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The role of reformulation, nutrition labelling and hedonic eating stimulation

Terhi Junkkari

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All knowledge of reality starts from experience.
(inspired by Albert Einstein)

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ABSTRACT

Unhealthy diets are a major driver of lifestyle-related diseases, creating demand for interventions that foster healthier food choices. This dissertation examines three complementary strategies—food reformulation, nutrition labelling, and hedonic digital eating cues— to encourage healthier food choices within real-world food service environments, thereby providing ecologically valid evidence often missing from surveys and laboratory-based research.

The first study assessed recipe reformulation of both "vice" and "virtue" products to improve nutritional quality without compromising taste or consumer acceptance. The results demonstrate that reformulation is technically feasible and can be integrated into the catering sector, but it requires adequate resources for product development, sensory testing and systematic monitoring to ensure acceptance.

The second study evaluated the real-life effectiveness of nutrition labels, in this case the Finnish Heart Symbol, in guiding healthier food choices. Findings confirm that labels supported healthier selections, but also reveal unintended consequences, including compensatory behaviours in the use of flavour enhancers that may offset intended benefits. These results highlight the importance of integrated strategies that combine labelling with supportive food environments and other complementary approaches.

The third study explored digital interventions, including hedonic, video-based prompts, which can influence satiety, appetite, and food choice through grounded cognition mechanisms. Findings highlight their potential as scalable, technology-driven nudges, though further research is required on long-term effects.

Together, the studies highlight the complexity of food choices and show that no single measure alone can shift diets towards healthier patterns. Achieving sustained change requires combining reformulation, nutritional labelling, and digital nudges with broader interdisciplinary actions that consider consumer behaviour and habits, beliefs, sensory experiences, and the long-term maintenance of dietary patterns.

KEYWORDS: food reformulation; nutrition labelling; digital nudges; eating cues; consumer behaviour; foodservice sector; grounded cognition; healthy diets; public health nutrition

TURUN YLIOPISTO
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TIIVISTELMÄ

Epäterveellinen ruokavalio on keskeinen elintapasairauksien riskitekijä ja lisää tarvetta keinoille, jotka tukevat terveellisempiä ruokavalintoja. Tämä väitöskirja tarkastelee kolmen toisiaan täydentävän menetelmän—reseptien terveellisemmäksi muokkauksen (reformulointi), ravitsemusmerkintöjen (Sydänmerkki) sekä hedonisten videoärsykkeiden—vaikutuksia ruokakäyttäytymiseen todellisissa ruokapalveluympäristöissä.

Ensimmäinen osatutkimus tarkastelee reformulointia nk. “pahe”- ja “hyve”-tuotteissa, tavoitteena parantaa niiden ravitsemuksellista laatua ilman, että maku tai kuluttajien hyväksyntä kärsi. Tulokset osoittavat, että reformulointi on teknisesti toteuttamiskelpoinen, mutta sen laajamittainen käyttöönotto edellyttää resursseja tuotekehitykseen ja kuluttajatesteihin sekä kansallista seurantajärjestelmää edistymisen arvioimiseksi.

Toinen osatutkimus tarkastelee ravitsemusmerkintöjen, tässä tutkimuksessa suomalaisen Sydänmerkin, toimivuutta terveellisempien valintojen tukena. Tulokset osoittavat, että merkinnät ohjaavat terveellisempiin valintoihin, mutta samalla ilmenee kompensoivaa käyttäytymistä maunvahvistajien käytössä, mikä voi heikentää kokonaishyötyjä. Tämä korostaa tarvetta yhdistää ravitsemusmerkinnät ruokailuympäristön muutoksiin ja muihin valintoja tukeviin keinoihin.

Kolmas osatutkimus tarkastelee hedonistisia, videopohjaisia ruokaärsykkeitä, joiden vaikutus kuluttajien kylläisyyteen, ruokahaluun ja valintoihin perustuu grounded cognition -teoriaan. Tulokset osoittavat, että dynaamisilla aistiärsykkeillä on potentiaalia skaalautuvina digitaalisina tuuppausstrategioina, mutta niiden pitkäaikaisvaikutuksista tarvitaan lisätutkimusta.

Tutkimus vahvistaa aiempia havaintoja ruokavalintojen monimutkaisuudesta ja osoittaa, ettei niitä voida muuttaa terveellisemmiksi yksittäisin keinoin. Pysyvä muutos edellyttää reformulaation, ravitsemusmerkintöjen ja digitaalisten tuuppausten yhdistämistä laajempiin monitieteisiin toimiin, jotka huomioivat kuluttajien käyttäytymisen ja tukevat ruokavalioiden pitkäaikaista muutosta.

AVAINSANAT: reformulaatio; ravitsemusviestintä; tuuppaus; digitaaliset ruoka-ärsykkeet; kuluttajakäyttäytyminen; ruokapalvelusektori; grounded cognition -teoria; terveelliset ruokavaliot; kansanravitsemus

Table of Contents

Abbreviations

FOP	Front-of-package label
NCD	Non-communicable disease
SSR	Self-service restaurant

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I **Junkkari Terhi**, Hopia Anu, Paakki Maija, Mattila Saija, Arjanne Leena, Kantola Maija, Luomala Harri. (2023). Simple ways to improve nutrient content and health profile in different types of catering products. *Journal of Foodservice Business Research*, *28*(5), 955–975. https://doi.org/10.1080/15378020.2023.2298626

II **Junkkari Terhi**, Kantola Maija, Arjanne Leena, Luomala Harri, Hopia Anu. (2024). The effect of nutrition labels on lunch buffet consumption: A real-life experiment. *British Food Journal*, *126(*13), 18–39. https://doi.org/10.1108/BFJ-06-2023-0532

III Kantola Maija, **Junkkari Terhi**, Hopia Anu, Luomala Harri. Sinfully good: The effect of hedonic eating simulation, choice motivations, and taste beliefs on (un)healthy food consumption. Manuscript. This original publication will also be included in the thesis book of MSc Maija Kantola.

1 Introduction

Unhealthy dietary habits significantly increase the risk of lifestyle-related diseases and impose substantial economic burdens on healthcare systems. Food reformulation has emerged as an essential strategy for improving nutritional quality in products consumed both at home and in foodservice settings, which account for an increasing share of total food consumption and where nutritional information is less standardized (WHO, 2022). In this work, reformulation is defined as compositional changes targeting key dietary risk factors for non-communicable diseases (NCDs)—namely salt, sugar, fat, and fibre—excluding fortification and allergen removal, which serve distinct nutritional and regulatory purposes. Although reformulation techniques have been increasingly adopted within the food and catering industry, their application within the foodservice sector remains limited. This is partly due to concerns about consumer acceptance, particularly regarding changes in taste and sensory profiles, which chefs and restaurant operators fear might lead to decreased customer satisfaction and sales (Earle et al., 2017; Murray et al., 2015). Consequently, empirical evidence on how reformulation influences consumer behaviour in real-world foodservice contexts remains limited.

At the same time, European policymakers have considered implementing mandatory front-of-package (FOP) nutrition labels, such as the Nutri-Score, to help consumers make informed, healthier food choices (European Commission, 2023). While promising, these labels have not yet been adopted uniformly due to complexities in food choosing and varying consumer responses (Suher et al., 2016; Wansink & Chandon, 2006). In Finland, the Heart Symbol (Finnish Heart Association, n.d.) has been in use since 2000 to help consumers identify the healthier options within a product category. Current evidence on the real-world effectiveness of nutrition labels remains scarce, necessitating further empirical investigation into consumer responses within authentic eating environments (Ballco & Gracia, 2022; Naicker et al., 2021; Zlatevska et al., 2024). Also, Finland's national policy emphasizes preventive health and well-being through improved nutrition, particularly among children and youth, with a focus on healthier food environments and sustainable public meals (Ministry of Social Affairs and Health, 2024). The

National Nutrition Commitment, started from 2017, engages major food industry actors in reformulating products (Finnish Food Authority, 2021). While the model is promising, challenges like limited public awareness and evaluation difficulties remain. Nonetheless, it is seen as a viable long-term tool for promoting healthier food choices (Pättiniemi-Fagerström, 2021).

Beyond reformulation and explicit health labelling, recent research indicates that consumer behaviour can also be subtly influenced through eating stimulation, grounded in cognitive theory. Visual and sensory stimulus—such as food images or videos—may trigger subconscious mental processes influencing appetite, cravings and satiety. Although existing studies suggest these stimuli can both enhance and diminish food consumption depending on exposure duration and cognitive engagement, empirical data on their effectiveness, especially in real-life settings, remains limited (Otterbring et al., 2023; Papies et al., 2020). Additionally, previous research highlight the increasing integration of sensory and consumer sciences, emphasizing that consumer food choices are shaped not only by sensory experience but also by informational and environmental cues (Grunert, 2015).

This dissertation addresses key knowledge gaps through three interconnected studies conducted in the foodservice industry. The first study investigates practical approaches to implementing basic food reformulation techniques, aiming to improve nutritional quality without compromising taste or consumer acceptance. The second evaluates the real-life effectiveness of nutrition labelling in guiding consumers toward healthier choices. The third explores how video-based, hedonic visual eating cues influence eating behaviour in real-world contexts.

Together, these studies provide actionable insights and empirical evidence to support healthier dietary behaviours through reformulation strategies, labelling interventions, and video-based approaches. Although product reformulation has been used as a public health strategy since the 1970s, its emphasis and implementation have varied over time, reflecting shifts in societal priorities and the roles of different stakeholders—from government-led initiatives to industry-driven innovations. However, despite its widespread application, the real-world impact of reformulation on consumer behaviour remains underexplored, particularly in naturalistic foodservice settings. This dissertation addresses this gap and offers a novel contribution by examining how nutrition communication and visual stimuli influence consumer behaviour in real-world foodservice contexts. By integrating theories of nudging (Thaler & Sunstein, 2003) and grounded cognition (Barsalou, 2008), the research highlights how subtle, context-sensitive multimodal cues can influence food choices without limiting autonomy. Unlike much of the existing research, which mostly relies on surveys and controlled laboratory experiments, this study provides ecologically valid insights that reflect actual decision-making processes in everyday environments. The findings are relevant not only for public health and policy development but also for the food industry sector, offering practical strategies for aligning health goals with commercially viable and consumer-accepted practices.

2 Review of the Literature

2.1 Food reformulation: a method for improving public health through better nutrition

Food reformulation refers to the process of redesigning food products to make them healthier while maintaining their sensory appeal, safety and functionality (Drewnowski et al., 2022; WHO, 2022). This often includes reducing harmful components like saturated fats, sugars and salt or enhancing products with beneficial nutrients such as fibre or vegetable oils (Fanzo et al., 2023; Onyeaka et al., 2023; Scott et al., 2017; Tedstone et al., 2018; van Raaij et al., 2009; WHO, 2022). The primary aim of reformulation is to promote health and wellbeing by aligning food products with nutritional recommendations. Authorities have been advocating for reformulation over the past few decades to mitigate the risks associated with unhealthy eating habits, including those high in salt, sugar and fat (WHO, 2018a). Reformulation can range from minimal modifications, such as reducing sugar content, to more complex changes, including restructuring the food matrix to improve nutritional quality and digestion (Capuano et al., 2018). However, these efforts are not without technical challenges; for instance, sodium acts as a preservative and a flavour enhancer, making its reduction more complicated due to potential impacts on microbial safety and product stability (Department of Health and Aged Care, 2021).

Reformulation has become a critical strategy in mitigating the global epidemic of NCDs, including obesity, type 2 diabetes and cardiovascular diseases. Excessive consumption of energy-dense, nutrient-poor foods rich in salt, sugar and unhealthy fats has been directly linked to these conditions and also to some type of cancers (Afshin et al., 2019; Pineda et al., 2018; WHO, 2003). Thus, unhealthy eating habits significantly increase societal healthcare costs and contribute to individual suffering and mortality (Goryakin et al., 2019; Murray et al., 2020). Reformulation offers a pathway to reduce these burdens by creating food products that meet dietary guidelines while remaining accessible and acceptable to consumers. In order to improve public health, food reformulation should be complemented with a range of approaches, including subsides, food taxes, restrictions on food marketing and FOP labelling (Fanzo et al., 2023).

Globally, numerous countries have established ambitious targets for improving food products to promote healthier diets. In recent decades, various global and national commitments and actions have been made to improve product quality. Poor diets and worsening nutrition among vulnerable populations have led a major initiatives aimed at reducing micronutrient deficiencies and harmful ingredients such as salt, added sugar and unhealthy fats (Herforth et al., 2019; Springmann et al., 2020; Trieu et al., 2015). Global commitments like the Sustainable Development Goals (SDGs) 2 and 3 and the WHO Global NCD Action Plan (2013–2020) aim to address malnutrition and reduce premature mortality from NCDs. These initiatives emphasize dietary recommendations, including limiting salt, sugar and unhealthy fats (WHO, 2018b, 2022, 2023a). At the EU level, several initiatives have encouraged member states to adopt national reformulation targets and collaborate with the food sector industry. These include the EU Salt Reduction Framework (European Commission, 2008), the Sugar Reduction Strategy (European Commission, 2015), the EU Roadmap for Action on Food Product Improvement (Dutch EU presidency, 2016), and more recently, the Farm to Fork Strategy (European Commission, 2020), which frames reformulation as a key tool for promoting healthier diets.

Reformulation is closely associated with fortification and the removal of food allergens. Common examples include lactose-free and low-fat dairy products, as well as gluten-free cereals (Munday & Bagley, 2017). Fortification with essential nutrients—such as vitamins, minerals, and omega-3 fatty acids—is implemented globally. For example, vitamin A-fortified cassava has improved nutrient intake in areas where it is a staple (Olson et al., 2021), while programs for salt iodization and the fortification of foods with vitamin D, zinc, and iron have reduced micronutrient deficiencies worldwide (Das et al., 2019; Jääskeläinen et al., 2017; Keats et al., 2019; Kumar et al., 2022; WHO, 2023a). Omega-3 enrichment of dairy products through dietary modification of cows has also shown positive effects on cardiovascular health (Hadrová et al., 2021), and probiotics are increasingly used in reformulated products like yogurts, juices, and snacks (Fanzo et al., 2023). While fortification and allergen removal are relevant to the broader reformulation agenda, this work focuses specifically on modifications targeting dietary risk factors for NCDs—namely salt, sugar, fats, and fibre.

2.1.1 Historical development of food reformulation

Food reformulation priorities have evolved over time in response to shifting health, technological, and societal demands across decades. In the **1970s and 1980s**, reformulation emerged as a public health response to rising cardiovascular disease rates. Efforts were largely state-led and aimed at reducing population-level intake of salt and saturated fats. A key example is Finland’s North Karelia Project, which demonstrated the potential of modifying widely consumed foods to meet health guidelines (Vartiainen, 2018). Similarly, the US Dietary Goals of 1977 encouraged reduced fat and cholesterol intake (van Raaij et al., 2009).

In the **1990s**, the focus broadened to include functional foods—products enhanced with health-supporting components such as probiotics and omega-3 fatty acids. Regulatory developments, including the U.S. Food and Drug Administrations' (FDA) 1994 approval of health claims, supported the commercialization of these innovations. Reformulation thus became both a public health measure and a marketing strategy (Buttriss, 2013).

The **2000s** brought a more structured and regulatory-driven approach. As concern over obesity and NCDs grew, the WHO promoted reformulation efforts to reduce salt, sugar, and trans fats. National strategies began to incorporate nutrient profiling systems to guide product improvements and enhance overall dietary quality (Fanzo et al., 2023; Federici et al., 2019).

During the **2010s**, reformulation became increasingly consumer oriented. Industry actors began to prioritize taste, texture, and affordability alongside nutritional improvement. Public–private partnerships, such as the UK Sugar Reduction Programme (2016–2020) and Finland's National Nutrition Commitment (2017–), encouraged voluntary engagement while aiming to balance health outcomes with product appeal (Pättiniemi-Fagerström, 2021; van Gunst et al., 2018).

In the **2020s**, reformulation strategies have increasingly aligned with sustainability and equity goals. There is growing attention to environmental impact, alongside increasing demand for plant-based, allergen-free, and no-added-sugar products. Reformulation is thus evolving into a systems-level intervention that supports both planetary and public health, in line with the United Nations Sustainable Development Goals (Buttriss, 2020; Onyeaka et al., 2023).

2.1.2 Stakeholder cooperation crucial for success

The success of food reformulation depends on effective collaboration between governments, food manufacturers, consumers and other stakeholders, such as non-governmental organizations and academic institutions. Each plays a unique and critical role in advancing reformulation initiatives, overcoming challenges and ensuring public health benefits are realized. Governments act as the primary drivers of reformulation by setting clear regulatory standards, establishing compositional requirements for specific food categories and implementing policies to encourage healthier food production. Examples include taxation on sugary beverages, mandatory labelling requirements and formal partnerships with industry to reduce harmful ingredients (Gressier et al., 2020; Tedstone et al., 2018). Authorities and food industry sector, including also catering and food service sector, has been working intensively to reformulate unhealthier foods and thus making supply and dining environments healthier (Buttriss, 2013; Fanzo et al., 2023; Gressier et al., 2020; Harastani et al., 2020; Institute of Medicine (U.S.), 2010; Lehmann et al., 2017; Outila et al., 2006). Many public health campaigns, such as salt reduction programs, have successfully mobilized manufacturers to achieve significant reductions in sodium content while maintaining consumer satisfaction (Food Safety Authority of Ireland, 2023; Onyeaka et al., 2023; Santos et al., 2021; Tedstone et al., 2018; WHO, 2012, 2023a; Young & Swinburn, 2002). Governments can also implement subsidies or other financial incentives to encourage innovation, particularly in reformulating traditional or artisanal foods in developing economies, where challenges such as cost and technical capacity are more pronounced (Spieldenner & van der Horst, 2018).

Food manufacturers play a key role in translating regulatory goals into tangible product innovations. Through investments in research and development, they develop advanced processing techniques and ingredients to reduce harmful components like sugar, trans fats and sodium while preserving taste, texture and shelf life. For example, high-intensity sweeteners, structured lipids and salt replacers like potassium chloride have become staples in reformulation efforts (Buttriss, 2013; Fanzo et al., 2023; Onyeaka et al., 2023). Reformulation also offers manufacturers opportunities to expand into health-conscious markets, leveraging products with improved nutritional profiles and potential health claims as a competitive advantage (OECD, 2010, 2019). However, manufacturers must balance reformulation costs with affordability to ensure products remain accessible, particularly for low-income populations (Gatta, 2015).

Consumers, as end-users, play a decisive role in the adoption and success of reformulated products. Their preferences, perceptions and willingness to accept possible changes in taste, price or packaging significantly influence reformulation outcomes. Educational campaigns that highlight the health benefits of reformulated foods, such as reduced sugar or salt content, are crucial for fostering acceptance. Transparent labelling and clear communication about reformulation efforts can further build consumer trust and demand for healthier options (Buttriss, 2020; Carruba et al., 2022; Scott et al., 2017; Spieldenner & van der Horst, 2018). However, resistance persists, as consumers often associate healthier alternatives with inferior sensory qualities, necessitating innovative approaches to enhance the appeal of reformulated products. Naturally, reformulated foods need to have consumer acceptance, and if needed, reformulation should be done gradually and thus give consumers enough time to adapt new taste profiles (Federici et al., 2019; Gibson et al., 2017; Goryakin et al., 2019; Gressier et al., 2020, 2021; Jaenke et al., 2017; Onyeaka et al., 2023; Young & Swinburn, 2002).

2.1.3 Strategies and approaches to food reformulation

Food reformulation involves both product and process development, which may include recipe modifications, the introduction of new technologies or adjustments to manufacturing processes. For example, basic taste compensation techniques are crucial to maintaining sensory quality while reducing harmful components (Earle et al., 2017; Hoppu et al., 2017; Scrinis & Monteiro, 2018; WHO, 2022). Food reformulation strategies generally fall into three main categories: (1) reducing harmful components, (2) increasing beneficial nutrients and (3) altering food structure to improve its nutritional profile. The first two approaches, reducing or adding ingredients, are the most employed because they are generally simpler to implement and align with existing production processes (Fanzo et al., 2023; Onyeaka et al., 2023). For example, the reduction of salt can, depending on the product type, be compensated for by balancing sweetness, acidity or spiciness (Buttriss, 2013; Hoppu et al., 2017; Liem et al., 2011). In contrast, modifying the physical structure of foods—such as their texture or matrix—presents greater technical and economic challenges, making it a less widespread approach (Fanzo et al., 2023; Onyeaka et al., 2023). Structural changes often require advanced food engineering techniques and achieving consumer acceptance for such modifications can be difficult due to changes in sensory properties like texture and mouthfeel (Capuano et al., 2018; Hoppu et al., 2017). Additional challenges include the need for detailed physicochemical knowledge and access to expensive equipment, which may not be feasible for all and especially for small-scale producers (Aguilera, 2019). Examples of food reformulation techniques is presented in Table 1.

2.1.3.1 Examples of nutritional modification in food reformulation

One of the most prevalent food reformulation strategies involves reducing components like salt, sugar and unhealthy fats. In this field a wide range of reformulation initiatives have yielded notable successes globally during last decades. In response to public demand, many global food companies have introduced products with up to 30% less sugar, especially in categories like candy and breakfast cereals. (Nestlé, 2017, 2018). Advancements in sweetener technologies have enabled significant sugar reductions in beverages and confections. High-intensity sweeteners, such as stevia and aspartame, have been widely adopted in soft drinks and candies to replace sugar while maintaining sweetness, offering lower-calorie alternatives that appeal to health-conscious consumers (Di Monaco et al., 2018; Onyeaka et al., 2023). However, in 2023 the WHO cautiously recommended that non-sugar sweeteners should not be used as a means of achieving weight control or reducing the risk of NCDs (WHO, 2023b).

Successful salt reduction programs conducted, for example, in meat, bread and cereal products have lowered average sodium intake, contributing to improved blood pressure levels and reduced risks of cardiovascular diseases (Buttriss, 2013; Institute of Medicine (U.S.), 2010; Santos et al., 2021; Wang et al., 2023; Webster et al., 2011, 2014; Wyness et al., 2012). For instance, sodium reduction in bread has been achieved by up to 40% through techniques such as reducing salt particle size to optimize distribution and enhance saltiness perception without increasing sodium levels (Jaenke et al., 2017). Among global food companies, Nestlé has implemented a systematic approach to reducing the salt content of its products. Between 2005 and 2014, the company reformulated 2 400 products, leading to a cumulative reduction of approximately 14 500 tons of salt used in its product portfolio (Nestlé Global, 2014). These approaches highlight the importance of maintaining sensory quality while reducing salt content. Strategies such as using coarse-grained salt and incorporating umami-enhancing compounds (e.g., glutamates or soy sauce) have shown promise in enhancing perceived saltiness while lowering actual sodium content. However, maintaining microbial safety at lower sodium levels remains a significant challenge, particularly in products like cheese (Department of Health and Aged Care, 2021; Hoppu et al., 2017). Other salt reduction strategies include the use of mineral salts (i.e., partial replacement of sodium with other minerals such as potassium, magnesium and/or iodine) as well as phosphates, spices, and taste enhancers (Briggs et al., 2017). It is also important to recognize that reducing salt can affect product palatability and may cause undesirable characteristics such as bitterness or a metallic taste (Liem et al., 2011).

These efforts align with global health recommendations to reduce excessive intake of salt and sugar, which contribute to hypertension and obesity, respectively (Webster et al., 2011; WHO, 2012). The reduction of harmful saturated fats and trans fats has also been a focal point of reformulation initiatives. For instance, reductions in trans-fat consumption following bans in Denmark and other countries have also significantly decreased cardiovascular mortality rates and improved common wellbeing (Hutchinson et al., 2018; Leroy et al., 2016; Restrepo & Rieger, 2016; Stender et al., 2014). On the other hand, some studies have proved that companies often add sugar to replace saturated fats in reformulated products, thus creating negative health consequences (Murray et al., 2020; Temple, 2018).

Similarly, adding dietary fibre or plant-based proteins to snacks, cereal products and other processed foods can enhance their health benefits while aligning with consumers' growing preference for healthy, functional foods. (Fanzo et al., 2023; Goryakin et al., 2019; Onyeaka et al., 2023; Vázquez et al., 2009).

2.1.3.2 Examples of structural and technological modifications in food reformulation strategies

Although less common, modifying food structure to alter its nutritional profile offers unique advantages, such as slowing digestion in starch-rich foods to reduce glycaemic response (Pellegrini et al., 2020). Also, porous chocolate sugars have been developed to enhance sweetness perception while reducing overall sugar content, but this method requires expensive food engineering tools (Di Monaco et al., 2018). The manipulation of food matrices to improve nutrient bioavailability also holds potential but faces technological and financial hurdles that limit its widespread application, particularly in low-resource settings (Onyeaka et al., 2023). In margarine production, technological innovations have replaced hydrogenated oils with healthier options like structured lipids and oil blends that do not produce trans fats during processing. For instance, blending palm, rapeseed or sunflower oils has allowed manufacturers to maintain the desired texture and spread ability of margarine while eliminating harmful trans fats (Buttriss, 2013).

Table 1. Examples of technological and formulation strategies for food reformulation

Strategy	Technique	Purpose	Examples	References
Ingredient-based	Recipe modification	Reduce sugar, salt or fat through recipe modifications	Small steps reductions, increased use of spices, use of mineral salts and taste enhancers	(Buttriss, 2013)
Ingredient-based	Macronutrient substitution	Reduce sugar, salt or fat using alternatives	High-intensity sweeteners/sugar alcohols, potassium chloride/mineral salts, fat replacers like hydrocolloids	(Briggs et al., 2017; Cooper, 2017; Francis & Chidambaram, 2019; Liberty et al., 2019)
Ingredient-based	Use of dietary fibers, thickeners and other viscosity enhancers	Improve nutritional profile and satiety	Inulin, fiber, xanthene	(Buttriss, 2013; Msomi et al., 2021; Vázquez et al., 2009)
Processing and structural approaches	Biotechnology/ fermentation	Enhance taste, reduce salt	Fermented vegetables	(Buttriss, 2013)
Processing and structural approaches	Physical processing techniques	Alter texture, safety or shelf life	High-pressure processing, ultrasonication, homogenization	(Guo et al., 2017; Myers et al., 2013; Wang et al., 2016; Wang et al., 2017)
Processing and structural approaches	Encapsulation and microstructural techniques	Protect sensitive components or mask taste	Encapsulation/ crystallization of salt granules, porous structure of sugar	(Di Monaco et al., 2018; Jaenke et al., 2017; Noort et al., 2012)
Processing and structural approaches	Structured food systems	Create specific texture and stability	Emulsions, gels	(Harastani et al., 2020; Lee et al., 2013)

2.1.3.3 Reformulation as a public health tool: European approaches and evidence

According to a review by Kleis et al. (2020), 23 European countries have introduced reformulation strategies, mainly targeting salt, fat, and sugar. National approaches vary widely, with most measures based on voluntary agreements between governments and industry representatives. Only a few countries enforce legal limits or use tax incentives to regulate nutrient content, such as Bulgaria (salt reduction in food served to children), Lithuania (salt reduction in bread and sugar reduction in processed food, with penalties for non-compliance), and Portugal (limits on salt in bread). In few others (Denmark, Latvia, Netherlands, Norway, Austria, Sweden, Switzerland, Hungary), upper limits for salt and/or fat are set by law (Kleis et al., 2020).

In Denmark, regulatory measures have had a notable impact. The country was the first in the world to ban industrial trans fats in 2003 and introduced a fat tax in 2011, which was repealed after one year. These actions, along with the Keyhole FOP-label, have influenced both product reformulation and consumer behaviour. The trans-fat ban, in particular, has been credited with reducing cardiovascular mortality without negatively affecting food prices or availability (Breda et al., 2020; Fanzo et al., 2023; Restrepo & Rieger, 2016). In addition, the Danish Whole Grain Partnership has been recognised as a successful public–private initiative that increased whole-grain intake at the population level and stimulated product reformulation by creating market demand and favourable conditions for the development of whole-grain products (Boyle et al., 2025).

The United Kingdom has led some of the most structured and impactful initiatives, including a progressive Salt Reduction Programme and a Sugar Reduction Strategy, supported by regular monitoring and industry engagement. Between 2003 and 2011, the UK achieved a 15% reduction in average salt intake, from 9.5g to 8.1g per day, resulting in estimated savings of £1.5 billion annually for the National Health Service. Similarly, a Soft Drinks Industry Levy led to a 29% reduction in the average sugar content of soft drinks between 2015 and 2018 (Bandy et al., 2020; Goryakin et al., 2019; Tedstone et al., 2018). A summary of reformulation outcomes in selected European countries is provided in Table 2.

According to Kleis et al. (2020), eight European countries have implemented systematic monitoring of reformulation outcomes. The methods vary, ranging from household purchasing data (e.g., France) to product-level composition analysis (e.g., Netherlands, UK), and mandatory laboratory testing (e.g., Latvia). These systems enable the ongoing evaluation of progress in reducing salt, sugar, and fat content. In many other countries, however, monitoring is fragmented or conducted voluntarily by companies, rather than systematically led by the state or an independent authority. A recent European study further highlights that monitoring often relies on food composition databases that do not consistently track the same products over time, thereby limiting comparability across countries and across time (Steenbergen et al., 2024).

Finland has combined government-led voluntary commitments with consumer-facing tools to improve public health. The National Nutrition Commitment (2017–) and the Heart Symbol labelling system (2000–) have both contributed to positive health outcomes. According to a pilot report evaluating the Nutrition Commitment between 2017 and 2020 (Pättiniemi-Fagerström, 2021), most reformulation measures were implemented as planned. However, inconsistent indicators, unclear product group classifications, and limited outcome reporting have hindered reliable assessment of the overall impact. To improve effectiveness and guide future actions, better standardization and systematic follow-up are needed. The number of commitments rose from 74 in June 2021 to 116 by June 2025. While this growth reflects some level of engagement, it also suggests that the food industry has yet to adopt these opportunities broadly or systematically. Despite this, many Finnish food companies have taken independent steps to improve the nutritional quality of their products. For example, the salt content in bread has been reduced by 25% over the past decades, and sugar in yogurts by 20–50%. In addition, sugar-free alternatives have been introduced to the market (Laakso, 2024; Leipätiedotus ry, 2022). The range of lighter meat products—with more than 30% less fat compared to the original versions—has also increased (Lihatiedotus ry, n.d.). Between 2020 and 2024 Atria reduced the salt content of its products by an average of 15% through new product launches and recipe updates (Atria, 2025). Companies have further developed technological solutions to reduce salt in food products, for example ValSa® by Valio and Makusuola by HKFoods (HKFoods, 2025; Valio, 2024).

While some reformulation efforts have shown promising results, the available information on their outcomes is still limited. Moreover, there is no standardized method for assessing their impact. Existing data vary widely in type and source, ranging from surveys and laboratory analyses to retail sales figures and industry-reported composition. As a result, findings should be interpreted with caution, and outcomes reported by different countries are not directly comparable. Nevertheless, the summary table (Table 2) demonstrates that notable improvements in the nutritional quality of products have been achieved across Europe in certain product categories, offering consumers healthier options.

Table 2. Examples of reformulation outcomes in selected European countries since the early 2000s.

Country	Strategy	Nutrients	Key findings	References
Belgium	Voluntary	Salt	2004–2012: salt reduction in several product groups e.g., bread -22%, meat -8 to -28%, sauces -10 to -29%, cheeses -8 to -20%.	(van de Casseye, 2013)
Ireland	Voluntary	Salt	2003-2015: salt content in bread reduced from -8% to -32%.	(Feehan et al., 2016)
Italy	Voluntary	Salt, sugar, fat	2008–2017: breakfast cereals sugar -14% and sodium -33%; biscuits sugar -20% and saturated fats -9%; soft drinks sugar -18%.	(Ministry of Health, Directorate General for Food Hygiene, Safety and Nutrition., n.d.)
Netherlands	Voluntary/ upper limit in law for salt content in bread	Salt, sugar, fat	2011–2016: salt in bread -19% and some soups, sauces and crips -12 to -26%, and saturated fat in biscuits -42% and in processed meats -8%; 2014–2018: added sugar in milk drinks and milk desserts -5% and salt in meat products -10%.	(Milder et al., 2017; National Institute for Public Health and the Environment, 2018; Temme et al., 2017)
Switzerland	Voluntary	Sugar	2016–2017: newly introduced yoghurts and cereals contained from -3 to -8% less sugar.	(Bundesamt für Lebensmittelsicherheit und Veterinärwesen, 2017)
Slovenia	Voluntary	Salt	2011–2015: sales-weighted sodium content reductions in cheese -57%, meat spreads -29%, but increases in pasta sauces +11% and ready meals +12%.	(Pravst et al., 2017)
United Kingdom	Voluntary	Salt, sugar	2005–2014: salt intake -11%: 2015–2018: salt content in breakfast cereals -47%; sugar reduction in beverages -29%.	(Bandy et al., 2020; Tedstone et al., 2018)

2.1.4 Challenges in food reformulation

2.1.4.1 Technological and economic barriers

Food reformulation offers considerable public health benefits but entails technical, economic and consumer-related challenges. One of the most significant technical barriers arises from the multifunctional roles of ingredients such as salt, sugar and fats in food production. Sodium, for instance, serves as a flavour enhancer, preservative and texture modifier, making its reduction particularly complex. Lowering sodium levels can compromise not only product taste but also food safety, texture and shelf life, necessitating alternative preservation methods to maintain microbial stability. Similarly, reducing sugar affects not only sweetness but also moisture retention and browning properties in baked goods, while replacing saturated fats can alter melting characteristics and mouthfeel in products like margarine. Adding fibre is often challenging because it may drastically alter the texture and taste of the product. These technical adjustments often require advanced technologies, adding further complexity (Buttriss, 2013; Evans, 2020; Fanzo et al., 2023; Gibson et al., 2017; Komitopoulou & Gibbs, 2012; Munday & Bagley, 2017; Onyeaka et al., 2023; van Gunst et al., 2018).

Moreover, reformulation involves trade-offs. Reducing one harmful ingredient may lead to the unintended increase of another, potentially offsetting health benefits. For example, lowering fat content can lead to higher sugar levels, while reducing sugar may in turn result in increased fat content to preserve desirable sensory properties. Without careful nutritional planning, such substitutions may undermine the original health objectives. Reformulation is therefore a complex process requiring both technical innovation and a holistic approach to health.

Reformulating food products may also incur significant costs. Healthier alternatives, such as high-intensity sweeteners, dietary fibres, or unsaturated fats, are often more expensive than their conventional counterparts. Moreover, modifications to the food matrix or structure to maintain product quality require sophisticated and costly technological solutions, which can strain the resources of manufacturers, particularly small- and medium-sized enterprises. These costs are often transferred to consumers, potentially reducing the affordability and accessibility of reformulated products, which could undermine public health objectives (Muth et al., 2019; Onyeaka et al., 2023).

2.1.4.2 Consumer acceptance and behavioural challenges

Consumer acceptance is another critical challenge. Reformulated products often face resistance due to perceived changes in taste, texture or overall quality, and thus even “silence” reformulation approaches have been suggested for the retailers and manufacturers (Bédard et al., 2020; Briers et al., 2020; Fanzo et al., 2023; Jensen & Sommer, 2017; van Gunst et al., 2018). For example, reduced-fat or sugar-free products are sometimes associated with inferior sensory qualities, such as diminished sweetness or creaminess, which can deter consumers (Young & Swinburn, 2002). Nutritional labels, health claims and reduced fat or sugar content claims can decrease the perceived taste and sensory expectations of healthier products compared to those without such claims (Bialkova et al., 2016; Ikonen et al., 2020; Lähteenmäki et al., 2010; Orquin & Scholderer, 2015).

Meijer et al. (2021) suggested that transparent labelling and effective communication about the health benefits of reformulated foods are essential to gaining consumer trust, yet many individuals neither read nor understand product labels. This highlights the need for widespread education campaigns to increase awareness and foster acceptance of reformulated products (Meijer et al., 2021). Despite the importance of consumer acceptance, current evidence suggests that this dimension remains underexplored in the context of high-fat, salt, and sugar foods -reducing strategies. Gillison et al. (2022) found in a meta-analysis of 49 systematic reviews that public attitudes and acceptability were addressed in only a small subset of studies, primarily those focused on sugar-sweetened beverages. Moreover, much of the existing research is based on artificial or hypothetical scenarios, such as laboratory taste tests or survey experiments, which may not accurately capture real-world consumer behaviour. This indicates a significant research gap: to design effective and publicly acceptable reformulation policies, a deeper understanding is needed of how consumers perceive and respond to such interventions in everyday contexts. Ultimately, without robust, real-world consumer insights, reformulation efforts risk limited impact or even resistance, regardless of their nutritional merit (Gillison et al., 2022).

Given these challenges, additional strategies are often needed to effectively steer consumers toward healthier choices. FOP-labels have emerged as one such approach, aiming to help consumers identify healthier alternatives immediately (Ikonen et al., 2020; Kelly et al., 2024). Various FOP-systems have been introduced across the globe, the most common including Guideline Daily Amount, Nutri-Score, Traffic Lights, Health Star Rating, Key Hole and Heart Symbol (Carruba et al., 2022; Cecchini & Warin, 2016; Ikonen et al., 2020; Kantola et al., 2023; Roseman et al., 2018; Vandevijvere & Vanderlee, 2019; Vyth et al., 2010). For example, the Heart Symbol, which has been available on the Finnish market since the early 2000s, is nowadays used in over 50 product categories and more than 2500 products. The symbol is well known among consumers, with 92% recognizing it (Hietalahti, 2025). While there is limited evidence on the real-life effectiveness of these systems, it is generally observed that FOP-labels tend to be more effective among health-oriented consumers (Ikonen et al., 2020). However, the food selection is a complex process influenced by multiple factors, like mood, environment and beliefs, such as the relatively common belief that unhealthy food is tastier (Goukens & Klesse, 2022; Mai & Hoffmann, 2015; Paakki et al., 2022; Raghunathan et al., 2006). Importantly, reformulated products must first gain consumer acceptance, being indistinguishable from the original product before additional strategies, such as nudging, can effectively guide consumers toward healthier choices.

2.1.4.3 Aligning health and sustainability goals

Another emerging challenge in reformulation is the integration of environmental sustainability into nutritional goals. As Buttriss (2020) points out, improving the nutritional profile of foods should ideally occur in parallel with reducing their environmental footprint. This includes favouring plant-based protein sources, reducing red meat consumption, and increasing dietary fibre intake through ingredients like legumes and whole grains (Buttriss, 2020). However, as shown by Kyttä et al. (2025), achieving both health and sustainability simultaneously at the product level is far from straightforward. Their nutrient-based sustainability assessment (NI-SFPM) of 559 food products found that only a small fraction met both nutritional adequacy and environmental thresholds. For instance, while some products may be nutritionally beneficial, their production may cause significant environmental harm through land use, greenhouse gas emissions, or biodiversity loss. Ingredients like palm oil illustrate this tension: commonly used in reformulation for functional purposes, yet linked to deforestation and negative ecological impacts (Kyttä et al., 2025).

These findings highlight a critical dilemma for future reformulation efforts: healthy food is not always sustainable, and sustainable food is not always healthy. As reformulation continues to evolve, it will need to balance nutritional optimization with environmental integrity—particularly within the limits set by planetary boundaries. Looking ahead, this dual focus may require new profiling tools, more granular environmental data, and stricter evaluation frameworks. If reformulated products are to support both human and planetary health, reformulation strategies must adopt a systems-thinking approach that considers trade-offs, long-term effects, and product-specific sustainability performance across multiple dimensions.

Taken together, these challenges highlight that, despite its recognized public health potential, food reformulation is not a straightforward solution at the population level. Its implementation remains uneven and context-dependent, constrained by technical feasibility, economic considerations, consumer acceptance, and the need to balance nutritional improvements with environmental sustainability.

2.2 Understanding and influencing food choices

2.2.1 Complexity of food choices

Food choices are complex and dynamic, influenced by a combination of individual, social and environmental factors (Figure 1). Although people often perceive their dietary decisions as deliberate, they are frequently shaped by automatic, habitual processes that require little active thinking. These habits, influenced by past experiences, cultural norms, social cues and beliefs, emphasize the less rational aspects of decision-making (Chen & Antonelli, 2020; Ensaff, 2021; Goukens & Klesse, 2022). Complementing this perspective, sociological research suggests that food choices are socially and culturally embedded practices shaped by shared routines, meanings, conventions, and social distinctions (Holm et al., 2019; Lindblom & Mustonen, 2019; Warde, 2005).

In this context, social norms and environmental factors play a crucial role in shaping food preferences and consumption patterns. People are highly responsive to cues such as food availability, placement and prevailing social norms that define "normal" eating behaviour (Devine, 2005; Ensaff, 2021; Higgs, 2015). These quick, instinctive decisions are often more emotional than rational. From this perspective, eating practices are embedded in everyday life and social contexts, where routines, social relations, competences, values, and cultural expectations guide behaviour (Jallinoja et al., 2016; Lindblom & Mustonen, 2019; Niva & Jallinoja, 2018). Food environments, or "foodscapes," can either support or undermine healthy eating habits (Bucher et al., 2016). For instance, environments saturated with energy-dense foods promote obesity, while limited access to nutritious options restricts healthier choices. Nudging strategies capitalize on these environmental and behavioural influences by subtly modifying the foodscape—through tactics like product placement or default settings—to encourage healthier decisions without restricting choice (Bucher et al., 2016).

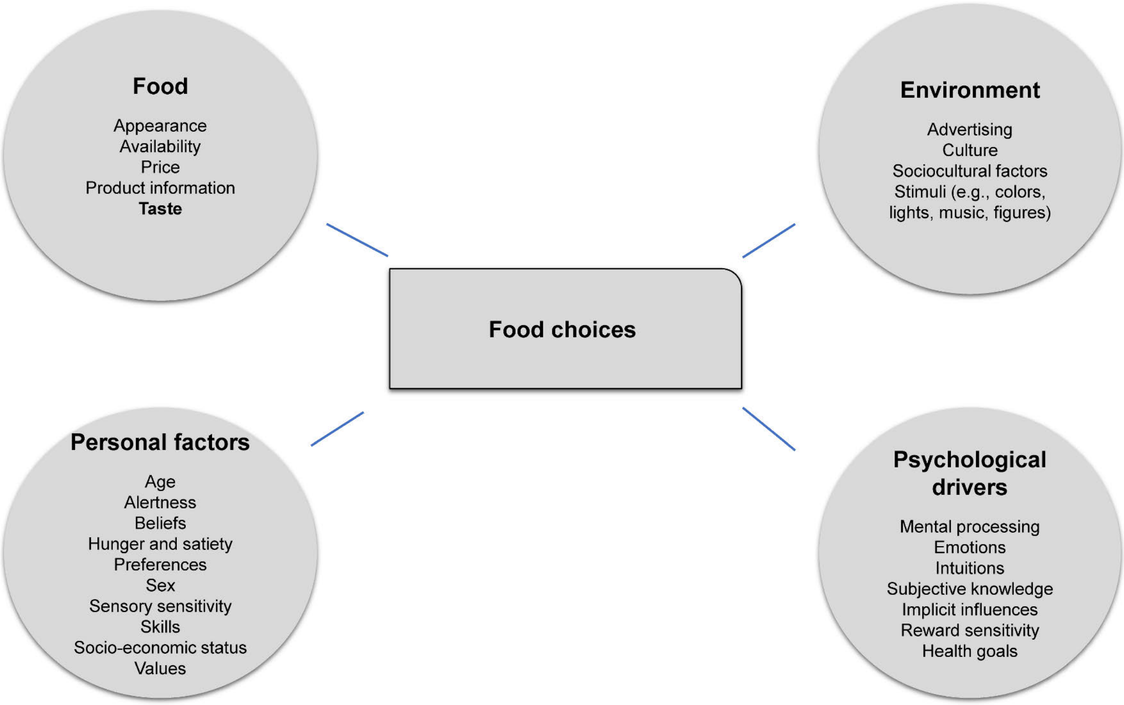


Figure 1. Factors influencing food choices. Food choices are influenced by a complex set of factors, commonly grouped into four main categories: (1) food properties, such as appearance, texture, and taste; (2) environmental and sociocultural factors, including cultural norms, the social setting, and economic conditions (3) personal factors, such as individual preferences, alertness, and physiological needs; and (4) psychological drivers, including mental processing and subjective knowledge (adapted from Chen & Antonelli, 2020; Khan & Pandey, 2023). It is well known that among food properties, taste plays a particularly significant role in guiding our choices (Clark, 1998).

2.2.2 Nudging strategies in promoting healthier food choices

2.2.2.1 Background of nudging theory

Nudging theory, rooted in behavioural economics, explores how subtle changes in choice architecture can steer individuals toward better decisions in predictable ways without restricting their freedom of choice or significantly altering economic incentives. It acknowledges that human decision-making is often influenced by cognitive biases and simplified thinking patterns, making choices less than fully rational (Thaler & Sunstein, 2008).

The concept of nudging involves strategically altering the environment to guide behaviour in a predictable manner while preserving freedom of choice. Central to this is choice architecture—the way options are presented—which draws on psychological and sociological theories about the impact of environmental factors on behaviour. Nudging integrates behavioural economics with the principles of libertarian paternalism, encouraging beneficial decisions without imposing restrictions (Ensaff, 2021; Marteau et al., 2011; Thaler & Sunstein, 2003, 2008).

Choice architecture encompasses various strategies such as default settings, strategic placement of items, provision of information and the use of social norms to subtly influence behaviour (Bucher et al., 2016; Ensaff, 2021). The versatility of nudging has made it a prominent tool in addressing public health challenges, particularly in encouraging healthier eating habits. By leveraging behavioural insights, nudging provides an effective, voluntary means to shape behaviour for the common good (Ensaff, 2021).

2.2.2.2 Key nudging strategies and the role of nutrition labelling

The framework for presenting food options through choice architecture plays a central role in nudging strategies. It influences decisions through the layout, order and presentation of food items. Typically, nudging strategies are minor, unobtrusive and don’t require physical effort or cognitive load (Ensaff, 2021). As Ensaff (2021) and Bucher et al. (2016) highlight, effective nudging techniques include placement manipulation, availability and presentation of food options, using labels and prompts and emphasizing social norms (Table 3).

Table 3. Nudging techniques to promote healthier food choices (adapted from Bucher et al., 2016; Ensaff, 2021).

Nudging technique	Description	Examples
Placement manipulation	Positioning healthier options closer to consumers or at eye level while placing less healthy options farther away.	Displaying fruits and vegetables prominently in stores or cafeterias to boost their purchase and consumption.
Availability and presentation of options	Setting healthier choices as the default to encourage better decisions, requiring effort to select less healthy alternatives.	Offering salads as the default side dish instead of fries.
Labels and prompts	Using visual cues (e.g., traffic light labels, heart symbols, descriptive names) to guide choices.	Using nutrition labels for healthy items or naming dishes attractively.
Emphasizing social norms	Highlighting peer behaviour to promote healthier options.	Displaying messages like "Most customers choose this healthy option".

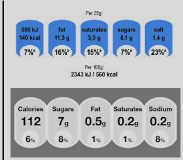
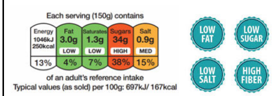
Empirical studies have demonstrated the effectiveness of these nudging strategies. While reported intervention effects help illustrate their impact, comparisons across studies are limited by differing methods, settings, and populations. For example, placement nudges have been shown to increase fruit and vegetable purchases and reduce snack selection, typically resulting in 5–15% more healthier choices, depending on context and setting (Arno & Thomas, 2016; Broers et al., 2017; Hollands et al., 2019; Marteau et al., 2011). Also, food items placed first on menus or serving lines are more likely to be chosen, with some evidence suggesting 100% relative increase, although typical gains are more modest (Cesareo et al., 2022; Dayan & Bar-Hillel, 2011). Changing accessibility, such as requiring additional effort (e.g. unwrapping or reaching), has been shown to meaningfully reduce the consumption or selection of indulgent items. Participants in one study consumed significantly fewer chocolate pieces when minor effort was required; average intake dropped from 5.5 to 3.2 pieces, representing a reduction of approximately 40% (Brunner, 2013). Similarly, when unwrapped chocolates were made slightly less accessible, their selection decreased by up to 40%, demonstrating how small physical barriers can nudge consumers away from impulsive choices (Knowles et al., 2020). Research has also shown that "unit bias effect", like changing portion sizes and halving item-sizes, leads to reduced consumption as people tend to perceive a single unit as an appropriate amount regardless of its actual size. For example, consumption increased by 1.7 to 2.3 times when larger units of candy or snacks were offered, illustrating the powerful influence of unit bias on eating behaviour (Geier et al., 2006). Enhancing the brightness and colour of healthier foods has been found to significantly increase their visual appeal and likelihood of being selected, in some cases leading to a twofold increase in selection likelihood (Dai et al., 2020). Social norm messaging, which involves informing individuals about what others typically choose (i.e., descriptive norms, referring to what most people do), can promote healthier food choices (Burger et al., 2010; Robinson et al., 2014). For instance, Burger et al. (2010) found that descriptive norm cues increased healthy snack selections from 40% to 68% in one experiment, and from 22% to 57% in another.

Nutrition labels can serve as a nudging tool that shapes the food environment and choice architecture to better promote healthier diets (Cadario & Chandon, 2020). The EU definition of a nutrition label is "any tag, brand, mark, pictorial or other descriptive matter, written, printed, stencilled, marked, embossed or impressed on, or attached to the packaging or container of food" (European Court of Auditors, 2024). So far, nutrition and health labels as well as FOP-labels are voluntary in EU, even there has been discussion and preliminary initiatives to make Nutri-Score -label mandatory (European Commission, 2023). Generally, nutrition and health claims are classified reductive (nutrient specific information, like amount of nutrients /serving) or interpretive (either nutrient specific information like traffic lights, nutrition content claim, or summary indicator logos, like health logos, health star rating) (European Court of Auditors, 2024; Ikonen et al., 2020), Table 4. Ikonen et al. (2020) found that simplified, interpretative labels are easier for consumers to understand than reductive labels.

According to Cadario and Chandon's (2020) meta-analysis, cognitively oriented nudges such as health labels reduced energy intake by approximately 64 kcal per day. Affective nudges, such as emotionally framed healthy eating messages, led to reductions of around 129 kcal per day, while behaviourally oriented interventions, including portion resizing, achieved the largest effect, up to 209 kcal per day. This suggests that nudges which evoke emotions or simplify healthy choices are generally more effective than those relying solely on factual information. Studies also indicate that combining label types, such as using evaluative colour codes (e.g., traffic lights) alongside simplified claims (e.g., "low fat"), may enhance both consumer understanding and behavioural impact, especially in real-world environments like grocery stores or cafeterias. Earlier findings suggest that even the most effective label combinations typically lead to only small to moderate improvements, increasing healthy food selection by approximately 5–15% with corresponding effect sizes usually below 0.5 depending on the context and consumer group (Bialkova et al., 2016; Cadario & Chandon, 2020; Ikonen et al., 2020; Mertens et al., 2022). However, meta-analyses have found that the effects tend to be larger in restaurant and café settings compared to grocery store studies, suggesting that contextual factors play a significant role in shaping the effectiveness of labelling interventions (Cadario & Chandon, 2020).

Although nutrition labels have been extensively studied, there is still no clear consensus on their overall impact on consumer behaviour. Sunstein (2021) argued that individuals may develop new preferences and values based on the information they receive. Research has highlighted the difficulties consumers face in accurately interpreting labels (Ikonen et al., 2020; Meijer et al., 2023). Even when consumers can identify the healthier option, labels do not always succeed in nudging them toward that choice (Ikonen et al., 2020). Bialkova et al. (2016) further emphasized that the effectiveness of nutrition labels is influenced by consumers' motivation to maintain a healthy lifestyle. Additionally, labels may affect taste perception, sometimes reinforcing the "unhealthy = tasty" bias (Ikonen et al., 2020; Mai & Hoffmann, 2015; Raghunathan et al., 2006).

Table 4. Classification of health and nutrition claims (adapted from European Court of Auditors, 2024; Ikonen et al., 2020).

Classification		**Examples**	
Reductive (objective information without interpretation)	*Nutrient specific*	Reference intake (/serving or /100g) Guideline Daily Amounts (GDA)	
Interpretative	*Nutrient specific*	Traffic lights Nutrition content claim	
	Summary indicator	Health label Keyhole Nutri-Score	NUTRI-SCORE

2.2.2.3 Possibilities and challenges in food nudging

Nudging, particularly through choice architecture, represents a promising and cost-effective strategy for promoting healthier eating habits. Its success across various contexts demonstrates the potential of nudging as a tool for improving population health while preserving individual autonomy and freedom of choice. However, the role of taste for individual choices must be respected and the tastiness of food must be satisfied, prior to nudging strategies. Several reviews and meta-analyses have shown that nudging can promote healthier food choices, with relative increases in healthy selection typically ranging from 10% to 30%, depending on intervention type and setting (Arno & Thomas, 2016; Nørnberg et al., 2016; Skov et al., 2013; Wilson et al., 2016). However, the impact on actual food consumption and long-term health outcomes remains unclear, as most studies measure food selection rather than intake or health metrics (Bucher et al., 2016; Wilson et al., 2016). Moreover, more real-life studies are needed to assess people's actual food consumption behaviour during nudging interventions (Ballco & Gracia, 2022; Zlatevska et al., 2024). While some interventions have been implemented in semi-natural environments such as school cafeterias (Skov et al., 2013; Nørnberg et al., 2016), many others rely on laboratory settings, short-term cafeteria studies, or hypothetical choice tasks involving student samples (Arno & Thomas, 2016; Wilson et al., 2016). Studies such as those by Broers et al. (2017) and Ensaff (2021) highlight the difficulty of generalising findings from tightly controlled experimental settings to broader, real-world public health contexts. To improve ecological validity and better assess the long-term impact of nudging strategies on dietary behaviour, more research is needed in everyday environments such as supermarkets, schools, and diverse workplace settings.

In addition, nudging is not consistently effective across all interventions. Several systematic reviews and meta-analyses have highlighted studies with null or negligible results. For example, Bucher et al. (2016) and Skov et al. (2013) reported that many interventions, especially those implemented in school settings, did not significantly influence actual consumption. Wilson et al. (2016) noted that the overall quality of evidence is mixed, with only a few high-quality studies available, and some strategies, such as cognitive nudges like calorie labels, often produce weak or statistically insignificant effects (Cadario & Chandon, 2020). A review by Hummel and Maedche (2019) found that 62% of nudging interventions reported statistically significant positive outcomes nudging, with corresponding effect size 0.43. However, the effectiveness varied depending on the type of nudge, context, and outcome measured, and limited ecological validity were noted as key limitations (Hummel & Maedche, 2019). These limitations highlight the need for more rigorous, real-world evaluations that go beyond food selection and accurately measure actual consumption and long-term health outcomes.

Despite its potential, food nudging faces several challenges. Ethical concerns are often raised about its subtly manipulative nature, as nudges can influence behaviour without individuals being fully aware of it, potentially reducing perceived freedom of choice. For instance, repositioning less healthy items out of reach may be seen as restrictive rather than supportive (Selinger & Whyte, 2012). The lack of transparency in some nudging strategies—especially those not explicitly communicated—can lead to distrust, particularly when individuals feel they are being steered without their knowledge or consent. Moreover, nudging can have unintended side effects. The "health halo" effect, where foods labelled as healthy are perceived to be lower in calories and thus consumed in larger amounts, is a well-documented issue. Wansink and Chandon (2006) found that products labelled "low fat" were consumed in up to 50% larger portions, leading to higher total caloric intake. Similarly, Ikonen et al. (2020) reported that FOP-labels can increase perceived healthfulness even for relatively unhealthy products, potentially undermining actual dietary quality. Compensatory behaviours present an additional concern. When nudged toward a healthier choice in one context, individuals may later indulge in less healthy behaviours as a form of reward. For example, choosing a salad at lunch may be followed by a dessert in the evening. This behavioural rebound can offset or even reverse the benefits of nudging (Ensaff, 2021; Sunstein, 2021).

Cultural and contextual variability further limits effectiveness. Strategies that succeed in one setting may fail or backfire in another. For example, in collectivist cultures, individual-focused nudges may be less effective compared to group-oriented approaches. Likewise, nudges effective in controlled or school environments may not translate into home or restaurant settings. Tailoring interventions to local norms and values is essential for both acceptance and efficacy (Selinger & Whyte, 2012).

Another key challenge is the long-term sustainability of these effects. Many nudging strategies rely on visual or spatial cues in the immediate environment. While these can influence momentary decisions, they often do not result in lasting behavioural change unless supported by habit formation and intrinsic motivation (Ensaff, 2021; Wilson et al., 2016). Some studies have found that individuals adapt to nudges over time, reducing their salience and effect. Furthermore, nudges that overlook taste preferences, which are a major driver of food choice, may be ignored or rejected (Bucher et al., 2016; Ensaff, 2021).

There is also a growing debate about the use of nudging in commercial contexts. While nudging is often framed as a public health tool, similar techniques are also widely used in marketing, sometimes to promote unhealthy food consumption. This raises important ethical questions: Who designs the nudges? Whose interests are being served? Without clear governance, nudging could reinforce rather than reduce health inequalities (Marteau et al., 2011; Selinger & Whyte, 2012).

Finally, nudging alone cannot solve structural problems such as food insecurity, socio-economic inequalities, or long-term diet-related health issues. These challenges are often linked to deeper problems in society, like poverty, limited access to healthy food, and unequal distribution of resources. As Selinger and Whyte (2012) point out, nudging is not enough when people lack real freedom to choose because of their environment or financial situation. Wilson et al. (2016) also highlight that many nudging interventions do not reach the most disadvantaged groups and often ignore barriers like cost, availability, or cultural fit. Ensaff (2021) adds that for people with low incomes, food choices are shaped more by affordability and access than by nudging strategies. Without addressing these basic needs, nudges alone are unlikely to bring lasting improvements. Therefore, nudging should be part of a broader strategy that includes regulation, public education, financial support, and changes to the food system. Only by combining these efforts can we hope to improve diets and health outcomes for everyone, especially for those most in need.

2.2.3 The influence of visual food stimulus on eating behaviour: a grounded cognition approach

As digital and visual stimuli increasingly shape modern food environments, understanding their impact on eating behaviour is crucial. While health labels and nudge strategies primarily target conscious decision-making to encourage healthier eating, video-based stimuli such as hedonic food imagery and eating videos tend to operate on a more implicit cognitive level by activating subconscious processes.

These processes are explained by the grounded cognition framework, which suggests that perceptual experiences and prior interactions with food are reactivated through sensory simulation when individuals are exposed to food-related cues (Barsalou, 2008; Krishna & Schwarz, 2014; Papies et al., 2020).

According to grounded cognition theory, visual exposure to food cues reactivates prior eating experiences through mental simulations, triggering physiological responses like salivation and hunger (Papies et al., 2020; Spence et al., 2016). Papies and Barsalou (2015) highlight that food cravings and desires frequently arise from these simulations, as merely observing appetizing food imagery strongly activates neural reward pathways. Although such cues generally increase appetite and food intake, prolonged or repeated exposure to the same type of food can result in sensory-specific satiety, a phenomenon in which the food's appeal and consumption motivation diminish over time (Hetherington & Havermans, 2013; Morewedge et al., 2010; Papies & Barsalou, 2015; Rolls, 2011), (Figure 2).

Cadario and Chandon's (2020) meta-analysis on healthy eating nudges further supports these insights, showing that affective interventions leveraging sensory-rich imagery are more effective in reducing unhealthy consumption compared to purely cognitive interventions such as nutritional labelling. Therefore, food aesthetics and multisensory simulations could be strategically harnessed to influence both desire and satiety mechanisms, ultimately promoting healthier eating habits (Cadario & Chandon, 2020).

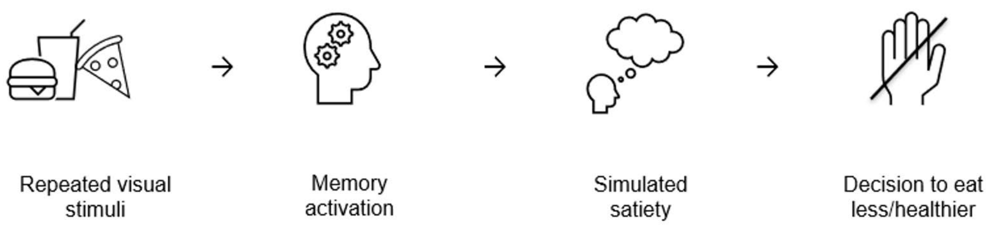


Figure 2. Based on grounded cognition theory, visual food stimuli activate prior eating experiences and sensory memory traces, influencing appetite and eating behaviour. Repeated exposure to food imagery stimuli (1) reactivates stored food-related associations (2), triggering mental simulations of eating, which can lead to simulated satiety (3). This aligns with sensory-specific satiety, where repeated visual exposure to the same food decreases its appeal and reduces motivation to consume it. This mechanism may reduce appetite for food-related desires, supporting healthier eating decisions (4) (adapted from Barsalou, 2008; Hetherington & Havermans, 2013; Papies et al., 2020; Papies & Barsalou, 2015; Rolls, 2011). In the figure, arrows represent the primary progression of the process. However, in real-life this pathway is not strictly linear and may be modified or interrupted by individual (e.g. hunger and satiety state, preferences, sensory cues) and environmental factors (e.g. food availability, portion size, social context, and time pressure).

2.2.3.1 Visual stimulations, mental imagery and food consumption

Visual food stimulation has dual effects on eating behaviour, either enhancing appetite and food consumption or, conversely, promoting satiety and reducing intake, depending on the nature and duration of exposure. Research demonstrates that merely looking at food ("visual hunger") increases appetite and food-related desires, particularly in digital environments (Spence et al., 2016). The brain rapidly processes the caloric content of food images, activating reward-related neural systems and taste pathways, thereby intensifying motivation to eat (Toepel et al., 2009). Additionally, watching television has been shown to disrupt habituation to food cues, increasing appetite and energy intake. In one experiment, children consumed up to 218 kcal more when watching continuous television compared to non-viewing conditions (Temple et al, 2007). Furthermore, food advertising on television can unconsciously prime eating behaviour, increasing snack consumption in both children and adults regardless of hunger levels. Experimental studies show that children exposed to food advertisements consumed approximately 1.5 times more snacks. Among adults, intake-related responses increased markedly following exposure, with standardised measures indicating up to nearly sevenfold higher levels. These findings suggest that advertising can influence eating behaviour independently of physiological hunger (Harris et al., 2009). On the contrary, exposure to indulgent food imagery can prime the brain to anticipate rewarding experiences, but when multisensory pleasure cues are emphasized, people may feel equally satisfied with up to 25% smaller portions, suggesting that pleasure can substitute for quantity (Cornil & Chandon, 2016).

Under certain conditions, repeated visual or mental exposure can induce sensory-specific satiety, thereby decreasing rather than increasing subsequent food consumption. Studies found that mentally simulating eating a specific food repeatedly (e.g., 30 vs. 3 times) reduced both pleasures derived from the food and subsequent consumption (Andersen et al., 2023; Larson et al., 2014; Morewedge et al., 2010). Morewedge et al. (2010) found that imagining the consumption of M&Ms (candy-coated chocolates) 30 times reduced actual intake by up to 50% compared to minimal or no imagery. Comparable reductions were also observed with savoury food (cheese), suggesting stimulus-specific habituation and sensory-specific satiety induced through repeated mental simulation. Consistent with these findings, other studies using both sweet and savoury foods and varying simulation formats (e.g., different exposure times to food images) have demonstrated similar effects (Andersen et al., 2023; Larson et al., 2014). For example, Larson et al. (2014) demonstrated that participants who viewed 60 salty food images rated the subsequent enjoyment of salty peanuts nearly 30% lower than those who viewed only 20 images, consistent with nonconscious sensory-specific satiety limited to foods with similar taste profiles.

Biswas and Szocs (2019) found that brief exposure (<30 seconds) to indulgent food-related ambient scents (e.g. cookie or pizza scents) increased the likelihood of selecting unhealthy foods, whereas longer exposure (>2 minutes) reversed this effect. Prolonged exposure reduced the share of unhealthy choices (approximately 15–18% points across studies), with a corresponding increase in the selection of healthier options (Biswas & Szocs, 2019). Liu (2023) further showed that cognitively engaging digital exposure to unhealthy food (e.g. rating food images) led to over 20% reduction in subsequent consumption of unhealthy food. This effect was especially pronounced in mobile (touchscreen) environment, suggesting that device context may enhance cognitive engagement and its dietary consequences (Liu, 2023).

Policastro et al. (2019) highlighted the role of sensory perception in moderating intake, demonstrating that sensory-rich verbal cues can enhance perceived satiety and enjoyment, making it possible to reduce portion size by 50% without diminishing the eating experience. These findings suggest that visual and verbal sensory cues can effectively influence satiety and eating behaviour, supporting the use of strategic portion control to mitigate overeating (Policastro et al., 2019). Chang et al. (2018) compared sensory immersion and mindful detachment as cognitive strategies influencing food choices. They found that while sensory imagery heightened desire for indulgent foods, mindful detachment, which involves recognizing cravings as transient mental events, reduced unhealthy snack choices by approximately 10%. These findings suggest that mindfulness-based strategies may effectively counteract sensory-driven impulses and support healthier eating behaviour (Chang et al., 2018).

2.2.3.2 Influencing eating behaviour: leveraging visual stimulus interventions

Given the significant influence of visual stimulation on eating behaviour, it is essential to explore how these effects can be strategically managed in interventions to promote healthier food choices. Papies (2016) suggests that food-related simulations can be consciously directed and utilized in interventions aimed at modifying eating behaviour. Grounded cognition theory provides a robust framework for designing interventions that either mitigate unintended consequences of visual food cues or strategically leverage these cues to foster healthier dietary choices (Papies, 2016; Petit et al., 2016).

Although previous research has demonstrated that imagining hedonic eating can promote healthier food intake, video-based simulations remain underutilized in intervention design, despite their potential to enhance the vividness and effectiveness of mental simulations (Birau et al., 2022; Biswas & Szocs, 2019; Liu, 2023). Ceylan et al. (2024) conducted a meta-analysis examining the effectiveness of positive consumption simulations, including both static imagery and video-based formats, on actual food consumption. They found that video simulations were notably more effective than static images, with an average effect size 0.38 compared to 0.20 for images. This indicates that dynamic and immersive exposure enhances simulation strength and behavioural impact. In addition, the interventions were effective across both sweet and savoury food categories, suggesting wide applicability. The authors also emphasized that video-based simulations may be particularly useful for translating mental simulations into real-world actions, making them a promising tool for behaviour change interventions (Ceylan et al., 2024).

However, as most existing studies have been conducted in controlled laboratory or survey environments, there is a growing need for research that examines how visual-based interventions influence behaviour in real-world settings (Otterbring et al., 2023; Stelick & Dando, 2018). Many of these experiments have relied on university students and online or lab-based simulations, limiting the generalisability of their findings (Andersen et al., 2023; Ceylan et al., 2024). Only a few studies, including Harris et al. (2009), have investigated visual food cues in more naturalistic contexts like television viewing among children and adults. Generating such ecological evidence is essential for advancing the practical application of grounded cognition theory, which emphasises the role of consumption-related mental simulations in shaping eating behaviour. Particularly, the simulation of hedonic eating experiences has been shown to influence appetitive responses, perceived satiety, and subsequent food choices. A deeper understanding of these cognitive-affective mechanisms may inform the development of scalable, cost-effective interventions that are adapted to real-world decision-making contexts.

3 Aims

This dissertation aims to examine how food-related health interventions can be effectively designed and communicated to ensure both impact and acceptability in real-world foodservice settings. The research builds on a dual-theoretical foundation: nudging theory, which focuses on subtle cues that guide decision-making without restricting choice, and grounded cognition theory, which emphasises the role of mental simulations and sensory experiences in shaping behaviour. These theories were selected as they offer complementary perspectives on food choice, capturing both external influences related to the choice environment and internal cognitive processes related to sensory experience and simulation. This integrated approach allows for a nuanced examination of both explicit, cue-based strategies, and implicit, simulation-based influences in dietary behaviour change, and is particularly relevant in foodservice settings where decisions are often made quickly and are influenced by both environmental cues and sensory experiences.

The research is structured around three interconnected studies (Figure 3). The first study investigates basic reformulation strategies aimed at improving the healthiness of food products while maintaining sensory appeal and consumer acceptance. The second study evaluates how explicit communication cues (nutrition labels) affect real-life food choices, drawing on principles from nudge theory. The third study examines how implicit, sensory-based stimuli (hedonic eating video exposure) shape consumer behaviour through mechanisms aligned with grounded cognition. Together, the studies form a comprehensive framework that links product reformulation, communication strategy design, and behavioural outcomes.

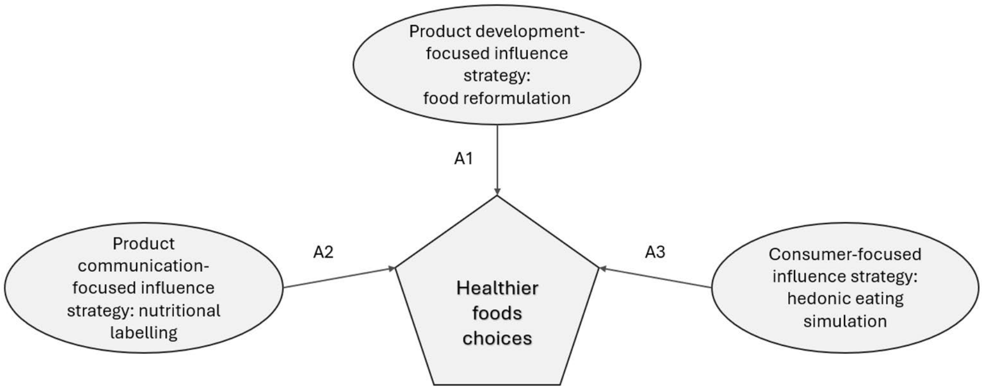


Figure 3. Conceptual framework illustrating the dissertation's three interconnected studies aimed at influencing consumer behaviour towards healthier food choices. Study I focuses on product reformulation and consumer acceptance. Study II investigates how nutrition labelling influences consumer choices, drawing on nudge theory. Study III examines the influence of hedonic eating stimuli on food choices, based on grounded cognition theory. Together, these studies provide a comprehensive basis for developing practices and communication strategies that promote healthier dietary decisions.

To support the promotion of healthier dietary habits, more knowledge is needed about the mechanisms that influence consumer choices—particularly in authentic settings where decisions are made in practice. While previous research has often relied on laboratory or survey methods, this dissertation brings the consumer perspective into focus by investigating food choice behaviour as it unfolds in everyday foodservice contexts. The findings offer insights that theoretically grounded and practically relevant for developing feasible, consumer-informed strategies that support both health goals and positive user experience.

Based on the preceding literature review and existing research findings, the specific research aims (A), and propositions (P) are as follows:

Study I:

• A1: To evaluate the potential of basic food reformulation techniques in foodservice sector to develop nutritionally improved products without compromising consumer acceptance.

• P1: Reformulated foodservice products with improved nutritional profiles, when developed through systematic and carefully tested methods, can maintain perceived taste and consumer acceptance, regardless of the product type.

Study II:
• A2: To examine the effectiveness of nutrition labelling in guiding customers toward healthier food choices in real-life foodservice settings.
• P2: Nutrition labels shift consumers' meal selections toward healthier dishes and influence overall food intake and waste patterns when applied in real-life foodservice environments.

Study III:
• A3: To investigate the effects of prolonged exposure to hedonic, video-based eating cues on customers' food choices and consumption in real-life foodservice settings.
• P3: Prolonged exposure to hedonic, video-based eating cues influences customers' food choices and consumption in real-life foodservice contexts, as reflected in meal selection, total intake and plate waste.

4 Materials and Methods

4.1 Study I: Product reformulation and consumer acceptance

4.1.1 Product reformulation

Study I aimed to investigate whether two common foodservice products—a vegetable lentil soup (representing a healthy food image) and French fries with sausage (representing an unhealthy food image)—could be reformulated to fulfil Finnish Heart Symbol nutritional criteria without compromising consumer acceptance. Products were reformulated through recipe modifications and using basic taste compensation techniques; by reducing salt content and compensating flavours using organic acids (apple and lemon juices) and by enhancing flavour intensity with onion and spices such as chili powder. Fat content adjustments were made by substituting full-fat cream (35% fat) with a lighter cream option (15% fat) in a vegetable lentil soup and adjusting vegetable oil content in French fries with sausage.

4.1.2 Consumer acceptance evaluation and sensory profile analysis

Consumer acceptance was assessed in a multisensory research laboratory with 123 participants (mean age 38.5 years, 74.8% female). Participants evaluated both original and reformulated products using 7-point Likert scales (1 = very unpleasant, 7 = very pleasant), rating the appearance, smell, taste, texture and overall pleasantness of each product.

Sensory profiling was conducted by a trained panel of nine sensory professionals. The analysis comprised four training sessions and three evaluation sessions, resulting in comprehensive descriptive profiles. Each product's sensory attributes (odor, mouthfeel, taste, flavour) were rated on a 0–10 scale, facilitating comparisons between original and reformulated recipes.

For more detailed study method information, see Appendices, Original Publication I.

4.2 Studies II and III: Real-Life field experiment in self-service restaurants lunch buffets

Studies II and III employed a similar experimental framework, involving real-life field experiments conducted in two self-service restaurants (SSRs) located in South Ostrobothnia, Finland. Each restaurant served distinct customer populations: a vocational school restaurant (SSR1) catering mainly to students aged 16–19 and a spa hotel restaurant (SSR2) predominantly serving pensioners. In Study II, SSR1 served 998 customers (mean 333/day) during the control period and 985 customers (mean 328/day) during the intervention. SSR2 served 827 customers (mean 276/day) during the control period and 803 customers (mean 268/day) during the intervention. In Study III, SSR1 had 704 customers (mean 235/day) during the control period and 870 customers (mean 290/day) during the intervention. SSR2 had 972 customers (mean 324/day) during the control period and 611 customers (mean 204/day) during the intervention. The methodological procedures of the studies are outlined in the following chapters, while detailed methodological descriptions can be found in the Appendices, Original Publication II and III.

4.2.1 Study design

Both studies included a control period (three days) and an intervention period (three days). The interventions differed between the studies, with Study II implementing nutrition labels (Heart Symbol) and Study III utilizing hedonic video stimulus. During both periods, the restaurants offered identical menus in their buffet serving lines, presented in the same order. However, the menu composition varied between the two SSRs. A pilot day was conducted at both restaurants before the research began to ensure effective data collection practices.

4.2.1.1 Study II: Nutrition labelling intervention

Study II involved an intervention using point-of-choice nutrition labels (Heart Symbol), which were placed visibly on food items that met Heart Symbol criteria based on Finnish nutritional recommendations. These items included main courses, salads, milk, bread, margarine and condiments. Researchers verified food's compliance based on the Heart Symbol criteria, and any unverified foods were left unlabelled.

4.2.1.2 Study III: Hedonic video stimulus intervention

In Study III, the intervention featured a hedonic eating stimulus—a 6-minute food-related video displayed continuously on digital screens during lunchtime (four screens in SSR1, two screens in SSR2). The video comprised 14 clips showcasing the preparation, serving and consumption of high-calorie savoury foods such as hamburgers, fries, pizza and creamy pasta. To minimize disruptions, the video was presented without sound.

4.2.2 Calculation of consumption

In both Studies II and III, trained field researchers manually collected food consumption data. This involved pre-weighing each buffet item served, recording the amount of leftovers, and weighing plate waste at the end of each service. The studies followed an unobtrusive research approach, meaning that researchers integrated seamlessly into the restaurant staff to ensure participants remained unaware of the study, preserving authenticity in customer behaviour.

Average food consumption per customer was calculated by dividing total food intake over each three-day period by the number of customers. The customer count was determined based on the number of washed plates.

4.3 Data analysis

In study I, one-way ANOVA was performed to detect differences in consumer acceptance ratings between original and reformulated products. Sensory profile differences were analysed using Student's t-tests. All analyses were conducted using IBM SPSS Statistics (version 28.0).

In Studies II and III, changes in consumption data between control and intervention periods were statistically analysed using independent sample t-tests and two-sample tests for proportions, performed using Microsoft Excel (2016) and IBM SPSS Statistics (version 28.0).

4.4 Ethical considerations

All three studies adhered to ethical guidelines outlined by the Finnish National Board on Research Integrity and the Helsinki Declaration. Ethical review was either conducted (Study I, approved by the Ethics Committee for Human Sciences at the University of Turku) or waived by the relevant ethics committee (University of Vaasa Human Science Ethics Committee, Studies II and III).

4.5 Assessment of validity and reliability

The validity and reliability of this dissertation are assessed across three empirical studies conducted in authentic foodservice environments, providing strong ecological validity and a coherent methodological foundation.

In Study I, content and construct validity were ensured by grounding recipe modifications in national nutrition recommendations and by defining reformulation through quantifiable nutrient changes verified with standard nutrient-calculation methods. Nutrient composition calculations were additionally reviewed by experts from the Finnish Heart Association. Standardised preparation procedures and repeated cooking cycles strengthened internal validity and reliability, while the research kitchen’s similarity to real foodservice operations enhanced external validity.

In Study II, which examined the effects of nutrition labelling in two buffet restaurants, ecological validity was high as customers acted under natural conditions without awareness of being studied. Internal validity was supported by identical menus and service routines across control and intervention weeks, and consumption was measured using an established weighing protocol. Construct validity was reinforced by applying a nationally recognised nutrition symbol with defined nutrient criteria.

In Study III, a six-minute food-video stimulus was shown on multiple restaurant screens and played continuously both before meal selection and throughout the dining period, creating a sustained and immersive hedonic cue exposure. The study followed the same field-based design and measurement procedures as Study II, ensuring methodological continuity and reliable data collection. The continuous presence of the stimulus during real dining situations further strengthened ecological validity.

Across all studies, reliability was supported by clearly defined and repeatable protocols, standardised procedures, calibrated measurement tools and trained personnel. Although real-life settings involve natural variability, the consistency of measurement procedures ensured that observed effects reflected genuine behavioural and nutritional phenomena rather than random or procedural variation.

5 Results

5.1 Study I: Product reformulation and consumer acceptance

5.1.1 Reformulated recipes and nutritional improvements

The reformulated vegetable lentil soup successfully met the Heart Symbol criteria, showing substantial nutritional improvements: a reduction of 25% in energy, 47% in total fat, 62% in saturated fat and 17% in salt content. Salt reduction (-17%) was achieved through compensatory increases in apple juice (+40%) and lemon juice (+20%). Rapeseed oil was reduced by 20%, and full cream (35% fat) was replaced with lighter cream (15% fat). For the French fries with sausage, salt content was reduced by 46%, compensated by increased onion (+30%) and chili powder (+31%), significantly improving its nutritional profile primarily through the decreased salt content (-28%).

5.1.2 Consumer acceptance

The reformulated French fries with sausage received significantly higher consumer ratings for appearance ($p<0.001$) and smell ($p=0.016$), but no difference was found in overall pleasantness compared to the original. Similarly, the reformulated vegetable lentil soup scored higher in smell ($p=0.019$), showed no significant change in overall pleasantness, and displayed a conditional positive effect on appearance ($p=0.071$).

5.1.3 Sensory profiles

A trained sensory panel found that the original vegetable lentil soup had a richer mouthfeel texture ($p=0.039$) and marginally higher creaminess ($p=0.058$) compared to the reformulated version. For French fries with sausage, no significant differences in sensory attributes were detected between original and reformulated products.

5.2 Study II: Nutrition labelling intervention in self-service restaurant lunch buffets

5.2.1 Effects of point-of-choice nutrition labelling on the consumption of main courses and salads

During the intervention with nutrition labelling, both main course and salad consumption decreased across sites SSR1 and SSR2. In SSR1, main course consumption dropped by 44.2 g (-12.9%, $p<0.001$, Cohen's $d=0.52$), and salad consumption by 9.7 g (-11.6%, $p<0.001$, $d=1.35$). In SSR2, main course consumption decreased by 7.3 g (-2.6%, $p<0.01$, $d=0.24$), and salad consumption by 16.0 g (-11.2%, $p<0.001$, $d=1.03$) (Table 5). In Study II, the effect size calculations (absolute and percentage change, effect size with Cohen's d) presented in Table 5 are author-derived and were not reported in the original publication. They are included here to provide a clearer basis for interpretation and comparison with other studies.

Table 5. Mean consumption of main courses and salads (g/customer) during control and intervention (nutrition labelling) periods in SSR1 and SSR2 in study II. ***p<0.001; **p<0.01 summary independent t-test, N; three days average.

Food items	SSR	Control period, g (N)	Nutrition labelling, g (N)	Absolute change, g	% change	Effect size, Cohen's d
Main courses	SSR1	343 (235)	299*** (335)	-44.2	-12.9	0.52
	SSR2	278 (324)	271** (278)	-7.3	-2.6	0.24
Salads	SSR1	84.3 (235)	74.6*** (335)	-9.7	-11.6	1.35
	SSR2	143 (324)	127*** (278)	-16.0	-11.2	1.03

5.2.2 Healthy vs. less healthy dishes and salads

A closer examination of main course choices revealed that the observed reductions were primarily due to decreased consumption of less healthy options. In SSR1, consumption of less healthy main courses decreased significantly by 42.1 g (-17.3%, $p=0.011$, $d=0.21$). There was no significant change in the consumption of healthier main courses (−3.1 g, −2.1%, $p = 0.849$, $d < 0.1$). In SSR2, a similar pattern was found: consumption of less healthy main courses decreased significantly by 10.7 g (−6.1%, $p < 0.001$, $d = 0.38$), while there was a slight upward trend in the consumption of healthier main courses (+3.4 g, +3.3%), although the change was not statistically significant ($p = 0.096$, $d = 0.14$).

These findings suggest that the nutrition labelling intervention was more effective in reducing consumption of less healthy options, while it had little to no impact on the intake of healthier main courses.

5.2.3 Bread and condiments

Regarding bread and condiments, the effects of the nutrition labelling intervention were mixed. In SSR1, bread consumption remained stable, with only a 0.3% non-significant increase ($p = 0.965$, $d < 0.1$). However, salt use more than doubled, increasing by 130% (from 0.010 g to 0.023 g per customer), and although the absolute amount was small, it was statistically significant ($p < 0.001$, $d = 2.40$). Ketchup consumption increased by 4.47 g (+21.5%), but it was only available on one intervention day, limiting interpretability. In contrast, SSR2 showed a significant increase in bread consumption, which rose by 6.1 g (+39.7%, $p < 0.001$, $d = 1.58$). Ketchup use also increased significantly by 0.77 g (+137%, $p < 0.001$, $d = 0.54$). In SSR2, salt consumption also appeared to increase; however, the data were considered unreliable and therefore excluded. This was due to customers obtaining additional salt independently from spice counters near the lunch area, which prevented accurate quantitative measurement during the intervention week.

These results suggest that while the health labelling intervention reduced main course and salad intake, it may have indirectly increased the use of salt and bread, particularly in SSR2, with older customer profile.

5.2.4 Plate waste

During the nutrition labelling intervention, younger customers (SSR1) generated more plate waste (+8.1%, $p = 0.025$, $d = 0.21$), whereas older customers (SSR2) decreased their plate waste accumulation (-5.6%, $p < 0.001$, $d = 0.41$).

5.3 Study III: Video stimulus intervention in self-service restaurant lunch buffets

5.3.1 Effects of hedonic video stimulus on the consumption of main courses and salads

During the hedonic eating simulation intervention, total food consumption per customer decreased by 14.35% in SSR1 and 16.05% in SSR2. In SSR1, average food intake dropped from 460 g to 394 g per customer, and in SSR2, from 436 g to 366 g. Category-specific data are presented in Table 6.

A significant decline in the proportion of main courses relative to overall consumption was detected in SSR1 ($P_{control}$=79.03% vs. $P_{intervention}$=74.36%, Z =–2.17, p=0.029, h=0.111), corresponding to a 19.3% per-customer reduction. While main course intake also fell in SSR2 (–15.7% per customer), the change in its share of total consumption was not statistically significant ($P_{control}$=63.78% vs. $P_{intervention}$=64.01%, Z=0.093, p=0.928, h=0.005).

Similarly, salad consumption per customer declined in both locations –8.09% in SSR1 (Z=0.549, p=0.582, h=0.028) and –19.0% in SSR2 (Z= –0.556, p=0.582, h=0.029), but neither result reached statistical significance in relation to total consumption.

Table 6. Consumption of main courses and salads (g/customer) during control and intervention (video stimulus) periods in SSR1 and SSR2 in study III.

Food items	SSR	Control period, g (N)	Video stimulus, g (N)	Absolute change, g	Consumption shares[a] in control vs video stimulus periods	Z-value, p-value (Cohen's h)
Main courses	SSR1	363 (704)	293 (870)	-70	79.03 vs 74.36	-2.171, 0.029* (0.111)
	SSR2	278 (972)	234 (611)	-46	63.78 vs 64.01	-0.093, 0.928 (0.005)
Salads	SSR1	58.1 (704)	53.1 (870)	-5	12.64 vs 13.58	0.549, 0.582 (0.028)
	SSR2	142 (972)	115 (611)	-27	32.69 vs 31.35	-0.556, 0.576 (0.029)

[a] relative to total food consumption

5.3.2 Healthy vs. less-healthy dishes and salads (only in SSR2)

In the study conducted in SSR2 where the customer base was generally older, a total of 16 main course options were offered during the intervention period. Of these, 12 dishes were based on vegetables or fish and were thus classified as healthy, while the remaining 4 meals, containing either meat or sausages, were considered less healthy. The categorization followed Finnish nutritional guidelines, which recommend increasing the intake of vegetables and fish while reducing red meat consumption (National Nutrition Council, & Finnish Institute for Health and Welfare, 2024). For the salad buffet, 15 items were vegetable-based and classified as healthy, while 5 salads—including those made with mayonnaise, pasta, or cheese—were deemed less healthy.

During the intervention, the proportion of healthy salads in relation to total salad consumption increased by 5.37%, rising from 73.45% to 78.82% ($Z=2.248$, $p=0.024$, $h=0.117$), a statistically significant improvement. No significant change was observed in the main courses: the relative share of healthy dishes was 74.78% at baseline and 77.00% during the intervention ($Z = 1.001$, $p = 0.317$, $h = 0.052$).

As the lunch buffet in SSR1 predominantly featured foods consistent with national dietary recommendations, the intake of healthy and less-healthy items was not evaluated in SSR1.

5.3.3 Bread consumption

Interestingly, bread consumption per customer increased slightly in both study locations during the intervention period (+9.2 g in SSR1, +1.6 g in SSR2). The change was statistically significant in SSR1, where the proportion of bread intake relative to total food consumption rose by 44.78% ($P_{control} = 8.33$ vs. $P_{intervention} = 12.06$, $Z = 2.411$, $p = 0.016$, $h = 0.124$).

A closer breakdown of bread types revealed that rye bread consumption decreased in both restaurants, while wheat bread intake increased. In SSR1, the share of rye bread dropped by 2.33 percentage points ($P_{control}=6.45$ vs. $P_{intervention}=4.12$, $Z=1.971$, $p=0.038$, $h=0.105$), and in SSR2, the reduction was even greater—6.65 percentage points ($P_{control}=27.78$ vs. $P_{intervention}=21.13$, $Z=2.966$, $p=0.003$, $h=0.155$). This classification of breads as healthy (rye bread) and less healthy (wheat bread) was based on their nutritional profiles: rye bread typically contains more dietary fibre and has a lower glycaemic index, promoting better blood glucose control and increased satiety, whereas refined wheat bread is digested more quickly and has a higher glycaemic index, leading to rapid spikes in blood glucose (Atkinson et al., 2008; Iversen et al., 2022).

5.3.4 Plate waste

In both study sites, the hedonic eating simulation cue had no significant effect on plate waste, either in absolute terms or relative to total food intake. In SSR1, the proportion of plate waste remained unchanged ($P_{control}=4.27\%$ vs. $P_{intervention}=4.86\%$, $Z=0.556$, $p=0.576$, $h=0.028$), while in SSR2 it showed a modest, non-significant increase ($P_{control}=3.26\%$ vs. $P_{intervention}=4.38\%$, $Z=1.150$, $p=0.250$, $h=0.059$).

6 Discussion

This dissertation examined three interconnected strategies—reformulation, nutrition labelling, and digital eating cues—within real-world food service environments. Together, the studies address key gaps identified in previous research, which has often relied on laboratory experiments or survey tasks with limited ecological validity (Arno & Thomas, 2016; Otterbring et al., 2023; Papies et al., 2020). By situating the research in authentic settings, the dissertation responds to calls for more real-life evidence on how food environments shape dietary behaviour (Ballco & Gracia, 2022; Wilson et al., 2016). This broader framing highlights the relevance of the findings not only for academic debates on nudging and grounded cognition, but also for public health policy and practical implementation in the food service sector.

6.1 Reformulation – rediscovering an underutilised strategy

The results from Study I demonstrate that reformulation of recipes towards healthier options is both feasible and effective when systematically tested. Despite its potential, reformulation has remained an underutilised strategy in recent years, with less research and monitoring than might be expected. The present findings suggest that reformulation should be reconsidered and revitalized as a promising approach for improving population diets. Reformulation has repeatedly been highlighted by international organizations such as the WHO and the EU authorities as a cost-effective public health tool to reduce salt, sugar, and unhealthy fats (European Commission, 2020; WHO, 2022). While some successful national programmes exist, for instance, the UK's salt and sugar reduction initiatives and Denmark's trans-fat ban, progress is uneven across countries. In many cases, reformulation has relied heavily on voluntary industry action, resulting in heterogenous outcomes and fragmented monitoring systems (Kleis et al., 2020). A clear limitation at present is the absence of harmonised and systematic follow-up, as indicators, methods, and reporting vary widely, making it difficult to gain a comprehensive picture of progress either nationally or internationally. Without stronger, standardised monitoring, it remains challenging to evaluate the true public health impact of reformulation.

From a practical perspective, reformulation is not limited to nutrient reduction but often requires complex adjustments to recipes, production processes, and ingredient functions. Reducing sodium, sugar, or fats may compromise microbial safety, texture, or sensory appeal, highlighting the technical challenges that must be solved through innovation and careful product testing (Department of Health and Aged Care, 2021; Fanzo et al., 2023). Importantly, such changes cannot be implemented successfully without adequate resources for testing, iteration, and consumer research. This is particularly critical in the food service sector, including restaurants and public catering, where reformulated products must not only align with health guidelines but also maintain taste, quality, and operational feasibility in large-scale preparation and service contexts. In Finland, for example, Tampere's *Voimia Pata* central kitchen produces around 33 000 meals daily for schools and daycare centres, illustrating both the scale and the specific sensory and technical demands of centralised catering systems (Tampereen Tilapalvelut, n.d.; Tanninen, 2022).

Consumer acceptance remains another decisive factor. Evidence shows that consumers often perceive reformulated products as less tasty, which can undermine adoption (Ikonen et al., 2020; Young & Swinburn, 2002). Gradual changes, targeted communication, gastronomic expertise and the use of compensatory methods in recipes to preserve taste and texture are therefore essential to ensure both nutritional improvement and consumer satisfaction. By recognising the dual focus on nutrition and sensory experience, this dissertation also points to educational implications. Training in food and nutrition sciences should more strongly integrate gastronomy and sensory sciences at multiple levels, including vocational schools, universities, and professional programmes.

Taken together, the findings of Study I suggest that the perceived barriers to reformulation—particularly concerns related to taste and consumer acceptance—may be overstated in practice. The successful reformulation of both "vice" and "virtue" products without compromising consumer acceptance indicates that even relatively simple recipe modifications can lead to meaningful nutritional improvements. This has broader implications for public health: rather than relying solely on consumer-driven behaviour change, reformulation allows for population-level impact by improving the nutritional quality of widely consumed foods.

At the same time, the findings highlight that the effectiveness and scalability of reformulation depend on context-specific expertise, iterative testing, and organisational capacity. In the foodservice sector, particularly in central kitchen models, reformulation has the potential to function as a scalable intervention, improving the nutritional quality of large volumes of meals. However, realising this potential requires that reformulation is embedded into organisational practices, procurement criteria, and quality standards, rather than treated as a one-off product development activity. From a policy perspective, this underscores the need for coordinated monitoring and evaluation frameworks at national and international levels. Without such systemic support, reformulation efforts risk remaining fragmented and dependent on individual actors, limiting their long-term population-level impact.

6.2 Nutrition communication and labelling – opportunities and risks

This dissertation confirms previous evidence that nutrition labels can reduce overall consumption and guide consumers towards healthier choices (Bialkova et al., 2016; Cadario & Chandon, 2020; Hummel & Maedche, 2019; Ikonen et al., 2020). However, a novel and unexpected contribution from Study II was the identification of potential unintended consequences, such as the increased use of flavour enhancers and condiments following exposure to health cues. While this pattern resembles "health halo" effects described in earlier research, where foods perceived as healthy are consumed in greater quantities or with additions that undermine the intended benefits, (Ikonen et al., 2020; Wansink & Chandon, 2006), in the present case it reflects compensatory behaviour aimed at restoring taste rather than increasing portion size. The differential effects observed in plate waste—decreasing among older consumers but increasing among younger ones—highlight that nutrition labelling may influence not only food selection but also consumption patterns in unintended ways. This further supports the view that improvements at the point of choice do not automatically translate into improved overall outcomes. Such responses highlight the complexity of food choices and call for careful interpretation of labelling effects. The percentage changes and effect sizes observed in this dissertation are broadly consistent with earlier evidence, which typically reports small to moderate improvements in healthier food choices (5–15%) and effect sizes below 0.5 (Bialkova et al., 2016; Cadario & Chandon, 2020; Ikonen et al., 2020; Mertens et al., 2022). The slightly larger effects found for salads can be explained by the real-life restaurant context, where decisions are more immediate and guided by visual and situational cues. As noted in previous meta-analyses, labelling effects tend to be stronger in restaurant and café settings than in grocery stores, suggesting that contextual factors can amplify behavioural responses (Chadario & Chandon, 2020). These dynamics help explain why the present findings align with earlier research while showing somewhat stronger effects for certain product categories.

The present findings add nuance to the ongoing scholarly debate, which has repeatedly emphasised the need for real-world evidence on labelling effectiveness. Much of the existing research relies on controlled or semi-natural settings, whereas actual consumer behaviour is shaped by complex everyday contexts, including taste expectations, cultural norms, and availability (Broers et al., 2017; Ensaff, 2021). As highlighted in systematic reviews, labels and other cognitive nudges often produce only modest or inconsistent effects, with impacts on food choice more evident than on actual consumption or long-term health outcomes (Bucher et al., 2016; Cadario & Chandon, 2020). These limitations align with the current study's observation that unintended consequences may arise even when interventions appear to succeed at the point of selection.

Ethical and practical considerations also deserve attention. Nutrition labels are often framed as empowering tools that preserve autonomy, yet they may be perceived as manipulative or confusing if not communicated transparently (Selinger & Whyte, 2012). Moreover, as previous research has noted, the effectiveness of labelling interventions is uneven across socio-economic groups, with disadvantaged populations less likely to benefit due to barriers such as affordability, availability, and health literacy (Ensaff, 2021; Wilson et al., 2016). Without careful design and inclusive strategies, labels risk reinforcing rather than reducing dietary inequalities. Taken together, these insights suggest that while nutrition communication and labelling remain important components of public health strategies, they are not sufficient on their own.

From a behavioural perspective, the present findings further suggest that nutrition labelling does not operate as a purely informational tool but rather interacts with sensory expectations and compensatory behaviours. The observed increase in the use of condiments indicates that consumers actively adjust their eating behaviour to maintain hedonic satisfaction, even when making healthier choices. This highlights a critical limitation of labelling-based interventions: improving choice at the point of selection does not necessarily translate into improved dietary quality at the point of consumption. Consequently, labelling should be understood as one component within a broader system of interventions, rather than a standalone solution.

Based on these insights, it is recommended that labelling initiatives designed with particular attention to consumer beliefs, taste expectations, and socio-economic diversity. Labels should be accompanied by transparent communication and integrated with complementary strategies such as reformulation, supportive food environments, and education. Such an integrated approach can help to minimise unintended consequences, reduce inequalities, and enhance the overall effectiveness of nutrition communication in promoting healthier dietary behaviour.

6.3 Digital interventions – new directions in consumer behaviour research

The third thematic contribution of this dissertation lies in the use of digital stimuli, such as video prompts, to influence food choice. The findings from Study III provide pilot-level evidence that digital tools can be effective in shaping consumer behaviour in real-life contexts. This aligns with grounded cognition theory, which suggests that visual and eating cues reactivate prior food experiences and trigger mental simulations that influence appetite, satiety, and subsequent food intake (Barsalou, 2008; Papies et al., 2020). Research has demonstrated that while brief exposure to indulgent food imagery often increases cravings and energy intake, longer or repeated exposure can instead induce sensory-specific satiety and reduce consumption (Biswas & Szocs, 2019; Morewedge et al., 2010). These dual effects highlight the importance of stimulus duration, modality, and context in determining behavioural outcomes.

Recent meta-analyses also support the potential of video-based simulations, which have been found to produce stronger effects on eating behaviour than static images, likely due to their dynamic and immersive qualities (Ceylan et al., 2024). Such digital simulations may therefore represent a promising but still underutilised approach for shaping consumer choices. Moreover, cognitive engagement during digital exposure, for instance through interactive tasks or gamified features, has been shown to amplify positive effects, increasing healthy choices and reducing unhealthy food selections (Liu, 2023). These findings suggest that mobile platforms, applications, and gamification could provide scalable ways to integrate nudging principles into everyday food environments.

However, much of the evidence to date comes from laboratory or survey-based settings, often with student samples, which limits ecological validity and generalisability (Andersen et al., 2023; Otterbring et al., 2023). More research is needed in real-world contexts, such as supermarkets, restaurants, and school environments, where multiple cues, distractions, and social dynamics influence behaviour. Furthermore, ethical considerations must be taken into account when designing digital nudges, especially regarding transparency, consumer autonomy, and the potential for unintended counterproductive effects, such as compensatory eating.

From a broader perspective, the findings suggest that digital eating cues may represent a shift from information-based interventions towards experience-based behavioural strategies. Unlike traditional nudges, which rely on conscious processing, hedonic video stimulation appears to influence behaviour through embodied and affective mechanisms, highlighting an alternative pathway for shaping food choices. However, the observed effects remain context-dependent and may vary across consumer groups, motivations, and exposure conditions, underscoring the importance of identifying boundary conditions and potential unintended effects.

These insights suggest that digital tools, including video-based and interactive formats, could be integrated into broader nutrition interventions to complement more traditional approaches such as labelling and reformulation. To maximise their impact, such interventions should be tested in diverse real-world environments and tailored to specific consumer contexts. By leveraging grounded cognition mechanisms through scalable digital platforms, public health initiatives may move towards more engaging and context-sensitive approaches to promoting healthier eating behaviour.

6.4 Methodological reflections – strengths and limitations

A major strength of this dissertation is its real-life research setting, which enhances the ecological validity of the findings in Studies II and III. Unlike much of the previous evidence on nudging approaches such as labelling, or on digital stimuli grounded in embodied cognition, which has often been derived from controlled laboratory experiments or short-term cafeteria studies (Arno & Thomas, 2016; Broers et al., 2017; Ensaff, 2021; Otterbring et al., 2023), the present studies were conducted in naturalistic environments. This strengthens the relevance of the results for everyday food choices and addresses a gap frequently noted in earlier reviews (Ballco & Gracia, 2022; Wilson et al., 2016).

At the same time, the scope was limited to the food service sector, posing both strengths and constraints since the sector is increasingly moving towards central kitchen models and reformulation initiatives (Fanzo et al., 2023; Kleis et al., 2020; Pättiniemi-Fagerström, 2021; Tampereen Tilapalvelut, n.d.), but its generalizability to retail or household contexts remains uncertain. These aspects highlight the importance of careful piloting, recipe testing, and contextual adaptation before broader implementation in different settings, as well as the need for more standardized long-term evaluation framework.

6.5 Implications

6.5.1 Theoretical implications

This dissertation extends existing research by demonstrating the complementary potential of reformulation, nutrition labelling, and digital interventions in shaping healthier diets. It contributes to theoretical debates on the mechanisms of consumer behaviour by highlighting both conscious (e.g., cognitive nudges such as labels) and subconscious (e.g., grounded cognition through digital food stimuli) processes. The findings on unintended consequences add new nuance to nudge theory and communication models, suggesting that a more systematic consideration of the contextual and habitual factors that shape everyday food choices is needed in explanatory frameworks. Moreover, the integration of sensory and gastronomic dimensions into health-focused strategies expands traditional nutrition research, which has often been dominated by biomedical or behavioural perspectives.

6.5.2 Managerial and practical implications

For practitioners, the findings point to concrete strategies for food service providers, policy-makers, and the food industry. Reformulation should be systematically monitored and supported with adequate resources for recipe development and sensory testing, particularly in central kitchen models where requirements for stability, flavour, and texture differ from on-site cooking. Nutrition communication must be carefully designed to avoid unintended consequences and should be transparent and consumer-oriented to maintain trust. Digital interventions, including video-based prompts and gamification, offer scalable opportunities for real-time nudging but require context-sensitive testing before broad implementation. Managers in both public and private sectors are therefore encouraged to allocate resources not only to product innovation but also to consumer testing, monitoring systems, and cross-sectoral collaboration.

6.5.3 Societal implications

At the societal level, the dissertation demonstrates that isolated strategies are insufficient: reformulation, labelling, and digital nudges should be seen as part of broader, multi-level efforts to promote healthy and sustainable diets. This includes regulatory frameworks, public education, and policies that ensure equity, affordability, and access to healthier options. Importantly, the results underscore the role of interdisciplinary education, calling for curricula that more closely integrate natural and health sciences, behavioural sciences, business and marketing, together with gastronomy. Such training will better equip future professionals to design food solutions that balance health, taste, consumer acceptance, and sustainability. Finally, by aligning with the planetary health agenda and the new Finnish and Nordic Nutrition Recommendations, the findings show that nutrition interventions must address both human and environmental health simultaneously.

7 Conclusions and future research

This dissertation advances understanding of how reformulation, nutrition labelling, and digital eating cues can promote healthier eating in real-world foodservice settings. Across the three studies, the findings show that reformulation can be implemented without compromising consumer acceptance. Nutrition labelling can promote healthier choices and reduce overall consumption, while also triggering compensatory behaviours such as increased use of condiments. In addition, digital eating cues can influence food choices through sensory-driven mechanisms beyond controlled laboratory settings.

Overall, the findings underline that lasting change requires a combination of strategies. Reformulation, labelling and digital interventions must be embedded within wider systemic changes in policy, education, and the food environment. By bridging nutritional, sensory, behavioural, and sustainability perspectives, this dissertation points the way towards approaches that are not only healthier, but also acceptable, equitable, and supportive of broader sustainability goals. Taken together, these findings highlight that interventions targeting food choice operate through different but complementary mechanisms, affecting not only what consumers choose but also how they perceive and consume food.

Building on these findings, future research should expand reformulation studies beyond the food service sector into retail and household settings, where consumer acceptance and contextual variation may differ significantly. Systematic monitoring frameworks should be further developed to provide harmonised and comparable data across countries, reducing the current reliance on fragmented and industry-led reporting.

In the area of nutrition communication, more work is needed to unpack the psychological mechanisms underlying counterproductive effects, including the roles of beliefs, motivations, and taste expectations. Such studies should be conducted in real-life environments with diverse populations, in line with calls from recent reviews for greater ecological validity.

For digital interventions, scaling up pilot studies to larger and more heterogeneous samples is a key priority. Longitudinal designs are needed to assess the durability of effects and to identify potential habituation or compensatory behaviours. Future projects should also evaluate the equity implications of digital nudges, ensuring that technological solutions do not widen socio-economic disparities in dietary behaviour.

Looking ahead, future work should be firmly embedded within the broader sustainability and planetary health agenda. By integrating nutritional, behavioural, and environmental perspectives, interventions can be designed to be health-promoting, acceptable, and ecologically viable. EU-level initiatives, such as the FutureFoodS partnership, offer an important platform for translating methodological innovation into systemic change.

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List of Figures and Tables

Figures

Tables

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