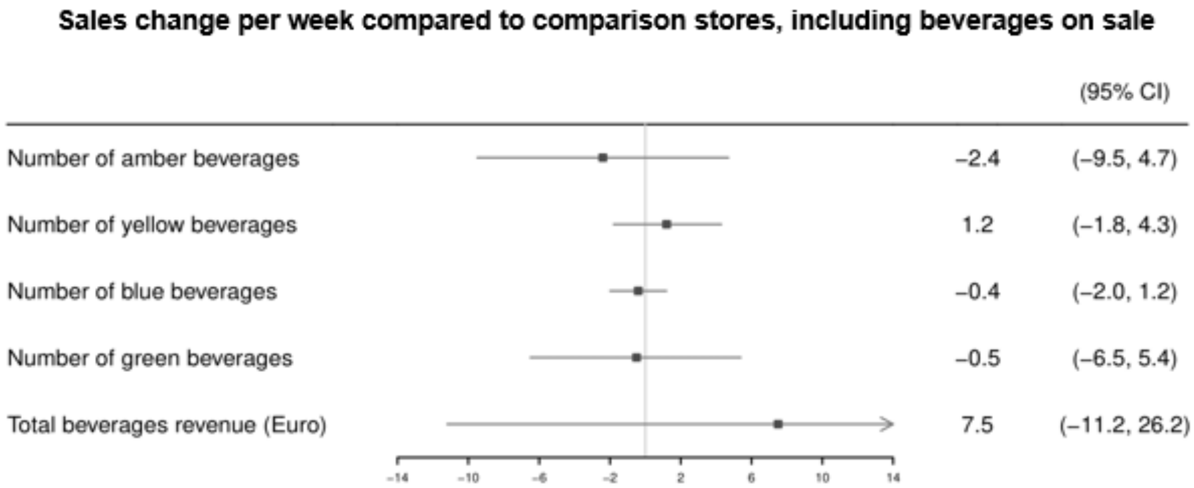
Supplementary Figure 6d. Change in revenue after implementation of on-shelf sugar labels of green beverages compared to comparison stores



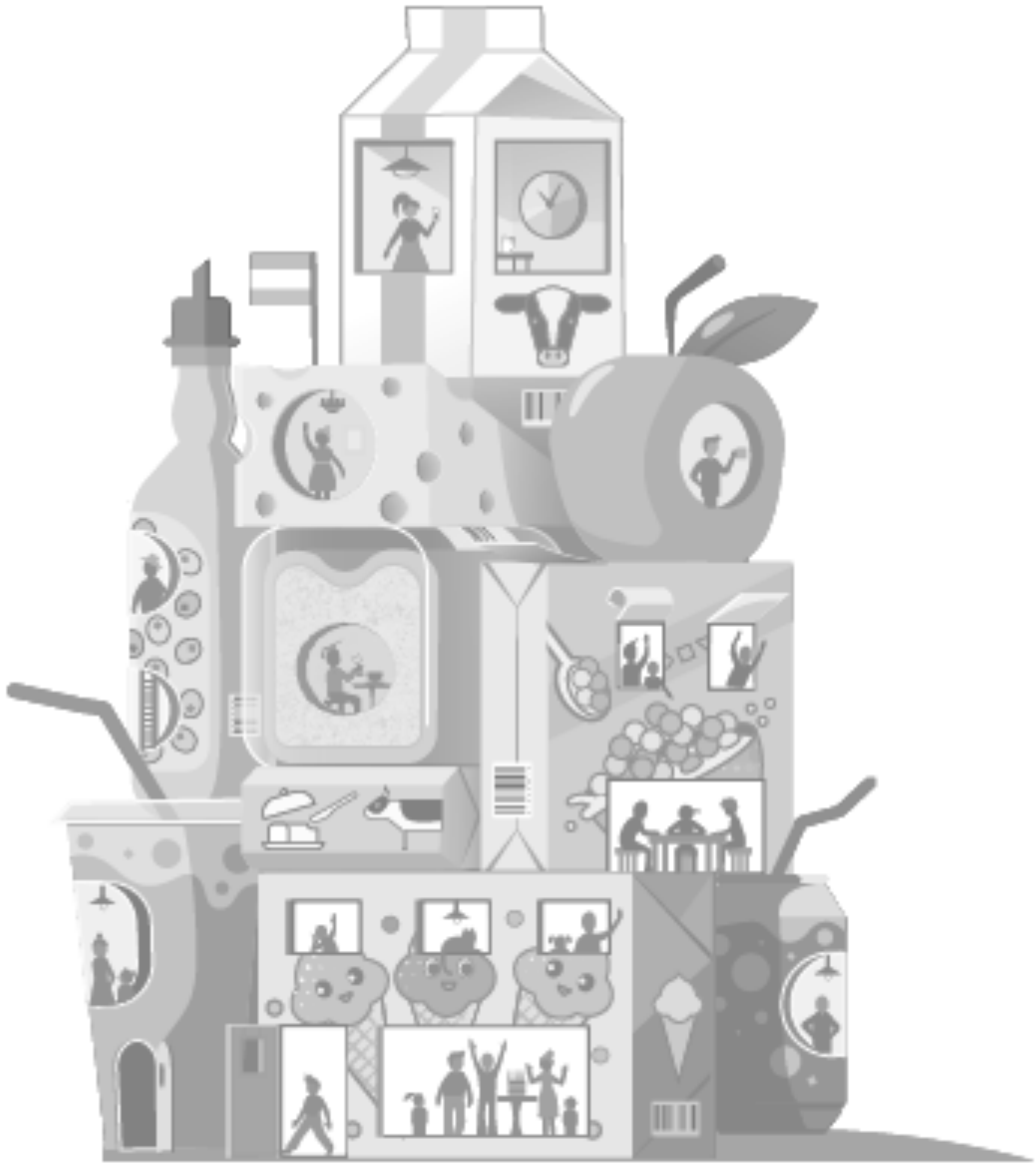
Supplementary Figure 7. Overall pooled change in sales after implementation of on-shelf sugar labels of amber, yellow, blue and green beverages and change in total beverage revenue



Supplementary Figure 8. Overall pooled change in sales after implementation of on-shelf sugar labels of amber, yellow, blue and green beverages and total revenue compared to comparison stores, when implementation timing is set at week 22 instead of week 18



Supplementary Figure 9. Overall pooled change in sales after implementation of on-shelf sugar labels of amber, yellow, blue and green beverages and total revenue compared to comparison stores, including beverages on sale



CHAPTER 6

Recruitment of participants for a virtual supermarket study: An observational study

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Recruitment of participants for a 3D virtual supermarket: Cross-sectional observational study

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6.1 Abstract

Background: Virtual supermarkets offer a practical and affordable setting to test the efficacy of different pricing and nudging strategies before they are implemented in the real world. Despite the advantages of using virtual supermarkets for this purpose, conducting studies in online settings is challenging with regard to recruitment and retention of sufficient and suitable participants.

Objective: To describe cost, time and retention with regard to participants recruited using various strategies and potential socio-demographic differences between participants recruited via different strategies.

Methods: This cross-sectional study used data from a randomized controlled trial in which 455 Dutch adults with low and high educational levels were invited to shop five times in a 3D virtual supermarket. Participants were recruited via social media and flyers. A log that tracked the costs of and time spent on the different recruitment strategies was kept by the study team. Outcome measures included the cost of recruitment strategies, the time investment by researchers, and recruitment and attrition rates of participants in the study.

Results: The median age of study completers was 31.0 (IQR 25.0) and 157 out of 346 study completers (45.4%) were highly educated. Out of the 455 included participants, 235 (51.6%) were recruited via social media campaigns, 131 (28.8%) via home-delivered flyers, 38 (8.4%) via flyers directly distributed by the study team and 46 (10.1%) via word-of-mouth. Of all paid recruitment strategies, social media campaigns were the cheapest and least time-consuming, whereas the distribution of flyers by the study team was the most expensive and time-consuming recruitment strategy. Age, sex, overweight status, employment situation and number of adults within the household varied by recruitment strategy.

Conclusions: Using different recruitment strategies resulted in the efficient recruitment of a representative study sample and retention of participants was relatively high. While 'word-of-mouth' was the most cost- and time-effective recruitment strategy, using only 1 type of recruitment strategy could result in a demographically skewed study population.

6.2 Introduction

Supermarkets are an important point-of-purchase setting (1) particularly applicable in studies targeting diet as an important risk factor for non-communicable diseases. Examples of promising strategies to improve population diets in supermarket settings include pricing and nudging strategies. Studies have shown that pricing (e.g. price promotions on healthier products) and nudging (e.g. prominent placement of healthier products) strategies can be effective in increasing purchases of healthy food (2-5). While pricing strategies can be seen as 'harder' approaches, nudges can be seen as 'softer', as nudges are less intrusive and simply alter the choice environment to make the healthy choice the easier choice, without removing the unhealthy choice (3). Despite their promise, investigating the effectiveness of pricing (especially increasing the price of unhealthy foods) and nudging strategies in real supermarkets is costly (e.g. purchases of materials or compensation of the supermarket for loss of revenue) and time consuming for researchers (e.g. recruitment of participants, collecting receipts, imputing purchasing data).

Virtual supermarket environments may offer a practical and affordable means of testing the efficacy of different pricing and nudging strategies *before* they are implemented in real-world settings. Virtual supermarket environments include online web shops for grocery shopping and 3D virtual supermarkets. The 3D virtual supermarket imitates a real-life supermarket by duplicating the layout and using 3D products. Once a virtual supermarket is constructed, researchers can easily manipulate the supermarket environment by adjusting prices, and adding nudges such as posters or frames around products, for example. A number of 3D virtual supermarkets have been developed to date (6-9). Overall, previous studies of 3D virtual supermarkets have indicated that they are a valid tool for investigating the effect of pricing strategies on food purchases (6), also when compared to real-life purchases (8). As such, 3D virtual supermarkets appear to be a valid alternative to real-world supermarkets as an environment in which the efficacy of nudging and pricing strategies can be studied.

Recruitment of a sufficiently large sample that adequately represents the target population can be difficult (10). Reporting on the effectiveness of recruitment strategies facilitates improvements in the design and methods of future studies. The effectiveness of recruitment strategies depends on several factors including the study design, setting, study population and the use of incentives (11). Despite the advantages of 3D virtual supermarkets, it may be more difficult to recruit participants for online studies compared to interventions in real-world settings, as participants need to be adept at using technology and need to have access to a smartphone or computer with internet access (12, 13). Difficulty with recruitment can lead to longer recruitment times, increased use of resources and reduced sample size and power. Besides, it may be more difficult to retain participants as compared to studies in real-world settings due to the lack of personal contact (11, 13), for example, which may lead to selection bias and loss of statistical power (12). Furthermore, particularly when using a within-subject study design where participants are asked to conduct multiple rounds of shopping over a specified time period, long waits between these shopping trips might lead to diminished interest, as the novelty of the online intervention decreases, and increased frustration, resulting in additional attrition. While some degree of attrition is largely inevitable, excessive attrition reduces statistical power, increases bias and leads to lower generalizability of results (13).

Evidence suggests that most intervention studies, that is, experimental studies online or in the real world in which investigators assign the exposure(s) to participants, use print advertising such as flyers, posters and newspaper advertisements to recruit potential participants (14, 15). Challenges related to the recruitment and retention of participants in online studies have led to the use of alternative recruitment strategies that rely on internet advertising and social media (13). These innovative recruitment strategies are attractive due to their potential to reach a larger number of people, apparent cost effectiveness and ability to reach populations that are considered hard-to-reach (e.g. young adults and adults with a lower educational level) (13, 15). Despite the growing popularity of recruitment via social media, data on the effectiveness of this strategy in the context of online studies are limited (15).

Online studies have reported on the use of several recruitment strategies (6, 11). However, as far as we are aware, no studies investigating the effectiveness of social media as a recruitment strategy have been conducted in the Netherlands to date (13). The aim of this study was to describe cost, time and retention rates with regard to different recruitment strategies (including innovative and traditional recruitment strategies), and the socio-demographic characteristics of participants recruited via these different strategies.

6.3 Methods

6.3.1 Study overview

This study is part of the 'Sustainable Prevention of Cardiometabolic Risk through Nudging Health Behaviours' (Supreme Nudge) project (16). Data presented in this paper describe the cost, time and retention rates associated with different recruitment strategies from a larger study investigating the efficacy of nudging and pricing strategies on food purchasing behaviour in a virtual supermarket and effect modification by socio-economic position (SEP). Results of this trial are reported elsewhere (17) and additional details about the study aims and design are presented in Appendix 1. The study design and procedures for this virtual supermarket study were approved by the Medical Ethics Review Committee of VU University Medical Centre (OHRP: IRB00002911), and all participants provided informed consent.

6.3.2 Inclusion Criteria

Inclusion criteria were that participants had to be 18 years or older, were able to communicate in Dutch, had access to a computer with internet, had a valid e-mail address, and regularly did the grocery shopping for their household. This study aimed to include an approximately equal number of adults with a lower and higher SEP determined using the proxy educational level. Given the known difficulties associated with recruiting individuals with a low SEP combined with the fact that only approximately 28% of the Dutch population is considered to have a low educational level (18), we included individuals with both low and medium educational level in the lower SEP group. Adults were considered low or medium SEP if their highest obtained educational level was primary education, intermediate vocational education or higher secondary education. As shopping was done for the household, only 1 person per household was allowed to participate.

6.3.3 Recruitment of Participants

According to the sample size calculation, at least 300 participants were needed to find a statistically significant difference in one of the main outcomes of the trial (vegetable purchases) between the control condition and experimental conditions (not yet accounting for possible attrition). Details regarding the sample size calculation can be found in the Supplementary File 1). Both traditional and more novel recruitment strategies were used to recruit participants. The traditional recruitment methods included advertising via flyers. The more novel recruitment strategy included using social media advertising, which has become an increasingly popular approach (11). Flyers were distributed directly to participants on the street, at local events and in real-world supermarkets. The flyers contained information on the inclusion criteria, activities within the study and the reward for completing the study (a guaranteed incentive of €25). Distribution of the flyers took place in October 2018. Flyers were also distributed around the University campus in October 2018. Approximately 500 flyers were printed at €0.35 per flyer. Flyers were also delivered to addresses in low-income neighbourhoods via postal services and by the study team. Low-income neighbourhoods (i.e. those with an average household income per resident under the median Dutch household income) were selected in order to increase participation rates of individuals with a lower SEP (19, 20). The social media campaign consisted of pay-per-click Facebook and Instagram campaigns and ran from mid-September to mid-December 2018. A professional was hired to set up the Facebook and Instagram campaigns. Campaigns were separated for low and high SEP target groups. Using existing and non-disclosed Facebook algorithms, the campaigns were adapted automatically based on what worked best for each target group. The target groups of the 2 Facebook campaigns were adjusted according to the characteristics of participants included in the study at a particular point in time. For example, if too few men had been recruited for the study after a few weeks, the Facebook campaign was adjusted to only include men in order to increase the recruitment of men. Also, a Twitter post was created using the Supreme Nudge account (with over 250 followers at that time). Participants recruited from Facebook, Instagram and Twitter were considered to be recruited using ‘social media strategies’. Although the researchers did not actively encourage participants to recruit others (e.g. there was no incentive for participants to recruit others for the study), participants were also recruited by word-of-mouth at no cost to the researchers. A log to track the costs of the different recruitment strategies was kept by the study team. Furthermore, a log tracking the development of recruitment material (e.g. posters and Facebook campaign) by the researchers and the distribution of posters by the researchers was kept. We intended to recruit participants between the periods of September and December 2018. If insufficient participants completed the study within this time period (N=300), recruitment would have continued in January 2019.

6.3.4 Study Procedure

The social media campaigns and the study flyers directed potential participants to a registration website where more information about the study was provided and visitors could be redirected to a Survalyzer questionnaire for informed consent by entering their email-address. Potential participants received an e-mail with a link to the baseline questionnaire, which included questions regarding their socio-demographic characteristics and shopping habits. Inclusion criteria were assessed using the baseline questionnaire. If participants met the inclusion criteria, they received a link to the virtual supermarket and were asked to download the virtual supermarket to their computer and conduct a trial shop in which they needed to find five specific products from a grocery shopping list. Participants that successfully retrieved at least 4 out of 5 products were included in the study. Participants were then asked to shop five times in the virtual supermarket over the course of five consecutive weeks. During the first virtual shopping trip, participants were asked the following: “Imagine that you only have herbs at home and you decide to do the shopping for the entire household (people for whom you normally do the grocery shopping for) for one week. You receive a budget from us. You buy all your daily meals, snacks and drinks for the entire week (toiletries and alcohol are not for sale in this supermarket). The budget is only a guideline; it is possible to spend a little less or a little more.” For the subsequent 4 shopping trips, this prompt was updated to include the information that their usual supermarket was now closed and, as such, that they had to do their shopping in a new supermarket. Participants received guaranteed incentives for completing weekly shops: after participants completed their first shopping trip, they received a €5 gift voucher and after completing all five rounds, participants received an additional €20 gift voucher.

6.3.5 Participant Characteristics

When assessing the eligibility of participants through a questionnaire, participants also answered questions regarding their age (years), sex (male, female), height (meters), weight (kilograms), household size (number of children and adults in the household), household net monthly income (ranging from <€1700 to >€5000), highest educational level attained (primary school, secondary school, vocational education or higher education), employment status (full-time employed, part-time employed, housewife/man, receiving benefits, retired, student and other), responsibility for household shopping (fully responsible, mostly responsible, partly responsible and someone else is responsible), frequency of household shopping (less than once a week, once a week, twice a week, three times a week and more often), weekly budget for food shopping (<€25, €26- €50, €51- €100, €101- €150, €201- €250, €251- €300 and > €300) and location of usual food shopping (at the market, in the supermarket, in small local shops, in organic food shops and other). After completing the final round of shopping, participants were also asked eight questions regarding their experience of the virtual supermarket. Examples of prompts were: “The program was easy to understand” and “The products I purchased in the virtual supermarket resemble my regular food purchases”. These items have been used in previous studies to assess participants’ experience of other virtual supermarkets (6, 7). Answering options were 5-point Likert scales ranging from “strongly disagree” to “strongly agree”. Results regarding participants their experience of the virtual supermarket can be found in Supplementary Figure 1.

6.3.6 Outcome Measures

We collected data on participant characteristics and recruitment method to describe the type of participants that were recruited and retained using the different recruitment strategies. Furthermore, data on the costs associated with the different recruitment strategies were collected.

6.3.7 Analyses

6.3.7.1 Overall Recruitment and Retention of Participants

We report descriptive statistics on the overall number of participants recruited and retained using the different recruitment strategies.

6.3.7.2 Recruitment Cost, Time and Retention Rates According to Recruitment Strategy

Descriptive statistics on the number of participants recruited and retained using the different recruitment strategies and the costs associated with these strategies are reported. The cost per recruitment strategy was calculated by dividing the total amount spent on a recruitment strategy by the number of participants recruited via the corresponding strategy. This was also done for the time researchers spent on each recruitment strategy.

6.3.7.3 Participant Characteristics

Differences in participant characteristics between those who signed up for the study and met the inclusion criteria, participants that successfully conducted a training shop, participants that completed the study (i.e. carried out all 5 rounds of shopping) and study non-completers were inspected visually and formally tested. Differences between completers and non-completers and differences in population characteristics between the different recruitment strategies were assessed using a one-way ANOVA for continuous outcome variables (i.e. BMI and age) and the Pearson chi-square test in the case of categorical outcome variables (e.g. educational level and income). Non-normally distributed continuous outcome variables were log transformed. Analyses were conducted in STATA version 14.1 and a p-value of 0.05 was used to indicate statistical significance.

6.4 Results

6.4.1 Overall Recruitment and Retention of Participants

Participants were recruited between September and December 2018. Figure 1 shows the flow of participants over the trial period. Regarding the recruitment campaigns, 3,427 people clicked on the advertisement and were directed to the registration website. Initially, the campaign was much more likely to reach women (often aged 45 and older), after which the campaign was adapted to reach more men. This resulted in the campaign mostly reaching men under the age of 25. Around 17,500 people received a study flyer in their mailbox and 450 people received a study flyer directly from the study team. After being recruited by the different strategies and registering via the website, 809 people provided informed consent and were eligible for participation. Of those, 455 successfully conducted the training shop and were included in the study. A total of 346 participants completed the study and 318 participants generated usable data for all five rounds of shopping (i.e. generated data that could be linked back to the participant and in which the login code corresponded to the participants' assigned budget). Of all participants who successfully conducted the training shop, 76.04% (346/455) completed the study.

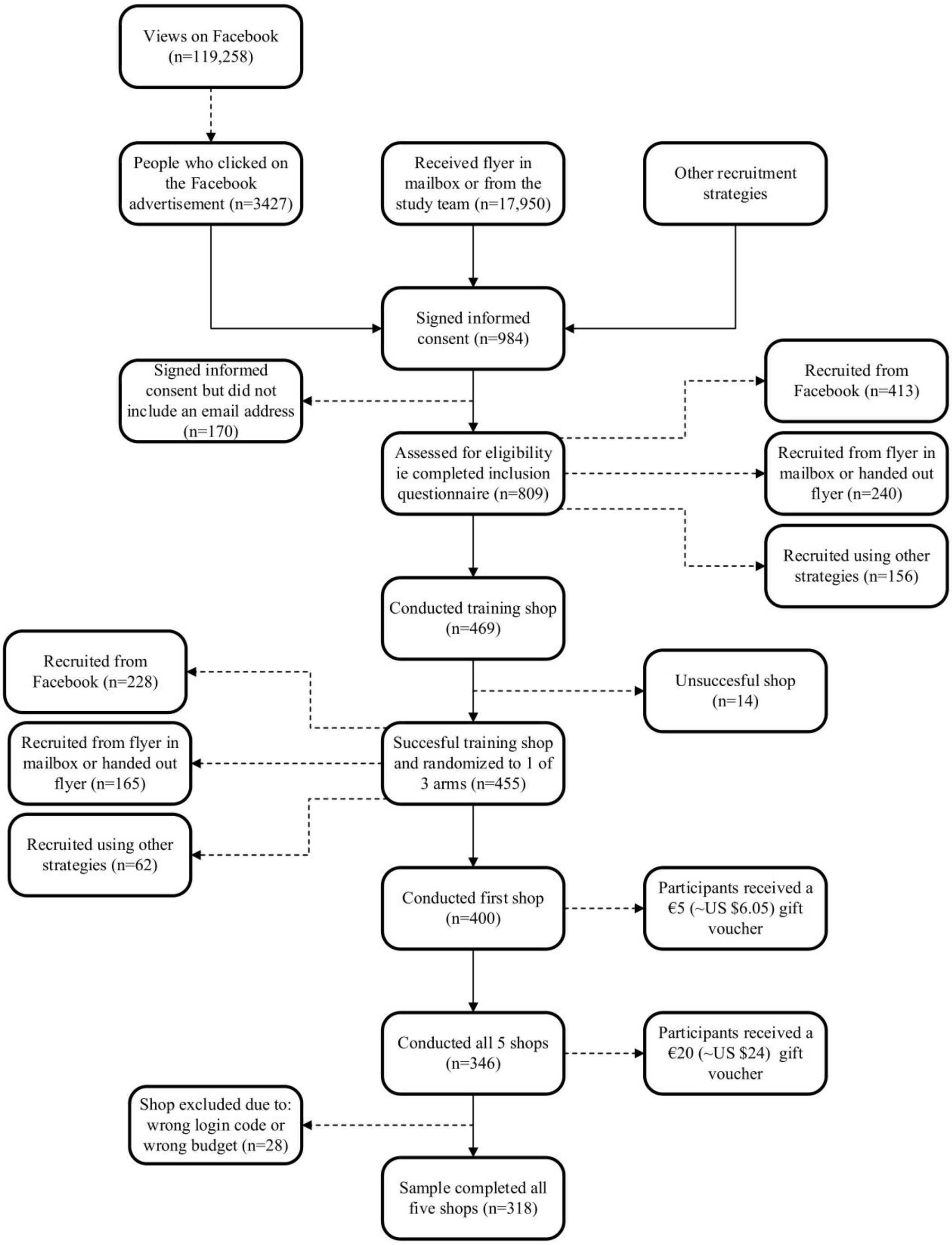

Figure 1. Flow chart of participant recruitment and retention

6.4.2 Recruitment Cost, Time, and Retention Rates According to Recruitment Strategy

In Table 1, the costs of various recruitment strategies and the number of participants recruited using the different recruitment strategies are displayed. Over half (n=426) of the 809 adults who signed up for the study were recruited using the social media campaigns (mostly Facebook) and 29.7% (n=240) were recruited using flyers distributed to home addresses. Social media campaigns resulted in the highest absolute registration, inclusion in the study and study completion. Distribution of flyers by the research team was the most expensive strategy, while the social media campaigns were the least expensive paid strategy in terms of the cost per person after completion of the study. Regarding the Facebook campaign, the cost per click was estimated to be €0.14. The unpaid recruitment strategy ‘word-of-mouth’ required no time investment by the research team and involved no recruitment costs. Regarding paid recruitment strategies, social media campaigns were the most time-efficient and flyers distributed directly by the study team were the least time-efficient for the researchers (8 minutes per study completer compared to 100 minutes per study completer, respectively). While the costs of flyers distributed by the team were similar to flyers distributed to home addresses (i.e. €21 and €20, respectively), the time-investment for flyers distributed directly by the study team were much higher compared to flyers distributed to home addresses (i.e. 100 minutes and 25 minutes, respectively). The highest study completion rate was achieved with the ‘word-of-mouth’ recruitment strategy (from 7% (N=55 out of N=809) of registered participants to 12% (N=40 out of N=346) of study completers). These results are also confirmed when calculating the percentage of participants that were included and completed the study compared to those that registered for each recruitment strategy (Table 3). In total, 72.7% (40/55) of participants recruited via word-of-mouth completed the study, compared to 39.9% (170/426), 44.2% (106/240), 54.0% (27/50) and 3.4% (3/88) of participants recruited via social media campaigns, flyers distributed to home addresses, flyers distributed directly by the study team and unknown recruitment strategies, respectively (Table 2).

Table 1. The cost, time and percentage of participants in each recruitment strategy during three phases of the study

Recruitment type	Cost (€)	Time (min)	Registered			Included			Completed		
			N (%)	Cost (€) per participant	Time (min) per participant	N (%)	Cost (€) per participant	Time (min) per participant	N (%)	Cost (€) per participant	Time (min) per participant
Social media campaigns	1.298	1440	426 (52.7%)	3	3	235 (51.6%)	6	6	170 (49.1%)	8	8
Flyers distributed to home addresses	2.142	2700	240 (29.7%)	9	11	131 (28.8%)	16	21	106 (30.6%)	20	25
Flyers distributed directly by the team	558	3000	50 (6.2%)	11	60	38 (8.4%)	16	71	27 (7.8%)	21	100
Word-of-mouth	0	0	55 (6.8%)	0	0	46 (10.1%)	0	0	40 (11.6%)	0	0
Unknown	N/A	N/A	38 (4.7%)	N/A	N/A	5 (1.1%)	N/A	N/A	3 (0.8%)	N/A	N/A
Total	3.998	7140	809 (100%)	23	74	455 (100%)	37	98	346 (100%)	49	133

Abbreviations: N/A = Not Applicable; min = minutes

Table 2. The percentage of participants that were included in the study and completed the study compared to those that registered in each recruitment strategy

Recruitment type	Registered N	Included n (%)	Completed n (%)
Social media campaigns	426	235 (55.2%)	170 (39.9%)
Flyers distributed to home addresses	240	131 (55%)	106 (44.2%)
Flyers distributed directly by the team	50	38 (76.0%)	27 (54.0%)
Word-of-mouth	55	46 (83.6%)	40 (72.7%)
Unknown	38	5 (13.2%)	3 (7.9%)

6.4.3 Participant Characteristics

Characteristics of participants who signed up for the study and met the inclusion criteria, participants that successfully conducted a training shop, participants that completed the study (i.e. carried out all 5 rounds of shopping) and study non-completers can be found in Table 3. The median age of participants included in the study was 31 (SD=25.0) and the majority of participants were female. Most participants included in the study had a medium educational level and a monthly household net income below €1700. Study completers were somewhat younger than study non-completers (median age of 31.0 compared to 37.0, respectively), but this difference was not statistically significant. Study non-completers were statistically significantly more often overweight and had older computers compared to study completers. No other large observable differences in participant characteristics were found between study completers and non-completers. For study completers, the average time in days between participants' first shop and last shop was 38.1 days (SD=13.1).

Table 3. Characteristics of the study population who completed and did not complete the study

Characteristics	Total sample (N = 809)	Sample included (N = 455)	Completers (N= 346)	Non-completers (N=463)	*P*-value
Median age in years; IQR	35.0; 27.0	31.0; 25.0	31.0; 24.0	37.0; 30.0	.21
Sex, N (%) female	515 (63.7%)	284 (62.4%)	215 (62.1%)	299 (64.6%)	.53
Mean BMI (SD)[a]	25.3 (5.3)	24.9 (4.8)	24.9 (4.9)	25.6 (5.5)	.05
Overweight status, N (%) overweight or obese[a,b]	348 (43.8%)	176 (39.9%)	129 (38.9%)	219 (48.8%)	.01
Educational level[c], N (%)					.07
Low educational level	90 (11.1)	43 (9.5)	31 (9.0)	59 (12.7)	
Medium educational level	379 (46.8)	212 (46.6)	158 (45.7)	221 (47.7)	
High educational level	337 (41.7)	200 (44.0)	157 (45.4)	180 (38.9)	
Monthly household income[d], N (%)					.32
0-1700 euros	306 (38.3)	172 (38.6)	123 (36.5)	183 (40.3)	
1701-2500 euros	195 (24.4)	105 (23.5)	81 (24.0)	114 (25.1)	
2501-3500 euros	140 (17.5)	84 (18.8)	69 (20.5)	71 (15.6)	
More than 3501 euros	159 (19.9)	90 (20.2)	70 (20.8)	89 (19.6)	
Employment situation, N (%)					.12
Full time job	183 (22.6)	108 (23.7)	90 (26.0)	93 (20.5)	
Part time job	206 (25.5)	112 (24.6)	84 (24.3)	122 (26.9)	
Student	187 (23.1)	118 (25.9)	85 (24.6)	78 (17.2)	
Unemployed[e]	204 (25.2)	101 (22.2)	78 (22.5)	126 (27.8)	
Entrepreneur or other	29 (3.6)	16 (3.5)	9 (2.6)	20 (4.4)	
Household composition, N (%)					
At least 2 adults	547 (67.6)	312 (68.6)	243 (70.2)	314 (69.2)	.40
At least 1 child	263 (32.5)	141 (31.0)	109 (31.5)	154 (33.9)	.60
Type of computer, N (%)					.56
Apple-based	106 (13.1)	54 (11.9)	44 (12.7)	62 (13.7)	
Windows-based	495 (61.2)	293 (64.4)	213 (61.6)	291 (64.1)	
Other or unknown	93 (11.5)	42 (9.2)	33 (9.5)	51 (11.2)	
Two or more computers/laptops	115 (14.2)	66 (14.5)	56 (16.2)	59 (13.0)	
Computer age in years, N (%)					<.001
Less than 3 years	411 (50.8)	245 (53.8)	183 (52.9)	228 (50.2)	
Between 3 and 6 years	310 (38.3)	175 (38.5)	140 (40.5)	170 (37.4)	
Older than 6 years	70 (8.7)	30 (6.6)	20 (5.8)	50 (11.0)	
Unknown	18 (2.2)	5 (1.1)	3 (0.9)	15 (3.3)	

[a] 14 missing values
[b] Participants with a BMI higher than 25.0 were considered overweight or obese
[c] Low educational level included participants with primary education, medium educational level included participants with lower or higher secondary education and high educational level included participants with tertiary education.
[d] 9 missing values
[e] Includes those who are retired, unemployed, unable to work and/or receiving social benefits and housewives/husbands

Participant characteristics by recruitment strategy can be found in Table 4. The participant characteristics age, overweight status, employment situation and the percentage of households with at least two adults differed statistically significantly by recruitment strategy. For example, the average age of participants recruited via social media was lower, and a larger proportion of overweight or obese participants were recruited via flyers distributed to home addresses.

Table 4. Characteristics of the study population for the entire sample and stratified by recruitment strategy[a]

Characteristics	**Total sample (N = 455)**	**Social media (N=235)**	**Flyers to home addresses (N=131)**	**Flyers from study team (N=38)**	**Word-of-mouth (N=46)**	***P*-value**
Median age in years (IQR)	31.0 (25.0)	25.0 (18.0)	46.0 (26.0)	39.0 (25.0)	27.0 (25.0)	.02
Sex, N (%) female	284 (62.4%)	131 (55.7%)	92 (70.2%)	26 (68.4%)	32 (69.6%)	.03
Mean BMI (SD)[b]	24.9 (4.8)	24.7 (4.9)	25.4 (4.4)	24.7 (5.4)	24.3 (5.4)	.63
Overweight status: overweight or obese status, n (%)[b,c]	176 (39.5%)	87 (38.5%)	65 (50.0%)	10 (27.0%)	11 (24.4%)	.01
Educational level[d], n (%)						.22
Low educational level	43 (9.5%)	19 (8.1%)	19 (14.5%)	1 (2.6%)	3 (6.5%)	
Medium educational level	212 (46.6%)	111 (47.2%)	63 (48.1%)	16 (42.1%)	22 (47.8%)	
High educational level	200 (44.0%)	105 (44.7%)	49 (37.4%)	21 (55.3%)	21 (45.7%)	
Monthly household net income[e], n (%)						.34
% 0-1700 euros	172 (38.1%)	100 (42.7%)	38 (29.0%)	15 (39.5%)	17 (37.0%)	
% 1701-2500 euros	105 (23.3%)	45 (19.5%)	39 (29.8%)	11 (28.9%)	8 (17.4%)	
% 2501-3500 euros	84 (18.6%)	41 (17.7%)	26 (19.8%)	5 (13.2%)	11 (23.9%)	
% more than 3501 euros	90 (20.0%)	45 (19.5%)	28 (21.4%)	7 (18.4%)	10 (21.7%)	
Employment situation, n (%)						.02
% Full time job	108 (23.7%)	50 (21.3%)	35 (26.7%)	9 (23.7%)	13 (28.3%)	
% Part time job	112 (24.6%)	48 (20.4%)	31 (23.7%)	14 (36.8%)	18 (39.1%)	
% Student	118 (25.9%)	89 (37.9%)	9 (6.9%)	6 (15.8%)	13 (28.3%)	
% Unemployed[f]	101 (22.2%)	42 (17.9%)	50 (38.2%)	5 (13.2%)	2 (4.3%)	
% Entrepreneur or other	16 (3.5%)	6 (2.6%)	6 (4.6%)	4 (10.5%)	0 (0.0%)	
Household composition, n (%)						
% At least 2 adults	312 (68.6%)	152 (64.7%)	97 (74.0%)	22 (57.9%)	38 (82.6%)	.01
% At least 1 child	141 (31.0%)	74 (31.5%)	43 (32.8%)	12 (31.6%)	12 (26.1%)	.93

[a] Unknown recruitment strategy was not included in the analyses
[b] 9 missing values
[c] Participants with a BMI higher than 25.0 were considered overweight or obese
[d] Low educational level included participants with primary education, medium educational level included participants with lower or higher secondary education and high educational level included participants with tertiary education.
[e] 4 missing values
[f] Includes those who are retired, unemployed, unable to work and/or receiving social benefits and housewives/husbands

6.5 Discussion

This study found that the recruitment strategy word-of-mouth involved zero costs, required no time effort on the part of the researchers and yielded the highest study-completion rate. Of all paid recruitment strategies, the least expensive strategy was social media campaigns. Social media campaigns also yielded the highest absolute registration and completion rates. Socio-demographic characteristics such as age, sex and overweight status varied with the recruitment strategy.

Effective recruitment approaches are those that lead to the creation of a representative and large enough sample of study participants (21). The combination of different recruitment strategies resulted in the recruitment of a relatively diverse study population in the space of 3 months. Social media campaigns were the most cost-efficient paid recruitment strategy employed and word-of-mouth was free, required no time effort on the part of researchers, and yielded in the highest retention rates. These results are comparable to previous studies carried out among the general population that report on the effectiveness and costs of recruitment via social media campaigns and other more traditional recruitment strategies (11, 15, 22). For example, a study by Frandsen et al. (15) found that social media drew more interest and was more cost effective than traditional methods such as flyering at baseline. Also, a systematic review investigating the effectiveness of Facebook as a recruitment strategy found reduced costs, shorter recruitment periods, better representation and improved participant selection compared to traditional recruitment methods (22). Surprisingly, a comparable study investigating the effectiveness of online methods to recruit participants for a virtual supermarket study found Facebook advertisements to be less successful as a recruitment strategy than was anticipated (6). The use of a guaranteed incentive in this study and other studies that have successfully used Facebook to recruit participants (e.g. (13)) may provide an explanation for the difference in findings between this study and the aforementioned study. A guaranteed incentive is likely to attract more people than no incentive or a prize lottery, for example. Future studies investigating the efficacy of social media campaigns for the recruitment of participants could investigate the role of incentives alongside this strategy.

Participants recruited via social media were less likely to complete the study compared to those recruited by flyers and word-of-mouth. In this study, word-of-mouth was found to be surprisingly effective; 10.1% of the study population was recruited via word-of-mouth without the researchers actively encouraging participants to recruit peers. A disadvantage associated with recruitment via word-of-mouth, or via the exclusive use of a single recruitment strategy in general, is that it may yield a demographically skewed study population (15). Contrary to the previous research finding that only age varied by recruitment strategy (11), we found that other demographic variables such as household composition, overweight status, sex, age and employment situation all varied by recruitment strategy. Overall, our results suggest that it is important to use several different recruitment strategies if the aim is to include a diverse population (e.g. younger and older adults with low and high SEP) in a study. Similarly, a systematic review investigating strategies for the successful recruitment of young adults to healthy lifestyle programs found that single recruitment strategies are less effective than mixed strategies, as fewer participants were recruited and higher attrition rates were reported when using a single recruitment strategy exclusively (14). Nevertheless, despite using several recruitment strategies and targeting the social media campaigns to people with specific characteristics (e.g. SEP, age and sex), the recruitment strategies did not result in a sample that perfectly represented the target population. Instead, the study included a slightly younger population with more females and individuals with a high educational level. Differences in socio-demographic characteristics between this study sample and the average Dutch population may have been caused by the inclusion criteria of the study such as being the primary shopper for the household (leading to inclusion of more female participants) and the type of recruitment strategy used (e.g. younger people may be more likely to be recruited via Facebook).

The current study results also suggest that recruitment strategies directly involving people (i.e. active recruitment strategies using word-of-mouth or flyers distributed by the study team) lead to higher retention rates compared to recruitment strategies that do not involve personal contact (i.e. passive recruitment strategies using social media campaigns and flyers distributed to homes). By contrast, the reach of social media campaigns and flyers sent to homes was much larger compared to the other recruitment strategies used. Moreover, social media campaigns can be used to target certain groups that are underrepresented in the study sample (22). As such, neither active or passive recruitment strategies are necessarily superior to the other (14). Rather, it appears to be important to use a combination of *both* strategies, as active recruitment methods enhance recruitment and retention rates, but also require the most resources. However, despite the higher attrition rates associated with recruitment by means of passive strategies, these strategies do
seem to have a wider reach and require only limited resources (especially when using social media) as compared to active recruitment strategies.

A strength of this study is the use of different recruitment strategies (e.g. Facebook and flyers), which led to the creation of a diverse study population in a relatively short period of time. Also, a relatively high completion rate of 76.0% was found; this is particularly interesting in light of the fact that participants were asked to conduct five rounds of shopping over the course of 5 consecutive weeks. A limitation of this study is the limited generalizability of the results. While this study successfully recruited a relatively representative sample using traditional and novel recruitment strategies within the specified timeframe, the same might not apply to different studies in different settings. For example, we do not know whether our recruitment efforts were successful because of the methods used, because of the type of study (virtual supermarket study) that participants signed up for or because of the guaranteed incentive of €25. Another limitation of this study is that the study population was self-selecting, which could have led to the creation of a non-representative study population (e.g. due to the inclusion of more highly motivated adults). This type of bias may be inherent to this type of research in a community-based setting in which participants, by definition, need to sign up for a study themselves rather than be recruited by a physician, for example. This self-selection bias could for example be quantified by comparing the socio-demographic characteristics of the study sample with the socio-demographic characteristics of adults who received the study flyers.

6.5.1 Conclusion

Regarding paid recruitment strategies, social media campaigns, particularly via Facebook, were more cost-effective than other more traditional methods. The unpaid recruitment strategy 'word-of-mouth' yielded the highest study-completion rate and required the least amount of time and effort on the part of the researchers. Employing only 1 recruitment strategy may lead to the creation of a demographically skewed sample.

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SUPPLEMENTARY MATERIAL CHAPTER 6

Recruitment of participants for a virtual supermarket study: An observational study

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Supplementary File 1

The virtual supermarket program

The Supreme Nudge VirtuMart (SN VirtuMart) described in this study was developed by a member of the study group (NvdL). The SN VirtuMart was adapted from an existing virtual supermarket (1). NvdL changed the layout of the virtual supermarket to replicate an average Dutch Coop supermarket (i.e. a supermarket chain in the Netherlands, partnering in the larger Supreme Nudge project). The virtual version was designed such that it reflects a medium-sized supermarket where people can conduct their weekly shopping. The gaming development platform UNITY was used to construct the 3D computer-based virtual supermarket (1). 3D models of food and beverages were created in Blender and were designed to replicate real products (e.g. branding, size, shape, color, and style of packaging). The nutrition information of products was not displayed within the SN VirtuMart: the front of the product was also used for the back of the product. In order to simulate real-life supermarket shopping experiences, common marketing, branding and promotion techniques as well as sounds and background noise were used. The SN VirtuMart could be downloaded using a zip file and unpacking this to install and open the SN VirtuMart program on either Windows or Apple computers.

Functionalities and user controls

Functionalities included the ability to move forward, turn left and right, look around, bend, view a product and the price up close, view the physical shopping basket and view a list of products within the shopping basket. Participants could use their arrow keys to turn left and right, go forward and to bend. Additionally, the mouse could be used to change the camera's orientation (to look around). Participants could view the functionalities at all times by pressing escape. Participants could directly select products by left-clicking on the product and put them in their basket or they could right-click on the product to view a close-up of a product and then select the product to go into the basket. Participants were able to leave the virtual supermarket environment by walking to the cash register or pressing escape and choosing the option to leave the supermarket.

Nudges within the SN VirtuMart

We implemented salience nudges to stimulate the purchases of healthier products and the substitution of unhealthier products for healthier ones. The salience nudges included bright orange frames around healthy low fat dairy products, a frame around the door of the frozen fruits and vegetables and orange arrows pointing from unhealthy to healthier high fiber variants.

Prices and budget within the SN VirtuMart

Food prices, food labels and food placing could be adapted in Unity via Excel or a text editor with the aim to create different research conditions. Participants' shopping budgets were based on self-reported real-life shopping budgets and implemented in the SN VirtuMart. Participants needed to spend at least 50% of their allocated budget in order to prevent participants from purchasing just a few items and quit the experiment. Participants could also overspend to a maximum of 125% to allow for overspending in the taxing arms (2). Login codes were used to assign participants to certain conditions and budgets. Each week, during five consecutive weeks, participants received a new log in code. The log in codes were connected to a specific virtual shopping budget and a specific condition (e.g. control, nudging or pricing condition) within the virtual supermarket.

Data collected in the SN VirtuMart

The virtual supermarket application stored information on time spent in the supermarket, participants' walking routes through the supermarket, what products were looked at up-close, what products were placed into the shopping basket, what products were ultimately purchased and the total amount of money spent during a shop. Data was stored on both the participants' computer as well as on the university server. Data was stored and sent to the server after participants clicked on the 'leave supermarket' button.

Selection of food and beverage products

The SN VirtuMart included 1179 unique name-brand and budget-brand products categorized into 12 large food groups. Nonfood items and alcoholic beverages were excluded from the virtual supermarket. The SN VirtuMart did not include all food products that are normally present in a supermarket because it is not feasible to model all these products. Within each food category we selected top-selling products from an average Coop supermarket to be included in the stock of the virtual supermarket. The quantity and variety of products was such that participants with a variety of household sizes and budgets were able to do their weekly shopping in the virtual supermarket. Usual prices (i.e. excluding offers) for the selected products were collected from the Coop supermarket website in the summer of 2018.

Study design

This study included a multi-period mixed study design consisting of three experimental arms (between-subjects design) and five experimental conditions (within-subjects design). The five experimental shopping conditions were: control, nudging, pricing, price salience and price salience with nudging. The order in which the participants received the conditions was randomized. The three study arms were exposure to subsidies, taxes and subsidies and taxes. Each week, during five consecutive weeks, participants received a new log in code which they could use to log into the virtual supermarket. The log in codes were connected to a specific virtual shopping budget and a specific condition (e.g. control, nudging or pricing condition) within the virtual supermarket. The shopping budget was based on participant's actual shopping budget. Participants needed to spend at least 50% of their allocated budget in order to prevent participants from purchasing just a few items and quit the experiment. Participants could also overspend to a maximum of 125% to allow for overspending in the taxing arms (2).

Sample size

A sample size calculation for a linear mixed model with three between-subjects factors and four within-subject factors (the control and nudging conditions should be equal across the three arms and therefore count as one within-subject factor) using delta values of vegetable purchases as an effect size was conducted. Assuming that purchases translate to intake, the baseline vegetable intake was set at 900 grams per week with a standard deviation of 370 for all conditions based on previous literature (3). Furthermore, we hypothesized that the target differences would be largest in the taxing and subsidy arm, that the differences for nudging would be smallest, that the price salience condition would have a larger difference than pricing alone and that the combination between price salience and nudging would lead to the largest difference with the control condition in increasing vegetable purchases. Based on these assumptions and previous research (4, 5), we filled in the values found in Table 1. A sample size of 50 participants per arm, leading to 150 participants in total was needed with 90% power and an alpha of 0.05. Because we also aimed to stratify for low and high SEP, the aim was to include 300 participants.

Table 1. The hypothesized purchase and consumption of vegetables in grams per week according to study condition and arm as input for the sample size calculation

Condition	Price increases Mean (SD)	Price decreases Mean (SD)	Price increases and decreases Mean (SD)
Control	900 (370)	900 (370)	900 (370)
Nudges	1035 (370)	1035 (370)	1035 (370)
Pricing	1130 (370)	1100 (370)	1160 (370)
Price salience	1160 (370)	1130 (370)	1190 (370)
Price salience and nudges	1240 (370)	1200 (370)	1280 (370)

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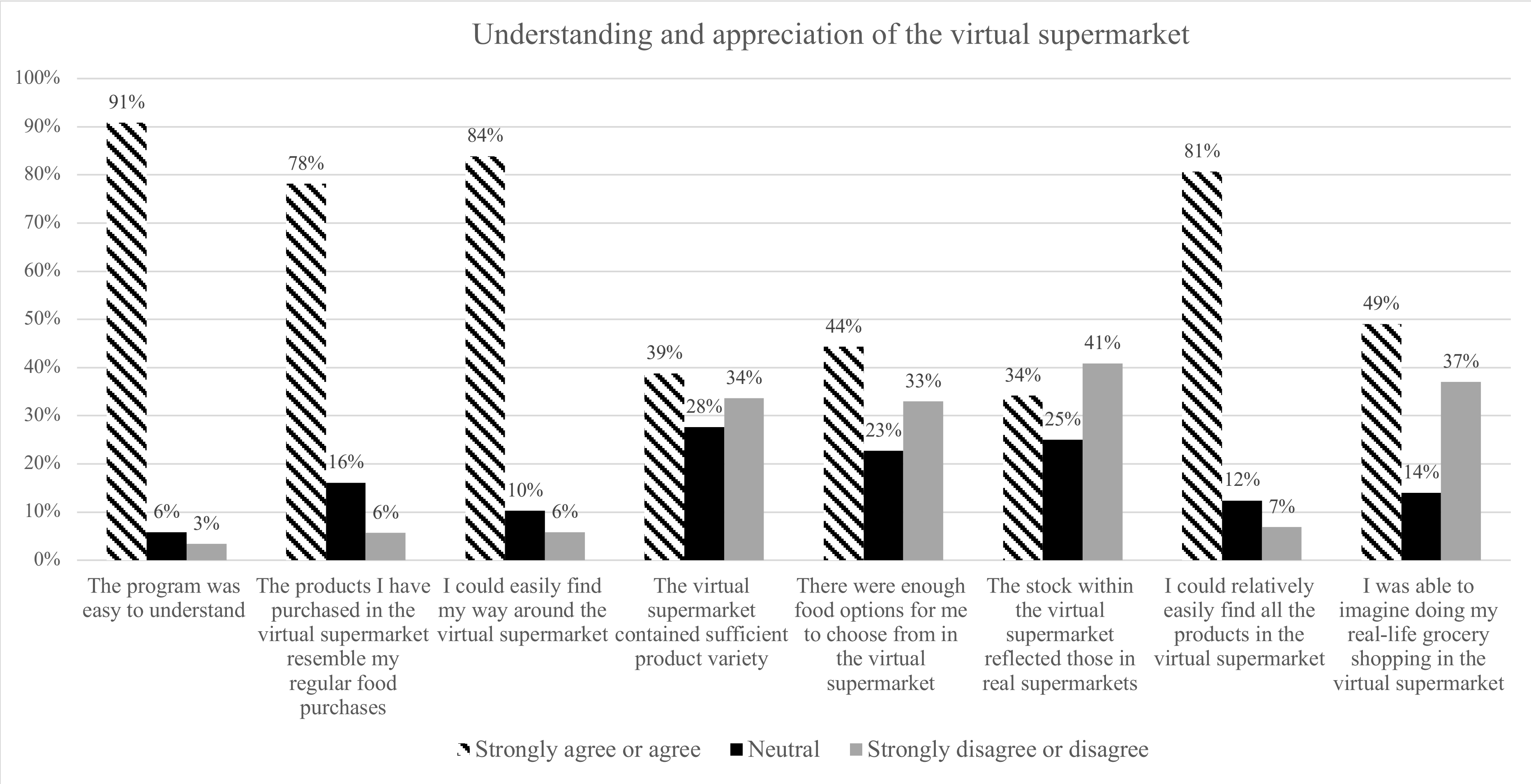

Supplementary Figure 1. Usability and appreciation of the virtual supermarket for participants who completed all five shops (n=346

CHAPTER 7

The effects of nudging and pricing on healthy food purchasing behaviour in a virtual supermarket setting: a randomized experiment

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The effects of nudging and pricing on healthy food purchasing behaviour in a virtual supermarket setting: a randomized experiment

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7.1 Abstract

Background: Evidence on what strategies - or combination of strategies - are most effective and equitable in promoting healthier diets is needed. This study examined the efficacy of nudging and pricing strategies on increasing healthy food purchases and the potential differential effect by socio-economic position (SEP) among Dutch adults in a virtual supermarket.

Methods: A randomized study design was conducted within a virtual supermarket (SN VirtuMart). Participants were exposed to five within-subject study conditions (control, nudging, pricing, price salience and price salience with nudging) and randomized to one of three between-subject study arms (a 25% price increase on unhealthy products, a 25% discount on healthy products, or a 25% price increase and discount). In total, 455 participants of low and high SEP (using either education or income as proxy) were randomized to conduct their weekly shopping in a virtual supermarket for five consecutive weeks. The primary outcome included the percentage of healthy purchases. Data were analysed using linear mixed models.

Results: In total, 346 (76%) adults completed all five shops within the SN VirtuMart. Median age was 32.5, 49.2% had high education and 32.8% had high income. Out of the 12 conditions, four conditions were statistically significantly different from the control condition. Nudging and non-salient pricing strategies alone did not statistically significantly increase healthy food purchases, whereas a combination of salient price increases and discounts led to an increase in the percentage of healthy food purchases (B 4.5, 95%CI 2.6; 6.4). Combining salient pricing and nudging strategies led to increases in the percentage of healthy products in all three pricing arms, with largest effects found in the combined price increase and discount arm (B = 4.0, 95%CI = 2.0; 6.0). Effects were not modified by SEP.

Conclusions: Combining health-related price increases and discounts and combining these salient pricing strategies with nudges in a supermarket setting seems to stimulate healthy food purchases for both low and high SEP populations. However, further research in real-world settings is needed.

7.2 Introduction

Population diets have shifted towards a greater consumption of unhealthy foods (1, 2), leading to an increase in the prevalence of diet-related chronic diseases such as type 2 diabetes (3). Interventions in food purchasing settings (e.g. supermarkets) are promising for the prevention of these diet-related chronic diseases. In particular, food taxes and subsidies aimed at improving dietary intake are becoming increasingly popular and the evidence base for the effectiveness of these strategies is rapidly growing (4-6). A systematic review investigating the prospective impact of pricing strategies on dietary consumption generally found that these are effective in increasing healthy food intake and decreasing unhealthy food intake (7). Combining pricing strategies with communication about the price changes (i.e. salience) may further enhance their effectiveness (8). Furthermore, even though evidence indicates that discounts on healthy foods significantly increase the purchases of the targeted foods (5), theory (8) and evidence (9) suggests that consumers respond more strongly to price increases, as they are experienced by consumers as losses, than to price discounts, which are perceived as gains.

Alternatively, nudges are often seen as a less invasive way of steering consumers towards healthier behaviours. A nudge can be defined as any aspect of the choice architecture that alter people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives (10). The use of nudges to promote healthier diets has been shown to be acceptable to the public (11), feasible in a range of settings (12) and, depending on context and type of nudge, moderately effective (13). Salience nudges (i.e. drawing an individual's attention towards a particular option) targeted at healthy products may be especially promising for supermarket environments, as they target the same type of decision making as traditional marketing strategies. However, to what extent salience nudges are effective in promoting healthier purchases in supermarkets is yet to be determined.

Due to budgetary constraints, individuals with low SEP may react more strongly to (salient) price changes compared to individuals with high SEP (9). There are mixed findings regarding the differential effects of economic interventions on food purchases by SEP, with one study finding more healthy purchases in women with a medium compared to low SEP (14) and other studies finding no difference in healthy purchases by SEP (15, 16). Given the mixed results found for pricing strategies, more research is needed regarding the differential effects of SEP in the association between pricing strategies and food purchasing behaviour. No studies to date have investigated the differential effects of salient nudging strategies across levels of SEP in a food retail setting. Identifying which nudging and/or pricing strategies are effective and equitable is important for wider implementation of such strategies.

While the independent effects of non-salient pricing and nudging strategies have been evaluated in previous studies (5, 13), combining both strategies could lead to larger health gains. There is a need for experimental studies in a supermarket environment that look into (1) the combined effects of nudges and pricing strategies, (2) the differential effects of health-related price increases and discounts, (3) the added value of salient price increases and discounts compared to non-salient price changes, and (4) whether effects differ between low and high SEP populations. Therefore, this study aims to examine the efficacy of nudging and several pricing strategies on increasing healthy food purchasing behaviour (by increasing healthy food purchases and decreasing unhealthy food purchases) and effect modification by SEP among Dutch adults in a virtual supermarket setting. We hypothesize that combining all nudging and pricing strategies will be most effective and that nudging strategies alone will be least effective in increasing healthy food purchases. Furthermore, we expect participants with a lower SEP to react more strongly to the pricing strategies compared to participants with a higher SEP. A virtual supermarket was used to answer these research questions because this offers a practical and affordable means to test the efficacy of nudging and pricing strategies before these are implemented in real-world settings (17). Virtual supermarkets are a valid tool to investigate the effect of pricing strategies on food purchases (18) and the purchases conducted within virtual supermarkets resemble those made in real life (19, 20).

7.3 Methods

We used a three-dimensional (3D) web-based virtual supermarket (the SN VirtuMart) to test the efficacy of nudging, pricing and combined nudging and pricing strategies. This experimental study was part of the 'Sustainable Prevention of Cardiometabolic Risk through Nudging Health Behaviours' (Supreme Nudge) project (21). This randomized trial (NTR7293) was registered in the Dutch trial registry.

The virtual supermarket was designed to simulate a real-life shopping experience by imitating a typical Dutch supermarket (i.e. layout of the shelves, colours, products and product prices). The virtual supermarket included almost 1200 unique name-brand and budget-brand products categorized into 12 food groups. The quantity and variety of products was such that participants with a variety of household sizes and budgets were able to do their weekly shopping in the virtual supermarket. For example, the proportion of healthy products within the SN VirtuMart was comparable to the proportion found in real-life supermarkets. In the SN VirtuMart, 19% (221 out of 1175) of products were considered to be healthy (as based on the Dutch dietary guidelines (22)) compared to 16% of products in Dutch supermarkets that are healthy in terms of being fresh, unprocessed or lightly processed foods (23). Common marketing, branding and promotion techniques as well as sounds and background noise were used in all shopping conditions to simulate real-life supermarket shopping experiences. The virtual supermarket software was pilot-tested prior to the study, but no formal usability test was conducted. The virtual supermarket was designed by co-author L.N. van der Laan(24). The study design and procedures were approved by the Medical Ethics Review Committee of VU University Medical Centre (OHRP: IRB00002911). More information regarding the SN VirtuMart program and selection of foods and beverages can be found in the Supplementary File 1.

7.3.1 Study design

This study used a mixed randomized experimental study design consisting of five study conditions (within-subject design) and three study arms (between-subject design). Participants were randomized into one of the three study arms (25% price increases, 25% price discounts, or 25% price increases and discounts) and within these arms exposed to five study conditions (control, nudging, pricing, price salience and price salience with nudging). A 25% price change was chosen based on the finding that at least a 20% price change is needed to result in significant effects on population health (25) and based on discussions with a Dutch supermarket chain regarding what price changes would be feasible in real-world supermarkets (26). The order in which the participants received the five study conditions was also randomized. Table 1 displays the study design.

The control condition represented regular supermarket price promotions and product placement. The nudge condition included salience nudges to promote high-fiber products, frozen vegetables and low-fat dairy products. Salience nudges are nudges that draw individual's attention towards a particular option through for example the use of arrows or frames (Supplementary File 1). The price condition represented discounts in the prices of healthy products and/or increases in the prices of unhealthy products, depending on study arm. In the price salience condition, price increases and discounts were implemented and communicated to participants. Price increases were communicated to participants by showing a newspaper announcement of an unhealthy food tax of 25% on their screen, before they entered the supermarket. Price discounts were communicated with price promotion signs within the virtual supermarket. The last shopping condition was a combination of the nudge and price salience condition.

Table 1. Study design

Condition[1]	Arm 1 – Price increases	Arm 2 – Price discounts	Arm 3 – Price increases and discounts
Control condition	Control	Control	Control
Nudging condition	Nudging	Nudging	Nudging
Pricing condition	Price increases	Price discounts	Price increases and discounts
Price salience condition	Salient price increases	Salient price discounts	Salient price increases and discounts
Price salience with nudge condition	Nudging + salient price increases	Nudging + salient price discounts	Nudging + salient price increases and discounts

[1]The order in which participants received the conditions was randomized

Participants randomized to the price increases arm were exposed to 25% price increases on 37% of the available unhealthy products (n = 356/955) (i.e. pizza, white bread, confectionary, sugary drinks, high-fat and/or high-sugar dairy products, salted nuts and sweet bread spreads). Participants randomized to the price discounts arm were exposed to 25% discounts on 89% of healthy products (n = 195/220) available within the virtual supermarket (i.e. all fresh and frozen fruits and vegetables, canned vegetables, high-fibre bread and bread alternatives, whole-wheat pasta and rice, low-fat and low-sugar dairy products, fish, unsalted nuts, water and tea). Participants randomized to the price increases and discounts arm were exposed to both the price increases and decreases. Products were considered to be healthy based on the Dutch dietary guidelines (22) and unhealthy products were all products not recommended by these guidelines.

7.3.2 Randomization and masking

Two online block randomizer generators were used to allocate participants equally to the arms and to determine the order of the conditions. Participants were masked to the nature of the conditions they were assigned to and were not aware that the study aimed to evaluate the effect of nudging and pricing strategies. Instead, they were told the study was about shopping behaviours in general. The online registration, randomization procedure and analysis of the data were all conducted by the research team.

7.3.3 Participants and recruitment

Details on the recruitment of participants are described elsewhere (17). Briefly, the aim was to include an approximately equal distribution of individuals with a low and high SEP. Participants were recruited from the general Dutch population through targeted Facebook advertisements and home-delivered flyers in selected low-SEP neighbourhoods throughout the Netherlands. The advertisements and flyers directed participants to the registration website. Upon signing online informed consent, participants received a questionnaire assessing eligibility criteria and socio-demographic characteristics. Inclusion criteria were: being an adult (18 years or older); being the main household shopper; being able to read in Dutch; and to have an email address. Participants were excluded if another household member was already participating in the study, or if they did not have a computer or laptop. Participants who met the inclusion criteria and completed a training task of ‘buying’ five specific products were included in the study.

7.3.4 Sample size

The sample size calculation was based on previous literature (12, 27). We determined that a sample of 150 participants (i.e. 50 participants in each pricing arm) completing all five conditions would be adequate to detect, among others, a target difference of 135 (SD: 370) grams of vegetables per week between the control condition and nudging condition (level of significance 0.05, power > 0.90). Larger differences were expected for the pricing conditions compared to the nudging condition. Also, we expected the salient pricing strategies to be larger than the non-salient pricing strategies and that the combination of price increases and discounts would be larger than the single pricing strategies. Lastly, the largest difference was expected when combining all strategies (i.e. nudges and pricing strategies and price increases and discounts). The same standard deviation of 370 was used for all conditions. In order to be able to have enough power to stratify the results by low and high SEP, we aimed to include double the sample, leading to a total sample of 300 participants who completed all five shops. We aimed to oversample participants and monitor their drop-out so that we would end up with 300 participants. More information regarding the sample size calculation has been reported elsewhere (17).

7.3.5 Purchasing task

Participants were asked to perform five shops in the virtual supermarket over five consecutive weeks. During each virtual supermarket visit, participants were asked to do their regular weekly household groceries, using a virtual budget. Participants’ shopping budgets (eight categories) were based on self-reported actual grocery shopping budgets and they were only able to leave the supermarket at the check-out if they had spent between 50% and 125% of their budget (17).

7.3.6 Outcome measures

The primary outcome was the percentage of healthy products based on the healthy and unhealthy purchases in grams per week. This outcome measure was chosen as pricing and nudging strategies aim to increase the proportion of healthy purchases through increasing healthy purchases and/or decreasing unhealthy purchases. The total grams of healthy and unhealthy products purchased per week were used as secondary outcome measures. These secondary outcome measures can help explain whether the percentage of healthy purchases changed due to; 1) a change in healthy purchases (which is expected in the cases of price discounts and nudges), 2) a change in unhealthy purchases (which is expected in the case of price increases), 3) or a change in both healthy and unhealthy purchases (which is expected when combining price increases and discounts). In the original trial registry, the primary outcomes included the percentage of healthy purchases as well as the purchases of healthy and unhealthy foods. However, given that price increases mostly affect the purchases of unhealthy foods and price discounts the purchases of healthy foods, it would not be very informative to calculate the purchases of healthy and unhealthy foods for the overall sample. These were therefore classified as secondary outcome measures.

To investigate if participants spent more money in the virtual supermarket, especially when exposed to price increases, we also investigated the total amount spent in the virtual supermarket per week in Euros (tertiary outcome). Sensitivity analyses were conducted with the number of healthy and unhealthy products purchased per week and the percentage healthy products based on the number of healthy and unhealthy products purchased.

7.3.7 Covariates

The baseline questionnaire asked participants for their age, sex, educational attainment, household net monthly income, usual weekly budget spent on groceries, weight and height. Self-reported height and weight were used to calculate body mass index (BMI - kg/m^2). BMI was dichotomized according at overweight status (BMI ≥ 25 kg/m^2).

Educational level and income were used as two separate proxies for SEP because they assess different aspects of SEP. Educational level was categorized into two groups: low educational level included those who completed primary education, intermediate vocational education and higher secondary education, and high educational level included those who completed higher vocational education or university. In order to adjust household income for household size, we used the OECD-modified equivalence scale (28). After this adjustment, low income was defined as a value equal to or below the median individual income of €1743 per month and high income was defined as all values above this median individual income. The average monthly gross income in the Netherlands in 2017 was €2667 (29).

7.3.8 Statistical analyses

Descriptive statistics for socio-demographic variables and the outcome variables were reported using percentages, means and standard deviations or medians and interquartile distances in case of non-normality. Mean changes from the control condition were analysed using a maximum likelihood-based repeated measures approach including a random intercept for participants to account for the clustering of shops within participants. An exchangeable covariance structure was used to model the within-participant errors. The research aim regarding the independent and combined effect of nudging and several pricing strategies was assessed using a linear mixed model with the percentage of healthy purchases as the only outcome (aim 1). Only for the single nudging condition, a linear mixed model was used to investigate the effect of nudges on the secondary outcome measures (i.e. healthy and unhealthy purchases) without stratifying for the pricing arms. The differential effects of price increases and discounts (aim 2) was assessed by stratifying the linear mixed model by the three pricing arms for both the primary (percentage of healthy purchases) and secondary outcome measures (amount of healthy and unhealthy purchases in grams). In order to investigate the third aim regarding the added value of salient price increases, the reference group included the pricing only condition instead of the control condition. To investigate effect modification by SEP (aim 4), the analyses were stratified for SEP indicators (i.e. educational level and income separately). For the within-subject analyses, participants that completed at least two shops contributed to the analyses. Whether there were statistical differences between SEP strata was examined by comparing the model without interactions with the model with interactions between conditions and SEP using the likelihood ratio test, separately for the three pricing arms. Additionally, the total amount spent in the virtual supermarket for each experimental condition compared to the control condition was analysed and can be found in the Supplementary File 1. Furthermore, sex differences were investigated because males and females may react differently to price changes due to differences in competing factors such as perceived quality, price, taste and habit (Supplementary Material) (30). Lastly, in order to determine whether a possible order or learning effect occurred due to the study design, we investigated the effect of the intervention period (ranging from week 1 to week 5) on the percentage of healthy purchases (Supplementary Material). Also, we compared the unadjusted beta coefficients to the period adjusted beta coefficients of the effect of the experimental conditions on the percentage of healthy purchases (Supplementary Material).

Analyses were conducted in STATA version 14.1 and the absence of zero in the 95% confidence interval or a p-value of 0.05 or smaller was regarded as a statistically significant effect. We did not adjust for multiple testing given the fact that we used a single primary outcome, and the findings from the secondary outcomes were used to explain the primary outcome findings.

7.4 Results

In the winter of 2018/2019, 455 participants were randomized to one of three arms, 400 (88%) participants conducted at least one shop, 346 (76%) participants completed all five shops and 318 (70%) participants had usable data for all five shops (e.g. data where log in codes with the wrong budget assigned were excluded) (Figure 1). The median age of participants was 30.0 (IQD 24.0) and more than 60% were female, which varied from 59% to 65% depending on the study arm (Table 2). Mean BMI of participants at baseline was 24.7 (SD 4.8), and this was fairly equal across the three arms. A little over 49% of participants had a high educational level and almost 33% had a high income. In the control condition, approximately 46% of participants' purchases consisted of healthy foods, and participants on average spent 100.2 Euros (SD 44.4) per week on their groceries (Supplementary Table 1).

Figure 1. Flow chart of the selection of participants process

Table 2. Socio-demographic characteristics of the study population

Sociodemographic characteristics	**25% price increase arm (N= 128)**	**25% price discount arm (N= 136)**	**25% price increase and discount arm (N= 136)**	**Total sample (N = 400)**
Median age in years (IQR)	32.5 (25.0)	39.5 (24.5)	30.0 (23.0)	30.0 (24.0)
Sex (% female)	59.4%	58.8%	65.4%	61.2%
Mean BMI (SD)[1]	24.6 (4.8)	24.6 (4.9)	25.1 (4.7)	24.7 (4.8)
Overweight status (% overweight or obese)[1]	34.9%	35.8%	41.2%	37.3%
Educational level (% highly educated)	49.2%	42.7%	44.1%	45.3%
Income (% high income)[2,3]	40.9%	26.1%	31.9%	32.8%
Employment situation				
% Full time job	29.7%	22.8%	22.8%	25.0%
% Part time job	25.8%	25.0%	25.7%	25.6%
% Student	20.3%	26.5%	29.4%	25.5%
% Unemployed[4]	22.7%	22.8%	17.7%	21.0%
% Entrepreneur or other	2.4%	3.0%	4.4%	2.3%
Household composition				
Mean number of adults in the household	1.9 (0.8)	1.9 (1.1)	1.9 (0.8)	1.9 (0.9)
Mean number of children in the household	0.5 (0.9)	0.5 (0.9)	0.5 (1.0)	0.5 (0.9)

[1] 9 Missing values
[2] 4 missing values
[3] Calculated using the OECD-modified scale and the median cut-off value was €1743
[4] Includes those who are retired, unemployed, unable to work and/or receiving social benefits, and housewives/men
Abbreviations: IQR; Interquartile range, SD; Standard Deviation

7.4.1 The independent and combined effects of nudging and pricing strategies

In Table 3, the effects of the experimental conditions on the percentage of healthy purchases for the total sample are displayed. The nudging only (B 0.5, 95%CI -0.6; 1.6) and pricing only (B 0.4, 95%CI -0.7; 1.6) conditions did not increase the *percentage of healthy purchases* as compared to the control condition. The price salience and combined price salience and nudging conditions led to a 2.6% (95%CI 1.4; 3.7) and 3.1% (95%CI 1.9; 4.3) increase in the *percentage of healthy products*, respectively.

The effect of the nudges on the amount of healthy and unhealthy purchases (secondary outcomes) was investigated without stratifying the results by pricing arm. Nudging only did not statistically significantly increase *healthy purchases* (B -209.2, 95%CI -658.0; 239.5), but did statistically significantly decrease *unhealthy purchases* by 737.7 grams a week per household (95%CI -1306.2; -169.3).

7.4.2 Efficacy of nudging and several pricing strategies according to study arm

Table 3 also presents the effects of the experimental conditions compared to the control condition stratified by study arm (i.e. separate for the three different pricing arms) for the primary and secondary outcome measures. Regarding the outcome *percentage of healthy purchases*, neither the single price increase arm nor the single price discount arm resulted in statistically significant differences compared to the control condition. Combined salient price increases and discounts statistically significantly increased the *percentage of healthy purchases* with 4.5% (95%CI 2.6; 6.4). Within all three study arms, combining nudging and pricing strategies led to a statistically significant increase in the *percentage of healthy purchases*, with the largest increase found in the combined price increase and discount arm (B 4.0, 95%CI 2.0;6.0).

Mixed results were found for the secondary outcome measures *healthy purchases* and *unhealthy purchases*. A salient 25% price discount and both salient price increases and discounts statistically significantly increased *healthy purchases* by 1600 grams compared to the control condition and combining the salient price increases and discounts with nudging led to the highest increase of *healthy purchases* (B 1646.3, 95%CI 734.7; 2557.8). Statistically significant decreases were found for *unhealthy purchases* in the price only, price salience and combined price salience with nudging conditions, but only for the price increases arm. A combination of salient price increases and discounts also led to a statistically significant decrease in *unhealthy purchases* of 1681.3 grams (95%CI -2662.0; -700.7). No other statistically significant effects were found in either outcome measures (Table 3).

7.4.3 Added value of making price changes salient

Statistically significant differences between the pricing and price salience conditions can also be seen in Table 3. In almost all cases, if the price salience condition differed statistically significantly from the control condition, it also differed statistically significantly from the pricing condition.

Table 3. Effects of nudging and pricing strategies on the outcome measures for the total sample[1] and stratified by pricing arms

Conditions	25% increase arm (n=128)		25% discount arm (n=136)		25% increase and discount arm (n=136)		Total sample (n=400)	
	B	95%CI	B	95%CI	B	95%CI	B	95%CI
	Percentage of healthy purchases (primary outcome)							
Control	Ref.		Ref.		Ref.		Ref.	
Nudging	-0.5	-2.5; 1.5	0.2	-1.8; 2.2	1.8	-0.1; 3.7	0.5	-0.6; 1.6
Pricing	0.0	-1.9; 2.0	0.5	-1.5; 2.5	0.7	-1.2; 2.6	0.4	-0.7; 1.6
Price salience	1.4	-0.6; 3.4	1.9	-0.1; 3.9	4.5[2]	2.6; 6.4	2.6[1]	1.4; 3.7
Price salience and nudging	3.0	1.1; 5.0	2.3	0.3; 4.3	4.0	2.0; 6.0	3.1	1.9; 4.3
	Healthy purchases in grams (secondary outcome)							
Control	Ref.		Ref.		Ref.		NA	
Nudging	-416.3	-1173.7; 341.2	-286.4	-1050.4; 477.5	68.4	-741.1; 877.9	NA	NA
Pricing	-695.5	-1451.2; 60.1	44.2	-720.7; 809.0	-125.8	-949.5; 697.8	NA	NA
Price salience	-29.0	-791.2; 733.2	1038.5[2]	274.6; 1802.3	1025.7[2]	180.8; 1870.5	NA	NA
Price salience and nudging	-41.1	-804.1; 721.9	440.6	-320.3; 1201.5	1646.3	734.7; 2557.8	NA	NA
	Unhealthy purchases in grams (secondary outcome)							
Control	Ref.		Ref.		Ref.		NA	
Nudging	-534.6	-1480.6; 411.5	-756.4	-1781.4; 271.9	-907.4	-1868.4; 53.6	NA	NA
Pricing	-1194.0	-2134.6; -253.3	-534.7	-1569.2; 499.9	-608.8	-1576.6; 358.9	NA	NA
Price salience	-991.5	-1935.6; -47.3	90.0	-941.9; 1122.0	-1680.8[2]	-2657.0; -704.5	NA	NA
Price salience and nudging	-1802.7	-2742.3; -863.2	-993.0	-2028.8; 32.9	-885.5	-1917.1; 146.0	NA	NA

[1] Only applicable for the primary outcome measure percentage of healthy purchases
[2] Price salience condition statistically significantly differs from pricing condition
Bold values are statistically significant
Abbreviations: B; beta regression coefficient, CI; confidence interval, NA; Not Applicable, Ref; Reference group

7.4.4 SEP differences

Table 4 illustrates the effects of independent and combined nudges and pricing strategies for participants with a low and high SEP as measured by educational level and income for the percentage of healthy purchases. Overall, no statistically significant differences between participants with a low and high SEP for the outcome *percentage of healthy purchases* were found according to the likelihood ratio test (P>0.05). However, some small differences should be noted. A 25% price increase on unhealthy products combined with nudges only had a statistically significant effect on the *percentage of healthy purchases* in participants with a low education only. In participants with a high education, salient price discounts had a statistically significant effect on the *percentage of healthy purchases* (B 3.2%, 95%CI 0.3; 6.2). In the 25% discount arm, stronger effects were found for participants with a low income compared to a high income in the price salience and price salience with nudging conditions. For example, for low income participants in the price salience with nudges condition, the *percentage of healthy purchases* increased by 3.5% (95%CI 1.2; 5.8), while for high income participants no statistically significant increase was found (B -0.1, 95%CI -3.9; 3.7). Stratified results by SEP indicators for the secondary outcome measures can be found in Supplementary Tables 2 and 3.

Table 4. Effects of nudging and pricing strategies on the percentage of healthy purchases stratified by arm and SEP indicators

Conditions	**25% increase arm**					**25% discount arm**					**25% increase and discount arm**				
	Low educational level (n=65)		High educational level (n=63)			Low educational level (n= 78)		High educational level (n=58)			Low educational level (n= 76)		High educational level (n=60)		
	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test
Control	Ref.		Ref.		0.1	Ref.		Ref.		0.2	Ref.		Ref.		0.3
Nudging	2.0	-0.5; 4.5	-2.7	-5.8; 0.3		-1.3	-3.9; 1.4	2.0	-0.9; 5.0		0.6	-1.9; 3.1	**3.3**	**0.3; 6.2**	
Pricing	2.2	-0.3; 4.6	-2.0	-5.0; 1.1		-0.4	-3.0; 2.3	1.8	-1.2; 4.8		-0.9	-3.3; 1.6	2.7	-0.3; 5.7	
Price salience	1.8	-0.7; 4.3	1.1	-1.9; 4.2		0.9	-1.8; 3.5	**3.2**	**0.3; 6.2**		**2.8**	**0.3; 5.3**	**6.6**	**3.6; 9.6**	
Price salience and nudging	**4.4**	**1.9; 6.8**	1.8	-1.2; 4.9		2.6	-0.0; 5.3	1.9	-1.0; 4.9		**3.5**	**0.8; 6.1**	**4.8**	**1.7; 8.0**	
	Low income level (n=75)		High income level (n=52)			Low income Level (n=99)		High income level (n=35)			Low income level (n=92)		High income level (n=43)		
	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test
Control	Ref.		Ref.		1.0	Ref.		Ref.		0.2	Ref.		Ref.		0.7
Nudging	-0.5	-3.0; 2.0	-0.5	-3.8; 2.8		0.9	-1.3; 3.2	-1.5	-5.4; 2.4		1.6	-0.6;3.9	1.8	-1.6; 5.2	
Pricing	-0.5	-3.0; 2.1	0.8	-2.4; 4.0		0.7	-1.5; 3.0	0.8	-3.2; 4.7		0.9	-1.4; 3.2	-0.6	-4.1; 2.8	
Price salience	1.0	-1.5; 3.6	2.0	-1.3; 5.2		**2.9**	**0.6; 5.2**	-1.3	-5.2; 2.6		**4.0**	**1.7; 6.3**	**5.0**	**1.6; 8.5**	
Price salience and nudging	**2.8**	**0.4; 5.4**	3.1	-0.1; 6.4		**3.5**	**1.2; 5.8**	-0.1	-3.9; 3.7		**4.5**	**2.0; 7.0**	3.0	-0.6; 6.5	

Bold values are statistically significant

Abbreviations: B; beta regression coefficient, CI; confidence interval, lr-test; p-value of the likelihood-ratio test, Ref; Reference group

7.4.5 Additional analyses

The results of the sensitivity analyses with the number of healthy and unhealthy products were similar to the main results (Supplementary Table 4). The total amount of money spent in the virtual supermarket in the price increases arm did not differ for the experimental conditions compared to the control condition (Supplementary Table 5). In the discounts arm and the combined price increases and discounts arm, participants decreased the amount spent in the virtual supermarket in several pricing conditions compared to the control condition. Overall, no statistically significant differences between males and females were found (Supplementary Table 6). The intervention period did not influence the percentage of healthy purchases, and the beta regression coefficients barely changed after adjusting the model investigating the effect of the experimental conditions on the percentage healthy purchases for the intervention period (Supplementary Tables 7 and 8).

7.5 Discussion

In this study we investigated the efficacy of the independent and combined effects of nudging and pricing strategies on food purchasing behaviour in a virtual supermarket. Nudges and non-salient price strategies alone had limited effect. Also, salient price increases alone or salient price discounts alone did not increase the percentage of healthy purchases, while the combined salient price increases and discounts increased the percentage of healthy food purchases. Combining these salient price increases and/or discounts with nudges had the strongest effect on the percentage of healthy food purchases. There was limited evidence for differential effects across SEP groups.

The most important finding was that combining nudges with salient price strategies increased the proportion of healthy purchases in all three pricing arms. These results are in line with a previous study that found that price discounts and communication alone did not increase the sales of targeted products, while the combined approach statistically significantly increased the sales of promoted items (31). Combining pricing and nudging strategies may have a multiplicative effect because multiple intervention strategies target multiple levels of influence. Indeed, lessons learned from tobacco and alcohol control strategies indicate that it is necessary to address not only the affordability, but also availability and acceptability of such products (32). Therefore, combining pricing strategies (affordability) with strategies that encourage healthy foods through nudging (through availability and perhaps acceptability) may be more promising for increasing healthy food purchasing behaviour than nudging or pricing strategies alone. Additionally, people may have different reasons to change and subsequently maintain their behaviour. It is therefore important that interventions target as many pathways as possible. The relatively small effects of these independent pathways could then add up to an effect size relevant at a population level. Nudging and pricing policy measures may be seen as interfering with personal choice and the freedom to consume. However, they can also be seen as interventions enabling the freedom and right to health and a healthy environment by rebalancing and prioritizing the right to health over the right to consume (33).

Another finding in this study is that salient pricing strategies are more effective than non-salient price changes in increasing the proportion of healthy purchases. A previous experimental study among women found that salient subsidies alone and salient subsidies combined with taxes both increased healthy food purchases (34). These results suggest that the absolute price of food is not the only driver influencing food purchasing behaviour and that it may be important to communicate price changes to consumers. Salient price increases/taxes and discounts/subsidies may more accurately reflect real-life situations as well, as price changes are often communicated within mass media, governmental agent announcements and/or labels on supermarket shelves. What method of communication about price changes is most effective in reducing unhealthy purchases and increasing healthy purchases remains to be investigated. Other than communicating price changes, the results also suggest that it is important to combine price increases and discounts. Subsidies alone may lead to an increase in overall calorie consumption (35) and taxes may be more accepted by the public when the tax revenue is earmarked to subsidize healthy foods (36). Therefore, combining subsidies with taxes may be more effective than implementing just one of the two strategies. Alternatively, minimum pricing on confectionary foods may be implemented. This strategy is already applied to alcoholic beverages, where the minimum unit pricing on alcohol sets a floor price for a unit of alcohol, meaning that it cannot be sold for lower than the given floor price (37).

Non-statistically significant effects of nudging and non-salient pricing strategies have previously been reported. For example, a systematic review found that only 5 out of 11 studies using salience-type nudges were effective (38). Combining different types of nudges (e.g. salience and priming nudges) may be more effective in influencing food purchasing behaviour (38), especially in environments full of food cues such as supermarkets. Also, previous experimental studies have found mixed results regarding the effect of non-salient taxes and/or subsidies on increasing healthy beverage and food purchasing behaviour (16, 39). A possible explanation for the non-statistically significant effects of non-salient pricing strategies may be that participants did not have an accurate reference price due to shopping in a new supermarket environment. Even though the virtual supermarket was rated positively by participants (17), it may have been more difficult to read price tags on a computer screen compared to real-life.

Nudging and pricing strategies would be considerably less appropriate if people who already benefit from personal resources such as higher education or higher food budgets were the ones who responded best to the intervention, thereby increasing socio-economic inequalities in diet. In this study we found limited differences across individuals with a low and high SEP regarding the effect of nudging and/or pricing strategies on food purchases. An example of a difference between the two groups was the stronger effect of salient price discounts (with and without nudges) on healthy food purchases for participants with a low income compared to a high income, but not for participants with a low compared to high educational level. While, as far as we are aware, no comparable studies have investigated moderation by income or educational level in the association between salience nudges and food purchases, studies investigating the moderating role of SEP proxies in the association between pricing strategies and food purchasing behaviour also found no differential effects by educational level and income (15, 16). It may be possible that low and high SEP populations indeed do not respond differently to pricing strategies. However, our low SEP group was still relatively heterogeneous in education level (including participants with a low and medium education (17)). Therefore, caution is needed with generalizing these conclusions to those with the lowest SEP.

Although the nudging and pricing strategy effects may be relatively small on an individual level, they can translate into relevant changes at a population level. When combining salient price increases with discounts, healthy household purchases increased by a maximum of 1646g (in the price salience and nudging condition) and unhealthy household purchases decreased by a maximum of 1681g (in the price salience condition). This translates to approximately an 80g increase in healthy foods and an 80g decrease in unhealthy foods per person per day (i.e. by dividing the overall change in healthy/unhealthy purchases per day by the mean number of adults and children within a household). Given that the Dutch population consumes on average 268g of healthy products per day (27), an 80g increase in healthy purchases seems relevant from a public health perspective (assuming that purchases are comparable to consumption (40)).

However, further research into the single and combined effects of nudging and pricing strategies (especially price increases) in real-world settings and on long-term disease outcomes is needed. Therefore, we are currently planning on conducting an intervention within the Supreme Nudge project which aims to investigate the effect of nudging and pricing strategies on cardiometabolic disease risk in adults with a low SEP (26). The pricing strategies of this real-life study will include a price reduction of 25% on healthy foods and a price difference of 25% between unhealthy products and their healthier substitutes within the same food group (e.g. white bread and whole-grain bread) (26). Next to investigating the effect of pricing and nudging strategies in real-world settings, further research should investigate possible differential effects of nudging and pricing strategies by factors influencing purchasing habits (e.g. single-member households, age, impulsiveness and price sensitivity).

7.5.1 Strengths and limitations

The effectiveness of (salient) price increases have, as far as we are aware, not yet been studied within randomized controlled trials in real supermarket environments. One possible reason for the lack of real-life experimental studies may be the risk that the proposed pricing strategies negatively influence profits. Indeed, we found that participants spent considerably and significantly less when receiving a 25% discount. Therefore, a strong merit of this study is the use of the virtual supermarket tool that closely simulates real-life experiences, which allowed us to collect objective data, behavioural measures and control manipulations. Another strength of this study includes the between-within subject design where participants acted as their own control, resulting in a statistically powerful analysis as factors that may have caused variability between subjects were controlled for by the repeated measures design. Lastly, a relatively high completion rate of 76% was found where study completers did not significantly differ from study non-completers (17).

A limitation of the present study includes the limited generalizability of the study results. The experimental research design has a limited external validity as the results may not be directly translatable to the real world. Another limitation is that the food budget used in the study were declarative (i.e. participants did not actually purchase the items purchased in the SN VirtuMart). This may undermine the experimental results due to for example social desirability bias.

However, a study conducted by Waterlander et al. validated a virtual supermarket as a measure to collect food purchasing data in a supermarket setting by demonstrating that shopping patterns in a virtual supermarket resemble those in real life (19). Also, 78% of participants indicated that they feel that their virtual supermarket purchases simulated real life purchases (17). The limited generalizability of the results may also come from the relatively young and high SEP population included in the study, which does not reflect the average Dutch population (17). The heterogeneity of the low SEP group in our study limits the opportunity to study the effects of nudging and pricing strategies in the lowest SEP group. Therefore, the results in this study may have underestimated SEP differences. Lastly, this study attempted to investigate the effect of nudging on purchasing behaviour while only one type of nudge was implemented in the SN VirtuMart, which may have led to the limited evidence for nudges.

7.5.2 Conclusion

This study demonstrated that salient price increases and discounts combined with nudges increase healthy food purchasing behaviour, more so than each of the independent strategies. Moreover, nudging and/or pricing strategies do not seem to widen SEP inequalities. Further research is needed to investigate the single and combined effect of nudging and (salient) pricing strategies (especially taxes on unhealthy foods) in real-world settings.

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SUPPLEMENTARY MATERIAL CHAPTER 7

The effects of nudging and pricing on healthy food purchasing behaviour in a virtual supermarket setting: a randomized experiment:

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Supplementary File 1.

The virtual supermarket program

The Supreme Nudge VirtuMart (SN VirtuMart) described in this study was developed by a member of the study group (NvdL). The SN VirtuMart was adapted from an existing virtual supermarket (1). NvdL changed the layout of the virtual supermarket to replicate an average Dutch Coop supermarket (i.e. a supermarket chain in the Netherlands, partnering in the larger Supreme Nudge project). The virtual version was designed such that it reflects a medium-sized supermarket where people can conduct their weekly shopping. The gaming development platform UNITY was used to construct the 3D computer-based virtual supermarket (1). 3D models of food and beverages were created in Blender and were designed to replicate real products (e.g. branding, size, shape, color, and style of packaging). The nutrition information of products was not displayed within the SN VirtuMart: the front of the product was also used for the back of the product. In order to simulate real-life supermarket shopping experiences, common marketing, branding and promotion techniques as well as sounds and background noise were used. The SN VirtuMart could be downloaded using a zip file and unpacking this to install and open the SN VirtuMart program on either Windows or Apple computers.

Functionalities and user controls

Functionalities included the ability to move forward, turn left and right, look around, bend, view a product and the price up close, view the physical shopping basket and view a list of products within the shopping basket. Participants could use their arrow keys to turn left and right, go forward and to bend. Additionally, the mouse could be used to change the camera's orientation (to look around). Participants could view the functionalities at all times by pressing escape. Participants could directly select products by left-clicking on the product and put them in their basket or they could right-click on the product to view a close-up of a product and then select the product to go into the basket. Participants were able to leave the virtual supermarket environment by walking to the cash register or pressing escape and choosing the option to leave the supermarket.

Nudges within the SN VirtuMart

We implemented salience nudges to stimulate the purchases of healthier products and the substitution of unhealthier products for healthier ones. The salience nudges included bright orange frames around healthy low fat dairy products, a frame around the door of the frozen fruits and vegetables and orange arrows pointing from unhealthy to healthier high fiber variants (Figure 1).

Prices and budget within the SN VirtuMart

Food prices, food labels and food placing could be adapted in Unity via Excel or a text editor with the aim to create different research conditions. Participants' shopping budgets were based on self-reported real-life shopping budgets and implemented in the SN VirtuMart. Participants needed to spend at least 50% of their allocated budget in order to prevent participants from purchasing just a few items and quit the experiment. Participants could also overspend to a maximum of 125% to allow for overspending in the taxing arms (2). Login codes were used to assign participants to certain conditions and budgets. Each week, during five consecutive weeks, participants received a new log in code. The log in codes were connected to a specific virtual shopping budget and a specific condition (e.g. control, nudging or pricing condition) within the virtual supermarket.

Data collected in the SN VirtuMart

The virtual supermarket application stored information on time spent in the supermarket, participants' walking routes through the supermarket, what products were looked at up-close, what products were placed into the shopping basket, what products were ultimately purchased and the total amount of money spent during a shop. Data was stored on both the participants' computer as well as on the university server. Data was stored and sent to the server after participants clicked on the 'leave supermarket' button.

Selection of food and beverage products

The SN VirtuMart included 1179 unique name-brand and budget-brand products categorized into 12 large food groups. Nonfood items and alcoholic beverages were excluded from the virtual supermarket. The SN VirtuMart did not include all food products that are normally present in a supermarket because it is not feasible to model all these products. Within each food category we selected top-selling products from an average Coop supermarket to be included in the stock of the virtual supermarket. The quantity and variety of products was such that participants with a variety of household sizes and budgets were able to do their weekly shopping in the virtual supermarket. Usual prices (i.e. excluding offers) for the selected products were collected from the Coop supermarket website in the summer of 2018.

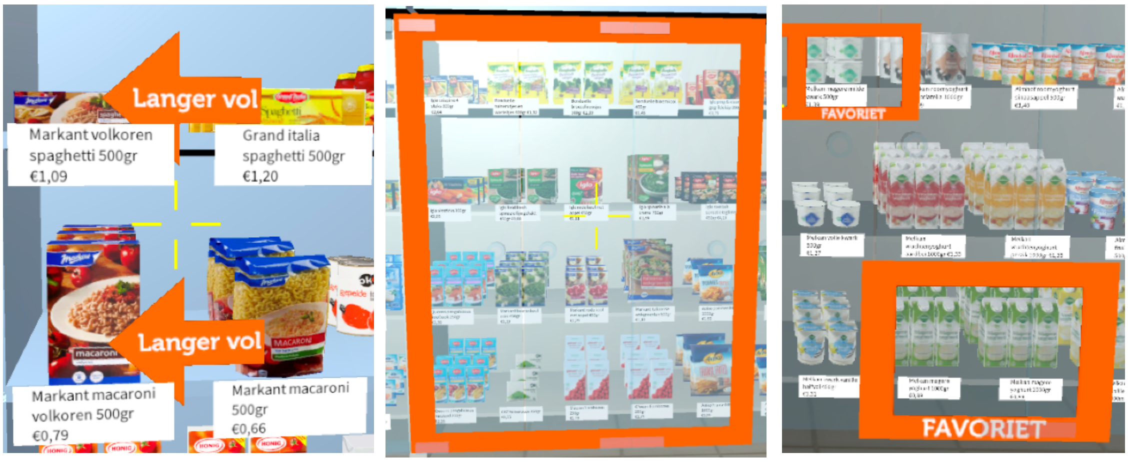

Figure 1. Three types of salience nudges used within the SN VirtuMart. Arrow pointing from a less healthy grain product to a healthy whole grain product (left), orange frame around the entire frozen fruit and vegetables door (middle) and small orange frames around low fat dairy products (right).

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Supplementary Table 1. Descriptive statistics of the outcome variables for the control condition

Outcome variables	25% increase arm (N= 119)	25% discount arm (N= 129)	25% increase and discount arm (N= 120)	Total sample (N = 368)
Mean percentage of purchased healthy products in grams	47.8%	45.4%	45.7%	46.3%
Mean purchased healthy products in grams (SD)	13591.5 (6441.1)	13165.3 (6615.7)	14559.4 (7296.7)	13757.7 (6797.8)
Mean purchased unhealthy products in grams (SD)	16014.1 (9483.6)	16795.0 (10287.9)	17839.9 (9415.1)	16883.2 (9753.1)
Mean amount spent on total purchases in euros (SD)	96.8 (42.6)	98.3 (45.3)	105.6 (45.0)	100.2 (44.4)

Abbreviations: SD; Standard Deviation

Supplementary Table 2. Effects of nudging and several pricing strategies on healthy and unhealthy purchases stratified for arm and educational level

Conditions	**25% increase arm**					**25% discount arm**					**25% increase and discount arm**				
	Low educational level (n=65)		High educational level (n=63)			Low educational level (n= 78)		High educational level (n=58)			Low educational level (n= 76)		High educational level (n=60)		
	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test
Healthy purchases in grams															
Control	Ref.		Ref.			Ref.		Ref.			Ref.		Ref.		
Nudging	338.0	-729.4; 1405.4	-1155.5	-2218.7; -92.3		-954.1	-1975.1; 66.8	557.1	-585.8; 1700.1		-818.1	-1841.2; 204.9	1208.7	-100.8; 2518.2	
Pricing	-383.7	-1444.5; 677.0	-1004.0	-2062.2; 54.2	0.1	-480.3	-1491.8; 531.2	725.8	-432.3; 1883.9	0.3	-474.8	-1499.5; 549.8	333.3	-994.3; 1660.9	0.2
Price salience	205.8	-857.7; 1269.2	-249.1	-1313.0; 814.7		444.1	-572.4; 1460.6	1792.4	649.0; 2935.9		521.1	-513.9; 1556.1	1683.4	345.9; 3020.8	
Price salience and nudging	877.2	-174.1; 1928.5	-994.5	-2059.3; 70.3		63.6	-947.1; 1074.3	914.6	-221.9; 2051.1		1362.8	264.5; 2461.0	2063.1	657.2; 3469.1	
Unhealthy purchases in grams															
Control	Ref.		Ref.			Ref.		Ref.			Ref.		Ref.		
Nudging	-1788.1	-3203.4; -372.8	632.0	-502.5; 1,928.5		-952.2	-2484.6; 580.3	-508.8	-1792.3; 774.7		-1202.9	-2630.2; 224.4	-541.9	-1752.9; 669.2	
Pricing	-2626.3	-4032.1; -1220.5	205.1	-949.7; 1,466.8	0.0	-1130.0	-2647.9; 387.9	226.5	-1074.1; 1527.1	0.3	-333.6	-1763.1; 1095.8	-966.5	-2194.8; 261.9	0.7
Price salience	-1271.7	-2681.0; 137.5	-766.2	-1,928.9; 500.2		81.9	-1443.8; 1607.6	76.3	-1207.8; 1360.5		-1572.7	-3016.6; -128.7	-1817.1	-3053.9; -580.3	
Price salience and nudging	-2441.5	-3835.8; -1047.2	-1223.9	-2,386.7; 44.8		-1815.8	-3332.6; -299.1	54.6	-1221.8; 1331.0		-1079.3	-2611.4; 452.8	-650.5	-1950.2; 649.1	

Bold values are statistically significant

Abbreviations: B; beta regression coefficient, CI; confidence interval, lr-test; p-value likelihood-ratio test

Supplementary Table 3. Effects of nudging and several pricing strategies on healthy and unhealthy purchases stratified for arm and income level

Conditions	**25% increase arm**					**25% discount arm**					**25% increase and discount arm**				
	Low income (n=75)		High income (n=52)			Low income (n=99)		High income (n=35)			Low income (n=92)		High income (n=43)		
	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test
Healthy purchases in grams															
Control	Ref.		Ref.			Ref.		Ref.			Ref.		Ref.		
Nudging	-97.2	-1118.8; 924.3	-837.7	-1983.8; 308.4		-422.9	-1341.6; 495.8	102.4	-1273.7; 1478.5		-41.7	-986.1; 902.7	140.1	-1417.7; 1697.9	
Pricing	-448.9	-1475.9; 578.1	-1019.9	-2143.1; 103.4	0.7	-368.8	-1284.7; 547.2	1281.3	-108.5; 2671.2	0.3	-101.0	-1051.0; 849.0	-301.2	-1873.4; 1271.0	0.3
Price salience	422.9	-600.7; 1446.4	-573.6	-1712.1; 564.8		1058.0	141.5; 1974.4	879.0	-494.8; 2252.8		455.6	-503.2; 1414.4	2003.9	418.9; 3588.9	
Price salience and nudging	308.6	-706.0; 1323.2	-587.1	-1724.1; 550.0		333.5	-582.2; 1249.2	784.0	-576.8; 2144.7		1374.5	342.6; 2406.5	2013.2	406.1; 3620.3	
Unhealthy purchases in grams															
Control	Ref.		Ref.			Ref.		Ref.			Ref.		Ref.		
Nudging	-189.5	-1378.0; 998.9	-1014.0	-2569.3; 541.0		-1295.0	-2559.7; -30.3	704.7	-1004.3; 2413.8		-1251.8	-2354.1; -149.5	-246.1	-2102.4; 1610.2	
Pricing	-861.4	-2055.3; 332.4	-1710.2	-3234.6; -185.9	0.5	-1220.9	-2481.3; 39.6	1194.4	-531.7; 2920.6	0.1	-756.7	-1865.7; 352.3	-189.2	-2062.8; 1684.4	0.6
Price salience	-246.5	-1436.1; 943.1	-1998.4	-3543.1; -453.7		-501.0	-1762.2; 760.2	1759.0	52.9; 3465.1		-2024.9	-3143.9; -905.9	-1000.1	-2888.9; 888.8	
Price salience and nudging	-1463.2	-2643.2; -283.2	-2217.3	-3761.3; -673.4		-1802.3	-3062.6.; -542.0	1092.7	-597.3; 2782.8		-1548.1	-2752.2; -344.0	259.8	-1656.7; 2176.3	

Bold values are statistically significant

Abbreviations: B; beta regression coefficient, CI; confidence interval, lr-test; p-value likelihood-ratio test

Supplementary Table 4. Effects of nudging and several pricing strategies on the primary outcome and secondary outcome measures for the total sample[1] and stratified for pricing arms

Conditions	25% increase arm (n=128)		25% discount arm (n=136)		25% increase and discount arm (n=136)		Total sample (n=400)	
	B	95%CI	B	95%CI	B	95%CI	B	95%CI
	Percentage of healthy purchases							
Control	Ref.		Ref.		Ref.		Ref.	
Nudging	-0.3	-2.0; 1.3	0.6	-1.2; 2.3	1.6	-0.0; 3.3	0.6	-0.4; 1.6
Pricing	0.6	-1.1; 2.2	1.0	-0.7; 2.8	1.4	-0.3; 3.1	1.0	-0.0; 2.0
Price salience	1.2	-0.4; 2.9	2.5	0.7; 4.3	5.5	3.8; 7.2	3.1	2.1; 4.1
Price salience and nudging	2.7	1.1; 4.4	2.6	0.8; 4.3	5.4	3.6; 7.2	3.5	2.5; 4.5
	Number of healthy purchases							
Control	Ref.		Ref.		Ref.		NA	
Nudging	-0.4	-1.6; 0.8	-0.1	-1.4; 1.2	0.2	-1.2; 1.6	NA	NA
Pricing	-0.5	-1.7; 0.7	0.6	-0.7; 1.9	0.2	-1.2; 1.6	NA	NA
Price salience	0.0	-1.2; 1.2	2.6	1.3; 3.9	2.6	1.2; 4.0	NA	NA
Price salience and nudging	-0.2	-1.5; 1.0	1.6	0.3; 2.9	3.2	1.7; 4.7	NA	NA
	Number of unhealthy purchases							
Control	Ref.		Ref.		Ref.		NA	
Nudging	-0.7	-2.6; 1.2	-1.4	-3.6; 0.8	-1.4	-3.4; 0.6	NA	NA
Pricing	-2.0	-3.9; -0.2	-1.5	-3.7; 0.7	-1.8	-3.8; 0.2	NA	NA
Price salience	-2.0	-3.9; -0.1	0.1	-2.2; 2.3	-3.8	-5.8; -1.8	NA	NA
Price salience and nudging	-3.8	-5.6; -1.9	-2.2	-4.4; 0.0	-3.7	-5.8; -1.6	NA	NA

[1] Only applicable for the primary outcome measure percentage of healthy purchases

[2] Price salience condition significantly differs from pricing condition

Bold values are statistically significant

Abbreviations: B; beta regression coefficient, CI; confidence interval, NA; Not Applicable

Supplementary Table 5. Effects of nudging and pricing strategies on the total amount spent on food purchases stratified for pricing arms

Conditions	25% increase arm (n=128)		25% discount arm (n=136)		25% increase and discount arm (n=136)	
	B	95%CI	B	95%CI	B	95%CI
	Total amount spent on food purchases in €					
Control	Ref.		Ref.		Ref.	
Nudging	-3.6	-8.1; 1.0	-3.4	-7.6; 0.8	-1.7	-5.9; 2.6
Pricing	-0.0	-4.6; 4.5	-7.2	-11.4; -3.0	-4.3	-8.5; -0.0
Price salience	0.4	-4.1; 5.0	-3.4	-7.7; 0.8	-5.0	-9.3; -0.6
Price salience and nudging	-2.5	-7.1; 2.0	-9.2	-13.4; -5.0	-4.5	-9.0; 0.1

Bold values are statistically significant

Abbreviations: B; beta regression coefficient, CI; confidence interval

Supplementary Table 6. Effects of nudging and pricing strategies for the percentage of healthy purchases stratified for arm and sex

Conditions	25% increase arm					25% discount arm					25% increase and discount arm				
	Males (n=52)		Females (n=76)			Males (n=56)		Females (n=80)			Males (n=47)		Females (n=89)		
	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test	B	95%CI	B	95%CI	lr-test
	Percentage of healthy purchases														
Control	Ref.				0.1	Ref.				0.2	Ref.				0.8
Nudging	-2.0	-5.3; 1.3	0.7	-1.7; 3.1		-2.0	-5.1; 1.2	1.6	-0.9; 4.1		1.5	-1.4; 4.5	1.9	-0.5; 4.3	
Pricing	-0.6	-3.9; 2.7	0.5	-1.9; 2.9		-1.8	-4.9; 1.3	2.1	-0.5; 4.6		0.4	-2.5; 3.3	0.8	-1.6; 3.3	
Price salience	2.5	-0.8; 5.8	0.6	-1.8; 3.0		-0.7	-3.9; 2.4	3.6	1.1; 6.2		2.9	-0.1; 5.8	5.3	2.8; 7.7	
Price salience and nudging	4.0	0.8; 7.3	2.3	-0.1; 4.7		1.2	-1.9; 4.3	3.1	0.5; 5.6		3.6	0.5; 6.6	4.3	1.7; 6.9	
	Healthy purchases in grams														
Control	Ref.				0.4	Ref.				0.2	Ref.				0.5
Nudging	-723.3	-1783.4; 336.9	-169.9	-1226.0; 886.2		-551.2	-1786.2; 683.7	-121.0	-1085.2; 843.1		637.8	-646.5; 1922.0	-194.5	-1229.9; 840.9	
Pricing	-727.9	-1784.7; 328.9	-672.4	-1721.8; 376.9		-120.6	-1343.8; 1102.7	162.8	-808.1; 1133.7		-544.2	-1822.6; 734.1	72.8	-975.5; 1121.1	
Price salience	178.4	-885.3; 1242.1	-167.7	-1218.9; 883.6		440.9	-785.8; 1666.8	1426.9	461.9; 2391.9		762.5	-526.4; 2051.5	1156.2	98.2; 2214.2	
Price salience and nudging	514.8	-534.2; 1563.9	-458.0	-1510.2; 594.1		952.4	-269.0; 2137.9	120.1	-837.9; 1078.2		1902.0	559.0; 3244.9	1548.0	422.4; 2673.6	
	Unhealthy purchases in grams														
Control	Ref.				0.7	Ref.				0.6	Ref.				0.7
Nudging	-278.6	-1884.7; 1327.6	-712.8	-1847.6; 422.0		-286.0	-2004.9; 1433.0	-1063.4	-2349.3; 222.5		-325.9	-2006.7; 1355.0	-1176.6	-2343.8; -9.3	
Pricing	-791.0	-2390.1; 808.2	-1474.0	-2601.4; -346.6		110.2	-1592.2; 1812.7	-963.2	-2257.9; 331.5		-197.3	-1870.9; 1476.3	-814.0	1995.8; 367.8	
Price salience	-1068.4	-2678.2; 541.3	-923.4	-2052.5; 205.6		815.0	-891.4; 2521.4	-367.8	-1654.7; 919.1		-1005.0	-2692.5; 682.6	-2010.2	-3202.7; -817.6	
Price salience and nudging	-2121.2	-3708.5; -534.0	-1568.1	-2699.9; -436.4		35.9	-1664.1; 1735.9	-1650.3	-2927.8; -372.8		93.0	-1665.4; 1851.5	-1376.3	-2645.1; -107.4	

Bold values are statistically significant

Abbreviations: B; beta regression coefficient, CI; confidence interval, lr-test; P-value likelihood-ratio test

Supplementary Table 7. Effect of the intervention period on the percentage of healthy purchases in the total sample

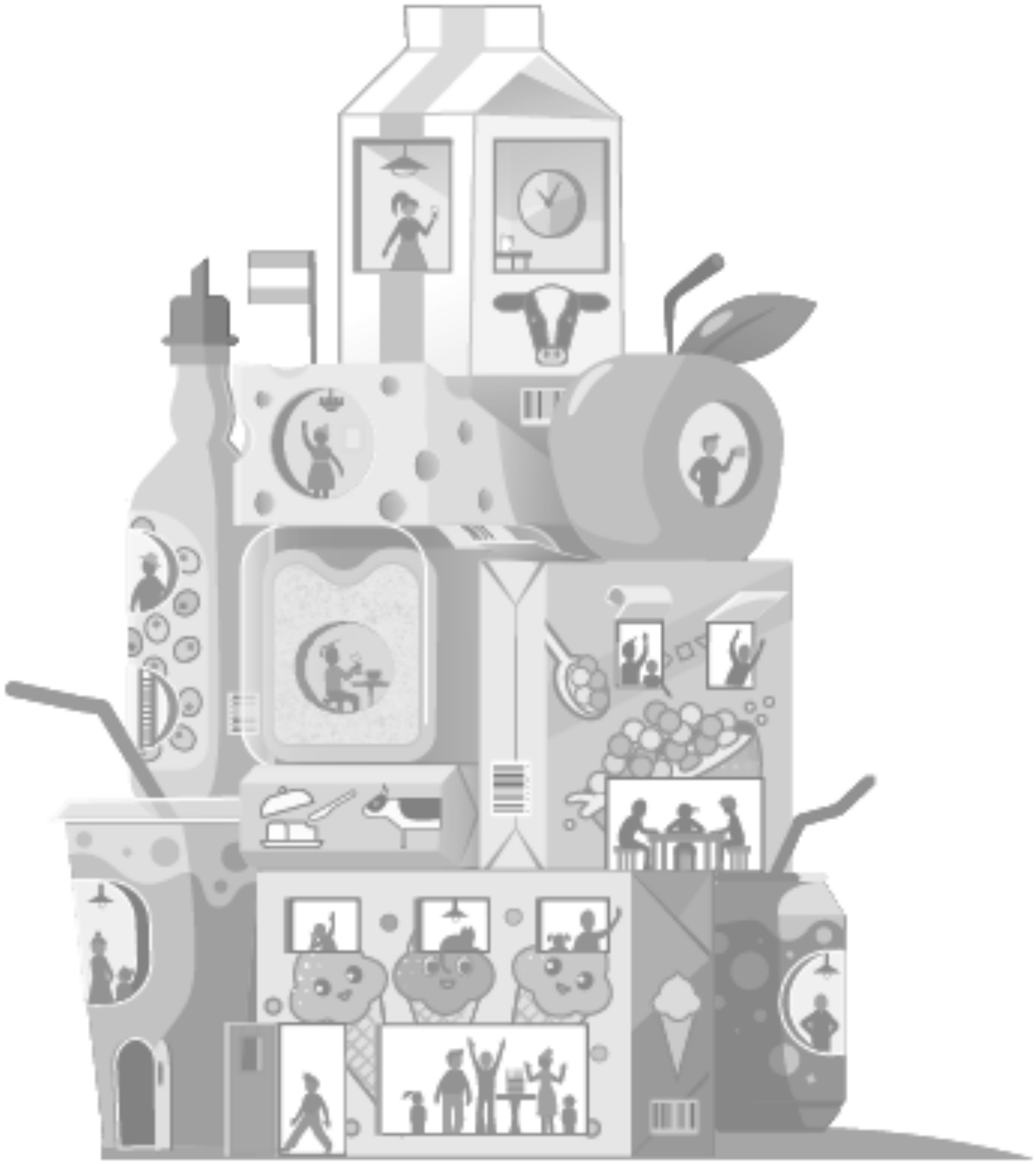
	Total sample (n=400)	
	B	95%CI
Week 1	Ref.	
Week 2	0.4	-0.7; 2.6
Week 3	-0.4	-1.6; 0.7
Week 4	0.4	-0.8; 1.6
Week 5	0.9	-0.3; 2.1

Abbreviations: B; beta regression coefficient, CI; confidence interval, Ref; Reference group

Supplementary Table 8. Unadjusted and adjusted effects of nudging and several pricing strategies on the percentage of healthy purchases for the total sample

Conditions	Unadjusted model		Adjusted model[1]	
	B	95%CI	B	95%CI
Control	Ref.		Ref.	
Nudging	0.5	-0.6; 1.6	0.6	-0.6; 1.7
Pricing	0.4	-0.7; 1.6	0.5	-0.6; 1.6
Price salience	2.6	1.4; 3.7	2.7	1.5; 3.8
Price salience and nudging	3.1	1.9; 4.3	3.2	2.0; 4.3

[1] Adjusted for the intervention period
Bold values are statistically significant
Abbreviations: B; beta regression coefficient, CI; confidence interval, Ref; Reference group



CHAPTER 8

Are nudging and pricing strategies on food purchasing behaviours equally effective for all? Secondary analyses from the Supreme Nudge virtual supermarket study

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8.1 Abstract

Nudging and pricing strategies are effective in promoting healthier purchases. However, whether the effects are equal across individuals with different personal characteristics is largely unknown. This study aimed to examine potential differential effects of nudging and pricing strategies on food purchasing behaviors across individuals' levels of impulsivity, price sensitivity, decision-making styles, and food choice motives. Data from a virtual supermarket experiment where participants were exposed to five study conditions (control, nudging, pricing, salient pricing, and salient pricing with nudging) was used. Participants completed questionnaires assessing their impulsivity, price sensitivity, decision-making styles, and food choice motives. The outcome was the percentage of healthy food purchases. Effect modification was analyzed by adding interaction terms to the statistical models and post-hoc probing was conducted for statistically significant interaction terms. In total, 400 participants completed at least one shop. The majority was female (61.3%) and the median age was 30.0 years (IQR 24.0). The effects of the nudging and pricing conditions on healthy food purchases were not modified by impulsivity, price sensitivity, decision-making styles, and the motives 'health' and 'price'. Only the interactions of 'natural content' x pricing (B = -1.02, 90%CI = -2.04; -0.01), 'weight control' x nudging (B = -2.15, 90%CI = -3.34; -0.95), and 'weight control' x pricing (B = -1.87, 90%CI = -3.11; -0.62) were statistically significant. Post-hoc probing indicated that nudging and/or pricing strategies were more effective in individuals who gave lower priority to these food choice motives. The positive effects of nudging and pricing strategies on food purchasing behaviors, at least in a virtual environment, are not influenced by personal characteristics. Therefore, it seems that these strategies can be implemented in supermarket settings without increasing existing health inequalities.

8.2 Introduction

Non-communicable diseases (NCDs) cause around 41 million deaths each year, which is equivalent to 71% of all deaths globally (1). A key risk factor for NCDs is an unhealthy diet (2). In the Netherlands, adults spend around 66% of their food purchasing budget in the supermarket (3). Therefore, supermarkets are important entry-points for population-level approaches to improve dietary behaviors.
Several strategies within the supermarket environment can be used to promote healthy food purchasing behaviors and generally include environmental (e.g. nudging) and economic (e.g. pricing) interventions (4). Environmental interventions such as labelling, placement and signage, and economic interventions such as health-related food taxes and subsidies can effectively alter food purchases and consumption (4-10). A recent study in a virtual supermarket showed that combining environmental interventions (i.e. salient nudges; a type of environmental intervention that draws an individual's attention towards a particular healthy product) with economic interventions (i.e. salient pricing strategies) leads to even larger effects (11).

Systematic reviews on the effects of nudging and pricing strategies on dietary behaviors highlight the importance of investigating possible differential effects of nudging and pricing strategies on dietary behaviors, and the limited evidence base that is currently available to address these possible differential effects (12-15). It is important to investigate whether nudging and pricing strategies differentially affect subgroups of the population as these interventions may attenuate or exacerbate health disparities (4, 15). There is some evidence to suggest that the effects of nudging and pricing strategies may differ across socio-economic position (SEP) or person-related factors such as Body Mass Index (BMI) and sex (13, 15-18). However, limited research has been conducted on the potential differential effects of nudging and pricing strategies by personal characteristics including impulsivity, decision-making styles, price sensitivity, and food choice motives.

According to the Dual Process Theory, individuals either make automatic or reflective decisions depending on the context (19). Furthermore, nudging and salient pricing strategies tend to target the automatic decision-making process and non-salient pricing strategies tend to target the reflective decision-making process. Therefore, it is relevant to investigate possible differential effects by factors that are associated with these two decision-making processes. For example, impulsive individuals or individuals who tend to make intuitive and spontaneous decisions may be more sensitive to nudging and salient pricing strategies that target the automatic decision-making process. Furthermore, price sensitive individuals may have more consumer knowledge of prices (including the evaluation and integration of prices in the memory) (20), and may therefore react more strongly to pricing strategies that utilize the reflective decision-making process. While impulsivity, decision-making styles, and price sensitivity are related to individuals their decision-making processes, evidence suggests that individuals who find certain food choice motives such as 'health', the 'natural content of foods', and 'weight control' of high importance, tend to purchase healthier food products compared to individuals that find these motives of less importance (21). Therefore, it is possible that individuals who find these food choice motives important react less to nudging and pricing

strategies compared to those who find these food choice motives less important.
The current study used secondary data from an experimental study that investigated the effects of nudging and pricing strategies on food purchasing behaviors in a virtual supermarket setting. Experimental studies in virtual settings allow for feasible and cost-effective collection of individual level data and can therefore also be used to compare the responses of different groups and examine the interactions between personal characteristics (15, 22). This study aimed to explore the modifying role of the personal characteristics impulsivity, general decision-making styles, price sensitivity, and food choice motives in the relation between nudging and (salient) pricing strategies and healthy food purchases within a virtual supermarket environment.

8.3 Methods

8.3.1 Study design

In this study, data from the Supreme Nudge Virtual Supermarket (SN VirtuMart) study was used (23). The development, design, and procedure of the SN VirtuMart have been described in detail elsewhere (11, 24). Briefly, the SN VirtuMart study used a within- and between-subjects design consisting of three experimental arms (i.e. exposure to taxes on unhealthy foods, exposure to subsidies on healthy foods, and exposure to both taxes and subsidies) and five experimental conditions (control, nudging, pricing, salient pricing, and salient pricing combined with nudging). Participants were randomized to one of the three study arms and were instructed to conduct five shopping trips within the virtual supermarket over five consecutive weeks. Each week, participants were exposed to a different condition. The control condition represented the prices and design of an average Dutch supermarket. The nudging condition included salience nudges by means of orange colored arrows pointing from unhealthy low-fiber products to healthier high-fiber variants, orange colored frames around sections of the frozen vegetables' division, and smaller, individual orange colored frames around healthy low-fat dairy products. The pricing condition included a change in the price of several products. Depending on the arm that participants were allocated to, the prices of unhealthy products were increased by 25% (price increase arm), the prices of healthy products were decreased by 25% (price discount arm), or both (price increase and discount arm). The salient pricing condition included the price changes conform to the pricing condition as described above, with additional active communication regarding these price changes to the participants. The last shopping condition included a combination of the nudging and salient pricing condition.

The results regarding the effects of nudging and pricing strategies on healthy food purchases within the SN VirtuMart have been previously reported (11). In short, we found that combining price increases and discounts and combining these salient pricing strategies with nudges effectively increased healthy food purchases for both adults with a low and high SEP. More information on the recruitment, inclusion, randomization, and flow of participants can be found in this previous study (11, 24), as well as more information on blinding, data collection, and sample size calculation. All participants provided informed consent, and ethical approval of the study design and procedures was obtained from the Medical Ethics Review Committee of the VU University Medical Centre Amsterdam (OHRP: IRB00002911).

8.3.2 Outcome measure

The outcome measure was the percentage of healthy food purchases calculated by dividing the amount of healthy products purchased (in grams) by the total amount of products purchased within one shopping trip (in grams). Healthy products were defined according to the 2015 Dutch dietary guidelines (25).

8.3.3 Effect modifiers

Given that we expected that more impulsive individuals and individuals with a more spontaneous and/or intuitive decision-making style are more easily influenced by the nudging and salient pricing strategies (26), we hypothesized that nudging and salient pricing strategies would be more effective in individuals with higher levels of impulsivity and intuitive and spontaneous decision-making styles. Furthermore, given that we expected that more price sensitive individuals and individuals that are strongly motivated to let their food purchasing choices be influenced by the factor 'price' are more influenced by price changes, we expected that pricing strategies (both non-salient as well as salient) would be more effective in individuals with higher levels of price sensitivity and the food choice motive 'price'. Lastly, because we expected individuals whom scored high on the food choice motives 'health', 'natural content of foods', and 'weight control' to purchase healthier products than individuals whom scored low on these food choice motives, we hypothesized that nudging and pricing strategies (both non-salient as well as salient) would be less effective in individuals with higher levels of these food choice motives. To examine these hypotheses, participants were asked to complete questionnaires before every purchasing task, assessing their impulsivity, decision-making styles, price sensitivity, and food choice motives.

8.3.3.1 Impulsivity

The shortened and previously validated form of the Barratt Impulsiveness Scale (BIS) was used to assess participants' levels of impulsivity (27). The BIS 15 was designed to examine common impulsive or non-impulsive behaviors and preferences and included 15 items measured on a 4-point Likert scale. The internal consistency of all 15 items combined showed a Cronbach's alpha of 0.82 in our data. The items were combined and then averaged, resulting in a total score that ranged from one to four, with higher scores representing greater impulsivity.

8.3.3.2 General decision-making styles

The previously validated General Decision Making Style questionnaire (GDMS) was designed to assess the decision-making style(s) that individuals are more inclined to use (28, 29). Only two out of the five decision-making styles were used as these were considered most relevant for nudging and pricing strategies. This questionnaire consisted of 10 items measured on a 5-point Likert scale and distinguished between an intuitive and spontaneous decision-making style. The internal consistencies of intuitive and spontaneous decision-making styles showed a Cronbach's alpha of 0.77 and 0.74, respectively in our data. Given that participants could have both an intuitive as well as a spontaneous decision-making style, these styles were assessed separately. The corresponding items were combined and averaged, creating total scores that ranged from one to five, with higher scores representing greater intuitive/spontaneous decision-making styles.

8.3.3.3 Price sensitivity

A shortened version of the Price Perceptions questionnaire (30) was used to assess participants' levels of price sensitivity. The previously validated Price Perceptions questionnaire was designed to assess different ways in which consumers may react to price and price promotions (30). The current questionnaire version consisted of 18 items measured on a 5-point Likert scale and included the constructs value consciousness (seven items), price consciousness (five items), and sale proneness (six items). The internal consistencies of the constructs' corresponding items combined showed a Cronbach's alpha of 0.65 for value consciousness, 0.83 for price consciousness, and 0.80 for sale proneness in our data. Given that individuals could be classified within all constructs, the three constructs were assessed separately. The corresponding items were combined and averaged, creating total scores that ranged from one to five, with higher scores representing greater price sensitivity as measured by their value consciousness, price consciousness, and sale proneness.

8.3.3.4 Food choice motives

The Food Choice Questionnaire (FCQ) (31) was used to assess the importance that participants felt towards factors associated with food choice. This previously validated questionnaire was designed to create an understanding of the factors governing food choice and consisted of 36 items (measured on a 5-point Likert scale) including nine food choice factors (31). In this study, only the food choice motives 'health' (six items), 'natural content' (three items), 'weight control' (three items), and 'price' (three items) were used because these were expected to be relevant for nudging and pricing strategies. The internal consistencies of the included food choice motives showed a Cronbach's alpha ranging from 0.70 (for price) to 0.87 (for natural content) in our data. The corresponding items were combined and averaged, creating total scores that ranged from one to five, with higher scores representing greater importance of the food choice motives 'health', 'natural content', 'weight control', and 'price'.

8.3.4 Covariates

To gain insights into the socio-demographic context of the study population, the baseline questionnaire included questions about the age, sex, weight, height, family composition, educational attainment (e.g. low, medium, high), employment situation, and net family month income of participants. Self-reported height and weight were used to calculate Body Mass Index (BMI - kg/m^2). Since covariates were unlikely to be related to the independent variables (i.e. the experimental conditions), no confounders were included in the statistical models.

8.3.5 Statistical analyses

Descriptive statistics for socio-demographic variables, the outcome variable, and all potential modifying variables were reported using percentages, means, and standard deviations (SD), or medians and interquartile ranges (IQR) in case of non-normality. To help interpret the results, the relationships between the modifying variables were examined by performing correlation analyses. The cut-off value indicating a correlation was set at Pearson's correlation coefficient ≥ 0.30. As not all participants conducted all shops, this resulted in varying numbers of participants for each questionnaire. Missing values for the characteristics of the study population included 2.3% for BMI and 1.0% for net family month income. Participants who conducted at least one shop in the virtual supermarket were included in the study and missing values were deleted listwise.

Generalized Estimating Equations (GEE) was used to account for the clustering of conditions within participants (32). As we did not expect any differences in the differential effects of nudging and pricing strategies by personal characteristics across the three study arms, all arms were analyzed jointly. Effect modification was investigated by including all four experimental conditions, the potential modifying variable, and interaction terms between all four experimental conditions and the modifier in the statistical models, separately for each potential modifying variable. However, only experimental conditions for which we hypothesized a-priori that a variable could modify the association were reported (e.g. sale proneness x pricing, but not sale proneness x nudging). Therefore, we reported on n=33 interaction terms. Following significant interaction terms (i.e. *p-value* ≤ 0.10 (33)), post-hoc probing was used to gain insight into the nature of the interaction(s) by examining the relationship(s) between the relevant experimental condition(s) and the percentage of healthy food purchases at different values of the modifying variable (33). These values varied from 'very low' (i.e. the mean value + 2SD) to 'very high' (i.e. the mean value – 2SD). This was done by creating models that included all four experimental conditions, one of the five newly created values of the modifying variable, and interaction terms between all four experimental conditions and the newly created value of the modifier, separately for each of the five newly created values of a modifying variable. Again only findings concerning the experimental conditions for which we hypothesized a-priori that a variable could modify the association were reported. For the probed models, statistical significance was set at a *p-value* ≤ 0.05. Secondary analyses included interaction analyses between the conditions and the potential modifiers stratified for the three intervention arms. Post-hoc probing was not conducted for these secondary analyses. All analyses were conducted using SPSS IBM version 25.

8.4 Results

A total of 400 participants conducted at least one shop (Table 1). The majority of the study population was female (61.3%), the median age was 30.0 years (IQR 24.0), and the mean BMI was 24.7 (SD 4.8). Overall, most households consisted of ≤ 2 adults (84.0%) and ≤ 1 children (85.8%). Furthermore, 45.3% was highly educated, 25.5% was student, and a little over 42% had a monthly net income between 1701 and 3150 Euros which is in the range of the average Dutch income. In the control condition, an average of 46.3% (SD 15.1) of the purchases was considered healthy. On average, participants had a score of 3.0 (SD 0.4) on the impulsivity scale. The mean scores for value consciousness, price consciousness, and sale proneness were 2.4 (SD 0.5), 2.5 (SD 0.8), and 2.6 (SD 0.6), respectively. Regarding the two decision-making styles, the mean score was highest for a spontaneous decision-making style (3.0±0.6). The mean scores for all four food choice motives ranged from 2.2 to 2.9 (Table 1).

According to the outcomes of the correlation analyses (Supplementary File 1), there were some correlations between personal characteristics and all of these were found to be fair (r = 0.30-0.50) (Chan, 2003). For example, impulsivity was positively correlated with a spontaneous decision-making style (r = 0.39), and value consciousness was positively correlated with price consciousness (r = 0.34) and the food choice motive price (r = 0.30).

Table 1. Sample characteristics of the analytical study population

	N	Percentage or Mean±SD
Socio-demographic variables		
Age (years - *median; IQR*)	400	*30.0;24.0*
Sex (% women)	400	61.3%
Body Mass Index (BMI – kg/m^2)	391	24.7±4.8
Number of adults in the household	400	
% ≤2 adults	336	84.0%
% >2 adults	64	16.0%
Number of children in the household	400	
% ≤1 children	343	85.8%
% >1 child	57	14.2%
Educational level[1]	400	
% Low	34	8.5%
% Medium	185	46.3%
% High	181	45.3%
Employment situation	400	
% Full time job	100	25.0%
% Parttime job	97	24.3%
% Student	102	25.5%
% Other[2]	101	25.3%
Net family income per month	396	
% 0-1700 Euros	150	37.9%
% 1701-3150 Euros	167	42.2%
% >3150 Euros	79	19.9%
Dependent variable		
Percentage of healthy products purchased in control condition	368	46.3±15.1
Potential modifying variables		
Impulsivity	364	3.0±0.4
Price sensitivity	370	
Value consciousness	370	2.4±0.5
Price consciousness	370	2.5±0.8
Sale proneness	370	2.6±0.6
General decision-making styles	366	
An intuitive decision-making style	366	2.3±0.6
A spontaneous decision-making style	366	3.0±0.6
Food choice motives	369	
Health	369	2.2±0.6
Natural content of foods	369	2.6±0.9
Weight control	369	2.9±0.8
Price	369	2.2±0.6

Abbreviations: N; number; IQR; Interquartile range; SD; Standard Deviation

[1]Low educational level included those who completed primary education, primary vocational education, or lower secondary vocational education. Medium educational level included those who completed higher secondary vocational education, higher general secondary education, or pre-university education. High educational level included those who completed higher professional education

[2]Retired; Unemployed; Housewife/man; Unable to work/Receiving social benefits; Student with part time job; Entrepreneur; Other

Overall, there were few statistically significant interaction terms between the experimental conditions and the personal characteristics (Table 2). The associations between any of the hypothesized experimental conditions and the percentage of healthy food purchases were not modified by impulsivity, price sensitivity (i.e. value consciousness, price consciousness, and sale proneness), the general decision-making styles (i.e. an intuitive and spontaneous decision-making style), and the food choice motives ‘health’ and ‘price’. Three statistically significant interactions were found; ‘natural content’ x pricing (B = -1.02, 90%CI = -2.04; -0.01), ‘weight control’ x nudging (B = -2.15, 90%CI = -3.34; -0.95), and ‘weight control’ x pricing (B = -1.87, 90%CI = -3.11; -0.62) (Table 2). The post-hoc probing outcomes are displayed in Table 3. Overall, the trends of the post-hoc probing results were similar across the different modifying variables and showed that the particular nudging and/or pricing strategies were more effective in individuals with lower values of the food choice motives ‘natural content of foods’ and ‘weight control’ compared to the control condition, and less effective in individuals with higher values of these modifying variables compared to the control condition.

Results regarding the interactions stratified for the three pricing arms can be found in Supplementary File 2. There were few statistically significant interaction terms. In none of the pricing arms did sale proneness, a spontaneous decision-making style, and ‘price’ as a food choice motive modify the relation between the hypothesized experimental conditions and the percentage of healthy food purchases. Out of the n=13 (12.8%) statistically significant interactions, most were found in the salient pricing combined with nudging condition including impulsivity, price consciousness, and the food choice motives ‘health’, ‘natural content’, and ‘weight control’.

Table 2. Interactions between the conditions and the potential modifiers for the percentage of healthy purchases

Interaction term	**B**	**90% CI**
Impulsivity		
Control x impulsivity	Ref.	Ref.
Nudging x impulsivity	2.62	-0.19; 5.43
Salient pricing x impulsivity	2.09	-0.15; 4.32
Salient pricing and nudging x impulsivity	2.62	-0.08; 5.32
Value consciousness		
Control x value consciousness	Ref.	Ref.
Pricing x value consciousness	1.64	-0.25; 3.54
Salient pricing x value consciousness	0.79	-0.90; 2.47
Salient pricing and nudging x value consciousness	0.50	-1.42; 2.43
Price consciousness		
Control x price consciousness	Ref.	Ref.
Pricing x price consciousness	-0.32	-1.58; 0.93
Salient pricing x price consciousness	-1.10	-2.31; 0.12
Salient pricing and nudging x price consciousness	0.09	-1.11; 1.30
Sale proneness		
Control x sale proneness	Ref.	Ref.
Pricing x sale proneness	0.06	-1.48; 1.60
Salient pricing x sale proneness	-0.66	-2.35; 1.03
Salient pricing and nudging x sale proneness	0.76	-0.65; 2.17
An intuitive decision-making style		
Control x an intuitive decision-making style	Ref.	Ref.
Nudging x an intuitive decision-making style	-1.18	-2.84; 0.47
Salient pricing x an intuitive decision-making style	0.07	-1.60; 1.73
Salient pricing and nudging x an intuitive decision-making style	-1.44	-3.20; 0.31
A spontaneous decision-making style		
Control x a spontaneous decision-making style	Ref.	Ref.
Nudging x a spontaneous decision-making style	-0.57	-2.07; 0.94
Salient pricing x a spontaneous decision-making style	-0.44	-1.82; 0.95
Salient pricing and nudging x a spontaneous decision-making style	-0.84	-2.37; 0.68
Health		
Control x health	Ref.	Ref.
Nudging x health	-1.41	-3.07; 0.25
Pricing x health	-0.79	-2.23; 0.66
Salient pricing x health	0.22	-1.47; 1.91
Salient pricing and nudging x health	-0.62	-2.29; 1.05
Natural content of foods		
Control x natural content of foods	Ref.	Ref.
Nudging x natural content of foods	-0.55	-1.56; 0.47
Pricing x natural content of foods	**-1.02**	**-2.04; -0.01**
Salient pricing x natural content of foods	-0.10	-1.07; 0.87
Salient pricing and nudging x natural content of foods	-0.43	-1.53; 0.66
Weight control		
Control x weight control	Ref.	Ref.
Nudging x weight control	**-2.15**	**-3.34; -0.95**
Pricing x weight control	**-1.87**	**-3.11; -0.62**
Salient pricing x weight control	-0.46	-1.61; 0.70
Salient pricing and nudging x weight control	-0.78	-2.03; 0.47
Price		
Control x price	Ref.	Ref.
Pricing x price	-1.03	-2.59; 0.53
Salient pricing x price	-0.70	-2.22; 0.82
Salient pricing and nudging x price	-0.41	-2.16; 1.34

Abbreviations: B; regression coefficient, CI; Confidence Interval

Bold values indicate statistical significance as indicated by the absence of 0 in the 95%CI

Table 3. Post-hoc probing for the interactions between conditions and modifiers for the percentage of healthy purchases

	B	**95% CI**
Food choice motives		
Natural content of foods x pricing (mean)		
Very low value (0.86)	2.29	-0.20; 4.79
Low value (1.73)	1.40	-0.24; 3.03
Mean value (2.61)	0.50	-0.66; 1.66
High value (3.49)	-0.40	-1.91; 1.11
Very high value (4.36)	-1.29	-3.63; 1.04
Weight control x nudging (mean)		
Very low value (1.20)	**4.15**	**1.65; 6.65**
Low value (2.00)	**2.36**	**0.82; 3.90**
Mean value (2.86)	0.58	-0.56; 1.71
High value (3.69)	-1.21	-2.94; 0.53
Very high value (4.53)	**-2.99**	**-5.73; -0.25**
Weight control x pricing (mean)		
Very low value (1.20)	**3.58**	**0.92; 6.23**
Low value (2.00)	**2.03**	**0.39; 3.66**
Mean value (2.86)	0.47	-0.68; 1.63
High value (3.69)	-1.08	-2.82; 0.67
Very high value (4.53)	-2.63	-5.41; 0.16

Abbreviations: B; regression coefficient, SE; Standard Error
Bold values indicate statistical significance as indicated by the absence of 0 in the 95%CI

8.5 Discussion

In this study we examined whether the effects of nudging and (salient) pricing strategies on food purchasing behaviors differed across individuals' levels of impulsivity, price sensitivity, decision-making styles, and specific food choice motives in a virtual supermarket environment. We found no evidence for a modifying role of impulsivity, price sensitivity, decision-making styles, and the food choice motives 'health' and 'price' in the association between any of the experimental conditions and healthy food purchases conform to any of the hypotheses. We only observed that the 'natural content of foods' and 'weight control' as food choice motives modified the association between the experimental conditions nudging and/or pricing and healthy food purchases.

The few studies that also investigated effect modification by personal characteristics showed mixed results. Contrary to our results, a study investigating the effect of health-related taxes and subsidies within a virtual supermarket found that more impulsive individuals adjusted their calorie consumption with regard to the price changes, whereas less impulsive individuals were less influenced by these price changes (34). However, it is unclear if this study used salient or non-salient price changes. Another study within a virtual supermarket investigating the effect of a 25% discount on healthy food purchases found that price perception or habit strength did not modify this association (35). Furthermore, a study investigating the effect of nudging (increasing availability of healthy foods and energy labelling) on total energy ordered within a virtual fast-food restaurant found that the personality traits healthiness motivation or weight control motivation (two food choice motives), executive functioning, and self-control did not modify this effect (36). These results are comparable to our study. Interestingly, multiple studies that investigated interactions similar to this study have been conducted in virtual environments, probably due to the easier implementation of nudging and pricing strategies in virtual environments compared to a real retail-food environment (15, 22).

Given the very limited differential effects of nudging and pricing strategies on healthy food purchases by the personal characteristics under study, we can reject our hypotheses that personal characteristics modify the association between nudging/pricing strategies and healthy food purchases. The few significant interaction terms that were found indicated that 'weight control' as a food choice motive modified the association between nudging and healthy food purchases, and the 'natural content of foods' and 'weight control' as food choice motives modified the association between pricing strategies and healthy food purchases. The post-hoc probing results indicated that nudging and pricing strategies (mostly) statistically significantly increased the amount of healthy food purchases by approximately 2% to 4% in individuals who did not find 'natural content of foods' and 'weight control' important food choice motives. However, it should be noted that these significant interaction terms are potentially false positives (i.e. that these were found based on chance due to multiple testing).

8.5.1 Strengths and limitations

A strength of this study is the relatively large sample size, which ensured sufficient power to detect actual effects. Another strength is its within-subjects design, as this enabled participants to act as their own control, resulting in less bias and more reliable results (37). A limitation of this study includes the limited external validity. While virtual supermarket environments are regarded as a valid tool to investigate the effects of pricing strategies on food purchasing behaviors (22, 38), virtual supermarkets do not completely mimic a real-life supermarket (e.g. participants do not spend real money or receive their shopping basket when shopping in virtual supermarkets). Another limitation includes the issue of multiple testing (39). As we tested multiple interactions, this increased the probability of finding statistically significant interactions. However, as we found limited modification effects by personal characteristics, the possible consequences of multiple testing did not impact the overall conclusion.

8.5.2 Implications for practice and suggestions for future research

Overall, it seems that the effects of nudging and (salient) pricing strategies on food purchasing behaviors, at least in a virtual environment, are not influenced by personal characteristics. Furthermore, although the independent effects of nudging and pricing strategies are relatively small, combining nudges with pricing strategies could result in an effect size relevant at the population level (11). Given the effectiveness of nudging and pricing strategies in real-world supermarkets in increasing favorable food purchasing behaviors (40-44) and the fact that these strategies thus seem equally effective across subgroups with different personal characteristics, the results are in fact favorable as these strategies therefore can be implemented as generic health promoting interventions without increasing existing health inequalities. Nevertheless, it is recommended to further explore the modifying role of personal characteristics in the association between nudging and (salient) pricing strategies on dietary behaviors in real-world supermarket interventions. Furthermore, given the limited evidence base on effect modifiers in general, future research could also investigate the modifying role of other personal characteristics (e.g. dietary restraint and habit) in the association between nudging and pricing strategies and dietary behaviors.

8.5.3 Conclusion

We found limited evidence for differential effects of nudging and (salient) pricing strategies on food purchasing behaviors across different levels of personal characteristics. The findings suggest that nudging and (salient) pricing strategies are equitable across individuals with different personal characteristics. Given the effectiveness of nudging and (salient) pricing strategies in increasing healthy food purchases, these strategies can be implemented in supermarket settings without increasing existing health inequalities.

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SUPPLEMENTARY MATERIAL CHAPTER 8

Are nudging and pricing strategies on food purchasing behaviours equally effective for all? Secondary analyses from the Supreme Nudge virtual supermarket study

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Supplementary Table 1. Correlation analyses between the studied individual characteristics in the Supreme Nudge virtual supermarket

	Impulsivity	*Value consciousness*[1]	*Price consciousness*[1]	*Sale proneness*[1]	*Intuitive*[2]	*Spontaneous*[2]	*Health*[3]	*Natural content*[3]	*Weight control*[3]	*Price*[3]
Impulsivity	1.00									
Value consciousness[1]	-0.23	1.00								
Price consciousness[1]	-0.21	0.34	1.00							
Sale proneness[1]	0.01	0.23	0.08	1.00						
Intuitive[2]	0.04	0.05	0.09	0.16	1.00					
Spontaneous[2]	0.39	-0.06	-0.11	0.21	0.38	1.00				
Health[3]	-0.24	0.16	0.09	0.00	0.08	-0.11	1.00			
Natural content[3]	-0.18	0.14	0.09	-0.09	0.07	-0.15	0.48	1.00		
Weight control[3]	-0.14	0.04	0.09	0.10	0.16	-0.01	0.31	0.32	1.00	
Price[3]	-0.12	0.30	0.24	0.27	0.10	0.03	0.11	0.07	0.15	1.00

[1]Price sensitivity construct
[2]General decision-making styles construct
[3]Food choice motives construct

Supplementary File 2. Interactions between the conditions and potential modifiers for the percentage of healthy purchases stratified for the three experimental arms in the Supreme Nudge virtual supermarket study

Interaction	Price increase		Price discount		Price increase and discount	
	B	90%CI	B	90%CI	B	90%CI
Control x impulsivity	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x impulsivity	-3.10	-7.37; 1.18	6.24*	1.09; 11.39	5.20*	0.70; 9.71
Salient pricing x impulsivity	0.85	-3.03; 4.73	2.90	-1.20; 6.99	2.35	-1.36; 6.066
SPN x impulsivity	4.81*	0.95; 8.68	2.56	-2.26; 7.38	-0.50	-5.89; 4.88
Control x value consciousness	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Pricing x value consciousness	2.67	-0.54; 5.88	2.33	-1.17; 5.83	0.11	-3.03; 3.26
Salient pricing x value consciousness	4.05*	0.77; 7.34	-1.10	-4.11; 1.91	-0.49	-2.85; 1.88
SPN x value consciousness	0.11	-3.04; 3.26	0.43	-3.54; 4.39	0.89	-2.05; 3.82
Control x price consciousness	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Pricing x price consciousness	0.22	2.15; 2.58	1.70	-0.55; 3.94	-2.55*	-4.38; -0.71
Salient pricing x price consciousness	1.19	-0.93; 3.31	-1.75	-4.04; 0.53	-2.28*	-4.09; -0.47
SPN x price consciousness	0.39	-1.77; 2.55	1.43	-0.62; 3.47	-1.37	-3.33; 0.60
Control x sale proneness	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Pricing x sale proneness	-0.96	-4.42; 2.50	1.80	-0.44; 4.04	-1.21	-3.70; 1.28
Salient pricing x sale proneness	0.01	-3.03; 3.05	-0.16	-2.72; 2.40	-1.66	-4.90; 1.58
SPN x sale proneness	0.33	-2.61; 3.28	0.75	-1.54; 3.04	1.32	-0.92; 3.56
Control x intuitive	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x intuitive	-2.48	-5.76; 0.81	-0.75	-3.42; 1.92	-0.67	-3.41; 2.07
Salient pricing x intuitive	1.01	-2.03; 4.05	-0.20	-2.70; 2.30	-0.34	-3.33; 2.64
SPN x intuitive	-4.78*	-7.84; -1.73	-0.77	-3.64; 2.10	0.93	-1.86; 3.72
Control x spontaneous	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x spontaneous	-0.65	-3.13; 1.83	1.01	-2.31; 4.34	-1.77	-3.82; 0.28
Salient pricing x spontaneous	-0.65	-2.90; 1.59	-0.38	-3.25; 2.49	-0.39	2.47; 1.70
SPN x spontaneous decision-making style	-1.89	-4.18; 0.41	-0.35	-3.39; 2.70	-0.12	-2.70; 2.47
Control x health	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x health	-0.44	-2.32; 1.43	-0.56	-3.99; 2.86	-3.60*	-7.05; -0.16
Pricing x health	-0.11	-2.18; 1.96	-2.23	-4.76; 0.29	-0.45	-3.49; 2.59
Salient pricing x health	-0.41	-2.91; 2.08	1.11	-1.78; 4.01	-0.15	-3.22; 2.92
SPN x health	0.12	-2.51; 2.72	-2.38	-5.43; 0.67	0.12	-2.96; 3.19
Control x natural content of foods	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x natural content of foods	0.83	-1.26; 2.91	-0.23	-1.92; 1.46	-2.29*	-3.74; -0.84
Pricing x natural content of foods	-0.44	-2.34; 1.46	-1.24	-2.84; 0.37	-1.39	-3.18; 0.39
Salient pricing x natural content of foods	0.55	-1.39; 2.49	0.87	-0.66; 2.41	-2.02*	-3.49; -0.55
SPN x natural content of foods	0.12	-1.82; 2.07	-0.24	-2.01; 1.52	-1.21	-3.16; 0.74
Control x weight control	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x weight control	-2.28*	-4.49; -0.07	-2.02	-4.04; 0.00	-2.10*	-3.98; -0.22
Pricing x weight control	-1.88	-4.05; 0.30	-2.35*	-4.51; -0.20	-1.20	-3.25; 0.85
Salient pricing x weight control	0.28	-1.70; 2.26	-0.76	-2.89; 1.37	-0.73	-2.40; 0.94
SPN x weight control	-1.27	-3.44; 0.90	-1.12	-3.10; 0.89	0.30	-2.14; 2.73
Control x price	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Nudging x price	-1.03	-3.70; 1.63	0.53	-1.72; 2.77	-1.74	-3.92; 0.44
Pricing x price	-1.16	-4.19; 1.88	-0.76	-3.36; 1.84	-1.31	-3.95; 1.33
Salient pricing x price	-1.09	-4.20; 2.02	-0.37	-3.17; 2.44	-1.19	-3.28; 0.90
SPN x price	1.81	-1.44; 5.06	-0.74	-3.77; 3.28	-1.86	-4.69; 0.96

Abbreviations: B; regression coefficient, CI; Confidence Interval, SPN: salient pricing and nudging
*Statistically significant

CHAPTER 9

Shifting towards a healthier dietary pattern through nudging and pricing strategies: a secondary analysis of a randomized virtual supermarket experiment

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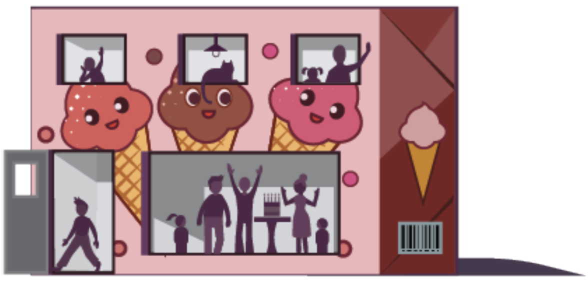

9.1 Abstract

Background: Nudging and salient pricing are promising strategies to promote healthy food purchases, but it is possible their effects differ across food groups.

Objective: To investigate in which food groups nudging and/or pricing strategies most effectively changed product purchases, and resulted in within-food groups substitutions or spill-over effects.

Design: N=318 participants successfully completed a web-based virtual supermarket experiment in the Netherlands. We conducted a secondary analysis of a mixed randomized experiment consisting of five conditions (within-subject) and three arms (between subject) to investigate the single and combined effects of nudging (e.g. making healthy products salient), taxes (25% price increase) and/or subsidies (25% price decrease) across food groups (fruits and vegetables, grains, dairy, protein products, fats, beverages, snacks, and other foods). Generalized linear mixed models were used to estimate the incidence rate ratios and 95% CI for changes in the number of products purchased.

Results: Compared to the control condition, the combination of subsidies on healthy products and taxes on unhealthy products in the nudging and price salience condition was overall the most effective, as the number of healthy purchases from fruit and vegetables increased by 9% (IRR=1.09;95%CI=1.02,1.18), grains by 16% (1.16;1.05,1.28), and dairy by 58% (1.58;1.31,1.89), while the protein and beverage purchases did not significantly change. Regarding unhealthy purchases, grains decreased by 39% (0.72;0.63,0.82) and dairy by 30% (0.77;0.68,0.87), whereas beverage and snack purchases did not significantly change. The groups of grains and dairy showed within-food group substitution patterns towards healthier products. Beneficial spill-over effects to minimally-targeted food groups were seen for unhealthy proteins (0.81;0.73,0.91).

Conclusions: Nudging and salient pricing strategies have a differential effect on purchases of a variety of food groups. The largest effects were found for dairy and grains, which may therefore be the most promising food groups to target in order to achieve healthier purchases.

9.2 Introduction

Unhealthy dietary patterns contribute to the development of obesity and non-communicable diseases (1). It is increasingly recognized in theory (2, 3) and through evidence (4-7) that unhealthy dietary patterns are partly driven by an unhealthy food environment. Within the food environment, supermarkets form an important leverage point to influence dietary patterns as they serve as a major source of food for populations. Supermarket interventions are therefore a promising strategy to promote healthy food and beverage purchases (8).

Previous studies (8-12) including our own (13) have shown that nudging and pricing strategies – and especially their combination – can effectively influence food purchases. In a virtual supermarket experiment, we demonstrated that salient pricing strategies (i.e. taxing, subsidies or both) and nudges combined significantly increased the total percentage of healthy purchases by 4%. However, these strategies may have differential effects across food groups that are masked when analysing all healthy purchases combined. Studies on price elasticities for example show that consumers are more responsive to price changes in some food groups than in others (14, 15). In general, staple products (e.g. potatoes) are less responsive to price changes than more 'luxury' foods (e.g. snacks)(16). Less is known about the responsiveness of different food groups to placement, promotion and salience (elements of nudging) (10, 17). Most previous nudging studies focused on a single food group (8, 18), thereby limiting the possibility to compare nudge effectiveness across food groups. Some studies suggested that staple foods, were purchases are largely driven by habitual behaviours, may be less responsive to nudging than non-staple foods – more often based on impulse (19, 20).

Indirect effects of nudging and pricing strategies may be within-food group substitutions (e.g. shifting from refined to whole grain bread) or between-food group spill-over effects to other (non-targeted) food groups (e.g. increased purchases of dairy products when merely targeting cereals). It is well known that price increases in one group may lead to changed purchases in other food groups (i.e. cross-price elasticity) (15). However, less is known about within-food group substitutions relevant for public health. Insight into substitutions from unhealthier to healthier products within-food groups requires detailed experimental data which is often unavailable. Moreover, current literature does not provide insight into spill-over effects of nudges (21). Potential substitution or spill-over effects may be favourable or unfavourable for the promotion of healthy diets and its public health impact.

Evidence on differential effects of strategies across food groups is required to provide better knowledge about what health effects may be expected from interventions, and what approaches yield the largest impact. In the present study we use data from the Supreme Nudge virtual supermarket experiment to explore as a secondary analysis in which food groups nudging and/or pricing strategies were most effective in changing healthy and unhealthy product purchases, and whether the applied strategies resulted in within-food groups substitutions or spill-over effects.

9.3 Methods

9.3.1 Study design and participants

This study is a secondary analysis of the Supreme Nudge virtual supermarket (SN VirtuMart) experiment (13). The SN VirtuMart is a three-dimensional web-based virtual supermarket designed to investigate the single and combined effects of nudging and various pricing strategies on food purchases in the Netherlands. In this SN VirtuMart we had set up a randomized mixed experimental study consisting of three study arms (between subject design) and five study conditions (within-subject design) (Table 1). Participants were individually randomized into one of the three study arms (25% tax, 25% subsidy, or 25% tax and subsidy) and within these arms, were exposed to five study conditions (control, nudging, pricing, price salience and price salience with nudging). The order in which the conditions were received within the study arms were individually randomized as well.

Table 1. Design of the Supreme Nudge virtual reality supermarket study

	Condition 1: Control	**Condition 2:Nudging[1]**	**Condition 3: Price[2]**	**Condition 4: Price salience[3]**	**Condition 5: Nudging[1] and price salience[3]**
Arm 1: 25% Tax	Control	Nudging	Taxes	Salient taxes	Nudging and salient taxes
Arm 2: 25% Subsidy	Control	Nudging	Subsidies	Salient subsidies	Nudging and salient subsidies
Arm 3: 25% Tax and Subsidy	Control	Nudging	Taxes and subsidies	Salient taxes and subsidies	Nudging and salient taxes and subsidies

[1]Nudging: bright orange coloured salience nudges promoting healthy products;

[2]Price: a 25% price change in comparison to the baseline price, either for taxing of unhealthy products, subsidizing of healthy products, or a combination of both;

[3]Price salience: a 25% price change in comparison to the baseline price, either for taxing of unhealthy products, subsidizing of healthy products, or a combination of both, which are actively communicated to the participant via '*Discount'* signage for subsidized products, and a digital 'news article' for the taxing.

Participants were recruited via a social media campaign using Facebook and Instagram. The social media campaign ran from mid-September to mid-December 2018. In October 2018, participants were also recruited via flyers distributed on the street, in real-world supermarkets, at local events, and by mail around the University campus, and by postal service across various areas in The Netherlands.

Respondents were considered eligible for study participation when aged 18 years or older, were able to communicate in Dutch language, had access to a computer with internet, had a valid e-mail address, and were responsible for the household groceries. After study inclusion, participants were asked to imagine they did not have any groceries left at home. Next, they were asked to hypothetically purchase their weekly groceries in the SN VirtuMart, during five consecutive weeks. They received a virtual budget based on their real-life grocery budgets as indicated by the participants in the baseline questionnaire. They could complete their weekly shop at the online check-out after spending between 50-125% of this weekly budget.

The original study protocol complies with the Declaration of Helsinki and was approved by the Medical Ethics Review Committee of VU University Medical Centre in Amsterdam (Office for Human Research Protections: IRB00002911). Informed consent was obtained from all the participants before they started the study.

9.3.2 Nudging and pricing strategies

The SN VirtuMart included 1,175 different food items with market-conform prices and price promotions, reflecting a real-life Dutch supermarket setting and floor plan; only non-food products and alcoholic beverages were excluded. All available products were categorized into eight food groups and divided by healthy and unhealthy products within these groups (Table 2), based on the Dutch dietary guidelines (22). We made a selection of the available products to intervene on, with the aim to most accurately reflect a real-life scenario in which intervening on all foods at once would be unlikely. In total, 356 unhealthy products were taxed (37% of all unhealthy products), 195 of the healthy products were subsidized (89% of all healthy products), and 38 healthy products were nudged, out of which 36 were nudged and subsidized simultaneously (17% and 16% of all healthy products, respectively) (Table 2).

The control condition represented a regular supermarket. In all conditions (including the control condition) the same realistic product promotions were placed at the end of aisles. The nudging condition included three types of bright orange coloured salience nudges. The first type of nudge consisted of shelf arrows pointing from a non-whole grain product towards a whole-grain product. The second type consisted of a frame on the transparent fridge doors, highlighting the frozen vegetables section. The third type consisted of a frame as well, however, this frame additionally included the text '*Favourite'* to additionally reflect a social norm. It was placed on the fridge doors around the skimmed dairy products and low-fat cheeses.

The pricing condition consisted of taxing of unhealthy foods and/or subsidizing of healthy foods. Both strategies encompassed a 25% price change in comparison to the baseline price. The price salience condition additionally included, next to the taxes and subsidies, a frame around the product indicating '*Discount'* for subsidized products, while presenting the regular price and the new subsidized price. For the taxed products, the price salience condition consisted of a digital 'news article' that was presented before participants entered the SN VirtuMart to make respondents aware of price increases. The article stated a '*Sugar and fat tax of 25%'* was now implemented in the Netherlands.

Table 2. Food groups by healthy and unhealthy products and their intervention allocation within the virtual supermarket

Food groups	Healthy products		Unhealthy or neutral products	
	Subsidized (-25%) and partly nudged	**No intervention**	**Taxed (+25%)**	**No intervention**
Fruits and vegetables (*n*=95)	Fresh, frozen and canned vegetables, fresh and frozen fruits, and apple sauce (*n*=82; 86% of healthy fruits and vegetables)	Canned fruits, and raw pre-cut vegetables (*n*=13; 14%)	N/A	N/A
Grains and potato (*n*=166)	Whole-grain products (bread, pasta, rice, and crackers) (*n*=14; 45% of healthy grains)	Whole-grain products (bread, crackers, breakfast grains) and fresh and unprocessed pre-cut potatoes (*n*=17; 55%)	Non-whole grain products (bread, crackers, pasta, rice) (*n*=36; 42% of unhealthy grains)	Non-whole grain products (wraps, noodles, breakfast grains, and crackers) fried potatoes, and processed mashed potatoes (*n*=49; 58%)
Dairy (*n*=138)	Semi-skimmed and skimmed dairy products, and low-fat cheeses (*n*=14; 88% of healthy dairy)	Skimmed coffee milk (*n*=2;12%)	Sweetened semi-skimmed and skimmed dairy products, full-fat dairy, custard, desserts, pudding, whipped cream, cooking cream, dairy drinks, chocolate milk, soy-dairy products (sweetened), and high-fat cheeses (*n*=105; 86% of unhealthy dairy)	Pudding, ice cream, cream cheeses, and coffee milk (*n*=17; 14%)
Other proteins (*n*=154)	Fresh, frozen and breaded fish, unsalted nuts , fresh and canned legumes (*n*=51; 72% of healthy other proteins)	Unprocessed and low-fat meats, eggs, and canned fish (*n*=20; 28%)	Salted nuts (*n*=11; 13% of unhealthy other proteins)	Processed and high-fat meats, and meat substitutes (salted) (*n*=72; 87%)
Fats (*n*=22)	N/A	Olive oil, sunflower oil, vegetable oil, and margarine (*n*=12; 100%)	N/A	Frying oil, butter, and baking butter (*n*=10; 100%).
Beverages (*n*=139)	Tea bags, water, and flavoured water (unsweetened) (*n*=34; 61% of healthy beverages)	Filtered coffee products (*n*=22; 39%)	Sodas, and energy drinks (*n*=32; 39% of unhealthy beverages)	Fruit juices, lemonade syrup, unfiltered coffee products (*n*=51; 61%)
Snacks (*n*=249)	N/A	N/A	Fried salty snacks, chips, popcorn, candy, cakes, chocolate, liquorice, and bubble-gum (*n*=149; 60% of unhealthy snacks)	Salty snacks, chips, popcorn, candy, cakes, cookies, rice crackers, bread sticks, dips, drinking broth, gingerbread, and water-based ice cream (*n*=100; 40%)
Other foods (*n*=262)	N/A	N/A	Pizza, sweet bread toppings (*n*=23; 9% of unhealthy other foods)	Ready-to-eat meals, pancakes, canned soup, savoury bread toppings, seasoning products, and baking products (*n*=239; 91%)

Abbreviations: N/A: Not applicable.

9.3.3 Study outcomes

The outcomes of this study were changes in the healthy and unhealthy product purchases within all food groups, between the four intervention conditions compared to the control condition. Changes were calculated based on the number of items purchased. Using the number of items purchased enabled a consistent comparison of purchase changes between all food groups, while also providing insights into within-food group substitution effects and within-food group spill-over effects. Within-food group substitution effects were defined as an increase in healthy purchases with a simultaneously decrease in unhealthy purchases within the same food group. Within-food group spill-over effects were defined as an increase or a decrease of purchases in food groups which were not targeted or minimally targeted by nudging or pricing strategies. Non-targeted was defined as the absence of an interventional strategy within the food group (e.g. group of fats), and minimally targeted when only a small proportion (<15%) of products were targeted (e.g. group of other foods). Detecting intervention effects derived from such a small proportion on the food group level was deemed implausible due to the initial sample size calculation of the SN VirtuMart experiment. The between group spill-over effects could either be beneficial (increase in healthy purchases) or non-beneficial (increase in unhealthy purchases) from a public health perspective.

9.3.4 Population characteristics

Data on participant characteristics were obtained via the online baseline questionnaire. Part of the baseline questionnaire asked participants about their sex (male/female), age (years), highest educational attainment (eight categorical levels), weight (kg) and height (cm). The BMI was calculated as weight divided by height squared (kg/m^2). Educational level was categorized into two groups; low educational level included those who completed primary education, intermediate vocational education and higher secondary education, and high educational level included those who completed higher vocational education or university. Further details on population characteristics have been described elsewhere (13).

9.3.5 Statistical analyses

Descriptive statistics included participant characteristics presented by study arm, consisting of age and BMI (mean (SD)), sex and educational level (n(%)), and the number of items purchased per food group in the control condition (median (Q_1-Q_3)). Graphical inspection of the number of items purchased within all food groups indicated a Poisson distribution of the outcome data. Regular Poisson models assume an equal variance to the mean. In almost all of our food group outcomes the variance was larger than the mean, indicating overdispersion. A few food group outcomes showed mild indications for overdispersion (e.g. for healthy grains and potatoes in the taxing arm a mean of 4.2 items were purchased with a variance of 4.7 items) where most others showed large indications for overdispersion (e.g. for healthy dairy in the subsidy arm a mean of 5.5 items were purchased with a variance of 17.2 items).

As the assumption of equal variance to the mean was violated, we selected the most suitable regression model for discrete count data using a model selection function via the R statistical software package *glmmTMB* (23, 24). The Akaike information criterion was used to select whether a generalized linear mixed model (GLMM), zero-inflated GLMM, and hurdle model, with a Poisson, Conway-Maxwell Poisson, or negative binomial distribution best fitted the outcome data (i.e. purchases within all individual food groups). The Akaike information criterion is a measure to rank the quality of each model, relative to all other fitted models. Based on this ranking, the GLMMs with a Conway-Maxwell Poisson distribution appeared the most adequate fit for our food group outcome data. Therefore, we fitted separate models for each of the food group outcomes using GLMMs with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% CI for products purchased within all food groups during the four experimental conditions in comparison to the control condition. IRRs in which the 95% CI did not include 1 were considered statistically significant.

The Conway-Maxwell Poisson distribution is a flexible generalization of the Poisson distribution which is suitable for modelling of overdispersed as well as for underdispersed count data. Modeled with the *glmmTMB* package, the Conway-Maxwell Poisson distribution is interpretable as a log-linear model(24, 25). The IRR reflects the percent change of the experimental condition compared to the control condition. For instance, a percentage increase for a positive IRR such as 1.09 reflects a 9% increase (26), and a percentage decrease for a negative IRR such as 0.89 reflects a (1 / 0.89 = 1.12) 12% decrease (27).

Data were a-priori stratified by study arm as previous analyses of this data revealed a decrease in unhealthy purchase in the taxing arm while there was no increase the healthy purchases (13). The only exception was the evaluation of the nudging condition, for which we analysed the total study sample (i.e. the three pricing arms combined) since all participants were exposed to the same nudging intervention irrespective to which pricing arm they were randomized to.

9.4 Results

In total, 455 participants enrolled in the study of which 346 completed all five shops. Useable data were available for 318 of those participants, as in the other cases participants received an incorrect grocery budget or used an incorrect login code (Supplementary Figure 1. Participant flow-chart). The study population consisted of approximately 40% males, with a mean age of 35 years, a mean BMI of 25 kg/m^2 and circa half of the study population completed a high level education (Table 3). These study characteristics were comparable across the pricings arms. Depending on the pricing arm, the median number of *fruit and vegetables* purchased in the control condition was 10 to 12 items and this food group was the most frequently purchased food group. Other frequently purchased food groups were *unhealthy other products* (median purchase 7 to 10 items), *snacks* (4 to 6 items), and *unhealthy dairy products* (4.5 to 5 items), in contrast to *healthy and unhealthy fats* which were the least frequently purchased food group (0 to 1 item) (Table 3).

The effects of nudging and pricing strategies on changes in purchases from various food groups compared to the control condition are graphically shown in Figures 1-4, separately for each experimental condition. A numeric overview of the results is additionally provided in Supplementary Table 1.

Table 3. Study population characteristics and the number of items purchased per food group in the control condition, by study arms (*n* = 318)

	25% Tax (*n* = 108)		**25% Subsidy (*n* = 119)**		**25% Tax and 25% Subsidy (*n* = 91)**	
Study population characteristics						
Sex, *n* males (%)	46	(43)	47	(40)	31	(34)
Age, mean (SD)	36.8	(15.4)	35.5	(15.8)	34.1	(13.4)
BMI, mean (SD)[1]	24.7	(5.0)	25.5	(5.0)	25.4	(4.6)
High educational level[2], *n* (%)	53	(49)	52	(44)	41	(45)
Number of items purchased in the control condition, median (Q_1-Q_3)						
Healthy fruits and vegetables	10.0	(7.0-14.0)	11.0	(8.0-15.0)	12.0	(7.0-18.5)
Healthy grains and potatoes	4.0	(3.0-5.0)	3.0	(2.0-5.0)	4.0	(3.0-5.0)
Healthy dairy products	2.0	(0.0-3.0)	1.0	(0.0-3.0)	1.0	(1.0-3.0)
Healthy protein products	3.0	(2.0-4.3)	3.0	(2.0-4.0)	3.0	(2.0-5.0)
Healthy beverages	1.5	(1.0-3.0)	1.0	(0.0-2.0)	2.0	(1.0-3.0)
Healthy fats	0.0	(0.0-1.0)	1.0	(0.0-1.0)	1.0	(0.0-1.0)
Unhealthy grains and potatoes	4.0	(2.0-6.0)	4.0	(2.0-6.0)	4.0	(3.0-7.0)
Unhealthy dairy products	4.5	(2.8-8.0)	5.0	(3.0-9.0)	5.0	(3.0-8.0)
Unhealthy beverages	2.5	(1.0-4.3)	3.0	(1.0-6.0)	4.0	(2.0-5.5)
Unhealthy snacks	4.0	(2.0-7.3)	4.0	(2.0-8.0)	6.0	(3.0-9.0)
Unhealthy other products	8.0	(5.0-11.0)	7.0	(4.0-12.0)	10.0	(6.0-12.5)
Unhealthy protein products	4.0	(3.0-6.0)	4.0	(2.5-7.0)	5.0	(3.0-7.5)
Unhealthy fats	0.0	(0.0-1.0)	0.0	(0.0-1.0)	0.0	(0.0-1.0)

[1]8 missing values
[2] Participant who completed higher vocational education or university;
Abbreviations: Q; Quartile.

9.4.1 Differential effects across targeted food groups

Differential effects of the nudging and pricing strategies were observed across all study conditions. The *nudging condition* showed an increase in the healthy grains purchases of 7% (IRR=1.07; 95%CI=1.01,1.14) and a non-significant increase of 10% in healthy dairy (1.10; 0.99,1.23), while no significant differences were found for vegetables and other protein products which were also targeted (Figure 1). The *price condition* showed that subsidies did not significantly increase the targeted healthy purchases (Figure 2). Taxes decreased the unhealthy dairy product purchases by 14% (0.88; 0.79,0.98), but did not significantly change purchases of other targeted unhealthy products (i.e. grains, beverages and snacks). In the *price salience condition*, subsidies increased all targeted healthy purchases (i.e. fruits and vegetables, grains, dairy products, and other protein products) except for beverage purchases (Figure 3). Taxes did not significantly decrease the targeted unhealthy purchases (i.e. grains, dairy, beverages, and snacks). Subsidies in the *nudging and price salience condition* resulted in an increase in healthy dairy purchases by 43% (1.43; 1.19,1.72), but did not significantly change the purchases of the also targeted fruits and vegetables, grains, protein products and beverages

(Figure 4). Taxes decreased the number of unhealthy grains by 30% (0.77; 0.68,0.87), unhealthy dairy products by 18% (0.85; 0.76,0.94), and unhealthy beverages by 18% (0.85; 0.75,0.97), while snack purchases did not significantly change (Figure 4).

Results from the combined *taxing and subsidy arm* in the *nudging and price salience condition* generally showed larger effects than the individual effects of the subsidies and taxes (Figure 4). More specifically, the combination of subsidies and taxes increased the number of fruit and vegetables purchases by 9% (1.09; 1.02,1.18), healthy grains by 16% (1.16; 1.05,1.28), and healthy dairy products by 58% (1.58; 1.31,1.89), while healthy protein and beverage purchases did not significantly change. Furthermore, unhealthy grain purchases decreased by 39% (0.72; 0.63,0.82) and unhealthy dairy by 30% (0.77; 0.68,0.87), whereas unhealthy beverages and snack purchases did not significantly change.

9.4.2 Substitution effects within-food groups

The *nudging condition* showed within-food group substitutions among dairy products. Purchases of the non-targeted unhealthy dairy products decreased by 19% (0.84; 0.79,0.90), while simultaneously the targeted healthy dairy product purchases increased non-significantly by 10% (1.10; 0.99,1.23) (Figure 1). Whereas the *price condition* showed non-significant trends towards increased purchases of healthy dairy products and grains with simultaneous decreased purchases of unhealthy dairy products and grains (Figure 2), the *price salience* and *nudging and price salience* conditions showed significant within-food group substitution patterns for dairy products and grains (Figure 3 and 4). The within-food group substitution patterns were not seen among beverages.

9.4.3 Spill-over effects to non-targeted or minimally-targeted food groups

Neither the *nudging condition* nor the *price condition* showed between-food group spill-over effects to non-targeted or minimally-targeted food groups (Figure 1 and 2). The *price salience condition* however showed beneficial between group spill-over effects within the combined subsidies and taxes arm among the minimally--targeted unhealthy other products, as purchases decreased by 14% (0.88; 0.81,0.96) (Figure 3). In the *nudging and price salience condition*, taxes decreased the purchases of the minimally-targeted unhealthy other products by 15% (0.87; 0.79,0.95), while the combination of subsidies with taxes decreased the minimally-targeted unhealthy protein products by 24% (0.81; 0.73,0.91) (Figure 4).

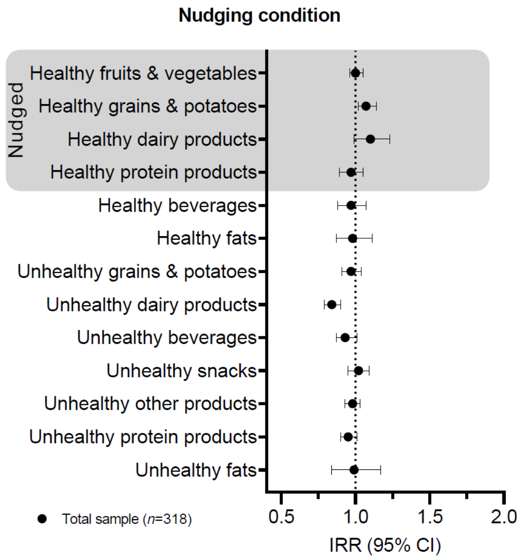

Figure 1. The effect of nudging on purchases from various healthy and unhealthy food groups. Analysis was based on a generalized linear mixed model with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% confidence intervals (CI) for changes in products purchased within all food groups in the nudging condition in comparison to the control condition (Total sample *n*=318).

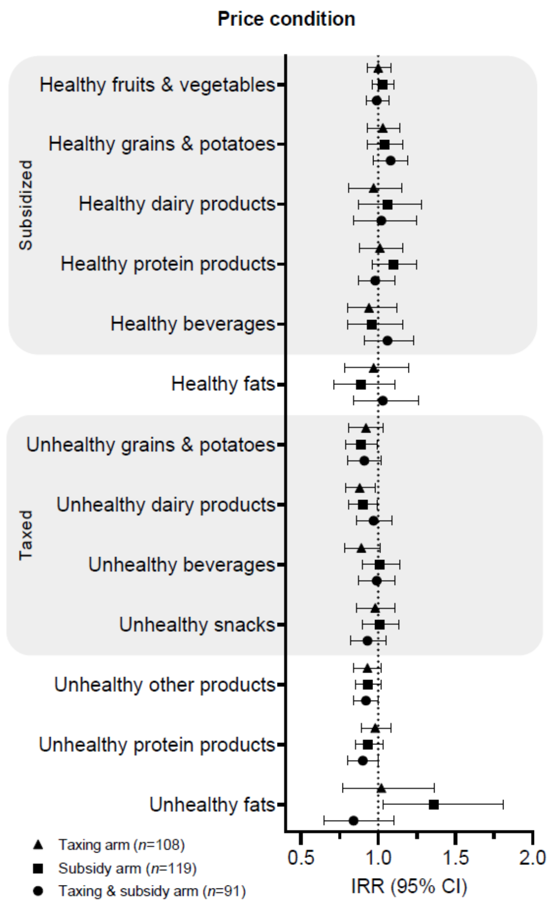

Figure 2. The effect of pricing strategies on purchases from various healthy and unhealthy food groups. Analysis was based on a generalized linear mixed model with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% confidence intervals (CI) for changes in products purchased within all food groups in the pricing condition in comparison to the control condition (Tax arm *n*=108; Subsidy arm *n*=119; Tax and Subsidy arm *n*=91).

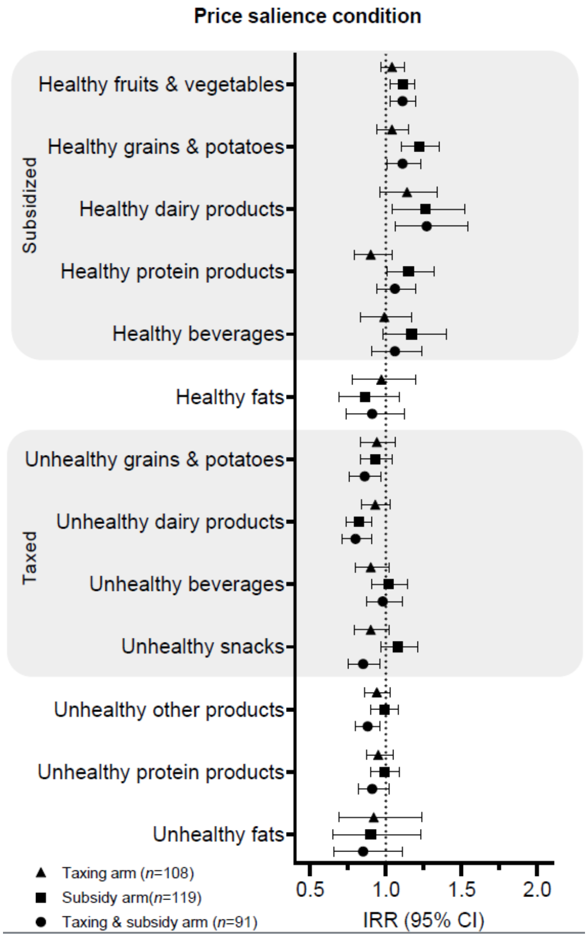

Figure 3. The effect of salient pricing strategies on purchases from various healthy and unhealthy food groups. Analysis was based on a generalized linear mixed model with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% confidence intervals (CI) for changes in products purchased within all food groups in the price salience condition in comparison to the control condition (Tax arm n=108; Subsidy arm n=119; Tax and Subsidy arm n=91).

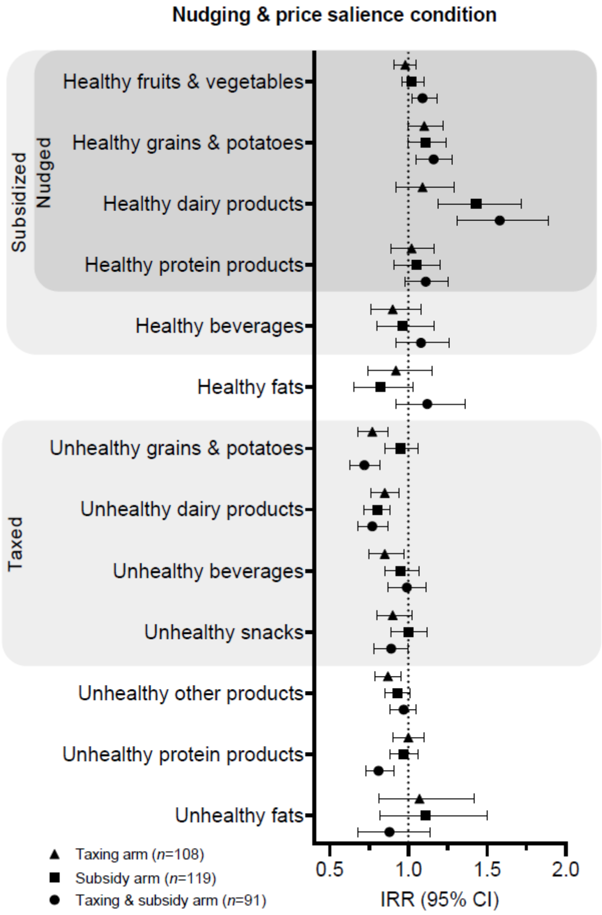

Figure 4. The effect of nudging and salient pricing strategies on purchases from various healthy and unhealthy food groups. Analysis was based on a generalized linear mixed model with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% confidence intervals (CI) for changes in products purchased within all food groups in the price salience and nudging condition in comparison to the control condition (Tax arm *n*=108; Subsidy arm *n*=119; Tax and Subsidy arm *n*=91).

9.4.4 Sensitivity analyses

The results of the sensitivity analyses where we explored the combined effects of the pricing arms in the total study sample showed the same pattern as the main results; i.e. the nudging combined with pricing strategies were the most effective and the largest effects were seen in the targeted groups of grains and dairy products (Supplementary Table 2). Healthy grains purchased increased by 12% (1.12; 1.06,1.19) and healthy dairy by 36% (1.36; 1.23,1.51), while simultaneously the unhealthy grains decreased by 22% (0.82; 0.77,0.88) and unhealthy diary by 25% (0.80; 0.75,0.86).

9.5 Discussion

Building on earlier results from the SN VirtuMart experiment, providing evidence for an overall beneficial effect of combined nudging and salient pricing strategies on healthy purchases (13), the current secondary analysis of this experiment shows that these strategies have differential effects across food groups. Nudging combined with pricing strategies were found to be more effective among grains and dairy as compared to other food groups (i.e. fruits and vegetables, other protein products, beverages, and snacks). Furthermore, the combined nudging and pricing strategies resulted in within-food group substitutions for the groups of grains and dairy. Last, the applied strategies also caused beneficial within-food group spill-over effects to the minimally-targeted groups of unhealthy protein and unhealthy other products.

This study was, to the best of our knowledge, the first to comprehensively investigate the single and combined effects of nudging and pricing strategies across various food groups. We used a strong experimental within-subject combined with a between-subject design where participants acted as their own control, and used objectively measured outcome data. Our results should however be considered in light of its limitations. First, the comparison of intervention effects within food groups is complicated by the fact that certain food groups were more heavily targeted by nudging and/or pricing strategies than others. Thus, the intervention allocation could partly explain the stronger effects seen in some food groups. This could explain the observed effects in the group dairy. In contrast, grains showed the second largest increase in healthier purchases, while it was less targeted by nudging and pricing strategies compared to beverages, other proteins, and fruit and vegetables. It therefore seems unlikely that such effects completely explain our results. Second, due to the original design of the SN VirtuMart, possibilities for food group categorization were limited to mostly large and sometimes heterogeneous food groups to secure adequate power; among protein products and beverages this may have attenuated potential effects. Third, our analytic approach did not account for multiple testing, and doing so would have led to less statistically significant findings. However, given our aim to provide insights into which food groups were accountable for the overall healthier purchases we think it is justified to mainly focus on effect sizes and patterns in findings across study arms and conditions, rather than statistical significance. Fourth, truly capturing real-life purchasing behaviour in a virtual supermarket setting may be challenging. Nevertheless, previous studies have shown that purchases made in a virtual setting are comparable to real-life (28, 29) and 78% of our participants indicated they felt their virtual purchases reflected their real-life purchases. Fifth, our study sample may not fully reflect the average Dutch population, as participants were on average younger, higher educated and more often female. Our inclusion criterion 'primary household shopper' likely resulted in more females, whereas the younger population is like due to the recruitment strategies utilized (e.g. Facebook).

Besides the intervention allocation across food groups and the heterogeneity within some of the groups, inherent food group differences may also explain the observed differential effects across food groups. Inherent group differences refer to the nature of the food groups itself that make them more or less prone to intervention effectiveness. Although some studies have suggested that staple foods may be less prone to nudging and pricing strategies(16, 19, 20), our results suggest otherwise. It may be hypothesized that products within the groups of dairy products and within the group of grains are relatively comparable in product types and taste.

Product substitutions with a comparable alternative may be easier. For instance, beverage purchases may be less subjected to impulse behaviours and more strongly depend on habitual behaviours (30), and soda may be less interchangeable with tea or water than high-fat yogurt with low-fat yogurt.

Other studies also observed differential effects of nudging and pricings strategies across food groups. The prospective effect of price changes across food groups on dietary intake was estimated in a meta-analysis (2). In line with our findings, subsidies were able to significantly increase fruit and vegetables consumption, while they did not significantly increase healthier beverage consumption. A study by Foster et al. (2014) found that a combination of supermarket nudges (placement, signage, and product availability) increased healthy dairy sales (31), while another comparable study (signage, prime placement, and taste testing) reported that dairy sales remained unaffected (32). Comparable to our study, the same study reported increased healthy grain sales following nudges (32). Effects of nudging and pricing on purchases from different food groups warrants further investigation.

To achieve within-food group substitutions, other studies also concluded that dairy is promising to target with nudging (31, 33) and pricing strategies (14). However, a study estimating between-food group cross-price elasticities found that a price increase on dairy decreased the demand for dairy, but simultaneously also unfavourably decreased the demand for fruit and vegetables (15). Our results do not confirm these non-beneficial spill-over effects. Our findings among beverages are in contrast to previous studies showing taxation reduces unhealthy beverage purchases and also promotes healthy beverage purchases (34, 35). Alternatively, similar to our findings, previous nudging studies on beverage sales show there were no substitution effects among beverages (31, 33). Regarding grains, a prediction study concluded that the cross-price elasticities within the groups of cereals and bread are very low (36). However, the food group categorization in this study did not differentiate between healthfulness of products. Although our results indicate otherwise, other nudging studies promoting healthy grains did not show evidence for within-food group substitutions (31, 33). Possibly due to the nudge type used and the specific grains products targeted.

This combination of findings indicates that especially the groups of dairy and grains are promising to target with nudging and pricings strategies to achieve healthier purchases. For grains, the combination of nudging and pricing strategies seems important to enhance within-food group substitutions, whereas for dairy solely implementing nudges also seems promising. Furthermore, real-life effect sizes of the combination of nudging and pricing strategies across food groups need to be established (29). Studies should focus on the promotion of a high number of the healthy foods while simultaneously discouraging unhealthy foods within the same group to promote within-food group substitutions. Multiple food groups across the supermarket should be targeted to enhance a shift towards a healthier dietary pattern on a population level and ultimately have an impact on public health (37).

9.5.1 Conclusion

The current secondary analysis of the SN VirtuMart experiment showed that nudging and pricing strategies do not have an equal effect on purchases for each food group. Dairy products and grains seem to be the most promising food groups to target in order to achieve healthier purchases. These two food groups showed the largest shift in purchasing behaviours to healthier products following the implementation of nudges, salient subsidies, or salient taxes and the combination of all strategies. Future studies should focus on investigating (real-life) purchasing effects of the combination of nudging and pricing strategies equally balanced across multiple food groups in the supermarket.

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SUPPLEMENTARY MATERIAL CHAPTER 9

Shifting towards a healthier dietary pattern through nudging and pricing strategies: a secondary analysis of a randomized virtual supermarket experiment

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Supplementary Figure 1. Participant flow-chart

Supplementary Table 1. The effect of nudging and salient pricing strategies on purchases from various healthy and unhealthy food groups, by study arm[1]

	Nudging condition		Price condition		Price salience condition		Nudging and price salience condition	
	IRR	**95% CI**	**IRR**	**95% CI**	**IRR**	**95% CI**	**IRR**	**95% CI**
Healthy fruits and vegetables								
Total sample	1.00	[0.96, 1.05]						
25% Tax arm			1.01	[0.93, 1.08]	1.04	[0.96, 1.12]	0.98	[0.91, 1.05]
25% Subsidy arm			1.03	[0.96, 1.10]	**1.11**	**[1.03, 1.18]**	1.03	[0.96, 1.10]
25% Tax and Subsidy arm			0.99	[0.92, 1.07]	**1.11**	**[1.03, 1.18]**	**1.09**	**[1.02, 1.18]**
Healthy grains and potatoes								
Total sample	**1.07**	**[1.01, 1.14]**						
25% Tax arm			1.03	[0.93, 1.14]	1.04	[0.94, 1.15]	1.10	[1.00, 1.22]
25% Subsidy arm			1.04	[0.93, 1.16]	**1.22**	**[1.10, 1.35]**	1.11	[1.00, 1.24]
25% Tax and Subsidy arm			1.08	[0.97, 1.19]	**1.11**	**[1.00, 1.23]**	**1.16**	**[1.05, 1.28]**
Healthy dairy products								
Total sample	1.10	[0.99, 1.23]						
25% Tax arm			0.97	[0.81, 1.15]	1.14	[0.96, 1.34]	1.09	[0.92, 1.29]
25% Subsidy arm			1.06	[0.87, 1.28]	**1.26**	**[1.04, 1.52]**	**1.43**	**[1.19, 1.72]**
25% Tax and Subsidy arm			1.02	[0.84, 1.25]	**1.27**	**[1.06, 1.54]**	**1.58**	**[1.31, 1.89]**
Healthy protein products								
Total sample	0.97	[0.89, 1.05]						
25% Tax arm			1.01	[0.88, 1.16]	0.90	[0.79, 1.04]	1.02	[0.89, 1.16]
25% Subsidy arm			1.10	[0.96, 1.25]	**1.15**	**[1.01, 1.32]**	1.05	[0.91, 1.20]
25% Tax and Subsidy arm			0.98	[0.87, 1.11]	1.06	[0.94, 1.20]	1.11	[0.98, 1.25]
Healthy beverages								
Total sample	0.97	[0.88, 1.07]						
25% Tax arm			0.94	[0.80, 1.12]	0.99	[0.83, 1.17]	0.90	[0.76, 1.08]
25% Subsidy arm			0.96	[0.80, 1.16]	1.17	[0.98, 1.40]	0.96	[0.80, 1.16]
25% Tax and Subsidy arm			1.06	[0.91, 1.23]	1.06	[0.91, 1.24]	1.08	[0.92, 1.26]
Healthy fats								
Total sample	0.98	[0.87, 1.11]						
25% Tax arm			0.97	[0.78, 1.20]	0.97	[0.78, 1.20]	0.92	[0.74, 1.15]
25% Subsidy arm			0.89	[0.71, 1.11]	0.86	[0.69, 1.09]	0.82	[0.65, 1.03]
25% Tax and Subsidy arm			1.03	[0.84, 1.26]	0.91	[0.74, 1.12]	1.12	[0.92, 1.36]
Unhealthy grains and potatoes								
Total sample	0.97	[0.91, 1.04]						

25% Tax arm			0.92	[0.81, 1.03]	0.94	[0.83, 1.06]	**0.77**	**[0.68, 0.87]**
25% Subsidy arm			**0.89**	**[0.79, 0.99]**	0.93	[0.83, 1.04]	0.95	[0.85, 1.06]
25% Tax and Subsidy arm			0.91	[0.80, 1.02]	**0.86**	**[0.76, 0.97]**	**0.72**	**[0.63, 0.82]**
Unhealthy dairy products								
Total sample	**0.84**	**[0.79, 0.90]**						
25% Tax arm			**0.88**	**[0.79, 0.98]**	0.93	[0.84, 1.03]	**0.85**	**[0.76, 0.94]**
25% Subsidy arm			**0.90**	**[0.81, 0.99]**	**0.82**	**[0.74, 0.91]**	**0.80**	**[0.72, 0.88]**
25% Tax and Subsidy arm			0.97	[0.86, 1.09]	**0.80**	**[0.71, 0.91]**	**0.77**	**[0.68, 0.87]**
Unhealthy beverages								
Total sample	0.93	[0.87, 1.00]						
25% Tax arm			0.89	[0.78, 1.01]	0.90	[0.80, 1.02]	**0.85**	**[0.75, 0.97]**
25% Subsidy arm			1.01	[0.90, 1.14]	1.02	[0.91, 1.14]	0.95	[0.85, 1.07]
25% Tax and Subsidy arm			0.99	[0.87, 1.11]	0.98	[0.87, 1.11]	0.99	[0.87, 1.11]
Unhealthy snacks								
Total sample	1.02	[0.95, 1.09]						
25% Tax arm			0.98	[0.86, 1.11]	0.90	[0.79, 1.02]	0.90	[0.80, 1.02]
25% Subsidy arm			1.01	[0.90, 1.13]	1.08	[0.97, 1.21]	1.00	[0.89, 1.12]
25% Tax and Subsidy arm			0.93	[0.82, 1.05]	**0.85**	**[0.75, 0.96]**	0.89	[0.78, 1.00]
Unhealthy other products								
Total sample	0.98	[0.93, 1.03]						
25% Tax arm			0.93	[0.85, 1.02]	0.94	[0.86, 1.03]	**0.87**	**[0.79, 0.95]**
25% Subsidy arm			0.93	[0.85, 1.02]	0.99	[0.90, 1.08]	0.93	[0.85, 1.01]
25% Tax and Subsidy arm			0.92	[0.84, 1.00]	**0.88**	**[0.81, 0.96]**	0.97	[0.89, 1.05]
Unhealthy protein products								
Total sample	0.95	[0.90, 1.01]						
25% Tax arm			0.98	[0.89, 1.08]	0.95	[0.87, 1.05]	1.00	[0.90, 1.10]
25% Subsidy arm			0.93	[0.85, 1.03]	0.99	[0.90, 1.09]	0.97	[0.88, 1.06]
25% Tax and Subsidy arm			0.90	[0.80, 1.00]	0.91	[0.82, 1.02]	**0.81**	**[0.73, 0.91]**
Unhealthy fats								
Total sample	0.99	[0.84, 1.17]						
25% Tax arm			1.02	[0.77, 1.36]	0.92	[0.69, 1.24]	1.07	[0.81, 1.42]
25% Subsidy arm			**1.36**	**[1.02, 1.81]**	0.90	[0.65, 1.23]	1.11	[0.82, 1.50]
25% Tax and Subsidy arm			0.84	[0.65, 1.10]	0.85	[0.66, 1.11]	0.88	[0.68, 1.14]

[1]Analysis was based on a generalized linear mixed model with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% confidence intervals (CI) for changes in products purchased within all food groups during the four experimental conditions in comparison to the control condition; Bold values represent statistically significant outcomes

Supplementary Table 2. The effect of nudging and various pricing strategies on purchases from various healthy and unhealthy food groups (*n*=318)[1]

	Price condition		Price salience condition		Nudging and price salience condition	
	IRR	**95% CI**	**IRR**	**95% CI**	**IRR**	**95% CI**
Healthy fruits and vegetables						
Total sample	1.01	[0.97, 1.05]	**1.09**	**[1.04, 1.13]**	1.03	[0.99, 1.08]
Healthy grains and potatoes						
Total sample	1.05	[0.99, 1.11]	**1.12**	**[1.06, 1.19]**	**1.12**	**[1.06, 1.19]**
Healthy dairy products						
Total sample	1.02	[0.91, 1.13]	**1.22**	**[1.10, 1.36]**	**1.36**	**[1.23, 1.51]**
Healthy protein products						
Total sample	1.03	[0.95, 1.11]	1.04	[0.97, 1.13]	1.06	[0.98, 1.14]
Healthy beverages						
Total sample	0.99	[0.89, 1.09]	1.07	[0.97, 1.18]	0.98	[0.89, 1.08]
Healthy fats						
Total sample	0.96	[0.85, 1.09]	0.91	[0.8, 1.04]	0.95	[0.84, 1.08]
Unhealthy grains and potatoes						
Total sample	**0.90**	**[0.84, 0.97]**	**0.91**	**[0.85, 0.98]**	**0.82**	**[0.77, 0.88]**
Unhealthy dairy products						
Total sample	0.91	[0.86, 0.97]	**0.85**	**[0.80, 0.90]**	**0.80**	**[0.75, 0.86]**
Unhealthy beverages						
Total sample	0.96	[0.90, 1.03]	0.97	[0.91, 1.04]	0.93	[0.87, 1.00]
Unhealthy snacks						
Total sample	0.97	[0.91, 1.04]	0.95	[0.88, 1.02]	**0.93**	**[0.87, 1.00]**
Unhealthy other products						
Total sample	**0.93**	**[0.88, 0.98]**	**0.94**	**[0.89, 0.99]**	**0.92**	**[0.87, 0.97]**
Unhealthy protein products						
Total sample	**0.93**	**[0.88, 0.99]**	0.95	[0.90, 1.01]	**0.93**	**[0.87, 0.98]**
Unhealthy fats						
Total sample	1.07	[0.91, 1.26]	0.89	[0.75, 1.06]	1.01	[0.86, 1.19]

[1]Analysis was based on a generalized linear mixed model with a Conway-Maxwell Poisson distribution with a random intercept at the participant level, to estimate the incidence rate ratios (IRR) and 95% confidence intervals (CI) for changes in products purchased within all food groups during the four experimental conditions in comparison to the control condition; Bold values represent statistically significant outcomes.

CHAPTER 10

Impact of taxes on purchases of close substitute foods: Analysis of cross-price elasticities using data from a randomized experiment

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10.1 Abstract

Objective To examine the effects of health-related food taxes on substitution and complementary purchases *within* food groups, including from unhealthier to healthier alternatives and between brands.

Methods We used data from a virtual supermarket experiment with data from 4,259 shopping events linked to varying price sets. Substitution or complementary effects within six frequently purchased food categories were analysed. Products' own- and cross-price elasticities were analysed using Almost Ideal Demand System models.

Results Overall, 37.5% of cross-price elasticities were significant ($p<0.05$) and included values greater than 0.10. Supplementary and complementary effects were particularly found in the dairy, meats and snacks categories. For example, a 1% increase in the price of high saturated fat dairy was associated with a 0.18% (SE 0.06%) increase in purchases of low saturated fat dairy. For name- and home-brand products, significant substitution effects were found in 50% (n=3) of cases, but only in one case this was above the 0.10 threshold.

Conclusions/policy implications Given the relatively low own-price elasticities and the limited substitution and complementary effects, relatively high taxes are needed to substantively increase healthy food purchases at the population level.

10.2 Introduction

A suboptimal diet is an important preventable risk factor for non-communicable diseases (NCDs) (1). For example, high consumption of sodium and sugar sweetened beverages is associated with cardiovascular disease (2) and type 2 diabetes (3). A systematic review investigating different intervention strategies found that health-related fiscal interventions showed the most promise in improving diets (4). Studies investigating the effect of health-related taxes and subsidies have generally found that subsidies on healthy foods effectively increase purchases of targeted products, and taxes on unhealthy foods decrease purchases of targeted products (4, 5). However, these effects may not necessarily translate into healthier diets. For example, while studies generally find that a sugar sweetened beverages (SSB) tax decreases SSB purchases (6, 7), the effect of taxes on diet may be weakened if the taxed foods and beverages are replaced by other untaxed or cheaper unhealthy foods and beverages (hereafter referred to as foods) such as home-brand products (8).

Substitution effects are an important determinant of the ultimate impact of health-related taxes and subsidies (9). For example, the Price ExaM Study examined the effect of subsidies and taxes on food purchasing behaviour and found that a saturated fat tax resulted in a 16.2% (95%CI -18.8; -13.6) decrease of saturated fat, but also a 5.0% (95%CI 2.1; 7.9) increase of sugar as a percentage of total energy purchased (10). These substitution effects can be quantified using cross-price elasticity values. Positive cross-price elasticities indicate that foods are substitutes and negative cross-price elasticities indicate that foods are complements (11) and cross-price elasticities are likely to be larger when there are close substitutes/complements for a certain food (e.g. within the same food group) (12).

Currently, adequate data for the estimation of cross-price elasticities is lacking (5, 13). When studies include cross-price elasticities, reported food groups are often highly aggregated (e.g. all soft drinks) as opposed to the level of disaggregation that is required to study detailed substitution effects (e.g. from regular soft drinks to diet soft drinks) (14). The high level of aggregation usually arises because most studies use nutrition survey data to estimate price elasticities (i.e. modelling studies), which often do not include the level of detail needed to sufficiently estimate the price elasticities of, for example, name- and home-brand products (15). Using empirical purchasing data provides a unique opportunity to construct the disaggregated food groups needed to be able to estimate price elasticities for smaller food groups.

Experimental studies in validated virtual supermarket environments allow for the measurement of own- and cross-price elasticities for food groups of interest before policies are implemented in real-world settings (16). The aim of this study was to examine the substitution and complementary effects of health-related food and beverage taxes within food groups, including from unhealthier to healthier alternatives and between different brand alternatives. Our hypothesis was that if the price of products high in sugar, sodium and saturated fat would increase, individuals would substitute these products with healthier alternatives within that same food group. Also, we expected that home-brand products were substitutes for name-brand products.

10.3 Methods

We used data from the Price Experiment and Modelling (Price ExaM) Study. A study protocol for the Price ExaM Study, including a full description of the experiment and modelling methods, has been published elsewhere (17) as well as the overall results of the Price ExaM study (10, 11). The Price ExaM Study was an experimental study conducted in 2016 in a virtual supermarket (VS) setting where participants were exposed to random price variations simulating an average New Zealand supermarket (the control price set), a fruit and vegetable subsidy, an SSB tax, a saturated fat tax, a salt tax, or a sugar tax. Full details about this study can be found elsewhere (10, 17), but a brief description is provided below.

10.3.1 Price ExaM Study

The main aim of the Price ExaM Study was to provide high quality evidence on the impact of health-related food taxes and subsidies by estimating precise and accurate own-price and cross-price elasticities (17). For this, 5000 different price sets were created with random price variations for all 1411 food and beverage products within the VS (17). In addition to including random price variations, the price sets also included systematic price variations for foods and beverages to simulate several subsidy and taxing policy scenarios, including a SSB tax (at either 20% or 40%), a saturated fat tax (NZ$2 per 100g and NZ$4 per 100g), a salt tax (NZ$0.02 per 100mg; equivalent to NZ$0.04 per 100mg sodium), a sugar tax (NZ$0.20 per 100g and NZ$0.40 per 100g), and a 20% fruit and vegetable subsidy. Some price sets included two or more tax and subsidy options affecting food prices.

From February 2016 to December 2016, 2352 participants were registered in the study. In total, 1132 participants were randomly assigned to the different price sets in the VS. Mean age of participants was 32.9 years (SD 12.5), 79.2% were female, 67% had completed tertiary level education, and 71.3% were New Zealand European.(10) Overall, 743 (71.6%) completed the study (i.e. conducted all five shops). The Price ExaM Study was approved by the University of Auckland Human Participants Ethics Committee (reference 016151) (17).

10.3.2 Data preparation for the current study

From the Price ExaM Study, we included data available from all 4259 shopping events; including price variations and correlating shopping patterns of 18 food categories. From this dataset, those food categories including products that were frequently purchased were selected, this included six food categories: beverages, grains, dairy, meat, sauces and snacks (including desserts). Fruit and vegetables were excluded because all products in this category are generally healthy and therefore the substitution effects within these groups are not of great interest from a public health perspective. All food categories were disaggregated into smaller food groups based on their sugar, sodium and saturated fat (SAFA) content. Cut-off values for low, medium or high levels of sugar/sodium/SAFA were based on the traffic light label threshold guidelines of the United Kingdom, which can be applied to all types of foods and non-alcoholic beverages (18, 19). Food categories were only disaggregated into the smaller nutritional clusters when these categories included products within all three levels of sugar, sodium and/or SAFA. An example of a nutritional cluster is dairy foods with low, medium and high levels of sodium and SAFA. The food category dairy was not further disaggregated into groups of products with varying levels of sugar as no dairy products fell into the high-sugar category. Supplementary Table 1 displays the different food groups and their cut-off points and Supplementary Tables 2a and 2b display the food items found within the nutritional clusters.

In order to assess the overall healthiness of purchases, foods were categorized as healthy or unhealthy. This is important as it is possible for foods to contain a low amount of one adverse nutrient (e.g. sugar) but a high amount of another nutrient (e.g. sodium), meaning that such foods are not necessarily healthier overall. Fresh fish and packaged foods eligible to carry a health claim based on the New Zealand and Australian government-endorsed nutrient profiling system (Nutrient Profiling Scoring Criterion (20)) were classified as healthy. All other foods were classified as unhealthy. Supplementary Table 3 displays the nutrient content and the percentage of products classified as healthy within the nutritional clusters. In all cases but one, low sugar/sodium/SAFA clusters included more healthy products compared to medium or high sugar/sodium/SAFA clusters. Also, nutritional clusters high in sugar/sodium/SAFA included far less healthy products compared to nutritional clusters with medium levels of sugar/sodium/SAFA. For beverages, grains, dairy and meats, the sugar/sodium/SAFA nutrients seem to cluster together, e.g. medium and high sugar beverages also contain relatively high amounts of sodium and medium and high sodium dairy also contain high amounts of saturated fat.

For name- and home-brand food groups, food categories with at least 20 home-brand products were selected. The resulting food categories that were divided into name- and home-brand food groups included beverages, grains and snacks. The name- and home-brand food groups generally included a similar percentage of healthy products, with the exception of grains where 59.7% of name-brand products were classified as healthy compared to 80.0% of home-brand products (Supplementary Table 3).

10.3.3 Data analyses

10.3.3.1 The Almost Ideal Demand System model

Using price elasticities, we can determine the percentage change in the demand for product X if its own price changes (own-price elasticity) or if the price of other products (Y, Z) changes (cross-price elasticity) (21). Typically, items that are consumed together (complementary products) have a negative cross-elasticity, while items that can be substituted (e.g. coffee for tea) have a positive cross-elasticity. In this study, substitution and complementary effects were examined using uncompensated cross-price elasticities modelled by the Almost Ideal Demand System (AIDS) (22). Uncompensated price elasticities estimate the impact of a price increase on food purchases when consumers' money income is held constant (23). Analysis was at the level of the household, not the individual, as participants in the virtual supermarket conducted shopping events for their entire household. Analyses were conducted using the package 'quaids' by Poi in STATA version 15.0 (24). The package 'quaids' is a user-friendly and widely used package (e.g. (25-27)) that allows researchers to fit the AIDS model without writing their own program and to adjust for demographic variables and clustered data. Using a validated econometrics package helps with model quality control as well. Censored data are usually not a problem within the 'quaids' model when analysing data from aggregated food groups.

However, given that estimations within the package only run at a minimum of three goods within disaggregated food groups, this presented a larger problem. While data on all 4259 shopping events were used to estimate the price elasticities (i.e. no distinction between the different taxing policy scenarios were made), the data was censored as zero-purchasers were excluded from the analyses; only shopping events where participants purchased at least one product in each nutritional cluster were included (e.g. only shops with products purchased from low, medium and high nutritional clusters within the dairy category). This led to each AIDS model consisting of different numbers of shopping events. Nevertheless, the AIDS model estimated by the 'quaids' package was preferred over other models to calculate cross-price elasticities as it satisfies micro-economics restrictions such as adding-up and allowed for the estimation of uncompensated (Marshallian) elasticities. Uncompensated price elasticities are most commonly reported in studies and are arguably most relevant for policy (28).

In total, N=12 AIDS models were run, leading to a total of N=36 own-price elasticities and N=72 cross-price elasticities across all food groups. Although we used data from a randomized experiment, our models were adjusted for age, sex, highest attained educational level, ethnicity of the main shopper and household size because the number of participants in certain arms were low (10). Statistical significance was set at a p-value of <0.05 and a relevant effect size for cross-price elasticities was set at cross-price elasticities ≥ 0.10. Results regarding the expenditure and compensated price elasticities can be found in the Supplementary Material.

10.3.3.2 The double log model

AIDS models with only two groups are reduced to only one equation to be estimated. Given the microeconomic restrictions such as adding-up and symmetry on the estimated parameters, the one equation will be reduced to a very strict functional form and hence can produce unreliable estimates (22). Therefore, the double log model was used to calculate price elasticities for name- and home-brand products within each aggregate food category (29). Linear mixed models with the quantity of name- or home-brand products sold within each food category were used as the dependent variable. The independent variables included the prices of the name- and home-brand products and demographic variables. In order to calculate own- and cross-price elasticities, the standard log-log functional form of the dependent and independent variables was applied, as was done in this previous study (29).

10.4 Results

Tables 1 and 2 show the data used to estimate the price elasticities for the nutritional clusters and name- and home-brand food groups (Supplementary Table 4 shows this information for the control condition and the experimental conditions separately). Fresh and frozen meats represent 24% of the total expenditure on average, while sauces only represent 6%. Also, purchases of at least one item within food groups during the five-week study period varied from 8% for low-sodium sauces to 90% for low-sugar grains. The price per 100 grams for nutritional clusters high in sugar/sodium/SAFA within the aggregate categories grains, dairy and meat are higher compared to the nutritional clusters that are low or medium in sugar/sodium/SAFA content. Regarding name- and home-brand food groups, the price per 100 grams of name-brand products was higher, while the purchases of name- and home-brand products was approximately equal, resulting in higher expenditures for name-brand compared to home-brand food groups (Table 2). The triangles in Figure 1 indicate that if the price of foods increased by one percent, purchases of targeted foods decreased by approximately 0.30% to 1.10%. Overall, 26 of 36 uncompensated own-price elasticities were inelastic (i.e. less than one) (Figure 1; symbolized by triangles). In 6 out of the 12 nutritional clusters, the own-price elasticities of clusters high in sugar/sodium/SAFA were lower than the price elasticities found in low and medium sugar/sodium/SAFA clusters.

Table 1. Median price, purchases, expenditure and expenditure shares for households in the nutritional clusters (excluding zero purchases)

Aggregate food categories[1]	Nutritional clusters	Number of shopping events (% of those included compared to overall shops)	Price per 100g in NZ$		Purchased quantity in grams		Expenditure in NZ$	
			Median	IQR	Median	IQR	Median	IQR
Beverages	Low-sugar	2386 (56%)	3.38	5.25	300	1400	7.89	8.29
	Medium-sugar	3530 (83%)	0.21	0.07	3500	3000	7.02	7.46
	High-sugar	582 (14%)	0.52	0.91	1000	1135	3.79	2.21
Grains	Low-sugar	3815 (90%)	0.52	0.33	1982	2300	10.52	11.22
	Medium-sugar	1361 (32%)	1.11	0.73	500	440	5.50	3.97
	High-sugar	932 (22%)	1.14	1.28	650	1000	6.00	4.49
	Low-sodium	2540 (60%)	0.32	0.29	1500	1650	5.38	5.82
	Medium-sodium	3696 (87%)	0.68	0.41	1360	1470	9.23	10.48
	High-sodium	906 (21%)	1.49	1.23	350	530	4.46	1.84
Dairy	Low-sodium	3599 (85%)	0.27	0.14	3000	2375	8.75	8.62
	Medium-sodium	474 (11%)	2.54	2.11	250	300	6.52	4.61
	High-sodium	2181 (51%)	1.85	1.59	900	750	11.15	7.24
	Low-SAFA	1271 (30%)	0.25	0.44	2000	1250	5.38	3.82
	Medium-SAFA	3114 (73%)	0.25	0.14	2225	2000	7.04	6.65
	High-SAFA	2455 (58%)	1.81	1.47	900	650	11.75	9.15
Meat	Low-SAFA	3065 (72%)	1.91	0.71	750	760	13.14	14.38
	Medium-SAFA	3155 (74%)	1.93	0.62	855	900	16.31	17.28
	High-SAFA	2512 (59%)	1.79	0.78	770	770	12.63	12.40
	Low-sodium	3491 (82%)	1.95	0.61	1210	1250	23.51	25.56
	Medium-sodium	2617 (61%)	1.72	0.62	600	610	9.90	10.64
	High-sodium	1522 (36%)	1.97	1.14	480	500	10.31	9.04
Sauces and seasonings	Low-sugar	1614 (38%)	1.18	1.35	495	470	4.89	4.27
	Medium-sugar	1212 (29%)	1.19	0.97	400	300	4.29	2.71
	High-sugar	1206 (28%)	1.10	0.60	520	460	5.04	4.28
	Low-sodium	357 (8%)	1.25	0.74	500	30	6.63	3.17
	Medium-sodium	1679 (39%)	0.90	0.62	500	581	4.87	4.53
	High-sodium	1664 (39%)	1.44	0.88	400	380	5.18	4.83
Snacks	Low-sugar	2589 (61%)	1.64	0.83	350	390	5.47	6.21
	Medium-sugar	1840 (43%)	1.33	1.26	420	750	5.52	4.90
	High-sugar	2828 (66%)	1.77	0.84	490	690	8.40	9.42
	Low-sodium	2675 (63%)	1.74	1.43	500	1062	7.93	9.02
	Medium-sodium	2723 (64%)	1.57	0.66	450	540	6.99	7.92
	High-sodium	1871 (44%)	1.66	0.75	250	270	4.19	4.32
	Low-SAFA	2011 (47%)	1.43	1.04	375	375	4.51	4.65
	Medium-SAFA	1729 (41%)	1.87	0.98	250	290	4.78	4.84
	High-SAFA	3163 (74%)	1.66	0.86	600	925	9.81	11.67

[1] Milk is considered a beverage as well as a dairy product – all other foods and beverages are mutually exclusive within the nutritional clusters

Abbreviations: IQR; Interquartile Range

Table 2. Median price, purchases, expenditure and expenditure shares for households in name- and home-brand food groups (excluding zero purchases)

Aggregate food categories	Name- and home-brand food groups	Number of shops (% of shops included compared to overall shops)	Price per 100g in NZ$		Purchased quantity in grams		Expenditure in NZ$	
			Median	IQR	Median	IQR	Median	IQR
Beverages	Name-brand	3189 (75%)	0.43	0.91	2000	3226	10.13	12.04
	Home-brand	2447 (58%)	0.19	0.06	2000	2000	4.89	4.69
Grains	Name-brand	3474 (82%)	0.81	0.48	1400	1555	10.74	11.98
	Home-brand	2619 (62%)	0.30	0.16	1500	1890	4.71	5.73
Snacks	Name-brand	3390 (80%)	1.76	0.72	647	870	10.99	13.46
	Home-brand	2021 (48%)	1.16	0.96	390	700	5.17	5.05

Abbreviations: IQR; Interquartile Range

The uncompensated cross-price elasticities show substitutive (Figure 1; symbolized by the dots above the zero) as well as complementary (Figure 1; symbolized by the dots below the zero) relationships with other foods within the same nutritional cluster. Larger uncertainty intervals apparent in Figure 1 correspond to more zero-purchases within the three levels found in nutritional clusters (Table 1; column 3). Exact price elasticities displayed in Figure 1 can be found in Supplementary Table 6. Statistically significant substitution and complementary effects were found in n=16 (22%) and n=26 (36%) of all cases, respectively. Of these significant cross-price elasticities, n=11 substitutions and n=16 complements were larger than the cut-off of 0.10. Patterns of substitution or complementary effects differed widely between nutritional clusters, i.e. no consistent pattern of substitution or complementary purchasing was evident. Within food groups with a high level of sugar/sodium/SAFA (i.e. food groups likely to be targeted by a health-related tax), some beneficial substitution and complementary effects were found in the food categories dairy, meats, and snacks. For example, a one percent increase in the price of high-sugar snacks was associated with 0.09% (SE 0.03) decrease in purchases of low-sugar snacks and a 0.20% (SE 0.03) increase in purchases of medium-sugar snacks (Supplementary Table 6).

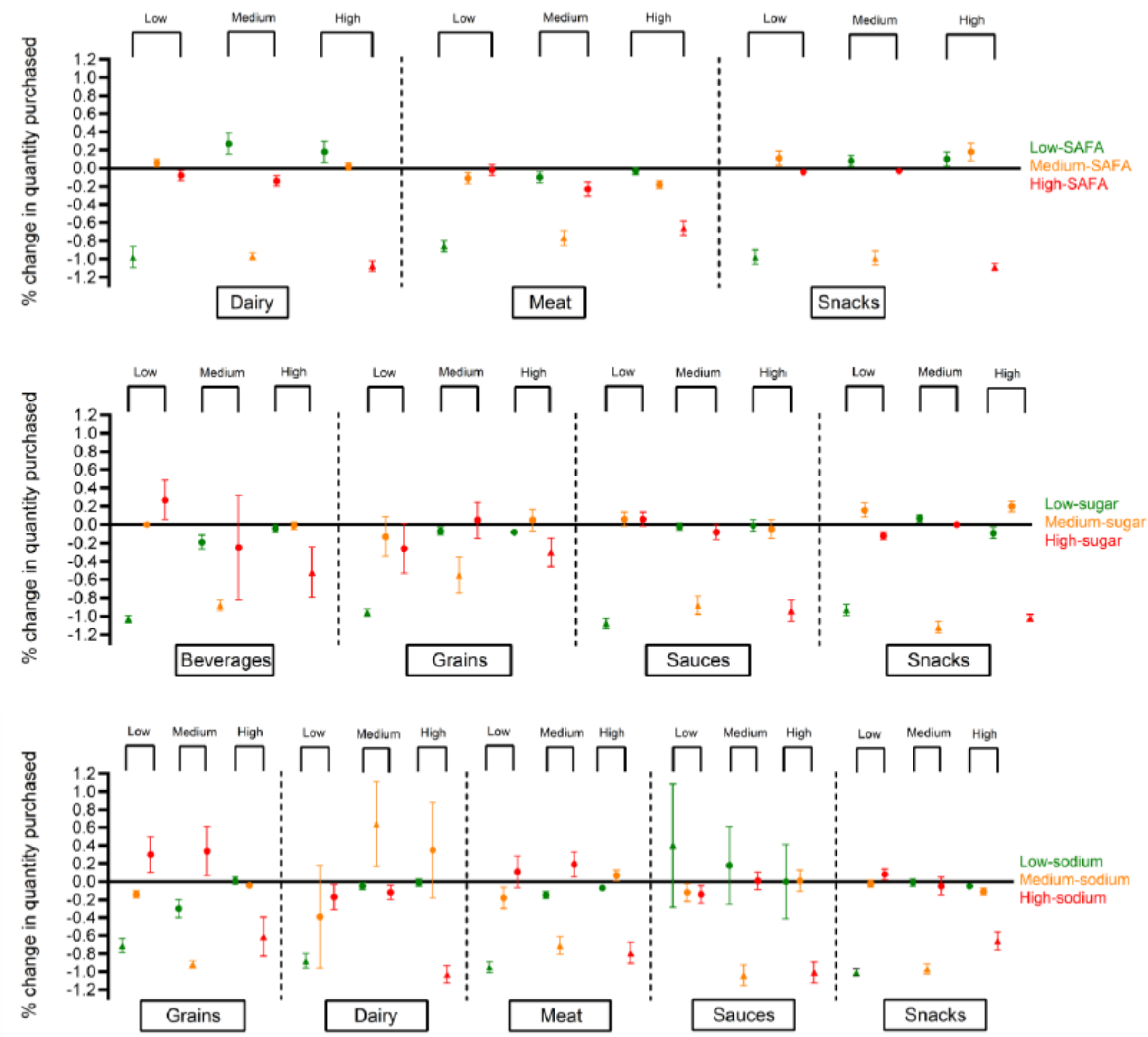

Figure 1. Change in demand (%) as a response to a 1% price increase of low, medium or high SAFA/sugar/salt containing categories adjusted for demographic variables. Uncompensated own-price elasticities are displayed as triangles and uncompensated cross-price elasticities are displayed as dots. Dots above the line represent substitution effects and dots below the line represent complementary effects.

For beverages and grains, own-price elasticities of name-brand products are higher than those of home-brand products (Figure 2 and Supplementary Table 8). Statistically significant substitution effects were found in n=3 (50%) of cases, but only in one case this was above the 0.10 threshold; a one percent price increase in name-brand snacks was associated with a 0.12% (SE 0.04) increase in purchases of home-brand snacks.

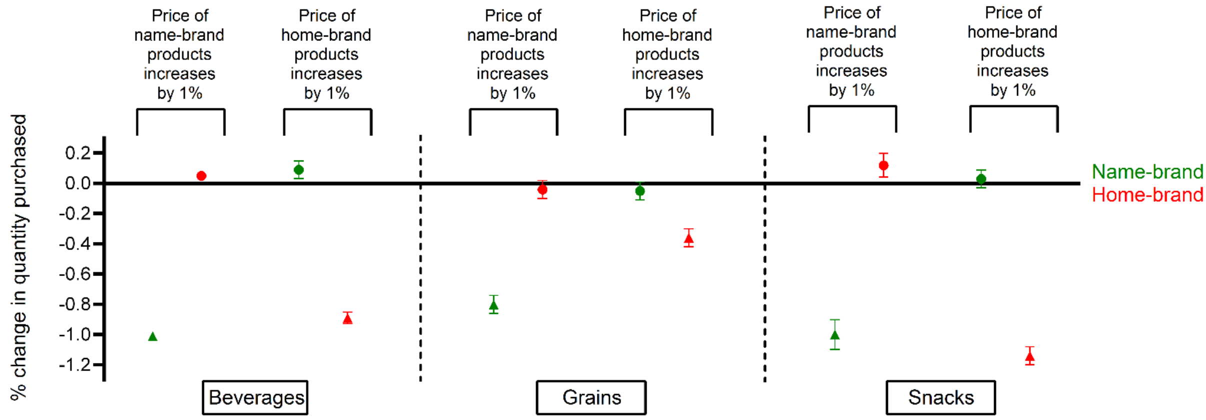

Figure 2. Change in demand (%) as a response to a 1% price increase in name- and home-brand categories adjusted for demographic variables. Own-price elasticities are displayed as triangles and cross-price elasticities are displayed as dots. Dots above the line represent substitution effects and dots below the line represent complementary effects.

10.5 Discussion

We investigated the effect of health-related food taxes on consumer purchases of targeted and non-targeted alternatives within the same food group in a supermarket setting. This led to the better understanding of the potential unintended product substitution and complementary effects. As also demonstrated in previous Price ExaM Studies (10, 11), taxing products high in sugar/sodium/SAFA (i.e. unhealthier foods) leads to modest decreases in purchases of targeted products according to their own-price elasticities. Uncompensated price elasticities showed both complementary and substitution effects within some specific unhealthier food clusters. Furthermore, substitutions from name-brand to home-brand beverages and snacks were observed, but these were relatively small (i.e. most were smaller than 0.10).

We found that if the prices of foods increased by 10%, purchases of targeted foods typically decreased by approximately 3% to 11%. Most uncompensated own-price elasticities were inelastic (i.e. smaller than 1 in absolute value). This finding is in line with previous studies (9, 30) and unsurprising given the fact that food is considered a necessity. In approximately half of the clusters, the own-price elasticities of clusters high in sugar/sodium/SAFA were lower compared to clusters with low and medium amounts of sugar/sodium/SAFA. The largely inelastic own-price elasticities and the even lower own-price elasticities of clusters high in sugar/sodium/SAFA compared to clusters with lower amounts of sugar/sodium/SAFA suggests that when implementing taxes to achieve health goals, it may be preferable to apply substantive taxes (i.e. above 20% (31, 32)). Although the percentage decrease in purchases is disproportionate to the percentage increase in price, larger taxes will lead to larger purchasing changes compared to smaller taxes.

We observed that health-related taxes alter food and beverage purchases in a rather complex fashion, with only some of the substitution and complementary effects supporting the goal of the health-related taxes. Patterns in uncompensated cross-price elasticities varied between food categories, where some substitution or complementary effects towards healthier options were observed in snacks, meat and dairy and no effects were observed in beverages, grains and sauces. When it came to substitutions from name-brand foods to home-brand foods, we found that within two of the three food categories examined (i.e. beverages and snacks), cheaper and equally unhealthy home-brand foods were substituted for name-brand foods.

Given the detailed data needed to estimate these cross-price elasticities, few similar studies are available with which to compare our results. The finding that name- and home-brand products are substitutes has been reported previously, but including smaller food groups (e.g. breakfast cereals and mayonnaise) (14). Regarding within food group substitutions to healthier alternatives, most studies to date have focused on beverages. Our findings suggest that if the price of sugary beverages increases, individuals purchase fewer taxed sugary beverages, but there is no change in the purchases of healthier beverages. However, previous evidence suggests that a SSB tax leads to substitutions with water (albeit not at a statistically significant level) (6, 33, 34). Furthermore, similar to this study, a paper investigating cross-price elasticities within nutritionally clustered food groups using supermarket food purchasing data found relatively small within food group substitution effects (30).

The results of the uncompensated price elasticities analyses seem to imply that within food group substitutions and complements contributed minimally to the effects found in the main Price ExaM Study where a saturated fat, sugar and salt tax led to a 16%, 5% and 20% decrease in purchases of saturated fat, sugar and sodium as a percentage of total energy (10). While the current study found limited substitution or complementary purchases, it is possible that between food group substitutions have taken place (30). A study that investigated between food groups substitutions found for example that a 10% price increase in high-sugar soft drinks led to a 1% increase in the purchases of chocolate and confectionary (21). Based on the small health-related substitution and complementary effects found in this study, it seems that the indirect effects of health-related food taxes do not necessarily enhance the overall health effects. However, these strategies also do not seem to lead to any unintended effects either.

While there is a wealth of evidence demonstrating that health-related taxes lead to healthier food purchases (4, 5, 9), it is still important to further investigate potential unintended effects of health-related taxes on food purchases and consumption. It is likely that not many studies have attempted to calculate cross-price elasticities within food groups due to the detailed and large dataset required. While we attempted to describe the unintended effects of health-related taxes on food purchases of close substitutes, our estimations may suffer from selection bias as the dataset is censored because zero-purchasers were excluded. This bias may differ by food groups; the percentage of shopping events included in the sauces and seasoning category ranged from 8% to 39% of the total observations, while this percentage in the meat category ranged from 36% to 82%. A previous study compared a quadratic AIDS model adjusted for zero purchases to a quadratic AIDS model unadjusted for zero purchases, and found that the price elasticities in the unadjusted model were smaller than those found in the adjusted model (12). The results from this previous study suggest that our results provide a conservative estimate.

Nevertheless, the AIDS model was preferred over more simple models that account for zero purchases (e.g. double hurdle models) as it satisfies micro-economics restrictions such as adding-up. Also, this study makes an implicit assumption that substitutions only take place *within* food groups; *between* food group substitutions could also take place. This may contradict the basis of AIDS models imposing prior constraints on the substitution process. Nevertheless, our approach implicitly assumed a multistage demand model (35) and this multistage demand model has been previously used in combination with an AIDS model (36). More research regarding substitution effects of name- and home-brand products within other food categories is needed. Also, the effects of price changes on substitutions from unhealthy to healthier products within other categories (e.g. ready-made meals) could be investigated, but would require an even larger sample size than the present. Furthermore, as responses to price changes likely vary by cultural norms, more culture-specific and context-specific research is needed (10).

By gaining more insight into substitution and complementary effects, health-related taxes can be adapted correspondingly to further increase its effectiveness on food purchases. One example of investigating the impact of unintended cross price elasticities is to model food pricing interventions through a multi-state lifetable in order to calculate health outcomes for a specific population (11). However, it should be noted that as our uncompensated cross-price elasticities were estimated based on the assumption that food expenditure was held constant, some adjustment must be made (e.g. using the total food expenditure elasticity) when using the price elasticities to calculate food purchases (37).

Strengths of this study included the randomized repeated measures design allowing us to collect precise and specific food price elasticity data (10) and the relatively large sample size. This allowed for the construction of nutritional clusters that represent distinct sets of products within various food categories, which is often not possible when using subjective measures and less-detailed data. A limitation of this study - not including the limitations with regards to the AIDS model described above - is that despite that the VS environment has been validated and reflects real life purchases, virtual purchases may not be directly generalizable to the real world. For example, price changes in the virtual environment were not conveyed to participants, whereas real-life price changes are often communicated to consumers, likely resulting in larger effects (38).

10.5.1 Conclusion

This study examined the impact of health-related food taxes on purchasing of close substitute foods. Analyses presented suggest that food taxes lead to minimal *within* food group substitutions or complements. Given the relatively low own-price elasticities and the limited health-related substitution and complementary effects, relatively high tax rates are needed to substantively increase the proportion of healthy food purchases at the population level.

10.6 References

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SUPPLEMENTARY MATERIAL CHAPTER 10

Impact of taxes on purchases of close substitute foods: Analysis of cross-price elasticities using data from a randomized experiment

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Supplementary Table 1. Food category and corresponding food classification to food groups based on sugar, sodium or SAFA content of products

Food category	Low cut-off value	Medium cut-off value	High cut-off value	Nutritional clusters
Beverages	<2.5g sugar per 100ml	2.5-11.25g sugar per 100ml	>11.25g sugar per 100ml	Low-sugar beverages
				Medium-sugar beverages
				High-sugar beverages
Grain products (cereals and bread)	<5g sugar per 100g	5-22.5g sugar per 100g	>22.5g sugar per 100g	Low-sugar grains
				Medium-sugar grains
				High-sugar grains
	<120mg sodium per 100g	120-600mg sodium per 100g	>600mg sodium per 100g	Low-sodium grains
				Medium-sodium grains
				High-sodium grains
Dairy	For food: <120mg sodium per 100g For milk: <120mg sodium 100ml	For food: 120-600mg sodium per 100g For milk: 120-300mg sodium per 100ml	For food: >600mg sodium per 100g For milk: >300mg sodium per 100ml	Low-sodium dairy
				Medium-sodium dairy
				High-sodium dairy
	For food: <1.5g SAFA per 100g For milk: <0.75g SAFA per 100ml	For food: 1.5-5g SAFA per 100g For milk: 0.75-2.5g SAFA per 100ml	For food: >5g SAFA per 100g For milk: >2.5g SAFA per 100ml	Low-SAFA dairy
				Medium-SAFA dairy
				High-SAFA dairy
Fresh and frozen meat	<1.5g SAFA per 100g	1.5-5g SAFA per 100g	>5g SAFA per 100g	Low-SAFA meats
				Medium-SAFA meats
				High-SAFA meats
	<120mg sodium per 100g	120-600mg sodium per 100g	>600mg sodium per 100g	Low-sodium meats
				Medium-sodium meats
				High-sodium meats
Sauces and seasonings	<120mg sodium per 100g	120-600mg sodium per 100g	>600mg sodium per 100g	Low-sodium sauces
				Medium-sodium sauces
				High-sodium sauces
	<5g sugar per 100g	5-22.5g sugar per 100g	>22.5g sugar per 100g	Low-sugar sauces
				Medium-sugar sauces
				High-sugar sauces
Snack foods and desserts	<120mg sodium per 100g	120-600mg sodium per 100g	>600mg sodium per 100g	Low-sodium snacks
				Medium-sodium snacks
				High-sodium snacks
	<1.5g SAFA per 100g	1.5-5g SAFA per 100g	>5g SAFA per 100g	Low-SAFA snacks
				Medium-SAFA snacks
				High-SAFA snacks
	<5g sugar per 100g	5-22.5g sugar per 100g	>22.5g sugar per 100g	Low-sugar snacks
				Medium-sugar snacks
				High-sugar snacks

Supplementary Table 2a. List of smaller food groups found within the aggregate food categories

Food category	Nutrient-based food groups	Smaller food groups found within nutritional clusters
Beverages	Low-sugar beverages	*Tea*
		Coffee
		Sugar free soft and energy drinks
		Flavoured water
		Water
		Soy milk
	Medium-sugar beverages	*Dairy milk*
		Fruit and vegetable juices
		Sugar-sweetened soft drinks
		Flavoured milk
	High-sugar beverages	Fruit and vegetable juices
		Sugar-sweetened soft drinks
		Flavoured soy milk
		Flavoured milk
Grain products (cereals and bread)	Low-sugar grains	*Unflavoured rice (white and wholegrain rice)*
		Flavoured white rice
		All pastas (i.e. packet, canned, plain dry and fresh)
		Flour
		Noodles
		Oats
		All breads (i.e. mixed grain, white and other)
		Couscous
		Wheat breakfast cereals
	Medium-sugar grains	*Muesli*
		Bagels
		Savoury pastries
		Quinoa
		Breakfast cereals
	High-sugar grains	*Oats*
		Sweet pastries
		Breakfast cereals
		Sugar
	Low-sodium grains	*Sweet pastries*
		Wholegrain rice
		Flour
		Muesli
		Noodles
		Oats
		Couscous
		Plain dry pasta
		Quinoa
		Breakfast cereal
		Sugar
		Unflavoured rice (white and wholegrain rice)
	Medium-sodium grains	*Mixed grain sandwich bread*
		Noodles
		Other bread
		Packet pasta
		Sweet pastries
	High-sodium grains	Flour
		Noodles
		Other bread
		Packet pasta
		Savoury pastries
		White sandwich bread
		Flavoured white rice

Dairy	Low-sodium dairy	*Sour crème & crème fraiche*
		Flavoured yoghurt
		Light/low fat yoghurt
		Cream
		Skimmed milk
		Flavoured milk
		Dairy milk
	Medium-sodium dairy	*Coconut milk*
		Flavoured milk
		Fresh cheese (i.e. mozzarella, cottage and ricotta)
		Softer cheese (i.e. brie)
	High-sodium dairy	*Hard cheese (i.e. 30+ and 48+)*
		Blue cheese
		Softer cheese (i.e. camembert)
		Processed cheese (e.g. spray can cheese)
	Low-SAFA dairy	Flavoured yoghurt
		Skimmed milk
		Light/low fat yoghurt
		Fresh cheese (i.e. cottage cheese)
	Medium-SAFA dairy	*Dairy milk*
		Flavoured milk
		Flavoured yoghurt
		Light/low fat yoghurt
		Fresh cheese (i.e. cottage cheese)
	High-SAFA dairy	*Hard cheese (i.e. 30+ and 48+)*
		Blue cheese
		Softer cheese (i.e. camembert)
		Processed cheese (e.g. spray can cheese)
		Cream
		Coconut milk
		Fresh cheese (i.e. mozzarella and ricotta)
Fresh and frozen meat	Low-SAFA meats	Fatty fish (i.e. tuna)
		Unflavoured lean fish
		Processed lean fish
		Poultry
		Processed meat
		Tofu
		Falafel
	Medium-SAFA meats	Fatty fish (i.e. salmon, tuna and sardines)
		Poultry
		Processed fish
		Processed meat
		Red meat
		Vegetarian burgers
	High-SAFA meats	Fatty fish (i.e. salmon)
		Processed poultry (i.e. sausages)
		Processed meat
		Red meat
	Low-sodium meats	Fatty fish (i.e. salmon)
		Unflavoured lean fish
		Poultry
		Red meat
		Tofu
	Medium-sodium meats	Fatty fish (i.e. tuna and sardines)
		Processed lean fish
		Processed poultry
		Processed meat
		Red meat
		Falafel
	High-sodium meats	Fatty fish (i.e. salmon and anchovies)
		Processed poultry
		Processed meat
		Vegetarian burgers

		Red meat
Sauces and seasonings	Low-sodium sauces	*Sweet sauces*
	Medium-sodium sauces	Asian sauces
		Chutney
		Dips
		Gravies
		Meal-based sauces
		Pasta sauce
		Pickles and vinegar
		Wok sauce
	High-sodium sauces	Asian sauces
		Chili sauce
		Dips
		Gravies
		Stock
		Hummus
		Mayonnaise
		Marinade
		Meal-based sauces
		Meat accompaniment
		Mustard
		Pasta sauce
		Paste
		Salad dressing
		Seasoning
		Soy sauce
		Wok sauce
	Low-sugar sauces	Asian sauces
		Dips
		Gravies
		Stock
		Hot sauce
		Hummus
		Meal-based sauces
		Pasta sauce
		Paste
		Soy sauce
		Wok sauce
	Medium-sugar sauces	Dips
		Meal-based sauces
		Meat accompaniment
		Mustard
		Pasta sauce
		Paste
		Pickles and vinegar
		Salad dressing
		Wok sauce
	High-sugar sauces	Asian sauces
		Meat accompaniment
		Pasta sauce
		Paste
		Pickles and vinegar
		Salad dressing
		Wok sauce
		Sweet sauces
		Chili sauce
		Chutney
		Mayonnaise
Snack foods and desserts	Low-sodium snacks	*Confectionary*
		Cereal-based bars
		Chocolate-based confectionary
		Fruit bars
		Gum

		Ice cream
		Nut-based bars
		Milk-based desserts
		Nuts
	Medium-sodium snacks	*Pie and cake*
		Cereal-based bars
		Chips
		Chocolate-based confectionary
		Muffins
		Nuts
		Plain dry biscuits
		Pudding
		Savoury biscuits
		Sweet filled biscuits
		Sweet unfilled biscuits
		Warm snacks
	High-sodium snacks	*Chips*
		Popcorn
		Nuts
		Other savoury snacks
		Plain dry biscuits
	Low-SAFA snacks	Pie and cake
		Confectionary
		Fruit bars
		Gum
		Fruit-based desserts
		Muffins
		Other savoury snacks
		Plain dry biscuits
		Savoury biscuits
		Warm snacks
	Medium-SAFA snacks	Pie and cake
		Cereal-based bars
		Chocolate-based confectionary
		Fruit bars
		Chips
		Muffins
		Nut-based bars
		Nuts
		Pudding
		Plain dry biscuits
		Savoury biscuits
	High-SAFA snacks	Pie and cake
		Confectionary
		Cereal-based bars
		Chips
		Chocolate-based confectionary
		Milk-based desserts
		Nut-based bars
		Nuts
		Savoury biscuits
		Sweet filled biscuits
		Sweet unfilled biscuits
	Low-sugar snacks	Chips
		Gum
		Muffins
		Popcorn
		Savoury biscuits
		Warm snacks
		Nuts
		Other savoury snacks
		Plain dry biscuits
		Chips

	Medium-sugar snacks	Fruit-based desserts
		Milk-based desserts
		Nut-based bars
		Other savoury snacks
		Pie and cake
		Savoury biscuits
		Sweet unfilled biscuits
	High-sugar snacks	Pie and cake
		Confectionary
		Chocolate-based confectionary
		Cereal-based bars
		Nut-based bars
		Nuts
		Sweet unfilled biscuits
		Toppings
		Pudding
		Sweet filled biscuits
		Fruit bars
		Fruit-based desserts
		Milk-based desserts
		Muffins

Products in italics are exclusively found in one nutrient-based food group

SupplementaryTable 2b. List of smaller food groups found within the aggregate home-brand and name-brand categories

Food category	Aggregate categories	Smaller food groups found within nutrient-based food groups
Beverages	Name-brand beverages	Coffee
		Tea
		Fruit and vegetable juices
		Flavoured water
		Dairy milk
		Soy milk
		Water
		Trimmed milk
		Flavoured milk
		Soft drinks
		Sugar-free soft drinks
		Energy drinks
	Home-brand beverages	Fruit and vegetable juices
		Tea
		Flavoured water
		Dairy milk
		Trimmed milk
		Soft drinks
Grain products (cereals and bread)	Name-brand grains	*Unflavoured rice (white and wholegrain rice)*
		Flavoured white rice
		All pastas (i.e. packet, canned, plain dry and fresh)
		Flour
		Noodles
		Oats
		All breads (i.e. mixed grain, white and other)
		Couscous
		Wheat breakfast cereals
		Breakfast cereals
		Muesli
		Quinoa
		Sugar
	Home-brand grains	Other bread
		White bread
		Fresh pasta
		Sugar
		Breakfast cereals
Snacks	Name-brand snacks	Cake
		Confectionary
		Cereal-based bars
		Chips
		Milk-based deserts
		Muffins
		Nuts
		Plain dry biscuits
		Savoury biscuits
		Sweet unfilled biscuits
		Toppings
		Chocolate-based confectionary
		Fruit bars
		Gum
		Fruit-based deserts
		Nut-based bars
		Other savoury snacks
		Popcorn
		Pudding
		Sweet filled biscuits
		Warm snacks
	Home-brand snacks	Cake
		Confectionary
		Cereal-based bars

	Chips
	Milk-based deserts
	Muffins
	Nuts
	Plain dry biscuits
	Savoury biscuits
	Sweet unfilled biscuits
	Toppings

Products in italics are only found in the name-brand food groups

Supplementary Table 3. Median nutritional content per serving and percentage of healthy foods within the aggregated categories

Food category	Nutritional clusters	Kilo calories	SAFA (g)	Sugar (g)	Sodium (mg)	% of healthy products[1]
Beverages	Low-sugar	1.2	0.0	0.0	1.3	94.6%
	Medium-sugar	44.2	0.0	8.9	11.0	60.4%
	High-sugar	61.0	0.8	14.0	6.7	50.0%
	Name-brand	37.3	0.0	1.0	5.0	78.4%
	Home-brand	34.7	0.0	7.0	8.0	72.0%
Grains	Low-sugar	251.0	0.5	2.3	422.0	73.6%
	Medium-sugar	365.7	1.5	8.4	385.5	46.9%
	High-sugar	385.9	0.8	30.9	104.0	31.8%
	Low-sodium	361.1	0.5	2.8	23.5	82.6%
	Medium-sodium	260.5	0.5	3.1	407.5	68.1%
	High-sodium	340.6	2.1	4.3	900.0	4.5%
	Name-brand	319.6	0.7	3.3	380.0	59.7%
	Home-brand	310.7	0.5	3.2	190.0	80.0%
Dairy	Low-sodium	89.7	1.9	4.95	40.0	66.7%
	Medium-sodium	334.6	14.9	1.0	430.0	50.0%
	High-sodium	358.5	19.2	1.0	708.0	16.2%
	Low-SAFA	47.8	0.4	4.8	41.0	100.0%
	Medium-SAFA	91.0	1.9	10.0	41.0	68.2%
	High-SAFA	358.5	19.1	1.0	687.0	19.2%
Fresh and frozen meat	Low-SAFA	113.3	0.8	1.0	310.0	81.4%
	Medium-SAFA	181.2	2.4	1.0	370.0	57.1%
	High-SAFA	248.6	6.8	1.0	559.5	2.9%
	Low-sodium	181.8	1.7	1.0	61.0	84.0%
	Medium-sodium	197.0	1.8	1.2	355.0	61.5%
	High-sodium	226.1	4.4	1.1	890.0	8.6%
Sauces and seasonings	Low-sugar	94.8	1.0	2.8	459.0	28.3%
	Medium-sugar	154.7	1.0	10.2	614.0	11.9%
	High-sugar	163.7	0.1	31.1	530.0	0.0%
	Low-sodium	285.6	0.0	67.8	13.0	7.4%
	Medium-sodium	95.1	0.5	4.4	380.0	29.9%
	High-sodium	175.7	1.0	10.6	1369.5	1.6%
Snack foods and deserts	Low-sugar	435.0	2.25	1.8	525.0	26.5%
	Medium-sugar	401.5	5.4	14.1	280.0	23.1%
	High-sugar	439.8	8.8	41.0	127.0	2.7%
	Low-sodium	395.55	5.8	30.9	37.0	17.2%
	Medium-sodium	437.4	8.1	28.2	300.0	9.5%
	High-sodium	466.1	2.7	3.4	780.0	6.7%
	Low-SAFA	319.6	0.5	13.4	200.0	29.9%
	Medium-SAFA	411.1	3.15	19.2	265.0	23.5%
	High-SAFA	475.6	11.1	30.8	175.0	1.6%
	Name-brand	437.4	6.5	27.1	180.0	12.3%
	Home-brand	420.7	5.9	24.0	250.0	11.1%

[1] All fresh fruit and vegetables, fresh fish, and packaged foods eligible to carry a health claim based on the Nutrient Profiling Scoring Criterion were classified as healthy

Supplementary Table 4a. Percentage change in price, expenditure and quantity between the control condition and the experimental conditions for nutrient-based food groups

Food categories	Nutrition clusters	N control	N experim-ental[1]	Price per 100g in NZ$ in control condition		Price per 100g in NZ$ in experimental conditions[1]			Expenditure in NZ$ in control condition		Expenditure in NZ$ in experimental conditons[1]		
				Med	IQR	Med	IQR	change[2]	Med	IQR	Med	IQR	change[2]
Beverages	Low-sugar	377	2009	3.32	5.27	3.39	5.22	2%	7.59	8.41	7.94	8.26	5%
	Medium-sugar	521	3009	0.20	0.05	0.22	0.08	10%	6.74	7.33	7.06	7.49	5%
	High-sugar	81	501	0.48	0.87	0.55	0.91	15%	3.63	2.37	3.79	2.16	4%
Grains	Low-sugar	572	3243	0.49	0.26	0.53	0.34	8%	9.81	10.58	10.63	11.30	8%
	Medium-sugar	192	1169	1.06	0.77	1.11	0.74	5%	5.11	3.67	5.62	4.04	10%
	High-sugar	123	809	0.68	1.26	1.16	1.28	71%	5.55	5.14	6.05	4.27	9%
	Low-sodium	375	2165	0.30	0.24	0.33	0.29	10%	4.82	5.36	5.45	5.90	13%
	Medium-sodium	554	3142	0.62	0.41	0.69	0.41	11%	8.67	9.60	9.34	10.64	8%
	High-sodium	151	755	1.44	1.22	1.50	1.21	4%	4.16	1.62	4.52	1.90	9%
Dairy	Low-sodium	534	3065	0.26	0.13	0.27	0.14	4%	8.38	7.81	8.83	8.73	5%
	Medium-sodium	65	409	2.81	2.23	2.53	2.08	-10%	5.78	4.67	6.55	4.53	13%
	High-sodium	348	1833	1.54	1.34	1.91	1.59	24%	10.55	6.10	11.32	7.50	7%
	Low-SAFA	161	1110	0.22	0.42	0.26	0.44	18%	5.24	3.90	5.41	3.81	3%
	Medium-SAFA	472	2642	0.23	0.14	0.25	0.14	9%	7.24	6.50	6.99	6.67	-3%
	High-SAFA	392	2063	1.48	1.22	1.86	1.49	26%	10.72	7.72	11.97	9.38	12%
Meat	Low-SAFA	470	2595	1.91	0.71	1.91	0.72	0%	13.98	14.41	13.05	14.35	-7%
	Medium-SAFA	468	2687	1.88	0.68	1.94	0.60	3%	15.42	16.52	16.59	17.39	8%
	High-SAFA	377	2135	1.75	0.81	1.80	0.77	3%	11.79	11.57	12.73	12.45	8%
	Low-sodium	535	2956	1.93	0.64	1.95	0.61	1%	22.36	24.72	23.65	25.78	6%
	Medium-sodium	387	2230	1.69	0.61	1.72	0.62	2%	10.04	10.85	9.88	10.62	-2%
	High-sodium	222	1300	1.89	1.12	1.97	1.13	4%	9.72	8.55	10.37	9.10	7%
Sauces	Low-sugar	242	1372	1.12	1.36	1.18	1.34	5%	4.49	3.59	5.02	4.33	12%
	Medium-sugar	184	1028	1.18	0.88	1.19	1.00	1%	4.20	2.41	4.31	2.76	3%
	High-sugar	179	1027	1.03	0.58	1.11	0.60	8%	4.66	4.06	5.10	4.31	9%

Food categories	Nutrition clusters	N control	N experim-ental[1]	Price per 100g in NZ$ in control condition		Price per 100g in NZ$ in experimental conditions[1]			Expenditure in NZ$ in control condition		Expenditure in NZ$ in experimental conditons[1]		
				Med	IQR	Med	IQR	change[2]	Med	IQR	Med	IQR	change[2]
	Low-sodium	59	298	1.21	0.79	1.27	0.71	5%	6.54	3.80	6.64	3.09	2%
	Medium-sodium	237	1442	0.86	0.70	0.90	0.60	5%	4.72	4.34	4.93	4.58	4%
	High-sodium	242	1422	1.38	0.73	1.45	0.91	5%	4.98	4.62	5.23	4.85	5%
Snacks	Low-sugar	387	2202	1.57	0.75	1.66	0.83	6%	5.73	5.90	5.46	6.29	-5%
	Medium-sugar	279	1561	1.26	1.38	1.35	1.24	7%	5.54	5.35	5.50	4.83	-1%
	High-sugar	431	2397	1.69	0.70	1.78	0.83	5%	7.77	8.83	8.50	9.51	9%
	Low-sodium	401	2274	1.71	1.46	1.75	1.43	2%	7.62	8.61	7.98	9.02	5%
	Medium-sodium	409	2314	1.45	0.61	1.60	0.66	10%	7.07	8.06	6.95	7.88	-2%
	High-sodium	286	1585	1.59	0.67	1.67	0.75	5%	4.16	4.42	4.20	4.27	1%
	Low-SAFA	296	1715	1.41	0.96	1.43	1.04	1%	4.60	4.81	4.50	4.66	-2%
	Medium-SAFA	265	1464	1.78	0.92	1.88	0.98	6%	5.36	4.99	4.70	4.82	-12%
	High-SAFA	470	2693	1.53	0.82	1.68	0.86	10%	9.00	11.43	9.98	11.66	11%

[1] Experimental conditions include all conditions with a sugar, salt and/or SAFA tax or a subsidy on fruit and vegetables

[2] Percentage change between the control condition and the experimental conditions

Med; Median, IQR; Interquartile range

Supplementary Table 4a continued. Percentage change in price, expenditure and quantity between the control condition and the experimental conditions for nutrient-based food groups

Food categories	Nutrition clusters	Purchased quantity in grams in control condition		Purchased quantity in grams in experimental conditions[1]		
		Med	IQR	Med	IQR	change[2]
Beverages	Low-sugar	300	1400	300	1400	0%
	Medium-sugar	3500	3500	3500	3000	0%
	High-sugar	1000	1275	1000	1135	0%
Grains	Low-sugar	2100	2230	1950	2340	-7%
	Medium-sugar	460	455	500	440	9%
	High-sugar	1000	1050	650	958	-35%
	Low-sodium	1500	1600	1500	1650	0%
	Medium-sodium	1345	1480	1360	1470	1%
	High-sodium	350	550	350	530	0%
Dairy	Low-sodium	3000	2250	3000	2400	0%
	Medium-sodium	250	200	250	300	0%
	High-sodium	928	672	900	750	-3%
	Low-SAFA	2000	1250	2000	1125	0%
	Medium-SAFA	2400	2000	2225	2000	-7%
	High-SAFA	900	717	900	650	0%
Meat	Low-SAFA	800	770	740	745	-8%
	Medium-SAFA	800	795	880	900	10%
	High-SAFA	770	793	770	770	0%
	Low-sodium	1170	1260	1230	1250	5%
	Medium-sodium	590	645	600	610	2%
	High-sodium	500	500	480	500	-4%
Sauces	Low-sugar	495	403	495	452	0%
	Medium-sugar	400	250	400	300	0%
	High-sugar	530	345	520	460	-2%
	Low-sodium	500	30	500	30	0%
	Medium-sodium	500	620	500	590	0%
	High-sodium	405	380	400	380	-1%
Snacks	Low-sugar	375	400	350	390	-7%
	Medium-sugar	420	900	418	730	-1%
	High-sugar	480	680	492	686	3%
	Low-sodium	520	1386	500	1004	-4%
	Medium-sodium	460	574	450	530	-2%
	High-sodium	250	255	250	270	0%
	Low-SAFA	375	380	375	375	0%
	Medium-SAFA	293	375	250	278	-15%
	High-SAFA	600	1000	600	910	0%

[1] Experimental conditions include all conditions with a sugar, salt and/or SAFA tax or a subsidy on fruit and vegetables
[2] Percentage change between the control condition and the experimental conditions
Med; Median, IQR; Interquartile range

Supplementary Table 4b. Percentage change in price, expenditure and quantity between the control condition and the experimental conditions for name- and home-brand products

Food categories	Food groups	N in control condition	N in experim-ental conditions[1]	Price in NZ$ in control condition		Price in NZ$ in experimental conditions[1]			Expenditure in NZ$ in control condition		Expenditure in NZ$ in experimental conditons[1]		
				Med	IQR	Med	IQR	% change[2]	Med	IQR	Med	IQR	% change[2]
Beverages	Name-brand	485	2704	0.44	1.14	0.20	0.06	-55%	9.55	10.93	10.24	12.24	7%
	Home-brand	378	2069	0.18	0.05	0.43	0.88	139%	4.41	4.32	5.01	4.73	14%
Grains	Name-brand	513	2961	0.74	0.46	0.82	0.50	11%	10.32	10.89	10.87	12.16	5%
	Home-brand	394	2225	0.27	0.13	0.30	0.18	11%	4.58	4.95	4.77	5.78	4%
Snacks	Name-brand	511	2879	1.70	0.69	1.76	0.73	4%	10.48	12.88	11.10	13.53	6%
	Home-brand	313	1708	1.06	0.97	1.18	0.95	11%	4.91	4.89	5.21	5.09	6%

Supplementary Table 4b continued. Percentage change in price, expenditure and quantity between the control condition and the experimental conditions for name- and home-brand products

Food categories	Food groups	Purchased quantity in grams in control condition		Purchased quantity in grams in experimental conditions[1]		
		Med	IQR	Med	IQR	% change[2]
Beverages	Name-brand	2000	3500	2000	3000	0%
	Home-brand	2000	2000	2000	2000	0%
Grains	Name-brand	1400	1495	1415	1700	1%
	Home-brand	1500	1850	1400	2040	-7%
Snacks	Name-brand	650	976	600	760	-8%
	Home-brand	390	650	375	500	-4%

[1] Experimental conditions include all conditions with a sugar, salt and/or SAFA tax or a subsidy on fruit and vegetables
[2] Percentage change between the control condition and the experimental conditions
Med; Median, IQR; Interquartile range

Supplementary Table 5. Mean expenditure elasticities and standard errors for all nutrient-based food groups

Food categories	**Relevant nutrient**	Low levels of sugar/sodium/SAFA		Medium levels of sugar/sodium/SAFA		High levels of sugar/sodium/SAFA	
		Elasticity	SE	Elasticity	SE	Elasticity	SE
Beverages	Sugar	1.26	0.06	0.90	0.03	0.50	0.28
Grains	Sugar	1.10	0.02	0.63	0.10	0.51	0.15
	Sodium	1.00	0.04	1.10	0.02	-0.03	0.13
Dairy	Sodium	0.95	0.04	-0.60	0.29	1.32	0.07
	SAFA	0.53	0.09	0.89	0.03	1.30	0.04
Meat	Sodium	1.16	0.02	0.83	0.05	0.49	0.08
	SAFA	0.99	0.02	1.06	0.02	0.91	0.03
Sauces	Sugar	1.11	0.04	0.87	0.04	0.96	0.04
	Sodium	-0.57	0.41	1.15	0.09	1.14	0.06
Snacks	Sugar	0.96	0.03	0.76	0.04	1.13	0.02
	Sodium	1.07	0.02	1.10	0.03	0.63	0.04
	SAFA	0.80	0.03	0.69	0.04	1.16	0.02

Adjusted for educational level, age, sex ethnicity and household size
SE; Standard Error

Supplementary Table 6. Uncompensated elasticities and corresponding standard errors (shaded boxes showing own price elasticities, others being cross price elasticities)

Food categories	Nutritional clusters based on sugar content				Nutritional clusters based on sodium content				Nutritional clusters based on SAFA content			
	Change in quantity	**Change in price**			**Change in quantity**	**Change in price**			**Change in quantity**	**Change in price**		
		Low-sugar	Medium-sugar	High-sugar								
Beverages		PE (SE)	PE (SE)	PE (SE)		NA				NA		
	Low-sugar	**-1.03** (0.02)	**-0.19** (0.04)	-0.04 (0.02)								
	Medium-sugar	0.00 (0.01)	**-0.88** (0.03)	-0.01 (0.02)								
	High-sugar	**0.27** (0.11)	-0.25 (0.29)	**-0.52** (0.14)								
		Low-sugar	Medium-sugar	High-sugar		Low-sodium	Medium-sodium	High-sodium		NA		
Grains		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)				
	Low-sugar	**-0.96** (0.02)	**-0.07** (0.02)	**-0.08** (0.01)	Low-sodium	**-0.71** (0.04)	**-0.30** (0.05)	0.01 (0.02)				
	Medium-sugar	-0.13 (0.11)	**-0.55** (0.10)	0.05 (0.06)	Medium-sodium	**-0.14** (0.02)	**-0.92** (0.02)	**-0.04** (0.01)				
	High-sugar	-0.26 (0.14)	0.05 (0.10)	**-0.30** (0.08)	High-sodium	**0.30** (0.10)	**0.34** (0.14)	**-0.61** (0.11)				
		NA				Low-sodium	Medium-sodium	High-sodium		Low-SAFA	Medium-SAFA	High-SAFA
Dairy						PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)
					Low-sodium	**-0.88** (0.04)	**-0.05** (0.02)	-0.01 (0.02)	Low-SAFA	**-0.98** (0.06)	**0.27** (0.06)	**0.18** (0.06)
					Medium-sodium	-0.39 (0.29)	**0.64** (0.24)	0.35 (0.27)	Medium-SAFA	**0.06** (0.02)	**-0.97** (0.02)	0.02 (0.02)
					High-sodium	**-0.17** (0.07)	**-0.12** (0.04)	**-1.03** (0.05)	High-SAFA	**-0.08** (0.03)	**-0.14** (0.03)	**-1.08** (0.03)
		NA				Low-sodium	Medium-sodium	High-sodium		Low-SAFA	Medium-SAFA	High-SAFA
Meat						PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)
					Low-sodium	**-0.95** (0.03)	**-0.15** (0.02)	**-0.07** (0.01)	Low-SAFA	**-0.86** (0.03)	**-0.10** (0.03)	-0.03 (0.02)

					Medium-sodium	**-0.18** (0.06)	**-0.71** (0.05)	**0.07** (0.03)	Medium-SAFA	**-0.11** (0.03)	**-0.77** (0.04)	**-0.18** (0.02)
					High-sodium	0.11 (0.09)	**0.19** (0.07)	**-0.79** (0.06)	High-SAFA	-0.02 (0.03)	**-0.23** (0.04)	**-0.66** (0.04)
		Low-sugar	Medium-sugar	High-sugar		Low-sodium	Medium-sodium	High-sodium				
Sauces		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)				
	Low-sugar	**-1.08** (0.03)	-0.02 (0.02)	-0.01 (0.03)	Low-sodium	0.40 (0.35)	0.18 (0.22)	0.00 (0.21)			NA	
	Medium-sugar	0.06 (0.04)	**-0.88** (0.05)	-0.05 (0.05)	Medium-sodium	**-0.12** (0.05)	**-1.04** (0.06)	0.01 (0.06)				
	High-sugar	0.06 (0.04)	-0.08 (0.04)	**-0.94** (0.06)	High-sodium	**-0.14** (0.05)	0.01 (0.05)	**-1.01** (0.06)				
		Low-sugar	Medium-sugar	High-sugar		Low-sodium	Medium-sodium	High-sodium		Low-SAFA	Medium-SAFA	High-SAFA
Snacks		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)
	Low-sugar	**-0.93** (0.03)	**0.07** (0.02)	**-0.09** (0.03)	Low-sodium	**-1.01** (0.02)	-0.01 (0.02)	**-0.05** (0.01)	Low-SAFA	**-0.98** (0.04)	**0.08** (0.03)	**0.10** (0.04)
	Medium-sugar	**0.16** (0.04)	**-1.12** (0.03)	**0.20** (0.03)	Medium-sodium	-0.02 (0.02)	**-0.97** (0.03)	**-0.11** (0.02)	Medium-SAFA	**0.11** (0.04)	**-0.99** (0.04)	**0.18** (0.05)
	High-sugar	**-0.12** (0.02)	0.00 (0.01)	**-1.02** (0.02)	High-sodium	**0.08** (0.03)	-0.05 (0.05)	**-0.66** (0.05)	High-SAFA	**-0.04** (0.01)	**-0.03** (0.01)	**-1.09** (0.02)

Bold values indicate a p-value < 0.05
Adjusted for educational level, age, sex, ethnicity and household size
NA; Not Applicable

Supplementary Table 7. Compensated elasticities and corresponding standard errors (shaded boxes showing own price elasticities, others being cross price elasticities)

Food categories	Nutritional clusters based on sugar content				Nutritional clusters based on sodium content				Nutritional clusters based on SAFA content			
	Change in quantity	**Change in price**			**Change in quantity**	**Change in price**			**Change in quantity**	**Change in price**		
		Low-sugar	Medium-sugar	High-sugar								
Beverages		PE (SE)	PE (SE)	PE (SE)		NA				NA		
	Low-sugar	**-0.60** (0.02)	**0.59** (0.02)	0.01 (0.02)								
	Medium-sugar	**0.30** (0.01)	**-0.33** (0.02)	**0.03** (0.01)								
	High-sugar	**0.44** (0.12)	0.06 (0.18)	**-0.49** (0.14)								
		Low-sugar	Medium-sugar	High-sugar		Low-sodium	Medium-sodium	High-sodium				
Grains		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)		NA		
	Low-sugar	**-0.07** (0.02)	**0.06** (0.01)	0.01 (0.01)	Low-sodium	**-0.45** (0.04)	**0.38** (0.04)	**0.07** (0.02)				
	Medium-sugar	**0.38** (0.10)	**-0.48** (0.09)	0.10 (0.06)	Medium-sodium	**0.14** (0.02)	**-0.17** (0.02)	**0.03** (0.01)				
	High-sugar	0.14 (0.14)	0.11 (0.09)	**-0.26** (0.08)	High-sodium	**0.29** (0.09)	**0.32** (0.11)	**-0.61** (0.11)				
						Low-sodium	Medium-sodium	High-sodium		Low-SAFA	Medium-SAFA	High-SAFA
Dairy		NA				PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)
					Low-sodium	**-0.29** (0.03)	-0.01 (0.02)	**0.30** (0.03)	Low-SAFA	**-0.91** (0.05)	**0.52** (0.04)	**0.38** (0.06)
					Medium-sodium	**-0.77** (0.25)	**0.61** (0.23)	0.16 (0.25)	Medium-SAFA	**0.19** (0.01)	**-0.55** (0.02)	**0.36** (0.02)
					High-sodium	**0.66** (0.05)	-0.06 (0.04)	**-0.60** (0.06)	High-SAFA	**0.10** (0.02)	**0.47** (0.02)	**-0.57** (0.03)
						Low-sodium	Medium-sodium	High-sodium		Low-SAFA	Medium-SAFA	High-SAFA
Meat		NA				PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)
					Low-sodium	**-0.21** (0.03)	**0.14** (0.02)	**0.07** (0.01)	Low-SAFA	**-0.51** (0.03)	**0.30** (0.03)	**0.21** (0.02)

					Medium-sodium	**0.34** (0.05)	**-0.50** (0.05)	**0.17** (0.03)	Medium-SAFA	**0.26** (0.03)	**-0.34** (0.03)	**0.08** (0.02)
					High-sodium	**0.42** (0.08)	**0.31** (0.06)	**-0.73** (0.06)	High-SAFA	**0.30** (0.03)	**0.13** (0.03)	**-0.44** (0.04)
		Low-sugar	Medium-sugar	High-sugar		Low-sodium	Medium-sodium	High-sodium				
Sauces		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)		NA		
	Low-sugar	**-0.60** (0.03)	**0.28** (0.02)	**0.32** (0.03)	Low-sodium	0.35 (0.33)	-0.08 (0.23)	-0.27 (0.21)				
	Medium-sugar	**0.43** (0.04)	**-0.64** (0.05)	**0.21** (0.05)	Medium-sodium	-0.02 (0.05)	**-0.52** (0.06)	**0.54** (0.05)				
	High-sugar	**0.47** (0.04)	**0.19** (0.04)	**-0.65** (0.06)	High-sodium	-0.04 (0.04)	**0.53** (0.05)	**-0.49** (0.05)				
		Low-sugar	Medium-sugar	High-sugar		Low-sodium	Medium-sodium	High-sodium		Low-SAFA	Medium-SAFA	High-SAFA
Snacks		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)		PE (SE)	PE (SE)	PE (SE)
	Low-sugar	**-0.61** (0.03)	**0.25** (0.02)	**0.36** (0.03)	Low-sodium	**-0.56** (0.02)	**0.41** (0.02)	**0.15** (0.01)	Low-SAFA	**-0.81** (0.03)	**0.23** (0.03)	**0.59** (0.03)
	Medium-sugar	**0.41** (0.03)	**-0.97** (0.03)	**0.56** (0.03)	Medium-sodium	**0.44** (0.02)	**-0.53** (0.03)	**0.09** (0.02)	Medium-SAFA	**0.26** (0.04)	**-0.87** (0.04)	**0.61** (0.04)
	High-sugar	**0.26** (0.02)	**0.23** (0.01)	**-0.49** (0.02)	High-sodium	**0.34** (0.03)	**0.20** (0.04)	**-0.54** (0.04)	High-SAFA	**0.20** (0.01)	**0.17** (0.01)	**-0.38** (0.02)

Bold values indicate a p-value < 0.05

Adjusted for educational level, age, sex, ethnicity and household size

NA; Not Applicable

Supplementary Table 8. Price elasticities and standard errors from the double log model for name- and home-brand products within the food categories

Food category	**Change in quantity**	**Change in price**			
		Name-brand		Home-brand	
		PE	(SE)	PE	(SE)
Beverages	Name-brand	**-1.01**	(0.01)	**0.09**	(0.03)
	Home-brand	**0.05**	(0.01)	**-0.89**	(0.02)
		Name-brand		Home-brand	
Grains	Name-brand	**-0.80**	(0.03)	-0.05	(0.03)
	Home-brand	-0.04	(0.03)	**-0.36**	(0.03)
		Name-brand		Home-brand	
Snacks	Name-brand	**-1.00**	(0.05)	0.03	(0.03)
	Home-brand	**0.12**	(0.04)	**-1.14**	(0.03)

Bold values indicate a p-value < 0.05
Adjusted for educational level, age, sex, ethnicity and household size

CHAPTER 11

General Discussion

11.1 Summary of main findings

11.1.1 Diet-related material and psychosocial factors only partly explain socio-economic inequalities in diet

My doctoral thesis started by exploring the cost and affordability of healthy and current diets for the average Dutch population as well as for households with a low, medium and high educational level. Depending on the household, healthy diets were on average between 10% to 36% more expensive than current diets (Chapter 2). This result indicates that the higher cost of healthy diets may hamper individuals from following healthy dietary guidelines. Indeed, in Chapter 3, I found that dietary cost played a modest role in explaining the relation between educational level and several dietary quality measures. In a second mediation study, I found that other material resources including food expenditure, perceptions of healthy food accessibility and healthfulness of the food retail environment did not explain the relation between SEP indicators and dietary quality (Chapter 4). When combining the results from Chapters 3 and 4, I find that approximately 30% of the relation between SEP indicators and dietary quality could be explained by diet-related material and psychosocial resources (i.e. dietary cost, cooking skills and resilience to unhealthy food environment). Even when taking into account the role of other diet-related material and psychosocial factors found in other studies (e.g. nutrition knowledge), approximately half of the association between SEP and diet quality still remains unexplained.

11.1.2 Nudging combined with pricing strategies improve dietary behaviours and are equitable across personal characteristics, but not food groups

Following the first exploration of factors that could explain socio-economic inequalities in dietary quality, my thesis then focused on possible intervention strategies that could improve dietary behaviours whilst possibly/preferably decreasing socio-economic inequalities. I decided to focus on nudging and pricing strategies as intervention strategies to improve dietary behaviours in the supermarket environment. Chapter 6 described the recruitment of participants in a Dutch virtual supermarket and the results suggest that it is important to use multiple recruitment strategies in order to recruit a somewhat representative sample in terms of SEP, age and gender. It was important to include adults with a low and high SEP in the study as I intended to stratify the results by SEP indicators. With regards to the intervention strategies, I found that on-shelf sugar labels did not affect the sales of non-alcoholic beverages in a real-world supermarket setting (Chapter 5). Similarly, salient nudging strategies did not affect the proportion of healthy food purchases within a virtual supermarket setting (Chapter 7). Therefore, I concluded that nudging strategies alone are not sufficient to improve the overall quality of food purchases or consumption. In Chapter 7, I further showed that while nudging and pricing strategies alone do not increase healthy food purchases, actively communicating price changes (i.e. salient pricing) and additionally combining these with nudges led to an approximately 3% increase in healthy food purchases compared to the control condition. The largest increase in healthy food purchases was found when all strategies were combined; combining price increases, price discounts and nudges led to a 4% increase in healthy food purchases. These findings demonstrate that it is important to combine nudging and pricing strategies, even if the single intervention effects show no statistically significant or even relevant effect.

Moreover, my findings in Chapter 7 suggest that nudging and pricing strategies work similarly for low and high SEP populations. As other factors besides SEP can also modify the relation between nudging/pricing strategies and dietary behaviours I aimed to explore the modifying role of the personal characteristics impulsivity, general decision-making styles, price sensitivity, and food choice motives in the relation between nudging and (salient) pricing strategies and healthy food purchases in Chapter 8. My findings suggest that the effectiveness of nudging and pricing strategies in a virtual supermarket setting does not differ by personal characteristics. These results are favourable as these strategies can therefore be implemented as generic health promoting interventions that do not increase existing health inequalities.

Whereas the effectiveness of nudging and pricing strategies does not seem to differ by socio-economic indicators or personal characteristics, its effectiveness does seem to depend on the food group targeted. In Chapter 9, I aimed to investigate in which food groups nudging and/or pricing strategies most effectively changed product purchases and resulted in within–food groups substitutions or spillover effects using data from the aforementioned virtual supermarket. My findings showed that grains and dairy products had the greatest increase in the proportion of healthy food purchases following the introduction of nudging and pricing strategies, suggesting that these food groups should be prioritised if only one or a few food groups can be targeted. In a different virtual supermarket described in Chapter 10, I examined the substitution and complementary effects of health-related food and beverage taxes within food groups, including from unhealthier to healthier alternatives and between different brand alternatives. As no consistent pattern of substitution of complementary purchasing was found, I was unable to conclude which food groups are best targeted by pricing strategies.

11.1.3 Conclusions

The main findings from this doctoral thesis can be summarised as follows: 1) diet-related material and psychosocial resources only partly explain socio-economic inequalities in dietary behaviours, and 2) nudging strategies alone do not effectively increase healthy food purchases in a supermarket setting while 3) salient pricing strategies and the combination of nudging and pricing strategies do effectively increase healthy food purchases. The effects of nudging and pricing strategies do not differ by socio-economic indicators or personal characteristics, but seem to be more pronounced for certain food groups such as grains and dairy compared to others.

11.2 Reflections on main findings

This section starts with a discussion on the use and efficacy of several intervention approaches. Then, I reflect on additional factors that may explain socio-economic inequalities and I end this section by discussing the need to combine interventions that will together lead to improvements in healthy dietary behaviours while simultaneously decreasing the socio-economic inequalities herein.

11.2.1 Downstream and upstream approaches

A great wave of research over the last few decades has attempted to develop techniques and evidence for behavioural changes targeting 'high-risk' individuals (e.g. providing motivational counselling to individuals with obesity) (1). While such individual-level or downstream approaches have shown to work in controlled settings, they seem to have a limited effectiveness on shifting population levels of obesity or NCDs by changing health behaviours on the long term (2-4). According to Thompson (5), downstream approaches targeting high-risk individuals are one of two strategies that can be used to deal with public health problems. The second strategy, which has been endorsed by both public health researchers as well as organizations such as the World Health Organisation (6, 7), includes a 'population' strategy. This strategy involves treating a much wider group of individuals, up to and including the entire population (5). Such upstream approaches generally aim to adapt the environment in which health behaviours take place.

With the aim of wanting to prevent/reduce the prevalence of obesity and NCDs (hereafter only referred to as obesity), upstream approaches have several benefits over more downstream approaches. First, unlike downstream approaches, upstream approaches generally do not require individuals to use their agency or personal resources to benefit from the intervention. According to Adams et al. (8), the amount of agency individuals must use to benefit from an intervention is a fundamental determinant of how and for whom it will work. Furthermore, as higher SEP populations tend to have more personal resources than lower SEP populations, downstream approaches may even increase socio-economic inequalities. Second, given that the prevalence of obesity has tripled worldwide between 1975 and 2016, it can be argued that entire populations are at risk of developing obesity (albeit some populations are at a greater risk of developing obesity/NCDs than others) (9). Thus, upstream approaches targeting a larger number of individuals should be implemented. Third, there are many factors outside of the individual that influence individuals' behaviour (e.g. as theorized in the socio-ecological model from the General Introduction). Unlike downstream approaches which generally target factors within the individual, upstream approaches target factors on the interpersonal, organizational, community and public policy levels that generally aim to make the healthy choice the easy choice.

The banning of trans-fatty acids is a real-world example of why upstream approaches are able to increase healthy dietary behaviours on a population level. Trans-fatty acids are a food additive that increases low-density lipoprotein cholesterol, and thereby increases risk of cardiovascular disease (10, 11). On average, lower SEP populations consume more ultra-processed foods (which often contain these trans-fatty acids) compared to higher SEP populations, and therefore more often experience the negative effects of these trans-fatty acids on their health (10, 11). Everyone who eats processed foods will experience the negative health effects of trans-fatty acids to some degree, including lower and higher SEP populations. Removing trans-fatty acids from the food supply increases equity by protecting the health of those who most often rely on processed foods (i.e. the lower SEP populations), while improving the overall health of the entire population (12). Therefore, a ban on trans-fatty acids is an example of a population-level regulatory change which improves the health of everyone, but especially those in a lower SEP group. The processes within this example also apply to other interventions such as the reduction of salt or sugar in processed foods, SSB taxes and banning unhealthy food advertisements aimed at children.

Instead of trans-fatty acid restrictions, the upstream factors that were investigated within this doctoral thesis were nudging and pricing strategies implemented in the important point-of-purchase setting the supermarket. These strategies generally require little personal resources and can be implemented within the organizational level, thereby creating a supportive environment for healthy eating for a large group of individuals. Just as the banning of trans-fatty acids, nudging and pricing strategies can be scaled up to the public policy environment through legislation mandating front-of-package labelling, SSB taxes and fruit and vegetable subsidies. However, the studies in this doctoral thesis suggest that some upstream approaches are more effective than others. For example, Chapters 7, 9 and 10, and previous research (13-17) all support the idea of using pricing strategies to improve healthy dietary behaviours. The evidence with regards to the effectiveness of nudging strategies on food purchases and consumption is more equivocal (14, 17, 18), and the evidence within this doctoral thesis suggests that nudging strategies alone do not influence the overall quality of food purchases/sales (Chapters 5 and 7). A possible explanation for the higher efficacy of pricing compared to nudging strategies stems from the same explanation as to why downstream approaches may be less effective than more upstream approaches, namely, some nudging strategies still require some degree of individual agency. Information nudges and campaigns are examples of 'soft' interventions that can fairly easily be placed in the current food environment as they do not aim to change current laws and regulations which is mostly the case in 'hard' interventions. Generally, interventions can be placed on a continuum that describes the amount of agency or personal resources individuals must use to benefit from an intervention (8). Downstream approaches require the most agency, soft upstream approaches fall somewhere in the middle of this continuum, and hard upstream approaches require the least amount of agency.

Despite that upstream approaches such as pricing strategies are effective in increasing healthy dietary behaviours combined with studies suggesting that pricing and nudging strategies are equally effective for low and high SEP populations (Chapter 7 and (18-20)), such strategies have not yet been widely implemented to prevent obesity (21, 22). Thus, despite that upstream approaches aimed at changing the food and physical activity environments should be the go-to approach to tackling obesity, there are some notable caveats with regards to these approaches. Namely, upstream approaches are limited to the public health domain and generally ignore the wider social economic determinants of health (e.g. housing and income). Furthermore, they generally do not aim to decrease socio-economic inequalities in dietary behaviours/health. A barrier to their implementation is that these upstream approaches, especially hard approaches, do not fit in the current neoliberal paradigm in which individual freedom, personal responsibility for health, and minimal regulation to sustain economic competitiveness is prioritized over health (23). Thus, in the upcoming sections some additional attention will be given to 1) factors and underlying mechanisms underpinning socio-economic inequalities and interventions that can decrease these inequalities, 2) research methodology that takes into account the settings in which upstream approaches are implemented and 3) suggestions for how the environment can be altered to accommodate upstream approaches.

11.2.2 Factors explaining socio-economic inequalities

Evidence suggests that material, psychosocial and behavioural factors such as financial problems, housing tenure, life events and smoking habits explain socio-economic inequalities in mortality (24). As material and psychosocial factors influence behavioural factors, I hypothesized that material and psychosocial factors more proximal to dietary behaviours (i.e. diet-related material and psychosocial resources) would explain socio-economic inequalities in dietary behaviour. Despite including such factors in Chapters 3 and 4, I found that only about 30% of the relation between SEP indicators and dietary quality was explained by dietary cost, cooking skills and resilience to unhealthy food environments in a Dutch setting. When also including evidence from previous studies (25-30), about 50% of this relation remains unexplained.

It is therefore likely that social causes (i.e. the causes of causes) such as the unequal distribution of income, foods and services, education, power and poverty not only explain socio-economic inequalities in mortality, but also in health behaviours (31). These social causes can influence dietary quality through attentional, emotional and material consequences. In the case of material consequences, we can think of the consequences low income has on material resources such as inadequate and temporary housing which can restrict diet quality through the lacking ability to store fresh food. Uncertainties and threats to one's well-being due to employment, food and housing insecurities can in turn lead to emotional responses such as stress, poor sleep and cognitive burdens (32, 33). Sequentially, high stress and cognitive burden can lead to poorer dietary choices through attentional consequences by depleting self-control and executive function (33, 34). Additionally, individuals with a lower SEP may experience discrimination and stigma due to their lower social standing, which can in turn lead to a reluctance to seek and accept help (e.g. using food banks) (35).

The acknowledgement that socio-economic inequalities in dietary behaviours are likely caused by both social causes as well as more proximal factors of dietary behaviour is also shared by Kumanyika (36). Kumanyika developed a framework for increasing the equity impact in obesity prevention programs, which is partly based on the ANGELO framework (first introduced in Chapter 1) and includes four quadrants identifying different intervention targets or approaches (36). The first quadrant includes the implementation of upstream approaches aimed at changing the food and physical activity environment by for example increasing healthy options in food retail provision and the built environment. The second quadrant includes reducing deterrents such as the promotion of unhealthy foods, threats to personal safety, discrimination, and social exclusion. The third and fourth quadrants include improved social and economic resources (e.g. nutrition programs, legal services and housing subsidies) and building community capacity (e.g. empowered communities and promotion of healthy behaviours), respectively.

Implementing the strategies discussed in this framework would not only decrease socio-economic inequalities, it also leads to decreases in the population prevalence of obesity. Obesity and NCDs are complex and multifactorial diseases that require multilevel and integrated solutions from downstream approaches targeting those at an increased risk all the way up to upstream approaches targeting both the social conditions of society as well as the food/physical activity environments in which health behaviours take place. Only tackling the social causes would not sufficiently decrease the prevalence of obesity as we still need to tackle the drivers of behavioural causes that are not shared with these social causes (31). Furthermore, while hard upstream approaches are likely more effective and equitable than soft upstream approaches, soft approaches also have an important place in public health research and policy as they are generally more accepted by the public/policy makers, are easier to implement in the current food environment and can enhance both the efficacy as well as the acceptability of harder upstream approaches. For example, while SSB taxes are likely more effective than nutrition labels, the introduction of mandatory labelling could have some beneficial indirect effects as it can lead to manufacturers limiting the amount of sugar/salt/fats within products in order to receive a healthier rating (as long as the introduction of such nutrition labels are not used as a smoke-screen or reason to not implement other approaches (37)). Indeed, as seen in Chapter 7, combining several upstream approaches are more effective than implementing single intervention strategies; actively communicating price discounts or price increases did not lead to statistically significant increases in healthy food purchases. However, combining these price increases/discounts with salience nudges (which also did not increase healthy food purchases alone) led to a statistically significant 3-4% increase in the proportion of healthy food purchases. Such a 3% increase may seem small, but this translated to an about 80g increase in healthy food purchases, which is quite a lot (assuming purchases are comparable to consumption) considering that the Dutch population consume on average 268g of healthy foods per day (38).

11.3 Methodological considerations

The studies in this doctoral thesis form a solid basis with regards to evidence about the effectiveness of nudging and pricing strategies on food purchases/sales using a mixture of different methods. While the methodological considerations for each chapter are presented within the chapters themselves, here I discuss some overarching and important considerations including the use of alternative research methods.

11.3.1 Study design

Epidemiology is a discipline that is concerned with identifying modifiable causes of disease (39). As randomised controlled trials (RCT) allow for the estimation of causal relationships by neutralizing *confounding bias*, they are generally considered the gold standard study design (40). RCTs are very capable of providing support for the focus on isolating factors that cause specific behaviours or health outcomes. Indeed, using an RCT study design, I was able to confirm that the implementation of salient pricing strategies leads to healthier food purchases among participants with a low and high SEP and that the combination of nudging and salient pricing strategies works best.

Nevertheless, RCT studies and other epidemiological study designs aiming to estimate causal relations have several limitations. One such limitation is that they are generally unable to consider real-world dynamics (e.g. the industry response after announcing the implementation of SSB taxes) (41). Current study evaluations are generally linear in the assumed effect; e.g. a 20% price increase on sugary beverages decreases the purchases of these beverages which in turn results in a decrease in the consumption of sugary beverages (42). As such, evaluations do not account for possible feedback loops wherein initial changes in behaviour can create the conditions for behaviour to change further (43). More specifically, in Chapter 7, I investigated the effectiveness of salient pricing strategies on food purchases. It would have been of interest to also study the change in public awareness resulting from the information provided to participants as to why a food item has been taxed. Furthermore, study evaluations are also very simplistic as most studies focus on the effect of a change in one factor on one outcome (e.g. a 20% price increase of unhealthy foods on unhealthy food purchases). The consequence of studying only one driver of unhealthy dietary behaviour in a linear and simplistic way is that it may lead to ambiguous results without clear benefits to diet and health (35). For example, system changes as a result of an intervention can take time to emerge as feedback loops build over time; e.g. in Chapter 5 I only investigated the effect on-shelf sugar labels had on beverage sales without taking into account possible product reformulations (i.e. a system change) as a result of this label. Thus, the short-term assessment of on-shelf sugar labels may only capture the initial wave of decreased sugar purchases from beverages prior to the feedback loop where manufacturers adjust the amount of sugar in beverages, thereby underestimating the effectiveness of the nutrition label. A third shortcoming of current study evaluations – including those found in this doctoral thesis – is that they are often conducted from the perspective of only one field of study (42). Based on the studies in this doctoral thesis and previous research (13, 14), public health researchers (including myself) conclude that pricing strategies are effective in influencing food purchases and consumption in the desirable direction. However, as evidence suggests that the public acceptability of health-related taxes are low due to the belief that such taxes are generally ineffective at improving healthy food purchases (44), studies should take into account factors such as public acceptability which may hamper the implementation and effectiveness of pricing strategies. To conclude, RCTs and other epidemiological study designs generally do not take into account that for many health outcomes there are numerous factors at different levels of influence that interact which can ultimately affect the overall effectiveness of intervention strategies. This may partly explain the generally mixed findings with regards to studies investigating the effect of SSB taxes on health outcomes such as obesity and diabetes risk (45-47).

Given that many factors influence health outcomes, it is unfair to expect that one or even a few approaches are able to lead to relevant changes in health outcomes. Therefore, while pricing strategies hold great promise for improving population health, they are not a silver bullet. Rather, multiple strategies should be implemented and evaluated as a whole. While RCT evidence in artificial and real-world settings as well as quasi-experimental studies and interrupted-time series designs in real-world settings are internally valid means of establishing how much change has occurred after the introduction of an intervention (41), in the section 'Recommendations for future research' I will reflect on which study designs are able to consider the real-world dynamics of upstream approaches.

11.3.2 Study population

The degree of *Selection bias* can be displayed on a type of continuum where research based in community settings (namely the type of research found in this doctoral thesis) is found higher up the continuum as compared to for example research where participants are recruited from physicians. Higher degrees of *selection bias* can in turn affect the generalizability of study results; because younger individuals and females with a higher education tend to willingly sign up for studies in community settings (48, 49), the study sample may not be representative of the population intended to be analysed (e.g. the general Dutch population). With regard to the studies included in this doctoral thesis, despite the efforts of recruiting individuals with a low SEP, I mostly managed to include individuals with a medium and high SEP (e.g. only 10% of adults within the Dutch virtual supermarket study had the lowest educational level compared to 21% of the general Dutch population (50)). Therefore, the results within this doctoral thesis are not generalizable to those with the lowest SEP. Furthermore, while it is unknown what the ethnic background of the study participants was, it is likely that ethnic minorities were also underrepresented, especially considering their share in lower SEP populations.

Even if *selection bias* was limited, the generalizability of the studies in this doctoral thesis investigating the effectiveness of upstream approaches on dietary behaviours and the socio-economic inequalities herein may have a limited generalizability as differences in the price of food and cultural differences in food habits and dietary behaviours can hinder the generalizability of results to other countries (especially to low and middle income countries). For example, contrary to most studies – including the study described in Chapter 2 – finding that healthy diets are more expensive than less healthy diets (51), studies from Australia and New Zealand suggest that healthy diets are as expensive or less expensive than current diets (52, 53). Perhaps other factors than price can account for their dietary choices, and due to the lower importance of price in food choice, pricing strategies aimed at increasing healthy food purchases may be less effective in the Australian setting compared to for example the Dutch setting. Therefore, replication studies in other contexts are important.

11.3.3 Measurements

Self-reported educational level, occupation and income are the most frequently used indicators of SEP (54), which were also the indicators used in the studies included in this doctoral thesis. A limitation of these measures is that they do not fully reflect all potentially relevant factors that operationalise a complex concept such as SEP. Some SEP proxies may be particularly prominent in some situations and comparison of different socio-economic measures can help explain the mechanism behind the association if some SEP indicators are associated with dietary outcomes, while other indicators are not. For example, in Chapter 3, I could only include the SEP proxy educational level, while income may have been more appropriate given that income is more strongly related to dietary cost than educational level. Nevertheless, in Chapter 4, I included educational level, occupation and income as SEP proxies and found that the three indicators acted similarly despite studies suggesting that SEP indicators cannot be used interchangeability (55, 56). Given that sociodemographic variables such as ethnicity and sex can influence SEP (57), it is possible that individual-level SEP indicators work similarly in some study populations, but not in others. For example, educational level may correlate highly with occupation in a predominantly Dutch study population, but not within ethnic minority groups due to a lack of opportunities and discrimination (58). Given that the participants in the studies included in this doctoral thesis were likely predominantly White, this could explain why I did not find differences between SEP proxies.

In several chapters, dietary quality was measured using self-reported measures from Food Frequency Questionnaires (FFQs) or 24-hour recalls. FFQs generally ask participants what they ate in the last month or year, which can cause *recall bias* as recently consumed foods are remembered better or in more detail compared to foods that were consumed a while back. Self-reported data may also be subject to *social desirability bias* by for example under-reporting dietary intake of unhealthy foods. Social desirability can bias the results if this is unevenly distributed across food groups and the population. Indeed, studies found that there are differing levels of social desirability according to sex and age (59, 60) and that snacks, condiments and beverages are more likely to be under-reported (61). Nevertheless, FFQs and 24-hour recalls remain popular as they prove a feasible and cost-effective measure of dietary intake at the population-level. Next to subjective measures of dietary quality, objective dietary quality measures were used in all the experimental studies included in this doctoral thesis (i.e. food purchasing and sales data). While purchasing and sales data are not prone to *recall* or *social desirability bias*, food purchases/sales do not directly translate to food consumption as not all purchased foods are consumed. In addition, usually one household member does the shopping for the entire household, limiting the results to households instead of individuals. In conclusion, both self-reported as well as objective measures have their strengths and limitations which should be considered when interpreting the findings. For example, while FFQ and purchasing data may not suitable for estimating individual consumption, it is possible to rank participants/households based on their dietary quality scores.

11.4 Recommendations for research, policy and practice

The studies included in this doctoral thesis demonstrate that the price of food influences food purchases, that pricing strategies are able to improve healthy dietary behaviours without increasing inequalities and that combining nudges with pricing strategies can have additive effects. In this section, I provide some recommendations for policy and practice. Furthermore, as some research gaps remain, I end this section by introducing an alternative study design that can answer different kinds of research questions that are essential to the sustainability and upscaling of upstream interventions. Research gaps specifically relating to nudging and pricing strategies can be found within the individual chapters.

11.4.1 Recommendations for policy and practice

Food and beverage corporations include producers, processors, manufacturers, fast food chains and retailers. Together, they shape food systems in ways that determine the availability, price, nutritional quality, desirability and ultimately the consumption of foods (62). These corporations can take corporate social responsibility by serving larger social purposes, such as environmental sustainability, besides making profits (63). In the public health domain, taking corporate social responsibility would entail that the food industry facilitates healthy food policies and uses their expertise, scale, innovation and marketing to develop, distribute and market healthier foods (64). While corporate social responsibility has value, it is likely that this principle alone will not be sufficient to prevent/reduce obesity (65). For example, the Dutch National Prevention Agreement (a document in which over 70 organisations have set around 200 agreements on how the Netherlands can become healthier in terms of smoking, overweight and alcohol abuse) states that manufacturers will make SSBs, candy and dairy products healthier (66). However, a recent leaked report by Nestlé declared that 70% of their food products cannot be considered healthy (of which 96% of beverages) and that some categories will never be healthy (67). With regard to food retailers, interviews with industry stakeholders within the Supreme Nudge project suggest that food retailers are open for the prioritization of health, but only if an equal playing field between supermarket chains is created (e.g. through SSB taxes). Governments can create such an environment by coordinating obesity prevention initiatives, act as a 'nudger' in other cases, and in other cases act as the agent of robust policy change (68).

With regards to governmental agencies acting as an agent of robust policy changes, the Nuffield council on Bioethics published a report which specifies the responsibilities of governments in terms of addressing the needs of the population (69). The report also included an intervention ladder which aims to assist the thinking about the acceptability and justification of different policy initiatives aimed at improving public health (70). The first and least intrusive steps in the intervention ladder include doing nothing or monitoring the situation, and the highest step includes eliminating choice. Currently, most governments use interventions located somewhere below or in the middle of the ladder (21, 22). I argue that there is sufficient urgency which warrants the use of harder upstream approaches, and as such, interventions/policies higher up the intervention ladder.

Several lessons can be learned from the current COVID-19 pandemic which are relevant to the public health problems discussed in this doctoral thesis. These lessons include 1) the importance of policies higher up the intervention ladder and 2) the simultaneous implementation of multiple intervention strategies. The COVID-19 pandemic has shown that when there is sufficient urgency, governments are able and willing to implement strategies at the top of the intervention ladder (i.e. those that restrict and eliminate choice entirely). Examples of restricting measures that can be used to fight the obesity epidemic include restricting the number of licenses provided to fast food restaurants and regulating unhealthy food advertisements. Pertaining to the regulation of food advertisement, the COVID-19 pandemic has provided further evidence on why the food industry needs to be regulated. A recent report found that the food industry was taking advantage of COVID-19 by using marketing strategies towards unhealthy foods to appeal to sentiments like nostalgia and comfort while people are quarantined at home (71). These results were further replicated in a study conducted in New Zealand (72). This study found that 14 out of 20 unhealthy food brands referenced COVID-19 and a quarter of these posts were even COVID-19 themed (72).

With regards to the second lesson, the COVID-19 pandemic has shown that the implementation of multiple strategies to prevent and reduce the spreading of the virus was necessary. For example, despite the debate around the effectiveness of face masks in the control and prevention of COVID-19 (73), governments implemented a combination of strategies including mandating face masks in public areas, restricting the number of visitors at home, implementing a curfew and closing indoor sport facilities and non-essential shops. While it is uncertain if the mandatory face mask policy alone has led to a decrease in the spread of COVID-19, the combination of multiple strategies has led to the decreasing spread of the virus. Similarly, lessons from other complex public health problems, such as road safety, alcohol, and drug use show that a sustained, comprehensive portfolio of complementary strategies, delivered at scale are both possible and required for major and sustained effects (74). A large number of interventions targeting different aspects of the obesity epidemic need to be implemented, including downstream approaches, soft and hard upstream approaches targeting the food environment and upstream approaches targeting the social conditions of society.

When implementing these upstream approaches within the environment, it is important to consider the health equity of interventions/policies. To achieve health equity, population-level strategies can be adjusted proportionate to need, which would resemble the principle used in downstream approaches that are aimed at high-risk individuals. This proportionate universalism entails having the same ultimate goals for everyone but using appropriately tailored strategies to achieve these goals (36). An example of a proportionate upstream approach is spending more money on urban renewal in the most disadvantages neighbourhoods compared to more advantaged neighbourhoods. Next to the proportionate implementation of upstream approaches in the food/physical environment, upstream approaches addressing the inequitable distribution of power and resources within society (i.e. the social conditions) are also needed to reduce socio-economic inequalities in health (75).

Despite the theory and evidence that upstream approaches are effective and necessary to tackle the current obesity epidemic, governments are hesitant to implement such upstream approaches. A 2019 Lancet Commission report described the concurrent challenges with regards to the rise in obesity and has put forward several reasons for this policy inertia (7). One such challenge relates to industry opposition to governments implementing health-related policies (7). Some ways in which the food industry disrupts the necessary legislations is through campaigns highlighting the role of individual choices in poor diets and questioning the harm of processed foods (76, 77). The food industry also wields indirect influence by producing distorted scientific evidence and policy advice (76). A review on the political economy of nutrition reported industry interference as the most important barrier to achieving strong regulatory actions on unhealthy diets, obesity and diet-related NCDs in high income countries (78).

According to the aforementioned Lancet report (7), another factor contributing to the current policy inertia is that, at this moment, there is insufficient formal public demand for action to address obesity and its socio-economic inequalities. Evidence suggests that public support for policies can lead to action, thereby overcoming the food industry opposition and government reluctance (7). Government intervention in individuals' behavioural choices is often met with concerns of becoming a 'nanny state' in media headlines (79). However, governments could reframe their policy strategies as those preventing obesity and protecting children (80), thereby becoming 'positive states' instead of 'nanny states' (68). Indeed, research has shown that framing of political attitudes as well as policies is important for its overall acceptance by the population (23). Ultimately, the government is protecting its citizens from the competing interests of profit-making companies promoting unhealthy products (79). Thus, the reframing of policies could create sufficient public demand, which could in turn remove the governments' fear of becoming a nanny state.

Industry opposition and insufficient public demand are two factors rooted within the current neoliberal paradigm that prioritizes economic growth without incorporating hidden costs (i.e. externalities in terms of public health or the environment) (81). Currently, policy-makers work in a neoliberal ideology where government action to address obesity should not hamper individual freedom, is a personal responsibility for health and minimal regulation should be used in order to sustain economic competitiveness. This has caused public policy to privilege business interests over public health in public policy decisions (23, 77). The neoliberal ideology in combination with the power the food industry currently holds with regards to influencing public health policy (82), has likely led to the implementation of suboptimal intervention strategies to combat the current obesity epidemic including media campaigns, education and counselling (21, 22). Furthermore, this neoliberal paradigm is a critical driver of the tension that exists when the health sector attempts to intervene using more upstream and effective approaches to increase the purchases and consumption of healthy products and deter that of unhealthy products (77); the food industry aims to sell as much food as possible, while the health sector tries to reduce this overconsumption of mainly unhealthy foods.

11.4.2 Recommendations for future research

Policy-inertia caused by industry opposition and insufficient public demand are likely only two of many factors that are hampering the wide-spread implementation of upstream approaches by governmental agencies. While some of the links between specific aspects of the food system, social and individual level factors have been studied in detail, the interconnections between factors and the effects of the whole system on dietary behaviours and its socio-economic inequities have barely been investigated. System science methods can be used to understand the current food system and how we can act on the prevention and amelioration of obesity.

System science is an interdisciplinary field that studies the complexity of systems with an emphasis on the whole picture and the interactions between variables (83). Similarly to social ecological models, system science thinking acknowledges that health behaviours are influenced by a large number of factors on the economic, environmental and cultural levels. However, rather than placing individuals at the centre of the model being influenced by many different factors, systems thinking sees (individual) health as the *outcome* of the interactions within the system, i.e. the emergent property. The knowledge obtained from system approaches could in turn help inform researchers on how intervention strategies can generate change in health outcomes given the system factors currently present in populations. For example, the engagement of different stakeholders across sectors can lead to the co-production of a shared mental model which can be used to visualize the system elements and causal structure of the obesity epidemic. Such a model can then be used to better understand how obesity and its inequalities have emerged from the current neoliberal paradigm affecting the risk commodity environment and to begin and identify more coherent intervention/policy options (77). A recent study applied system dynamic methods (a popular quantitative method used in system science) to gain insights into the complexity of obesity-related behaviours (84). An important finding from this study, which likely would not have emerged from observational or intervention studies, was that while interventions in home or school settings might be effective in changing behaviours in those particular settings, interactions with macroeconomic and urban systems make these effects hard to maintain in the real world (84). An example of a system science study more directly relating to the findings in this doctoral thesis is to come together with stakeholders from different sectors (e.g. agriculture, health and finance) to assess how the prices and availability of foods can be influenced.

While researchers and public health advocates could try and tackle the current policy-inertia factors by identifying additional hampering factors, reducing the influence of the food industry on policy-making and increasing public health support, the most upstream solution would be to intervene on the paradigmatic level of the food system by changing/abolishing the current neoliberal paradigm. This would force the revolution likely necessary to bring about coherent policy action across sectors for the prevention of obesity and NCDs (81). Changing this paradigm would require a fundamental shift in the core of the system itself. The first avenue for this shift includes innovation within the existing system in which the dominant forces in the system overcome its inherent stability, and enact meaningful changes in one or several aspects of the system (85). This generally requires substantial external pressure on the system in its current form to create a do-or-die scenario for the dominant forces. Such substantial external pressures include a health crisis such as the current COVID-19 pandemic and public health advocacy. Advocacy can eventually shift the political climate towards where healthy diets would take precedence over the principles of neoliberalism. Instead of, or combined with external pressure, situations where the profit driven interests of the system align with facilitating healthy dietary behaviours can be identified. This could be achieved in public, private and academic partnerships (e.g. the Supreme Nudge project (86)) where intensive cooperation between parties could lead to an exchange in values. Therefore it is important for researchers to work together with other disciplines as the exchange in values could lead to health receiving more priority, which leads to more healthy dietary practices.

While the first avenue included innovation within the existing system, the second avenue would be a transition in which the current system is abolished, and replaced by a new network of interacting actors and factors (87). This requires both a major destabilization of the current system, for example a crisis, as well as the presence of a viable alternative. Some research has been done in the cultivation and management of transitions, which could be an interesting avenue to explore (88). However, in order to further explore these two avenues within systems theory, it is important that researchers, research funders and journal editors also undergo their own paradigm shift with regards to the design and evaluation of obesity prevention efforts. Currently, research funding structures are often organised in a way that favours RCT evidence (41, 89). Instead, priority and interest should be given to more novel, and perhaps at this moment more relevant, evidence from the systems thinking approaches.

11.5 General conclusion

The research presented in this doctoral thesis shows that diet-related material and psychosocial factors only partly explain socio-economic inequalities in dietary behaviours. Furthermore, the results have demonstrated that pricing strategies and the combination of pricing with nudging strategies are able to increase healthy dietary behaviours without increasing socio-economic inequalities. Despite the promise of upstream approaches to improve healthy dietary behaviours, they are rarely implemented as governmental strategies to reduce the current obesity epidemic. System science methods are promising approaches to understanding and acting on the prevention and amelioration of obesity and NCDs. Ultimately, the complex and multilevel causes of obesity and NCDs require multilevel approaches to address these problems, ranging from downstream approaches targeting high-risk individuals to population-wide upstream approaches targeting the food environment and the social conditions of society.

11.6 References

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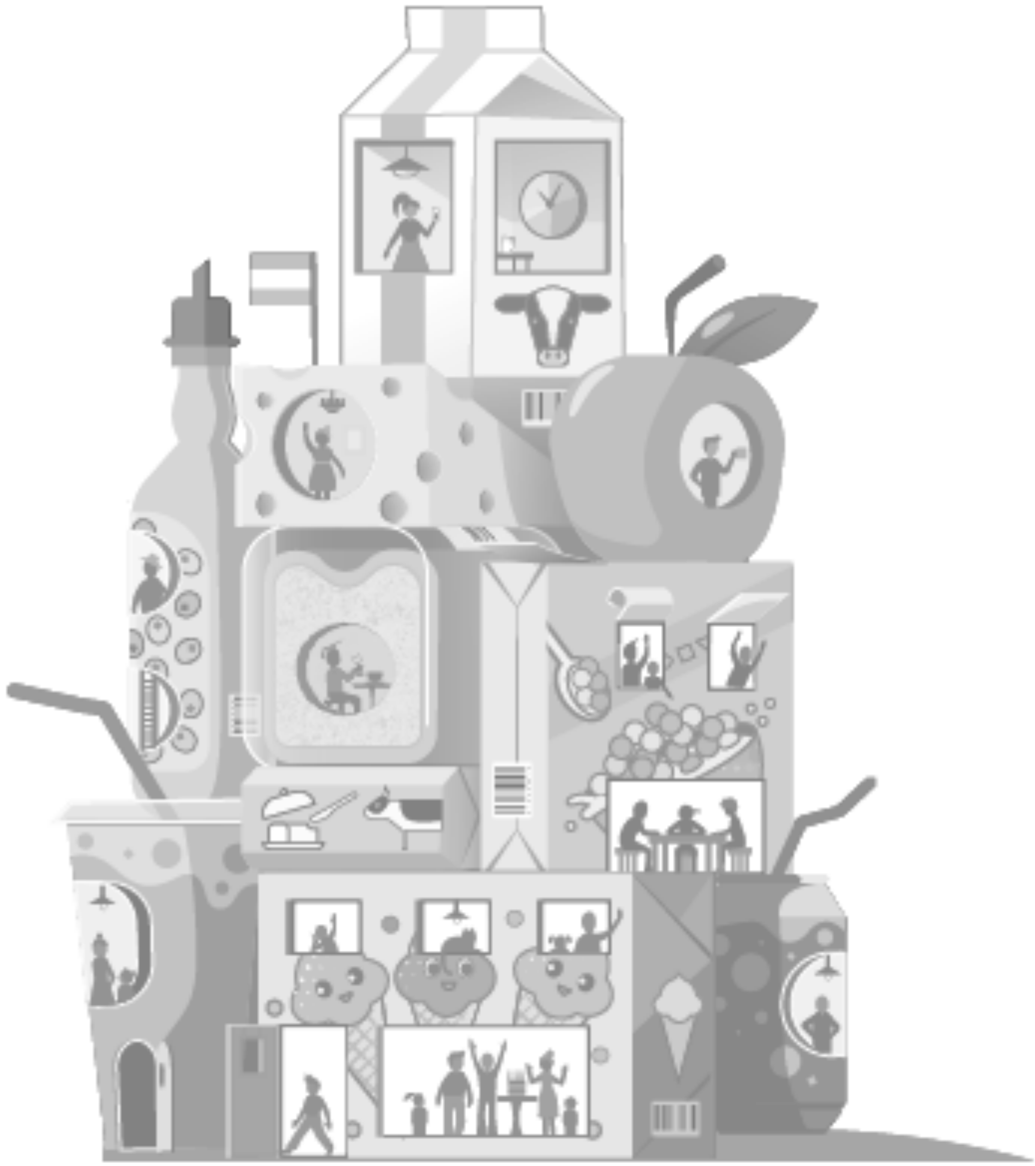


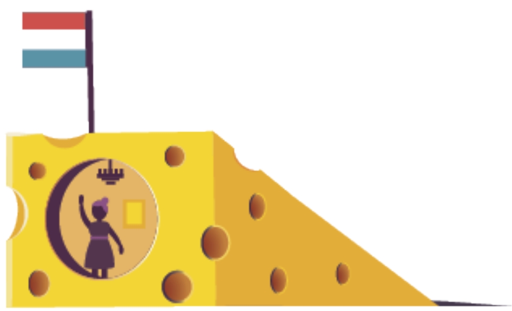
APPENDICES

Summary & Samenvatting

List of publications

PhD portfolio

Acknowledgements | Dankwoord



Summary of main findings

Non-communicable diseases (NCDs) such as cardiovascular disease and type 2 diabetes are major public health concerns, and unhealthy dietary intake is the strongest modifiable risk factor for these NCDs. Furthermore, the distribution and impact of NCDs and its risk factors are unequally distributed across groups of socio-economic position (SEP). As such, improving dietary behaviours will lead to reductions in the prevalence of NCDs. According to social ecological models, besides individual and interpersonal factors, upstream factors play an important role in influencing health behaviours. Examples of such upstream factors include the price of healthy and unhealthy foods, the proportion of healthy foods in the supermarket and the accessibility to food retailers. Nudging and pricing strategies are examples of intervention strategies that aim to change these upstream factors to promote healthy dietary behaviours. Nudges subtly modify peoples' behaviour without restricting choice (e.g. by placing healthy foods at eye-level or at check-out counters).

The relative contribution of some material and psychosocial factors in the relation between socio-economic inequalities and dietary behaviours is unknown. Furthermore, while evidence shows that pricing strategies are able to increase healthy dietary behaviours, the evidence on the effectiveness of nudging strategies and whether nudging and pricing strategies are able to decrease these socio-economic inequalities is equivocal. Combining nudging and pricing strategies will probably lead to the largest effects. However, very little research has evaluated the combined effect of several strategies aimed at increasing healthy dietary behaviours. The studies within this thesis aimed to close some of these aforementioned gaps in the literature. The first aim of this thesis was to gain insight into factors that explain socio-economic inequalities in dietary quality. The second aim of this thesis was to investigate the effectiveness of nudging and pricing strategies on food purchases and the possible differential effectiveness of these strategies across food groups and individuals with different SEP levels and personal characteristics.

In Chapter 2, I modelled the cost of healthy and current diets for an average Dutch household as well as for households with a low, medium and high educational level as the potentially higher cost of healthy diets could hamper households, especially households with a low SEP, from adhering to healthy dietary recommendations. On average, healthy diets were 24% more expensive than current diets and this difference increased by increasing educational level. The findings in Chapter 3 support those in Chapter 2 as I found that dietary cost partly explains socioeconomic inequalities in dietary quality measures. In another large cross-sectional studies (N>1400), I investigated the mediating role of other diet-related material and psychosocial factors in the relation between SEP indicators and dietary quality (Chapter 4). When combining the results from Chapters 3 and 4, I found that dietary cost as a material resource and cooking skills and resilience to the unhealthy food environment as psychosocial resources mediated around 30% of the association between SEP indicators and dietary quality. Food expenditure, perceptions of healthy food accessibility, healthfulness of the food retail environment, insensitivity to food cues and eating habits did not mediate this association. Thus, I concluded that diet-related material and psychosocial factors only partly explain socio-economic

inequalities in dietary behaviours and that perhaps deeper underlying mechanisms such as stress, housing and social capital are important factors to explore further.

Then, we developed a virtual supermarket in which nudging and pricing strategies were implemented to investigate the separate and combined effectiveness of these strategies on the proportion of healthy food purchases. I aimed to include an equal proportion of adults with low and high SEP to be able to stratify the results by SEP. As described in Chapter 6, a combination of different recruitment strategies led to the inclusion of 455 participants, of whom only a small proportion was truly low SEP. The virtual supermarket experiment showed that salient nudging strategies as well as pricing strategies (i.e. price increases, price discounts or both) alone did not lead to increases in healthy food purchases (Chapter 7). However, actively communicating these pricing strategies and combining these with nudges led to an approximately 3% increase in the proportion of healthy food purchases. The finding that nudging strategies alone may not be sufficient to increase healthy food purchases was confirmed in Chapter 5 where I conducted a natural experimental study in which I investigated the effectiveness of on-shelf sugar labels on beverage sales within 41 randomly selected supermarkets. The results indicated that after the implementation of on-shelf sugar labels, the sales of targeted beverages did not change compared to comparison stores. The findings in Chapters 5 and 7 led me to conclude that it is important to combine several strategies and that nudging strategies alone may not be sufficient to increase healthy dietary behaviours.

With regards to the possible differential effectiveness of nudging and pricing strategies, I investigated the modifying role of socio-economic indicators (Chapter 7) and other personal characteristics (Chapter 8) in the relation between nudging/pricing and healthy food purchases using the aforementioned virtual supermarket study. No evidence was found to suggest that nudging and pricing strategies in a supermarket setting work differently depending on individuals their SEP or personal characteristics (i.e. impulsivity, decision-making style, price sensitivity and food choice motives). This led to the conclusion that nudging and pricing strategies can be implemented in supermarket settings as generic health promoting interventions without increasing existing health inequalities. Whereas the effectiveness of nudging and pricing strategies does not seem to differ by socio-economic indicators or personal characteristics, according to the results presented in Chapters 9 and 10, its effectiveness does seem to depend on the food group targeted. Using data from the aforementioned virtual supermarket study, I investigated in which food groups nudging and pricing strategies most effectively change product purchases and where potentially within-food group substitution or spill-over effects occur (Chapter 9). The results indicated that the largest effects were found for dairy and grains. For example, when implementing both nudges and price decreases, healthy diary purchases increased by 43% while this was not the case for the food groups fruit and vegetables, protein products and beverages. These results suggest that dairy and grains may be the most promising food groups to target in order to achieve healthier food purchases in a Dutch setting. As little is known about *within* food group substitution and complementary behaviours, in Chapter 10, I used data from a New Zealand virtual supermarket study including over 4000 shopping events to investigate possible substitution and complementary effects of health-related taxes *within* food groups. As no consistent pattern of substitution of complementary purchasing was found, I was unable to conclude which food groups are best targeted by pricing strategies. However, I did observe that some substitution and complementary effects are in line with the goal of the health-related taxes (e.g. a 1.0% increase in the price of high saturated fat dairy was associated with a 1.0% decrease in purchases of high saturated fat dairy and a 0.2% increase in purchases of low saturated fat dairy).

In conclusion, the research presented in this doctoral thesis shows that diet-related material and psychosocial resources only partly explain socio-economic inequalities in diet. Furthermore, salient pricing strategies as well as a combination of salient pricing and nudging strategies are able to increase healthy purchases within a supermarket setting and perhaps dietary behaviours without increasing inequalities.

Samenvatting van de belangrijkste bevindingen

In 2018 werd 90% van alle sterftegevallen in Nederland veroorzaakt door chronische ziekten zoals hart- en vaatziekten, type 2 diabetes en kanker. Een ongezond voedingspatroon is de belangrijkste oorzaak van deze chronische ziekten. Bovendien is de prevalentie van chronische ziekten (evenals de risicofactoren) oneerlijk verdeeld over verschillende groepen in de samenleving. Zo lijden personen met een lager opleidingsniveau vaker aan chronische ziekten dan personen met een hoger opleidingsniveau. Onderzoek laat zien dat maar 8% van laagopgeleide volwassenen ten opzichte van 24% van hoogopgeleide volwassenen zich houdt aan de richtlijnen voor aanbevolen hoeveelheid groenteconsumptie.

Er zijn meerdere factoren die ons eetgedrag beïnvloeden, waaronder individuele factoren zoals geslacht, opleidingsniveau, inkomen en leeftijd. Naast deze individuele factoren beïnvloeden ook omgevingsfactoren ons eetgedrag. Denk hierbij aan de aanwezigheid van gezond eten in de supermarkt, het prijsverschil tussen gezond en ongezond voedsel en de afstand naar het dichtstbijzijnde fastfood restaurant.

De supermarkt is een belangrijke voedselaanbieder aangezien 70% van ons dagelijks eten hier vandaan komt. Nudging- en prijsstrategieën zijn voorbeelden van interventies die gezonde voedselkeuzes in de supermarktomgeving kunnen stimuleren. Een nudge is een duwtje in de goede richting, bijvoorbeeld door de supermarktomgeving zo aan te passen dat gezonde producten komen te staan op prominente plekken zoals op ooghoogte, in kopschappen en bij de kassa's. Prijsstrategieën zijn het duurder maken van ongezond eten en/of het goedkoper maken van gezond eten.

Er is nog niet veel bekend over factoren die het ongezonder voedingspatroon van laagopgeleiden ten opzichte van hoogopgeleiden verklaren. Echter toont onderzoek wel aan dat de kosten van voedingsproducten deels sociaaleconomische verschillen in voedingspatronen kunnen verklaren. Terwijl er duidelijk bewijs is dat het goedkoper maken van gezonde producten en/of het duurder maken van ongezonde producten de voedselkeuze beïnvloedt, is er minder bewijs voor de effectiviteit van nudges. Momenteel is er ook weinig bekend over de sterkte van het effect van het combineren van nudging- en prijsstrategieën op voedselkeuze.

In dit proefschrift heb ik onderzocht welke factoren sociaaleconomische verschillen in voedingsgewoontes kunnen verklaren. Het tweede doel van dit proefschrift was om het effect van nudging- en prijsstrategieën op eetgedrag te onderzoeken, waarbij ook gekeken werd naar mogelijke verschillende effecten binnen productgroepen en op basis van sociaaleconomische positie (SEP) of andere persoonlijke karakteristieken.

In Hoofdstuk 2 heb ik de gemiddelde prijs van gezonde en huidige voedingspatronen gemodelleerd voor zowel een gemiddeld Nederlands huishouden als voor huishoudens met een laag, midden en hoog opleidingsniveau. De resultaten toonden aan dat een gezond voedingspatroon gemiddeld 24% duurder is ten opzichte van het huidige voedingspatroon. Vervolgens heb ik gebruik gemaakt van twee grote Nederlandse cohorten met meer dan 1400 deelnemers om te onderzoeken welke materiële en psychosociale factoren sociaaleconomische verschillen in voedingspatronen verklaren. De resultaten van deze cross-sectionele studies gepresenteerd in Hoofdstukken 3 en 4 tonen aan dat de materiële en psychosociale factoren voedingskosten, kookvaardigheden en weerbaarheid tegen de ongezonde voedselomgeving uiteindelijk ongeveer 30% van SEP-verschillen in voedingspatronen verklaren. Voedseluitgaven, objectieve en subjectieve waarnemingen over de toegankelijkheid van gezonde voedselaanbieders, beïnvloedbaar zijn door voedselaanwijzingen en eetgewoontes verklaarden deze verschillen niet. Ik vermoed dat factoren op een hoger niveau (denk hierbij aan huisvesting, stress en het minimum inkomen) een rol spelen bij het verklaren van een ongezonder voedingspatroon bij populaties met een lage SEP.

Omdat zowel nudging- en prijsstrategieën ingezet kunnen worden om gezondere voedingsaankopen te stimuleren, ben ik niet alleen geïnteresseerd naar het individuele effect van de twee maatregelen maar ook naar het gecombineerde effect hiervan. Dit heb ik onderzocht in een virtuele supermarkt. In deze virtuele supermarkt konden deelnemers vanuit hun eigen computer of laptop rondlopen in een supermarkt en fictieve boodschappen doen. Aangezien wij ook wilden weten of nudging- en prijsstrategieën even effectief zijn voor mensen met een lage en hoge SEP, was het doel om beide groepen mee te laten doen aan het virtuele supermarkt onderzoek. In Hoofdstuk 6 heb ik beschreven hoe wij deelnemers voor de virtuele supermarkt hebben geworven. Ondanks het feit dat we genoeg deelnemers hebben kunnen includeren (namelijk 455 deelnemers), is het ons minder goed gelukt om voldoende mensen met een lage SEP te includeren.

In Hoofdstuk 7 zijn de resultaten van de virtuele supermarkt studie beschreven. De resultaten tonen aan dat alleen nudging- en prijsstrategieën niet voldoende zijn om het aantal gezonde productaankopen te beïnvloeden. Wat wél een succesvolle strategie bleek, is het mensen wijzen op de prijsveranderingen (prijsverhogingen, prijsverlagingen en beide) en dit te combineren met nudgingstrategieën. Het combineren van deze strategieën heeft ertoe geleid dat mensen gemiddeld 3% meer gezonde aankopen deden. De bevinding dat nudgingstrategieën alleen niet voldoende zijn om aankopen te veranderen bleek ook uit Hoofdstuk 5. Dit hoofdstuk beschrijft een studie waarin gekeken werd naar het effect van gekleurde etiketten met informatie over de hoeveelheid suiker in de dranken. De etiketten werden in 45 supermarkten opgehangen naast het prijskaartje van het product. In dit natuurlijke experiment hebben wij geen effect gevonden van de etiketten op de verkoop van dranken. Gebaseerd op deze resultaten heb ik geconcludeerd dat het belangrijk is om verschillende maatregelen te combineren en dat nudgingstrategieën alleen niet voldoende zijn om gezond aankoopgedrag te bevorderen.

De bevindingen beschreven in Hoofdstuk 7 tonen aan dat nudging- en prijsstrategieën even effectief zijn voor mensen met een lage en hoge SEP. Om er zeker van te zijn dat nudging- en prijsstrategieën vergelijkbare effecten hebben over mensen met verschillende eigenschappen, heb ik in Hoofdstuk 8 onderzocht of de effectiviteit van deze strategieën anders was voor mensen met verschillende persoonlijke karakteristieken zoals impulsiviteit en prijssensitiviteit. Net als voor SEP vonden we dat de effectiviteit van nudging- en prijsstrategieën vergelijkbaar is voor mensen met verschillende persoonlijke karakteristieken. Gebaseerd op deze bevindingen heb ik geconcludeerd dat nudging- en prijsstrategieën in de supermarkt geïmplementeerd kunnen worden als generieke gezondheidsbevorderende interventies, zonder daarmee bestaande gezondheidsverschillen te vergroten.

Hoewel nudging- en prijsstrategieën vergelijkbaar werken voor mensen met verschillende karakteristieken en sociaaleconomische indicatoren, lijkt dit niet het geval te zijn voor voedingsgroepen. In Hoofdstuk 9 maakte ik wederom gebruik van de virtuele supermarkt om het potentiële verschillende effect van nudging- en prijsstrategieën van voedingsgroepen te onderzoeken. De resultaten van deze studie toonden aan dat nudging- en prijsstrategieën het meest effectief waren voor zuivel- en graanproducten. Bijvoorbeeld, een combinatie van prijsverlaging en nudges leidde tot een toename in gezonde zuivelproducten van 43%, terwijl prijsverlagingen en nudges geen statistisch significante invloed hadden op de voedingsgroepen fruit, groenten en dranken. In Hoofdstuk 10 heb ik op basis van gegevens uit een Nieuw-Zeelandse virtuele supermarkt onderzocht of het implementeren van verschillende prijsstrategieën leidt tot substitutie of complementair gedrag *binnen* verschillende voedingsgroepen. Een voorbeeld van substitutiegedrag is dat de vraag naar bruin brood stijgt als de prijs van wit brood stijgt. Een voorbeeld van complementair gedrag is dat de vraag naar thee daalt als de prijs van koffie stijgt. Omdat ik geen consistent patroon van substitutie- of complementaire gedragingen heb gevonden, kon ik niet concluderen op welke voedingsgroepen interventies zich het beste kunnen richten om een gezond dieet te bevorderen. Wel lieten de resultaten zien dat sommige substitutie- en complementaire effecten zouden bijdragen aan het ontmoedigen van ongezond eten en het aanmoedigen van gezond eten.

Met de studies in dit proefschrift heb ik laten zien dat voedingsgerelateerde materiële en psychosociale factoren maar een klein gedeelte van de relatie tussen SEP en voedingspatronen verklaren. Verder heb ik aangetoond dat gecommuniceerde prijsstrategieën en een combinatie van verschillende maatregelen in de supermarkt bijdragen aan het bevorderen van gezonder aankoopgedrag en mogelijk een gezonder voedingspatroon zonder sociaaleconomische ongelijkheden in voedingsinname te vergroten.

List of publications

Manuscripts published and included in this doctoral thesis

I. **Hoenink JC**, Stuber JM, Lakerveld J, Waterlander W, Beulens JW, Mackenbach JD. The effect of on-shelf sugar labelling on beverage sales in the supermarket: a comparative interrupted time series analysis of a natural experiment. International Journal of Behavioral Nutrition and Physical Activity. 2021 Dec;18(1):1-1.

II. **Hoenink JC**, Mackenbach JD, Van Der Laan LN, Lakerveld J, Waterlander W, Beulens JW. Recruitment of participants for a 3D virtual supermarket: Cross-sectional observational study. JMIR formative research. 2021 Feb 9;5(2):e19234.

III. **Hoenink JC**, Mackenbach JD, Waterlander W, Lakerveld J, van der Laan N, Beulens JW. The effects of nudging and pricing on healthy food purchasing behavior in a virtual supermarket setting: a randomized experiment. International Journal of Behavioral Nutrition and Physical Activity. 2020 Dec;17(1):1-2.

IV. **Hoenink JC**, Beulens JW, Harbers MC, Boer JM, Dijkstra SC, Nicolaou M, Van Der Schouw YT, Sluijs I, Verschuren WM, Waterlander W, Mackenbach JD. To what extent do dietary costs explain socio-economic differences in dietary behavior?. Nutrition journal. 2020 Dec;19(1):1-2.

V. van der Molen AEH, **Hoenink JC**, Mackenbach JD, Waterlander W, Lakerveld J, Beulens JWJ. Are nudging and pricing strategies on food purchasing behaviors equally effective for all? Secondary analyses from the Supreme Nudge virtual supermarket study. Appetite. 2021 Aug 17:105655.

VI. Stuber JM, **Hoenink JC**, Beulens JW, Mackenbach JD, Lakerveld J. Shifting toward a healthier dietary pattern through nudging and pricing strategies: A secondary analysis of a randomized virtual supermarket experiment. The American Journal of Clinical Nutrition. 2021 Apr 7.

Manuscripts published but not included in this doctoral thesis

I. **Hoenink JC**, Mackenbach JD. Commentary: Addressing unfair and preventable inequalities in cancer. International Journal of Epidemiology. 2021.

II. **Hoenink JC**, Galenkamp H, Beune EJ, Hartman MA, Snijder MB, Dijkshoorn H, Peters RJ, Bal E, Stronks K, Nicolaou M. Body size ideals and body satisfaction among Dutch-origin and African-origin residents of Amsterdam: The HELIUS study. PloS one. 2021 May 26;16(5):e0252054.

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IV. Stuber JM, Mackenbach JD, de Boer FE, de Bruijn GJ, Gillebaart M, Harbers MC, **Hoenink JC**, Klein MC, Middel CN, van der Schouw YT, Schuitmaker-Warnaar TJ. Reducing cardiometabolic risk in adults with a low socioeconomic position: protocol of the Supreme Nudge parallel cluster-randomised controlled supermarket trial. Nutrition journal. 2020 Dec;19:1-9.

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Manuscripts in preparation or submitted

I. **Hoenink JC**, Waterlander W, Mackenbach JD, Ni Mhurchu C, Wilson N, Beulens JWJ, Nghiem N. Impact of taxes on purchases of close substitute foods: Analysis of cross-price elasticities using data from a randomized experiment. In revision at Nutrition Journal.

II. **Hoenink JC**, Waterlander W, Beulens JWJ, Mackenbach JD. The role of material and psychosocial resources in explaining socioeconomic inequalities in diet: A structural equation modelling approach. Under review at Public Health Nutrition.

III. **Hoenink JC**, Waterlander W, Vandevijvere S, Beulens JWJ, Mackenbach JD. The cost of healthy versus current diets in the Netherlands for households with a low, medium and high education. Under review at Public Health Nutrition.

IV. Eisink M, Mackenbach JD, Pinho MGM, **Hoenink JC**. Clusters of food retail use and the description of their socio-demographic characteristics and diet-related behaviours. In preparation.

PhD portfolio

Year	**Courses**	ECTs
2021	Causal Inference	2
2020	Clinimetrics: Assessing measurement properties	3
2020	Social epidemiology	1
2020	Grant writing skills	0.4
2020	Medische basiskennis	8
2019	Using R for data analysis	1.5
2019	BROK	1.5
2019	Mediation analysis	2
2019	A gentle introduction to Bayesian statistics	1.5
2018	Scientific integrity	2
2018	Scientific writing in English	3
	Conferences and other scientific meetings	
2021	20th Annual Meeting of the International Society of Behavioural Nutrition and Physical Activity (ISBNPA)	1
2021	Dutch Epidemiological Conference (WEON)	1
2020	19th Annual Meeting of the International Society of Behavioural Nutrition and Physical Activity (ISBNPA)	1
2019	New Zealand research visit	6
2019	The NUDGE Conference (WINK)	0.5
2019	Multilevel Conference	0.5
2019	18th Annual Meeting of the International Society of Behavioural Nutrition and Physical Activity (ISBNPA)	1
2018	17th Annual Meeting of the International Society of Behavioural Nutrition and Physical Activity (ISBNPA)	1
2018 - 2021	DIABOLO	2
2018 - 2020	Intervision meetings of the Amsterdam Public Health Research Institute	1
	Supervision and education	
2021	Supervision of Milou Eisink – Master Health Sciences Title: Clusters of food retail use and the description of their socio-demographic characteristics and diet-related behaviours	1
2020	Supervision of Annemarijn van der Molen – Master Health Sciences Title: Are nudging and pricing strategies on food purchasing behaviors equally effective for all?	1

2019	Supervision of Dianne van der Lans – Master Health Sciences Title: Nudging and pricing strategies for the promotion of healthy purchasing behaviour in a virtual supermarket setting	1
2019	Supervision of Naoual Sabiri – Master Health Sciences Title: The influence of weight status on the effectiveness of nudging in a virtual supermarket setting – the Supreme Nudge project	1
2018 - 2021	Education for the Epidemiology and Biostatistics Department	4
	Other activities	
2021	Peer review article for the journal Archives of Public Health	
2019 - 2021	Peer review articles for the journal Public Health Nutrition	
2019 - 2021	Epidemiology and Data Science (EDS) PhD committee member	
2020 - 2021	Association of Amsterdam UMC PhD candidates (ASAP) committee member	
2018 - 2021	Upstream Team member	

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We have finally arrived to the most read section of any doctoral thesis, namely the Acknowledgements section! This section has been four years in the making. I was definitely not able to write this doctoral thesis without the help of the individuals described in this section.

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While writing this Acknowledgements section, I needed some inspiration. Thus, I started googling and found an article that stated that there were broadly 3 factors that predict a successful PhD. The first factor included institutional and environmental factors including the culture at the department. The second and third factors included supervision and individual characteristics. As previously established, I had wonderful supervisors. However, next to that, I also had some great colleagues at the EDS departments that I could share my ideas, frustrations, and laughter with. I'll start by thanking the OG PhD students of the department, namely, Mirrelijn, Sharon, Sabine, Gabi & Josine. Wij zijn allemaal ongeveer gedurende dezelfde periode begonnen aan onze PhD. Mirrelijn, wat ga ik jouw positieve energie en lach missen! Sharon, ik kon altijd bij je terecht voor mijn statistiekvragen en om mij ook gewoon even te uiten over bepaalde frustraties samen met Sabine. Sabine, heel erg bedankt voor de altijd gezellige warme chocolademelkmomenten en wandelingen. Gaab, ik vond onze samenwerk- momentjes tijdens Corona en al onze wandelingetjes heel gezellig en ik hoop dat we nog lang kunnen fietsen met ons EDS fietsclubje! Josine, jij was een jaartje later van de partij maar ik kan mij eigenlijk niet meer herinneren hoe het was zonder jou. Bedankt voor de fijne samenwerking aan het Supreme Nudge project en ik wens je verder heel veel succes! Ik wil jullie allemaal bedanken voor de gezellige borrels, wandelingen, lunches en gesprekken.

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