USE OF INFORMATION AND COMMUNICATION TECHNOLOGIES, DATA AND KNOWLEDGE TO INCREASE THE IMPACT OF DIGITAL ENVIRONMENTS ON FOOD CHOICE

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Doctoral Dissertation
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This research was conducted under the auspices of the Jožef Stefan International Postgraduate School, Slovenia, and the College of Health, Medicine and Wellbeing, School of Health Sciences, Australia, and as part of a dual PhD program.

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Doctoral Dissertation

UPORABA INFORMACIJSKIH IN KOMUNIKACIJSKIH TEHNOLOGIJ, PODATKOV IN ZNANJA ZA POVEČANJE VPLIVA DIGITALNIH OKOLIJ NA IZBIRO ŽIVIL

Doktorska disertacija

Supervisor: Prof. Dr. Barbara Koroušić Seljak
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Ljubljana, Slovenia, June 2023

Doctoral Dissertation
submitted in fulfilment of the requirements for the dual degree of doctor between the

Jožef Stefan International Postgraduate School
by the authority of the Rector Magnificus, Prof. Dr. M. Horvat,

and

The University of Newcastle
by the authority of the Rector Magnificus, Prof. Dr. A. Zelinsky,

in the presence of the
Evaluation Board appointed by the Academic Boards of both universities
to be defended in public.

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Valenčič Eva

Acknowledgments

Embarking on this dual degree journey between Slovenia and Australia, I have started a remarkable adventure that is my PhD. Throughout this trilling experience, I have been blessed with the support and guidance of exceptional individuals who have shaped my path and stood by me every step of the way. Their presence and encouragement have been invaluable, and I am deeply grateful for their belief in me.

First and foremost, I want to thank to my supervisor, Prof. Dr. Barbara Koroušić Seljak. Her stoic calmness and faith in me have been important for my growth, both academically and personally. I am forever grateful for her role in making the double degree opportunity a reality. Though words fall short, I want to express my appreciation for her sweet nature, encouragement, and continuous presence, always ready to lend a helping hand day or night. I am grateful for the guidance, wisdom, constant support, and especially for the motherly care she has shown me throughout this path.

Equally deserving of my heartfelt appreciation is my other supervisor, Assoc. Prof. Dr. Tamara Bucher. With her, the bond transcends the boundaries of a typical supervisor-student relationship. She has been a guiding light, not only in my academic pursuits, but also as a friend and confidante in Australia. From sharing scholarly insights to belting out tunes at karaoke parties, our connection extends beyond the confines of academia. Your support, guidance, laughter, and genuine care have made it an unforgettable adventure.

I am truly privileged to have had the guidance and expertise of two exceptional co-supervisors, Dr. Emma Beckett, whose vibrant energy have provided me profound advice, and Laureate Prof. Clare E. Collins, whose wisdom and seasoned expertise have provided invaluable insights. Their endless support and gentle nudges for improvement have challenged me to reach new heights.

To my extraordinary crew of PhD adventurers and partners-in-fun, whether in Slovenia or Down Under, you have been my lifeline throughout this wild and wacky expedition. Maša, Anja, Žan, Aljoša, Blaž, Rebeka, Jerneja, Tina, Gordana, Nienke, Hailey, Saskia, Daphne, Angie, Berit, and the rest of the squad, I cannot thank you enough for the laughter, camaraderie, and endless shenanigans that have made this journey unforgettable. From our coffee-fuelled brainstorming to late-night dance parties. Remember the time we were in awe of the colossal size of Australian spiders and took on epic battles with cockroaches? Those moments may have induced screams and laughter simultaneously, but they have also bonded us in ways only you can understand. From our inside jokes to the 'eureka' moments that only we can appreciate. All of you near and far, you have been my rock, my cheerleaders, and the guardians of my sanity. Your presence in my life has made this adventure truly extraordinary, and I cannot wait to create more unforgettable memories together.

Heartfelt appreciation goes to my family. To my ever-supportive parents, thank you for raising me to be independent and for your faith in me. To Nika, who spent hours listening to my laughter and tears, and her wonderful family. Your presence, inspiration, and the innocent joys your children bring to me have been a constant source of strength. Amidst the struggles of the PhD journey, solving the mystery of lost Legos with them have served

as a delightful reminder of life's simple pleasures. Eon and Dija, your countless drawings created in support of my journey have brought joy to my heart. Your artistic talents made decorating my rooms so much easier and, even when we were on the other side of the world, made me feel at home. I love you!

To all those who have touched my life during this transformative period of my life, I extend my deepest gratitude. Your support, encouragement, and delightful moments of humour have made this experience worthwhile. This journey has taught me that amidst the challenges, there is room for laughter, celebration, and the pursuit of happiness. I am forever grateful for the role each of you has played in shaping my path and for the memories we have created together.

Abstract

Food and eating environments play a crucial role in shaping consumers' food choices. As food decision-making shifts more into the digital environment, it is essential to understand the impact of this setting on consumer's dietary behaviours. Online platforms and mobile apps provide great opportunities for the promotion of healthier food choices and the improvement of dietary behaviours. Moreover, food choices are frequently processed unconsciously, which underscores the importance of creating digital environments that support healthful decision-making. Ultimately, by leveraging the power of digital technology and applying effective nudging strategies, consumers' food choices can be improved, which can further lead to better dietary behaviours and improved overall health.

This doctoral dissertation addresses two main aims. Firstly, it is focusing on investigating and designing supportive digital environments for consumers, using nudging strategies, whereas the second aim is focusing on the provision of relevant and accurate food and nutrition data and knowledge for choice architects. To address these aims, four studies were conducted. Firstly, a scoping review was conducted to investigate the use of digital nudging strategies in online grocery stores, and to identify research gaps within this research area. The review revealed that only a few nudging strategies have been implemented within online grocery store user-interfaces. Furthermore, the review found that there was a lack of detailed descriptions of the design elements used. Next, a study to investigate whether specific design elements of a mobile app could influence consumers' snack choices, was conducted. This study found that background images may influence snack choice. The study also highlighted that there is a need for innovative approaches that integrate food and nutrition data and knowledge to effectively promote healthier food choices. To address this gap, a user-friendly web-based tool was developed that allows for easier and more efficient data and knowledge access and management. Lastly, an experimental online grocery store, where food products were re-positioned based on dietary fibre content, was designed and tested. This study demonstrated that the integration of data and knowledge into the development process of user-interface design elements can be an effective strategy to promote healthier food choices.

The main finding of this thesis is that creating effective digital environments requires a multi-faceted approach. First, these environments must be designed in a way that promotes healthier choices, which can be achieved through various nudging strategies. Next, choice architects responsible for designing the environments must have access to reliable and evidence-based data and knowledge. This includes integrated and interconnected data from various resources, to provide them with insights into the latest scientific evidence. Moreover, data and knowledge need to be transparent, traceable, and accessible by the choice architects and by information systems, to ensure that the design choices made, are well-informed and supported by evidence.

In summary, this dissertation adds to the existing literature by creating supportive digital environments for promoting healthier choices that consider both, user-interface design and access to relevant data and knowledge. By addressing these two elements, we can lead to impactful interventions that support consumers in making healthy food choices.

Povzetek

Prehransko in prehranjevalno okolje igra ključno vlogo pri oblikovanju potrošnikovih prehranskih izbir. Ker se odločanje o prehrani vse bolj seli v digitalno okolje, je ključno razumevanje vpliva tega okolja na potrošnikovo prehransko vedênje. Spletne platforme in mobilne aplikacije ponujajo odlične priložnosti za promocijo bolj zdravih prehranskih izbir in izboljšanje prehranskega vedênja. Poleg tega se prehranske izbire pogosto izvajajo podzavestno, kar poudarja pomen oblikovanja digitalnih okolij, ki podpirajo zdravo odločanje. Navsezadnje je mogoče z izkoriščanjem digitalnih tehnologij in uporabo učinkovitih strategij spodbujanja (angl. nudging strategy) izboljšati potrošnikove prehranske izbire, kar lahko vodi k izboljšanju prehranskega vedênja in splošnega zdravja.

Doktorska disertacija ima dva glavna cilja. Prvi se osredotoča na preiskovanje in oblikovanje podpornih digitalnih okolij za potrošnike z uporabo strategij spodbujanja, drugi pa na zagotavljanje ustreznih in bolj točnih prehranskih podatkov ter znanja za strokovnjake, ki načrtujejo in oblikujejo okolja (angl. choice architecsts). Za doseganje teh dveh ciljev so bile izvedene štiri študije. Z namenom preiskovanja uporabe digitalnih strategij spodbujanja v spletnih živilskih trgovinah in identifikacije vrzeli v raziskavah na tem raziskovalnem področju je bil opravljen sistematični pregled literature. Pregled je pokazal, da je bila prek uporabniških vmesnikov spletnih živilskih trgovin izvedena le peščica strategij spodbujanja. Poleg tega je bilo ugotovljeno, da manjkajo podrobni opisi uporabljenih oblikovnih elementov. Zatem je bila izvedena študija z namenom preiskovanja vpliva določenih oblikovnih elementov mobilne aplikacije na potrošnikove izbire prigrizkov. Ta študija je pokazala, da ozadje lahko vpliva na izbiro prigrizkov. Študija je tudi razkrila, da so za učinkovito spodbujanje zdravih prehranskih izbir potrebni inovativni pristopi, ki integrirajo podatke in znanje o prehrani in živilih. Ravno zato je bilo razvito tudi uporabniku prijazno spletno orodje, ki omogoča lažji in učinkovitejši dostop ter uporavljanje podatkov in znanja. Nazadnje je bila oblikovana in testirana eksperimentalna spletna živilska trgovina, kjer so bila živila prerazporejena glede na vsebnost prehranskih vlaknin. Študija je pokazala, da je integracija podatkov in znanja pri oblikovanju uporabniškega vmesnika lahko učinkovita strategija spodbujanja zdravih prehranskih izbir.

Glavna ugotovitev disertacije je, da je treba pri ustvarjanju učinkovitih digitalnih okolij uporabiti večplastne pristope. Ta okolja morajo biti oblikovana tako, da podpirajo bolj zdrave prehranske izbire, kar je mogoče doseči z različnimi strategijami spodbujanja. Poleg tega pa morajo oblikovalci teh okolij imeti dostop do zanesljivih in znanstveno dokazanih podatkov in znanja. To vključuje integrirane in medsebojno povezane podatke iz različnih virov, ki nudijo vpogled v najnovejša znanstvena dognanja. Da se zagotovi dobro informirane in znanstveno dokazane odločitve o oblikovanju okolja, morajo biti podatki in znanje pregledni, sledljivi in dostopni ljudem in informacijskim sistemom.

Če povzamemo, disertacija dopolnjuje obstoječo literaturo z novimi ugotovitvami o ustvarjanju podpornih digitalnih okolij za spodbujanje bolj zdravih prehranskih izbir, ki upoštevajo tako oblikovanje uporabniškega vmesnika kot dostop do ustreznih podatkov in znanja. Obravnava teh dveh področij lahko vodi do učinkovitih strategij, ki podpirajo potrošnike pri bolj zdravih prehranskih izbirah.

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Abbreviations

D&K	...	Data and knowledge
DKBMS	...	Data- and knowledge base management system
FCD	...	Food composition data
FCDB	...	Food composition database
FIR	...	Food image recognition
ICT	...	Information and communication technologies
KB	...	Knowledge base
UI	...	User interface

Chapter 1

Introduction

The prevalence of non-communicable chronic diseases, such as type II diabetes, coronary heart disease, stroke, cancer, obesity, and hospital malnutrition, is rising globally [1]-[3]. Among various reasons, this is due to major shifts in eating habits and food choices [1]. Contemporary, consumers are frequently exposed to enticing and less healthful food options.

The exposure to tempting foods occurs in physical food environments as well as through various online platforms, such as online grocery stores, food ordering apps, and other digital channels. Moreover, the recent COVID-19 pandemic has expedited the growth and dimensions of online food outlet use. In both physical and digital environments, there is a growing recognition of the need for innovative strategies to promote healthy dietary habits and overall health. These need to be developed focusing, not only on an individual's behaviour, but also on the food environment and the conditions in which consumers make food choices [2].

Food and eating environments refer to factors, independent of the food itself, that relate to the ambient elements associated with the eating of food (e.g., atmospherics, the effort of obtaining, social interactions), and to the way food is provided or presented (e.g., availability, salience, packaging, portion size) [3]. In the following subsections, the effect of food and eating environments on people's food choices will be discussed. Specifically, attention will be drawn to the relevance of virtual environments and their impact on food choice decision-making. Not knowing whether or how a specific environment or its specific elements affect food choices and whether they can trigger them, can present an obstacle in understanding particular drives of food selection. In addition, developing food environments that encourage healthier food choices is of great importance. However, human decision-making is a complex process, therefore sometimes environmental changes implemented in the belief that they will positively impact decisions, may have adverse effects and can cause more harm than benefits.

Designing (virtual) environments is being increasingly researched. However, most online environments are optimised to increase sales without taking public health considerations into account. Foods present a complex matrix. They contain beneficial compounds, such as energy and nutrients, but may also contain disadvantageous components, such as allergens. Hence, to be able to make healthier choices, consumers need to be also presented with all data relevant for their health. Improving our understanding of the impact of digital environments on choice with additional high-quality data and knowledge, can provide more information to help inform individuals, and the population.

The current challenges regarding designing health-promoting digital environments and obtaining relevant evidence-based information to support choice architects and consumers, need to be addressed from different perspectives. Choice architects, i.e., people who make

a conscious effort to create choice environments to promote better outcomes (e.g., public health researchers, user interface designers and other entities or individuals in charge of designing choice environments), need to be provided with the latest evidence-based knowledge to be able to strategically design environments that will positively impact food decision making. Moreover, they need to know which nudging strategies are effective, how to change environments and what to nudge (e.g., what nutrients, foods or food groups to focus on). The present doctoral dissertation addresses both perspectives.

1.1 Background

1.1.1 The influence of environments on food choices

Food and eating environments have a major impact on food choices and amounts consumed. Influences on eating patterns include the promotion of unhealthy foods [4], high accessibility and availability of convenient, and relatively inexpensive foods which are highly processed and energy-dense, nutrient-poor [2]. Food choices and amounts consumed are also influenced by the effort required for consumption [5], variety [6] and portion sizes [7] of food presented. While an unhealthy environment can lead to overeating and contribute to weight gain and other chronic conditions, a health-promoting environment can facilitate the formation of healthy eating habits [8]. Hence, strategically restructuring food choice environments is suggested to be a promising avenue to promote population health [8].

Promoting healthy eating by focusing on educating consumers has had a limited success [9]. Even though nutrition education provides consumers with knowledge and resources to help make informed food choices, it usually does not translate into action [9]. This might be because human food choice behaviour is a complex and multifactorial behavioural system. Consumer behaviour can be described as a function of the interaction between the individual and the environment [10]. Therefore, food and nutrition choices are influenced by factors both at the individual and environmental level. While some influencing factors are innate, many learned and modifiable factors also shape nutrition and eating habits, making the system very adaptive [11]. Finding which factors influence people's eating behaviours is of great importance in many research areas. Therefore, an interdisciplinary team created interactive framework of Determinants Of Nutrition and Eating (DONE) [11]. Within this framework the areas of priority for research and interventions were identified, based on rates of modifiability, relationship strength, and population-level effect of the determinants. The determinants of healthy eating can be organized into four main levels: Individual, Interpersonal, Environmental and Policy (Figure 1). While factors at all levels influence food choice, the DONE framework demonstrates that factors at the environmental level are among the ones with the greatest influences on our food choices.

Furthermore, a strong connection has been demonstrated between unconscious influences of environmental factors and food consumption [12]. Studies have shown that certain environmental cues can cause overconsumption and poor nutrition. Most importantly environmental factors are modifiable. Therefore, altering environment to be supportive and to assist consumers to make healthier choices, may be an effective strategy to promote and improve public wellbeing.

Creating such environments needs to be approached from different perspectives. Firstly, restructuring the environment in a way that it makes healthier choices the easier and more accessible ones, may have a positive influence on consumer's food decision making. This concept has been described as *nudging*. Secondly, experts need to have access to relevant

and trustworthy food- and nutrition-related data and knowledge, as this is essential to be able to promote the choices that improve consumers health.

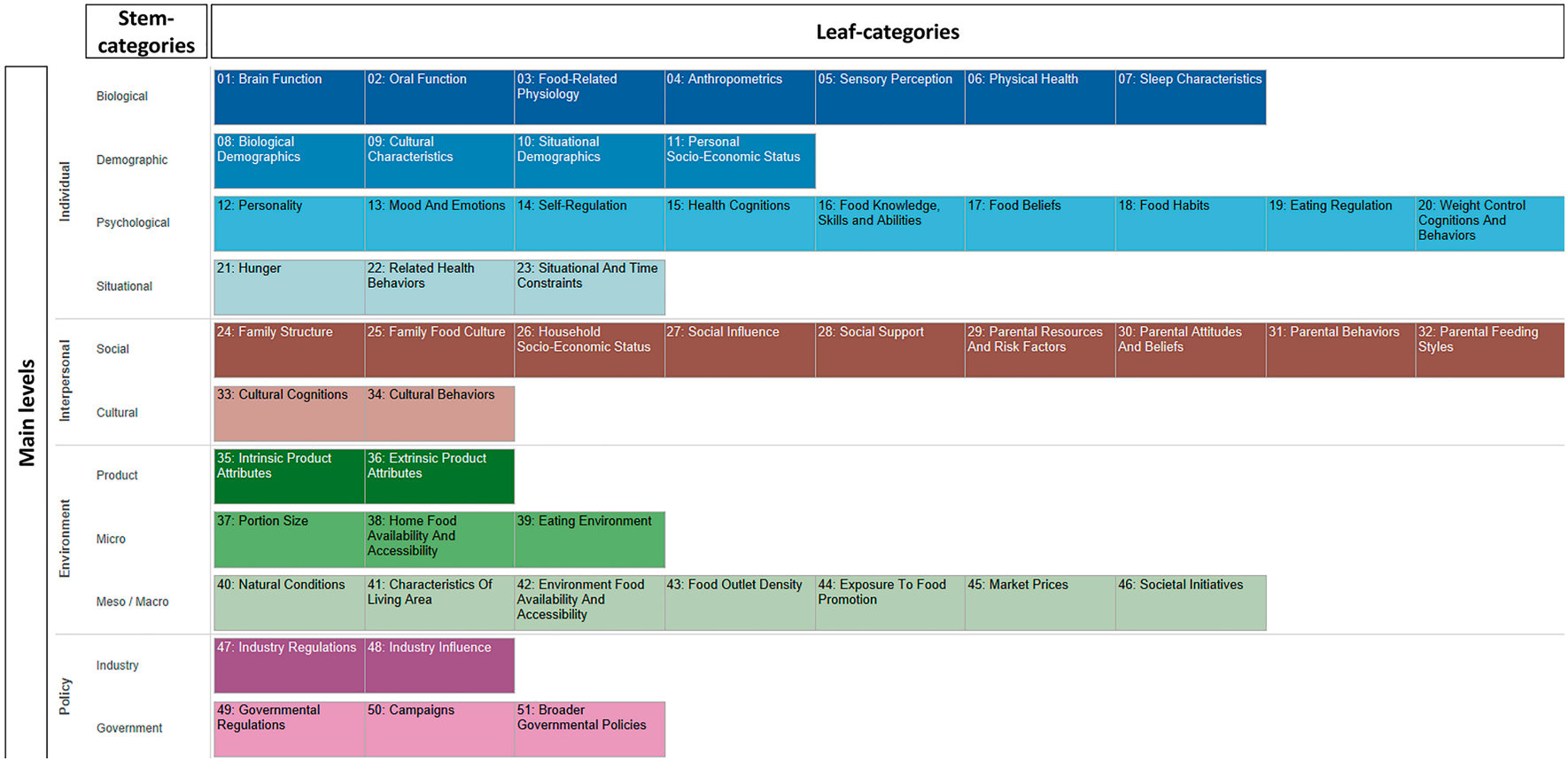

Figure 1: The DONE framework structure, consisting from four main levels, eleven stem categories and fifty-one sub-categories (leaf categories). Taken from [11].

1.1.2 Nudging

The concept of 'nudging' was defined by Thaler and Sunstein in 2008 [8] as "any aspect of choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing economic incentives." For example, increasing the salience of a product by placing it at the checkout in a supermarket would be considered a nudge, whereas taxing unhealthy foods is not considered as one.

The nudging approach, sometimes called also *choice architecture* or *persuasive design*, can be adopted and applied to encourage better choices and to discourage people from unwanted behaviours. In the context of the food and eating manipulating environmental cues can, therefore, be used to nudge healthy eating behaviours. For example, research has demonstrated that food choice and consumed amounts are influenced by the positioning of foods and the effort to obtain them [13], [14].

A broad range of nutrition interventions have sought to influence food choices through consciously changing the consumer behaviours [15] (e.g., by providing nutrition information), but to date there has been little evidence of any real benefits. However, there is potential for nudging to target subconscious decision making in order to make it more impactful.

1.1.2.1 The nudging theory

Historically, it was assumed that an individual's health behaviour was determined by conscious and systematic intentions. However, later it became evident that many actions of individual are guided by automatic, nonintentional and subconscious processes [16]. This is not surprising since the unconscious processes are effortless, quick, unintentional and can operate at any time [17]. It has been proposed that judgements, feelings and behaviours often mistakenly attributed to active thinking and reasoning, are actually driven by apparently unimportant and logically irrelevant external influences [18]. These can be physical (e.g., atmospherics), verbal (e.g., who communicates the information) or sensational (e.g., emotional associations), and each can be strategically used to nudge specific behaviours (e.g., food selection) [19], [20].

Conscious and unconscious human behaviours, and the mechanism of nudging can be explained by dual-processing theories, which divide people's information processing into two operating systems [21]–[23], System 1 and System 2 [24]. System 1 is intuitive, and the processes in this system are unconscious, rapid, automatic, effortless, emotional, and habitual. On the other hand, the processes in System 2 are conscious, slow, controlled, effortful, intentional, cognitively demanding and rule-based, as this system acts via reasoning. Many eating and food choices are part of System 1 since people often make food choices very quickly, spontaneously, and without considering the long-term consequences [25]. In addition, the dual-processing theory indicates that human behaviour is influenced by the available cognitive resources, which means that when fewer cognitive resources are available, consumer's reasoning (i.e., System 2 decisions) is compromised. This is because, when cognitive resources are limited, a consumer may conserve resources for other (complex) tasks, and increasingly relies on intuition and habitual behaviour in a way that long term goals are compromised [21], [26].

Therefore, restructuring of the food and eating environment, which is processed outside of conscious awareness, could help in targeting System 1 decisions and therefore nudge healthier food choices [27]. In line with this, it has been proposed that making healthier food choices will be easier and less demanding if little or no conscious effort is required (e.g., [27]).

1.1.3 Digital nudging

The advances in information and communication technologies (ICTs) have had an impact on consumers' everyday food and eating environments. While in the past the majority of the food choices were conducted in real-world settings, such as restaurants and supermarkets, contemporary this occurs increasingly in digital settings. Moreover, restrictions related to the COVID-19 pandemic lead to increased demand and made consumers more accustomed to online grocery shopping, online food ordering, and meal delivery [28], [29]. More importantly, online grocery shopping and pre-ordering systems as well as technology-facilitated food delivery services (e.g., food delivery smartphone applications), allow consumers to place orders from virtually anywhere. Therefore, these shifts provide great opportunities to promote healthier food choices and improve dietary habits within digital environments. However, this exceeds the nudging definition and raises the importance of research in *digital nudging*. Therefore, Weinmann *et al.* [30] extended the concept of nudging by including also digital environments. They defined it as the "use of user-interface (UI) design elements to guide people's behaviour in digital choice environments" [30].

In contrast to traditional food and eating environments, perception of visual cues within a digital setting is entirely mediated through a digital UI. As such, UI design may potentially strongly influence consumer perception, selection and purchases of food items. The online retailers use this knowledge to strategically promote sales of products [31]. Moreover, organizations often use natural landscape imagery to promote positive user experiences [32]. However, despite being used widely in practice, the literature on the influence of nature imagery on consumer perception and behaviour remains scarce [32].

The influence of physical food and eating environments on consumer behaviour are well described within current theoretical frameworks (e.g., the DONE [11] or the ecological framework [2]). However, the influence of digital food choice environments and the strategies to design them in a way to support healthier eating habits is currently lacking. For example, factors relevant for physical environments, may not be relevant within digital ones. In digital settings, distance to the checkout has no influence on consumers, whereas the effort needed to find and place a product into a shopping cart (measured as numbers of clicks or scrolling time) could potentially have a major impact on food selection. Currently, no food-related framework focuses on consumer behaviour within digital environments. Therefore, the understanding of the impact of different UI elements on food perception and product selection in online environment is lacking.

It is important to note that nudges in a digital setting are distinct from digital nudging. For example, sending a reminder via e-mail or message is not considered as digital nudging, since the UI design was not modified to influence food choice behaviour, rather a digital platform was used to provide a direct message to an individual. The difference between digital nudging and nudging in digital settings was further described and explained in a quantitative review of the effectiveness of nudging, conducted by Hummel and Maedche [33].

Furthermore, while UI elements such as background imagery, health-advice avatars, and colouring of the digital environment may influence food choice behaviours, these effects need further investigation. To date, little is known about how people make food choices within digital environments and which key elements of the UI design have an impact on food perception, selection and purchase. Although ICTs are becoming commonly used in the healthy-eating context, there is a paucity of data demonstrating that healthier choices can be promoted using technology to manipulate choices in the food environment [34]. This lack of theoretical understanding and empirical evidence limits the understanding of how digital environments could be used to nudge healthier food choices, or if they may have

the opposite effects. Therefore, using digital nudging strategies, understanding their effectiveness, and accordingly selecting the appropriate nudging types, is of greater importance, as decision-making has shifted into digital environments. Moreover, research needs to inform consumers, researchers, and practitioners about the impact of UI design elements on food choice in digital food environments. Hence, the development of novel, appropriately designed UIs and online tools may support consumers in making more advantageous decisions about their nutrition and further promote positive health outcomes. Therefore, which nudging strategies are effective in digital settings and whether a specific UI design can be used as an environmental cue to nudge healthier food choices, needs to be further explored.

Finally, the connection between food and digital nudging strategies must rely on the latest scientific data and knowledge (D&K) to be successfully implemented. Therefore, choice architects need to design and use such strategies, to gain access to relevant food and nutrition information. In addition, digitalisation requires that this information and D&K are structured so that they can be read and used, not only by humans, but also by information systems where D&K is hosted. Only then will choice architects be able to take full advantage of ICTs and construct supportive environments for consumers.

1.1.4 Food- and nutrition-related data and knowledge

Structuring environments to be supportive and helpful to people to make informed choices may have a positive influence on consumer's food decision making. However, creating such environments needs to be approached from different perspectives. Firstly, by nudging consumers and making healthier choices the easier and more accessible options. Secondly, to be able to provide choice architects with accurate food and nutrition D&K, which can contribute to informed food selection among consumers, they need to have access to relevant and trustworthy food- and nutrition-related D&K. However, research combining food and nutrition D&K with (digital) nudging theory is currently lacking. Therefore, my PhD research focuses specifically on this topic.

Food- and nutrition-related D&K are essential for both, consumers to make informed food choices, and choice architects to be able to select an appropriate nudging strategy. Moreover, various research domains can take advantage of them. For example, this is relevant for dietary and health assessment, promotion of public health and prevention of diseases, nutrition education, food safety and authenticity, food frauds preventions, agriculture, food policy and food labelling. [35]–[37]. Furthermore, D&K are necessary also for the food industry, retailers, NGOs and policy makers. While consumers rely on D&K when making informed food and nutrition decisions, other stakeholders use them to obtain accurate scientific evidence to design strategies required to promote public health and improve overall well-being.

1.1.4.1 Food composition data and databases

Food composition data (FCD) carries information on the amount of nutrients and non-nutrients (e.g., water, polyphenols) contained in different foods. Therefore, it is especially important for nutritionists, dietitians, public health clinicians, policy makers and consumers, as it is needed for dietary assessment and advising. Traditionally, FCD were published as printed tables. However, the advances in ICTs resulted in them being compiled online in the form of food composition databases (FCDBs). This offers new ways of using them, as they are then not accessible only by humans, but also by information systems.

Usually, FCDBs are compiled at the national level, however they are often used at the international level to conduct public health research [36]. In general, FCDBs contain data

on traditional, ethnic and local foods and dishes. However, FCDBs can contain data of varying quality due to different resources and ways of obtaining data (e.g., analytically obtained data or (re)calculated). Thus, different standards and frameworks for data classification and description have been developed [36], [38]–[44], and need to be taken into account when compiling a database. However, these resources should also be interconnected and to complement each other to achieve data harmonisation. The integrity of a FCDB can be distorted because of missing data. As complete food composition analyses are time-consuming and present a financial burden, many FCDBs do not contain a complete food composition dataset. To overcome this challenge, data can be borrowed between FCDBs. Additionally, to semi-automate this process, computer-supported methods for data imputation have been developed [45]–[47]. However, collected data is often not standardised and harmonised, thus experts may have trouble linking it or interpreting the results. Therefore, data production, compilation and management need to be described in detail and most importantly, marked transparently. To control and assure data quality, quality assessment systems and confidence codes have been developed and need to be taken into account during compilation processes. Quality evaluation needs to focus on factors such as detailed food description, sample handling or analytical method(s) used [48].

1.1.4.2 Food- and nutrition-related knowledge bases

While FCDBs contain information about food composition, knowledge bases (KB) provide knowledge based on information extracted from data. Therefore, they are as equally important as FCDBs. Food- and nutrition-related KBs contain food and nutrition knowledge and documentation that has been collected and organised in one place, where it is easily accessible. For example, an important part of such KB would be dietary guidelines, dietary reference values, standardised classifications and description coding, retention and yield factors needed to calculate nutrient composition of dishes [49]. All of these represent a baseline for further food indexing and data management.

In addition, the KBs provide access to the data needed at any time and from virtually anywhere, which is crucial given that contemporary new D&K are evolving on an almost daily basis. Moreover, KBs aim to reduce the time and effort needed to find evidence-based answers to specific questions. Moreover, as contemporary KBs are digitalised, information provided in different formats, such as plain text, images, video, audio, can be collected. Additionally, information can also be distributed in a format that is best understandable for the final user. Most importantly, KBs allow more optimal connectivity of D&K from different research areas. For example, combining food composition knowledge with food toxicology knowledge in one place, makes it easier for experts to access and process the data and to further disseminate the knowledge to consumers.

To maximise their potential, D&K need to be integrated within and among different research areas. In practice that means integrating for example, blood biomarker reference ranges with food composition D&K. Combining individual's low blood serum iron values and relevant D&K about foods rich in iron, would then allow experts to inform and educate consumers on how to meet recommended daily values and improve their health condition.

1.2 Purpose of the Dissertation

The main aim of the dissertation is two-fold. Firstly, it aims to create and test nudging strategies for digital environments that can aid consumers in making healthier food choices. Secondly, it seeks to supply precise food and nutrition D&K for both, experts and information systems. These goals are interconnected since the successful implementation of nudging strategies critically depends on evidence-based D&K.

The dissertation proposes four key research objectives. Firstly, the investigation of efficient nudging strategies for integration within digital environments and UIs. Secondly, the development of a research mobile application to explore the impact of physical and digital environments on people's eating behaviours. Thirdly, the creation of a user-friendly web-based tool in the form of a Data and Knowledge Base Management System (DKBMS) to link and integrate data from various FCDBs and KBs. Lastly, to leverage the FCDBs and KBs to inform the selection of food products for a digital nudging intervention aimed at promoting healthy food choices online.

1.3 Objectives of the Dissertation

The objectives of my dissertation are to:

O1. Gain insights into which digital nudging strategies can be used to encourage consumers to select healthier foods.

O2. Design and pilot test a mobile app for testing environmental influences and investigating the impact of different UIs on people's snacking choices.

O3. Design and test a DKBMS in the form of a web-based tool where experts can easily search through different FCDBs and KBs, compile them and further link different types of evidence-based food information.

O4. Update a Slovenian FCDB containing national and international generic foods, branded foods, and dishes (recipes) frequently and those traditionally consumed in Slovenia.

O5. Use the FCDB and KB to design an experimental web grocery store and identify efficient digital nudging strategies to promote healthier choices.

1.4 Hypothesis

The hypothesis tested in my dissertation are:

H1. Environmental cues subconsciously impact consumer’s food choices.

- **H1a.** UI design element modifications can be used to promote healthier choices in online grocery stores.
- **H1b.** The presence of specific background images within the UI influences food choices.

H2. Combining food- and nutrition-related data and knowledge into a single database, and enabling its connectivity with other systems, leads to easily accessible source of evidence-based food and nutrition data, information and knowledge.

H3. Well-structured, detailed and interoperable FCDBs and KBs are useful and effective for experts to create healthier (digital) food environments.

1.5 Scientific Contributions

The research presented in my dissertation results in the following scientific contributions. Each of the hypotheses is related to contributions that are relevant for the scientific community.

SC1. A scoping review conducted to investigate which digital nudging strategies are currently used in online grocery stores, and to identify possible research gaps within this field. The review revealed that the majority of studies was published recently, and that only four nudging strategies (or a combination of them) have been implemented through online grocery store UIs. In addition, differing effects of nudging strategies were found on nutritional outcomes, overall diet, healthiness of purchases and purchases within specific food groups. Moreover, the lack of detailed descriptions of UI design elements implemented, indicate that further research in this field is required. This work confirmed hypotheses **H1a,** and has been published in a peer-reviewed review journal [50]. Details can be found in Chapter 2.

SC2. An international feasibility study on consumer's food choices found that images of healthy and unhealthy snacks, added as a mobile app background, have an impact on user's food choices. Users were exposed to five different purposely designed mobile app backgrounds. In the study, it was found that presenting images of unhealthy foods may nudge choices of healthier snacks. The developed mobile app is available as open-source and can be used in further studies to explore how mobile app's UI design elements, impact consumers food choices or even dietary habits (if used over prolonged time). This work confirmed hypotheses **H1b.** The study has been published in a peer-reviewed journal article [51] and is further described in Chapter 3.

SC3. In order to enhance digital nudging strategies, food and nutrition D&K was collected and integrated with respect to the FAIR (Findable, Accessible, Interoperable, Reusable) principles [52]. Thereby, D&K become available not only for choice architects/experts, but also for various information systems (e.g., mobile apps, online grocery stores). In particular, Slovenian FCDB and KB were compiled and complemented with international FCDBs and KBs, to be applied in combination with digital nudging strategies.

SC4. Designing an experimental online grocery store where knowledge about digital nudging was combined with FCD and knowledge (SR3). This study showed that re-positioning food products (and making them obtainable with minimum effort) according to their fibre content, can promote healthier food choices. Within this study, relevant knowledge related to nudging (i.e., minimising effort may be an avenue to promote healthy choice) was combined with data on dietary fibre (which is not commonly available on food label) and knowledge (i.e., that insufficient fibre is consumed and that insufficient intake has health consequences). This work confirmed hypotheses **H3.** Study design and experimental results are further presented in Chapter 5. This study resulted in a scientific paper. The manuscript has

been submitted, but has not yet been published at the moment of dissertation submission.

SC5. Designing and testing a management system to be used by experts to compile FCDBs and to integrate FCD from different databases with knowledge in a distributed (non-centralised) database. This methodology for creating such as DKBMS and its application for compiling the Slovenian D&K (SR3) resulted in another scientific manuscript, however it has not yet been published. Details about the study can be found in Chapter 4.

SC6. Collaboration with a multidisciplinary team of researchers from different research areas in the process of development, implementation and testing of different computer methods, such as machine learning, natural language processing, recommendation systems for semi-automated food matching, missing data imputation, advanced searching and constructing food and nutrition related semantic resources. This resulted in many scientific publications not directly related to this dissertation (they are listed in the Bibliography section – Other Publications of the dissertation).

1.6 Dissertation Structure

The dissertation consists of seven Chapters.

In Chapter 1 – Introduction, an overview of related work and an explanation of the significance and relevance of the research topic, is provided. Next, the problem in hand, the research area that has been explored, and the current gaps in the literature, are defined. In addition, goals and research hypothesis to overcome these gaps, and the scientific contributions that are the outcome of this dissertation are explained. Chapter 2 contains the first published publication, the scoping review [50]. Chapter 3 contains the second published publication about the mobile tool to assess the influence of digital and physical environments on snack choice [51]. Both publications are included exactly as they appear in their respective journals, each with its own page and section numbering, abstract and references. Chapters 4 and 5 contain submitted, but at the moment of dissertation submission, not yet published manuscripts. Chapter 4 includes the paper related to the development of the management system used to integrate and connect food and nutrition D&K. Chapter 5 links two research areas, namely digital nudging and food and nutrition-related D&K and contains the second manuscript. This manuscript discusses how changing the default order of foods based on nutrient content can be used to positively impact more healthful food selection. See Figure 2 for a visual presentation of the research topics. Both manuscripts are included exactly as they were submitted to the journals (with its own page and section numbering, abstract and references). As such, the List of Figures, Abbreviations and References of this dissertation apply only to the dissertation text itself, and not to the publications and manuscripts. Finally, Chapter 6 – Discussion, contains a general discussion and provides recommendations for future research, and Chapter 7 – Conclusions, concludes the dissertation with final remarks.

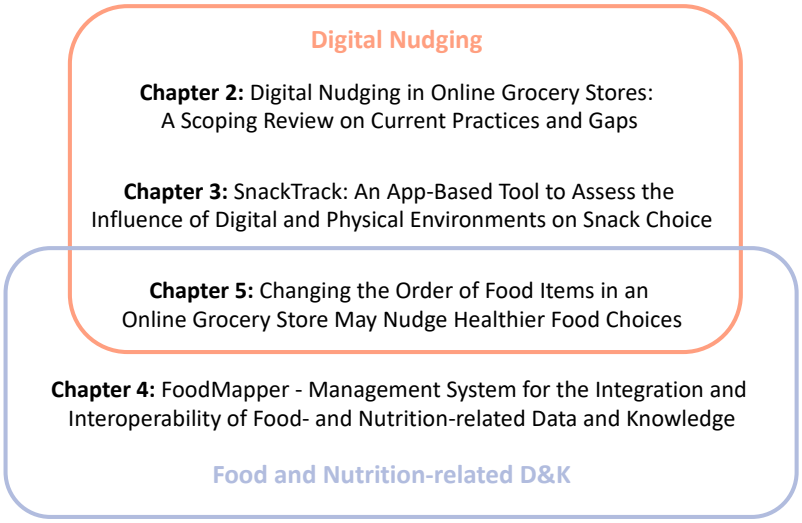

Figure 2: Visual presentation of the research topics discussed in this doctoral dissertation.

Chapter 2

Digital Nudging in Online Grocery Stores: A Scoping Review on Current Practices and Gaps

Published: Valenčič E., Beckett E., Collins C.E., Koroušić Seljak B., Bucher T., (2023). Trends in Food Science & Technology, 131.

So far, the impact of nudging food choices in physical environments has already been extensively researched. However, due to recent shifts in food choices, which are now increasingly conducted in digital settings, the impact of digital nudging needed further investigation. Therefore, the goal of this study was to provide insights into which nudging strategies can positively impact consumers' food choices in online grocery stores.

In this paper the available literature was reviewed, the results summarised and possible gaps identified.

The literature review sought to scope the breath of literature on online supermarkets or grocery stores, where the UI design changes were clearly described. That means that in this review only studies that focused on digital nudging and clearly described how UI design was modified were included.

The results suggests that the digital nudging strategies implemented within an online grocery store can be grouped into five groups. The included studies implemented nudging strategies through UIs in the form of food labelling, swapping products, default options, increased salience of a product or a combination of them while reporting different nutritional outcomes. Moreover, the study found that digital nudges can be effective, however, the strategies implemented have had varied effect on nutritional outcomes. In the review it was concluded that the lack of explicit description of overall UI and/or its specific elements, prevents us from gaining the needed insights of the most useful and effective strategies. This has consequences for the interpretation of existing results and for the conduct of independent review. Therefore, addressing this gap by inviting authors to annotate texts and datasets using a field specific ontology, is suggested. Moreover, unified terminology and development of theoretical frameworks can prevent confusion between digital nudging and nudges in digital settings.

This study provided us with a starting point for all of the subsequent studies, as it provided us with findings that warranted more research, and showed us that this is a research topic worth further investigation. Moreover, this work fulfills the dissertation goal **O1** - To gain insights into which digital nudging strategies can be used to encourage

consumers to select healthier foods. It also confirmed the hypothesis **H1a** - UI design element modifications can be used to promote healthier choices in online grocery stores.

Permission to include the publication "Digital Nudging in Online Grocery Stores: A Scoping Review on Current Practices and Gaps" [50] in this doctoral dissertation was confirmed by the publisher Elsevier in an email exchange on April 26, 2023.

Trends in Food Science & Technology 131 (2023) 151–163

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Digital nudging in online grocery stores: A scoping review on current practices and gaps

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ARTICLE INFO

Keywords:
Digital nudging
Online grocery shop
Persuasive technologies
Choice architecture
Choice behaviour
Behavioural economics

ABSTRACT

Background: As decision-making shifts more into digital environments, understanding how consumers assess and select foods, particularly healthy foods, in these environments is becoming increasingly important. Online services offer opportunities to improve consumer wellbeing through promoting healthier food choices and positively impacting purchasing behaviours.

Scope and approach: This scoping review presents a structured overview of the literature published up to February 2022 regarding the use of nudging strategies in online grocery stores. A systematic search of eight databases resulted in 2312 records for the title and abstract screening, with 138 relevant articles assessed for eligibility through full-text screening. Studies were included if they applied digital nudging strategies in online grocery stores and reported food choices.

Key findings and conclusions: Fifteen records met the inclusion criteria and four common nudging strategies were identified in these studies: i) applying different (already established) label(s) (n = 6), ii) healthier swap suggestions (n = 3), iii) default options (n = 2), iv) increasing the salience (n = 1) or a combination of strategies (n = 3). While multiple studies identified improved nutritional contents outcomes due to nudging, overall, studies frequently lack of a clear explanation and description of the implemented visual UI features, limiting insights into which factors attracts consumer's attention, and therefore further predicts consumer behaviours and decision making. Furthermore, gaining insights into which nudging strategies are ineffective could inform the design of online food choice environments. Lastly, theoretical frameworks that structure nudging interventions should also consider the digital environments.

1. Introduction

Consumer behaviours broadly, including food choice behaviours, are a function of both individual and environmental factors and the interactions between them (Schiffman et al., 2013). Environmental cues can influence food consumption (Stöckli et al., 2016) leading to overconsumption and poor diet quality (Kahn & Wansink, 2004; Rolls et al., 2002). Importantly, factors at the environmental level have greater influences on food choices than individual factors (Stok et al., 2017). Fortunately, environmental factors are modifiable, therefore modifying environmental cues to motivate healthier consumer food choices may potentially improve dietary patterns and overall consumer health and wellbeing (Waxman, 2004).

Therefore, restructuring the environment to increase the ease and accessibility of healthier choices may have a positive influence on consumer's food selection and eating behaviours. This strategy has been described as *nudging*. Nudging is defined as "any aspect of the choice architecture that alters people's behaviour in a predictable way without

Abbreviations: UI, User interface; RCT, Randomised control trial; SFA, Saturated fat; ED, Energy density; PAE, Physical Activity Equivalent; HCS, Healthier Choice Symbol; NS, Nutri-Score; MTL, Multiple Traffic Lights; DFLF, Dynamic Food Labels with real-time Feedback; HPI, Healthy Purchase Index; TLNI, Traffic-Light Nutrition Information.

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https://doi.org/10.1016/j.tifs.2022.10.018
Received 22 July 2022; Received in revised form 30 September 2022; Accepted 23 October 2022
Available online 29 October 2022

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forbidding any options or significantly changing their economic incentives" (Thaler & Sunstein, 2008). Presenting a healthy food item at the eye level in a supermarket, or making healthy food more salient using labels are examples of nudging, whereas taxing junk food is outside of the scope of the definition. Nudging can be applied to encourage healthier food choices and to discourage people from overindulging.

There is growing evidence that nudging can promote healthier food choices in real-life settings (e.g. (Bell et al., 1994; Bucher et al., 2016; Cadario & Chandon, 2020; Keller et al., 2015; Metcalfe et al., 2020; Stöckli et al., 2016)) or in lab setting (e.g. (Bucher et al., 2014)). However, advances in information and communication technologies have impacted consumers' everyday food choice environments. Currently, food choices conducted in digital settings, such as online grocery shopping and ordering food for delivery are becoming more common. During the COVID-19 pandemic, the demand for online grocery shopping has increased drastically. For example, the majority of French, Italian, Spanish, Swedish, Dutch and German consumers purchase more groceries online, and more than 80% of consumers who started purchasing groceries online during the pandemic, are planning to continue doing so (PwC, 2020). In addition, the US sales prediction for orders made via any online channel are expected to nearly double between 2021 and 2025 (Insider Intelligence, 2022). Therefore, online services can provide online grocery shops with great opportunities to promote healthier food choices and improve purchasing habits. This raises the relevance of research in digital nudging, which is defined as "the use of user-interface (UI) design elements to guide people's behaviour in digital choice environments" (Weinmann et al., 2016). For that reason, the scope of this review pertains specifically on the concept of digital nudging being used in online grocery stores.

Digital nudging strategies seem promising, and some studies using the concept even before the term was defined by Weinmann et al., 2016. For example, boosting recipe image attractiveness to increase healthier recipe choices (Starke et al., 2021), using labels to increase sustainable consumption of ecological products (Demarque et al., 2015) or setting a default option to nudge people into giving tips (Austin, 2013). As such, using digital nudging strategies, understanding their effectiveness and accordingly selecting the appropriate nudging types is becoming of greater importance, as decision-making has shifted into digital environments. A recent review has identified literature on the term 'digital nudging' and used bibliometric analyses to map the knowledge structure, historical roots, and evolution (Piper et al., 2021). The review identified 83 studies and confirmed that digital nudging is a rapidly growing field with strong historical roots in psychology. Additionally, the study showed that digital nudging has been increasingly investigated in food and health contexts (Piper et al., 2021).

Understanding how consumers assess and select foods, particularly healthy foods, in an online food choice environment is therefore crucial. Hence, the purpose of this scoping review was to map the effects and limits of studies conducted on nudging healthier food choices in online grocery shops, and to identify which types of nudges are currently being investigated in this setting. It is important to note that nudges in a digital setting are distinct from digital nudging. For example, sending a reminder via e-mail or short message service is not considered as digital nudging since the UI design was not modified to influence food choice behaviour, rather a digital platform was used to provide a direct message.

2. Methods

As 'digital nudging' is a relatively new research area (Piper et al., 2021), a scoping review approach was chosen to investigate nudging strategies currently used in online grocery stores; to examine the nature of research activities on this topic, to summarise research findings and to identify possible gaps in the literature. The main advantage of a scoping review is the inclusion of broader and less stringent inclusion criteria. Scoping reviews are also an efficient form of scientific enquiry in areas where the lack of conceptual clarity make it challenging to identify certain trends (Rumrill et al., 2010). Therefore, the methodology, described by Arksey & O'Malley, 2005, included i) identification of the research question; "What is available in the literature relating to digital nudging strategies in online grocery stores?", ii) identification of relevant studies, iii) studies' selection, iv) data charting, v) collating, cataloguing, summarizing, and reporting of the results. This review only included studies that focused on digital nudging and clearly described how UI design was modified. The difference between digital nudging and nudging in digital setting was further described and explained in a quantitative review about the effectiveness of nudging (Hummel & Maedche, 2019).

2.1. Literature search

A scoping review was conducted in accordance with the PRISMA extension for scoping reviews (PRISMA-ScR) guidelines advocated by Tricco et al. (Tricco et al., 2018). As a scooping review, the study protocol was not registered.

The literature search was performed in eight databases (Scopus, PubMed, Web of Science, Medline, PsycINFO, EMBASE and CINAHL complete) from the earliest available record until February 2022 using search terms (Table 1) in fields of the title, abstract and keywords.

2.2. Eligibility criteria

The search was limited to human studies and published in peer-reviewed journals in English. For inclusion, studies had to focus on using digital nudging (manipulated the UI) in online grocery stores or supermarkets, and report food choices or nutrient content of food choices in healthy populations. Study protocols, grey literature, reviews and conference abstracts lacking full-texts were excluded, as well as articles focusing on social media interventions, gamification or interventions focusing on digital environment but not using a digital nudging approach. Questionnaire and survey-based interventions where online stores were designed to resemble an actual online shopping interface, but did not mimic an actual shopping experience (e.g., no possibility to add the chosen products to a virtual shopping cart) or unclear explanation of the online grocery store appearance and usage were excluded. In addition, articles focusing on sustainable consumption (e.g., nudging purchases of organic products) even if the intervention was set in an online shop were excluded as the outcomes were beyond the scope of the current review.

2.3. Synthesis of results

Titles and abstracts were retrieved and de-duplicated in Covidence (Veritas Health Innovation, 2022), and then screened independently by two reviewers, with any studies marked as unclear included for full-text screening. Full-text screening considered the initial data-charting form (described below). Additionally, a search of reference lists of included studies was performed and eligible studies were included for data extraction. Any discrepancies during the screening and evaluation process were resolved by a third reviewer. About 25% of the full text articles

Table 1
Search terms.

Search terms
(digital OR online OR on-line OR on-screen OR web-based OR computer-based OR "user interface" OR "UI" OR "user interface design" OR imagery OR colo$r*)
AND ("persuasive systems" OR "choice architecture" OR nudg* OR "behavio$ral economic" OR "dietary behavio$r")
AND (food OR diet OR "food choice" OR fruit* OR vegetable* OR "energy intake")
+ humans + English

had to be further discussed in detail within the team.

An initial data-charting form was developed by the researchers to determine which variables to extract from the literature of the original search. Two reviewers independently charted the data, discussed the results and later updated the data-charting form. The data-charting form is presented in Table 2. In addition to the study characteristics, participants characteristics were extracted to provide readers with more information about the study.

3. Results

3.1. Study selection and characteristics

The systematic searches returned 2940 articles. Following the removal of duplicates, 2312 articles remained for titles and abstract screening. This led to exclusion of 2174 articles that did not meet inclusion criteria, resulting in 138 full-texts reviewed for eligibility. Of these 123 studies were excluded due to wrong setting/intervention (survey-based or studies including out of the scope of nudging definition strategies or theoretical frameworks); wrong outcomes (e.g., sustainable consumption); wrong population (non-healthy participants). The study selection flowchart is presented in Fig. 1.

After the full text screening 15 articles were included, of which six (40%) were from Europe (Blom et al., 2021; Bunten et al., 2021; Forwood et al., 2015; Koutoukidis et al., 2019; Marty et al., 2020; Stuber et al., 2022), four (26.7%) from Singapore (Finkelstein et al., 2019, 2020, 2021; Shin et al., 2020), three (20%) from USA (Blitstein et al., 2020; Coffino et al., 2020; Coffino & Hormes, 2018), and two (13.3%) from Australia (Huang et al., 2006; Sacks et al., 2011). Five studies (Coffino et al., 2020; Coffino & Hormes, 2018; Huang et al., 2006; Sacks et al., 2011; Stuber et al., 2022) used existing, online grocery stores, while the rest used experimental online stores. Of those, two (Blitstein et al., 2020; Blom et al., 2021) used 3-dimensional virtual supermarkets; one used web-based virtual supermarket (Blitstein et al., 2020), and the other used a realistic virtual-reality supermarket (Blom et al., 2021). One study was conducted in a laboratory setting (Coffino & Hormes, 2018), one took place at a university science festival (Blom et al., 2021), and the rest were conducted wholly online. Not all studies had the participants actually purchase groceries. In seven studies (Blitstein et al., 2020; Blom et al., 2021; Bunten et al., 2021; Coffino & Hormes, 2018; Forwood et al., 2015; Koutoukidis et al., 2019; Marty et al., 2020) participants did not purchase or receive the foods they added to the shopping cart (i.e., the choices were hypothetical), and in seven studies (Finkelstein et al., 2019, 2020, 2021; Huang et al., 2006; Sacks et al., 2011; Shin et al., 2020; Stuber et al., 2022) participants purchased or there was a possibility of being required to purchase the chosen foods. One study (Coffino et al., 2020) paid for the participant's grocery purchases and delivered the order to them. See Table 3 for a summary of participant information, study setting, study purpose, nudging types used and intervention description of included studies.

Table 2
Data charting form.

	Extracted information
Study characteristics	First author Year of publication Country Sample size Study setting Study purpose Study interventions/conditions (and description) Nutritional outcomes Key findings related to food choices Intervention effectiveness
Participant characteristics	Adulthood Mean age (and standard deviation) Sex (%)

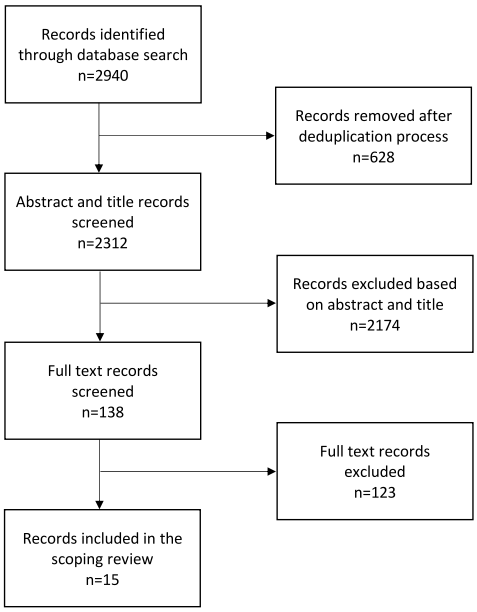

Fig. 1. Study selection flowchart.

The majority (60%) of studies were published in 2020 or later (Blitstein et al., 2020; Blom et al., 2021; Bunten et al., 2021; Coffino et al., 2020; Finkelstein et al., 2020, 2021; Marty et al., 2020; Shin et al., 2020; Stuber et al., 2022). All fifteen studies were experimental designs. Eight studies were either randomized control trials (RCTs) or randomized trials (Blitstein et al., 2020; Blom et al., 2021; Bunten et al., 2021; Coffino et al., 2020; Coffino & Hormes, 2018; Huang et al., 2006; Marty et al., 2020; Stuber et al., 2022), four were crossover RCTs (Finkelstein et al., 2019, 2020, 2021; Shin et al., 2020), two were factorial RCTs (Forwood et al., 2015; Koutoukidis et al., 2019), and one was a non-randomized control trial (Sacks et al., 2011).

Studies reported sample sizes ranging from 50 participants (Coffino et al., 2020) to 11,775 shoppers (Stuber et al., 2022), with one study (Sacks et al., 2011) not specifying the number of participants. While an inclusion criteria was having adult participants, only three studies further described participant characteristics, with one study recruiting female students (Coffino & Hormes, 2018), one recruited food insecure adults from a local food pantry (Coffino et al., 2020), and another recruited low-income parents with at least one child aged 4–12 year (Blitstein et al., 2020). The mean age of study participants ranged from 20 to 56 years, and the proportion of males was higher only in one study (Coffino et al., 2020).

One study tested the use of two existing online stores with completely different UIs, but sold the same products and compared sales (Sacks et al., 2011). The rest of the studies changed the UI only via the implementation of the digital nudges (e.g., adding a default option, offering product swaps).

3.1.1. Interventions: nudging types

The included studies implemented nudging strategies through UIs of the online grocery shops in the form of food labelling (n = 6), swapping (n = 3), default options (n = 2), increased salience of a food product (n

= 1), or a combination of different strategies (n = 3).

Default options is an option a consumer selects without making an active choice (Sunstein & Thaler, 2003). Two of the included studies used prefilled grocery carts as a default option (Coffino et al., 2020; Coffino & Hormes, 2018). The prefilled cart was considered as healthy and it met micro- and macronutrient requirements based on participant's sex and age. Participants could change (delete or exchange) the food items, which corresponds to the concept of using default option to shift consumer behaviour in a way that encourages welfare, but still allows individual freedom to choose. One study (Koutoukidis et al., 2019) altered the default order of foods based on the content of saturated fats (SFA) as one of the interventions. Participants viewed the list of products with the lowest SFA content on the top of the screen. The other intervention groups received an offer to swap products (described below) or a combination of default order and swaps.

Swaps offer consumers the opportunity to replace an already selected item with a (better) alternative (Forwood et al., 2015). For example, to replace a selected food with a healthier option. Five studies offered healthier swap suggestions during the participant online grocery shopping experience (Bunten et al., 2021; Forwood et al., 2015; Huang et al., 2006; Koutoukidis et al., 2019; Stuber et al., 2022). As before, this concept also allows participant to have freedom of choice, since they could accept or reject the suggestion provided to them. One study offered swaps only at the point of selection of a product (Koutoukidis et al., 2019), two studies offered it only at the checkout (Bunten et al., 2021; Huang et al., 2006) and two offered the swaps at the time of selection and/or at the checkout (Forwood et al., 2015; Stuber et al., 2022).

Healthy swaps with less SFA from the same food category were included immediately right after the selected item was added to the shopping basket (Koutoukidis et al., 2019). Conversely, the opportunity to swap the already selected packaged food for an alternative lower in SFA was presented to participants at checkout (Huang et al., 2006). The swaps were not strictly limited to within a category (e.g., swaps were offered within dairy product, but not necessarily within yoghurts). Another study (Bunten et al., 2021) had participants shop from a 12-item shopping list, and were allocated to viewing the benefits of lower-energy food swaps framed either in terms of cost savings, social norms or health (less calories). For example, a cheaper lower-energy food was offered in the intervention highlighting cost benefits. Swaps were offered at the checkout as a pop-up, where at least one (or two when identified) alternative was offered.

Swaps were introduced as a position nudge, into an existing Dutch online supermarket for five weeks, with the approval of supermarket e-commerce employees (Stuber et al., 2022). At the point of selection, unhealthy-to-healthy product swaps were suggested and displayed at the bottom of the product page marked as "*Also frequently purchased by other customers*". Further, healthy checkout swaps were suggested as four standardized healthy products (two packages of snack-sized vegetables and dried fruits) marked as "*Tasty alternatives*". Similarly, the swaps were introduced either as soon as an item was added to the basket or offered all at once at the end of the shopping task (Forwood et al., 2015). The inclusion of the swaps on the webpage was framed in the introductory message, either as something participants had consented to or it was imposed on them.

Food labelling provides consumers with nutrition-related information and can alter choice behaviour by helping them recognize a more suitable (healthier) food or beverage (Azman & Sahak, 2014). The included studies changed the UI of online grocery shops by including different labels next to the food products. Adding labels onto the online grocery shop will not limit consumer's freedom of choice, but it can attract their attention. Three studies designed and implemented a new label or badge (Finkelstein et al., 2020, 2021; Marty et al., 2020), three studies used already established nutrition labels (Blitstein et al., 2020; Finkelstein et al., 2019; Sacks et al., 2011), and one study used established nutrition labels but presented them dynamically (Shin et al., 2020).

In one study, a new lower-calorie label was added to the 20% of products with the lowest calorie per serving within- and across food categories (Finkelstein et al., 2020). The label focused on positive messages promoting lower calories, thus it included a smiley face, and was green to be perceived as healthier (Finkelstein et al., 2020). Similarly, a "healthier choice" badge was designed as a green tick in a circle, and was added next to the lower-energy density (ED) food products (Marty et al., 2020). Lastly, a simple physical activity equivalent (PAE) label was designed and implemented together with a Healthier Choice Symbol (HCS), used in Singapore (Finkelstein et al., 2021).

Four studies applied traffic light system indicators next to food products (Blitstein et al., 2020; Finkelstein et al., 2019; Sacks et al., 2011; Shin et al., 2020). All four color-coded the products' levels of fat, SFA, sugar and sodium, and three also presented the product energy content (Blitstein et al., 2020; Finkelstein et al., 2019; Shin et al., 2020). Two of the studies included the French Nutri-Score (NS) label (Santé publique France, 2022). One study, compared it with Multiple Traffic Lights (MTL) (Finkelstein et al., 2019), and one included it as a part of a dynamic food labels with real-time feedback (DFLF) (Shin et al., 2020). The latest was a complex label consisting of seven nutrient labels. Together with the seven labels, behavioural nudges were included next to DFLF. The seven nutrient labels were displayed as simple icon buttons, and participants could switch between them, which allowed them to evaluate products according to an attribute they were interested in (e.g., sugar content). A live visual indicator of the healthiness of the basket was displayed on the side of the web page, presented as a pie chart, and it showed the proportion of healthy/less healthy products by servings for the selected attribute, using traffic-light colours. In addition, a study conducted in a 3-D virtual supermarket compared a nutrient-specific label with a summary label, and a hybrid label (Blitstein et al., 2020) (details in Table 3).

Lastly, *the salience* of healthy foods was increased, by adding an orange frame around the healthy products in (Blom et al., 2021). Salience nudges intend to make product stand out and therefore render them more noticeable for consumers.

3.1.2. Nutrition outcomes

Eleven studies included in this review measured nutritional content of purchases (Bunten et al., 2021; Coffino et al., 2020; Coffino & Hormes, 2018; Finkelstein et al., 2019, 2020, 2021; Forwood et al., 2015; Huang et al., 2006; Koutoukidis et al., 2019; Marty et al., 2020; Shin et al., 2020; Stuber et al., 2022), with only one not measuring energy content or ED (Huang et al., 2006). The majority of studies reported fat and/or SFA content (Bunten et al., 2021; Coffino et al., 2020; Coffino & Hormes, 2018; Finkelstein et al., 2019, 2021; Huang et al., 2006; Koutoukidis et al., 2019; Marty et al., 2020; Shin et al., 2020), with some also reporting other nutrients, including sugar (Bunten et al., 2021; Finkelstein et al., 2019; Koutoukidis et al., 2019; Marty et al., 2020; Shin et al., 2020); sodium (Coffino et al., 2020; Coffino & Hormes, 2018) or salt (Bunten et al., 2021); fibre (Coffino et al., 2020); cholesterol (Coffino et al., 2020; Coffino & Hormes, 2018); and protein (Finkelstein et al., 2019). Specific food groups were reported in three studies (Coffino et al., 2020; Coffino & Hormes, 2018; Stuber et al., 2022). *Healthiness* or *healthfulness* (terms used by authors) were reported in two studies (Blitstein et al., 2020; Sacks et al., 2011), with the primary outcome in one (Blom et al., 2021) being quantity of healthier products selected, as perceived by participants. Diet quality measured by different indices was reported in three studies (Finkelstein et al., 2019, 2021; Shin et al., 2020). See Table 4 for a summary of the effectiveness of nudges, study outcomes and key findings arranged by the nudging type.

3.1.3. Energy content and energy density

Five studies applied different labels to items in the online grocery store UI and investigated how this impacted the energy content of the items in the shopping basket. The results were mixed. No effect on the total energy content of the shopping basket was observed in four studies

Table 3
Study characteristics.

Author, Year	Participant characteristics	Setting	Study purpose	Nudging type/Intervention	Other intervention(s)/ Control condition	Intervention description
Shin et al. (2020)	Adults; mean age 36.17 y (SD = 9.3); 72% female; n = 125; Singapore	Experimental online grocery store	To test the effectiveness of the customization of the labels based on consumer preferences and to offer real-time feedback on the nutritional quality of food purchases.	Label - dynamic food labels with real-time feedback (DFLF) consisting of seven nutrient labels and "behavioural nudges" (reordering products from most to least healthy, a real-time feedback of the basket's healthiness and a recommended target for a healthy basket)	No label (control).	Participants completed two weekly shopping trips (budget: SG $50–250) and were exposed to both intervention groups. DFLF features were explained prior shopping task. Participants were exposed once to both shopping conditions in random order.
Blitstein et al. (2020)	Low-Income Parents with at least 1 child aged 4–12 y; mean age 34.5 y (SD = 8.8); 83.5% female; n = 1452; USA	3D web-based virtual supermarket	To examine the impact front-of-package nutrition labels have on decision-making abilities among low-income parents.	Label - summary label (presents 0–3 stars) - nutrient-specific label (presents calories per serving and a color-coded, traffic-light indicator identifies nutrients - hybrid label (presents stars on the front of the package for sugar, fat and sodium at or below USDA-recommended amounts)	No label (control).	Participants chose 6 food products that they think are the healthiest choices for their family (from 18 products in total). Participants either shopped with a time limit (10 min) or with no time limit.
Finkelstein et al. (2019)	Adults; mean age 34.7 y (SD = 6.8); 68.8% female; n = 147; Singapore	Experimental online grocery store	To test two labels under consideration in Singapore, the Multiple Traffic Lights (MTL) label and Nutri-Score (NS).	Label - MTL label - NS label	No label (control).	Participants completed a typical weekly grocery shop for 3 weeks (3 shops in total); budget was SG $50–100. They were randomly exposed to each of three conditions.
Finkelstein et al. (2020)	Adults; mean age 35 y (SD = 5.7); 78.8% female; n = 146; Singapore	Experimental online grocery store	To determine which label implementation strategy (within-category or across-category) using 'Lower Calorie' label would have a greater effect on food purchasing patterns.	Label - within-category 'Lower calorie' label (20% of products lowest in kcal per serving within each product category) - across-category 'Lower calorie' label (20% of all products lowest in kcal per serving)	No label (control).	Participants completed a typical weekly grocery shop for 3 weeks (3 shops in total); budget was SG $50–250. They were randomly exposed to each of three conditions.
Finkelstein et al. (2021)	Adults; mean age 35.9 y (SD = 6.2); 66% female; n = 106; Singapore	Experimental online grocery store	To test weather adding Physical Activity Equivalent (PAE) label can target healthier choices and lower caloric intake.	Label - Healthier Choice Symbol (HCS) - HCS and PAE label	No label (control).	Participants completed a typical weekly grocery shop for 3 weeks (3 shops in total); budget was SG $50–250. They were randomly exposed to each of three conditions.
Sacks et al. (2011)	Customers (no further information specified); AUS	Real life online grocery store	To investigate the impact of the introduction of traffic-light nutrition information (TLNI) on online food purchases.	Label - TLNI in the form of four colour-coded indicators (intervention store)	No label (control) on the comparison grocery store website.	A set of four TLNIs (fat, SFA, sugar, sodium) were implemented to the retailer's own brand products for 10 weeks – intervention store. The comparison was made between two different online supermarkets owned by the same retailer (the same set of products and price, but different UI).
Marty et al. (2020)	Adults; mean age 39.5 y (SD = 13.1); 51.2% female; n = 899; UK	Experimental online grocery store	To examine how labelling of lower-energy density (ED) food products and increasing the proportion of lower-ED options affect the ED of shopping baskets among participants of lower vs. higher socioeconomic position.	Label/increasing availability: labelling lower-ED products and increasing the relative availability of them - labelling lower-ED products and using standard proportion of them - increasing the relative availability of lower-ED products (no labelling)	No labelling lower-ED products as healthier choices and using standard proportion of them.	Participants buying 10 items from a pre-determined shopping list (foods they and their household would be likely to eat), while being exposed to one of the conditions. The simulated online supermarket included only food

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Table 3 (*continued*)

Author, Year	Participant characteristics	Setting	Study purpose	Nudging type/Intervention	Other intervention(s)/ Control condition	Intervention description
						products and did not include drinks.
Coffino & Hormes (2018)	Students; mean age 20.15 y (SD = 5.28); 100% female; n = 59; USA	Real life online grocery store	To compare the effects of a default option, education and monetary incentives on the nutritional quality of foods.	Default option - a prefilled online shopping cart	- nutrition education - a $10 incentive (if selected groceries met recommended nutrient requirements).	Participants shopping goal was to "select nutritious, affordable, and tasty foods' for a week" (budget: $48.50). Afterwards they were exposed to one intervention group and had to repeat the task.
Coffino et al. (2020)	Food insecure adults; mean age 46.4 y (SD = 12.5); 75.5% male; n = 50; USA	Real life online grocery store	To examine the feasibility and initial efficacy of a default option to improve food choice behaviour in individuals with food insecurity.	Default option - a prefilled online shopping cart	Nutrition education.	Participants had to purchase "nutritious, affordable, and tasty groceries" for the week (budget: $48.50).
Koutoukidis et al. (2019)	Adults; mean age 37.6 y (SD = 11.25); 65.9% female; n = 1088; UK	Experimental online grocery store	To test the effectiveness of altering the default order of foods to show foods in ascending order of SFA and an explicit offer to swap to an alternative food with lower SFA.	Swap/default order - altering the default option (products within a category ranked in ascending order of SFA content) - swap to a product with less SFA - a combination of both interventions	No intervention (control).	Participants selected 10 'everyday' foods (major sources of SFA in the UK) from a prespecified shopping list (foods that they and their household would want to eat).
Stuber et al. (2022)	Adults; mean age 56.6 y (SD = 17.4); 66.1% female; n = 11,775; The Netherlands	Real life grocery store	To evaluate the effectiveness of swaps and information nudges to promote healthy food and beverage purchases.	Swap/information nudge: - information nudge (three types of labels highlighting tastiness, convenience or popularity) - position nudge increased the number of healthy product placement (introduction of swaps, and suggesting four standardized healthy products) - combination of both	No intervention (control).	Sales data were collected from all customers who placed a delivery order (except business-related customers and customers whose purchases consisted for >90% of alcohol, unhealthy other foods, or snacks). *Shoppers could theoretically participate multiple times in different trial arms.
Huang et al. (2006)	Adults; mean age 40 y (SD = 10); 87.5% female; n = 456; AUS	Real life online grocery store	To determine whether the provision of fully automated and purchase-specific dietary advice could reduce the amount of SFA in foods purchased.	Swap - automated, individually tailored advice offered and specific swap products suggested	General non-specific advice about diet lower in SFA offered with the opportunity to change planned purchases.	383 commonly purchased pre-packaged food items containing 1% or more of SFA were selected, and a suitable lower-fat alternate was identified for each. Participants shopped as usual and at checkout received either non-specific advice or the opportunity to swap foods with less than 1% SFA.
Bunten et al. (2021)	Adults; mean age 47.7 y (SD = 15.89); 52.4% female; n = 713; UK	Experimental online grocery store	To test whether framing the benefits of lower-energy food swaps in terms of cost savings or social norms will increase swap acceptance at the checkout.	Swap messages emphasising: - health benefits (fewer calories) - cost benefits (lower price) - social norms (others preferred this product)	No control.	Participants were provided with a 12-item shopping list, and chose products they would normally purchase or have purchased in the past (budget: £25). They saw only one of the message frames.
Forwood et al. (2015)	Adults; mean age 44.4 y (SD = 14.13); 62.2% female; n = 720; UK	Experimental online grocery store	To measure the impact on energy density (ED) of food purchases following the offer of lower ED alternatives at point of selection or at checkout, and with or without explicit consent to receive swap prompts.	Swaps - consented swaps at selection - consented swaps at checkout - imposed swaps at selection - imposed swaps at checkout	No swap (control).	Participants chose foods from an 11-item list (foods they have purchased in the recent past or would probably chose); budget was £25.
Blom et al. (2021)	Adults; mean age 30.7 y (SD = 10.9);	3D virtual reality supermarket	To examine whether nudging increases healthy food choices in a	Increased salience - an orange frame was added to one out of six of	No frames added (control).	Participants were asked to buy 4 products (withing a specific food

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Table 3 (*continued*)

Author, Year	Participant characteristics	Setting	Study purpose	Nudging type/Intervention	Other intervention(s)/ Control condition	Intervention description
	59.6% female; n = 99; The Netherlands		supermarket environment, and whether this presumed effect would hold especially when people are under time pressure.	the healthier options, per product category		category), from the shopping list displayed on a poster on the wall in the virtual supermarket. Participant were either put under high or low time pressure.

y = years; SD = standard deviation; n = number of participants; SFA = saturated fats; ED = energy density; DFLF = dynamic food labels with real-time feedback; TLNI = traffic-light nutrition information; MTL = Multiple Traffic Lights; NS = Nutri-Score; PAE = Physical Activity Equivalent; HCS = Healthier Choice Symbol.

(Finkelstein et al., 2019, 2020, 2021; Shin et al., 2020). Three studies (Finkelstein et al., 2019, 2020; Marty et al., 2020) found that specific label types led to reduced energy or ED of the shopping basket. Of those, one study found this occurred for beverage selection only (Finkelstein et al., 2020), and one (Marty et al., 2020) for three specific food categories (ready meals, sausages, crisps), and when labelling was combined with an increased proportion (relative availability) of lower-ED products.

Three studies measured energy content or ED of purchased baskets while implementing swaps as a nudging strategy. Two found that swaps did not reduce total energy or ED of the shopping basket (Forwood et al., 2015; Koutoukidis et al., 2019). However, one study (Bunten et al., 2021) found that swaps framed as promoting either health, cost or social norms did reduce total calorie content of participant's product choices in their final purchases by 30.5 kcal ($p < 0.001$). In another study by Forwood et al., 2015, researchers found that each swap accepted led to a reduction of 24 kJ/100g ($p < 0.0001$), and that offering swaps in combination with altering the default order of products based on SFA content reduced total energy and ED of the shopping basket (Koutoukidis et al., 2019).

Energy content was also measured in studies implementing default options as a nudging strategy. Two studies found that the application of a prefilled grocery cart (default option) (Coffino & Hormes, 2018) and altering the default order of products to ascending order of SFA (alone or combined with swaps) (Koutoukidis et al., 2019) reduced total energy content of purchases by approximately 850 kcal and 2000 kcal, respectively. Conversely, the study conducted among food-insecure people (Coffino et al., 2020) did not find significant differences in average daily calories purchased between a prefilled grocery cart and nutrition education group. However, participants purchased almost 700 kcal less in the default condition.

3.1.4. Total fat and saturated fat content

Four studies investigated how labels impacted fat and SFA content, three of them did not find significant effects of using labels (DFLF (Shin et al., 2020), HCS (+PAE) (Finkelstein et al., 2021), and a "healthier choice" badge (Marty et al., 2020)). However, the study by Finkelstein et al., 2019 found that using MTL label reduces fat content (1.03g/serving; $p = 0.03$) and NS label reduces total SFA per purchase (29.3g; $p = 0.01$), compared with control.

Furthermore, three studies found that default options can reduce fat and SFA content. A reduction in average daily grams of SFA in the selected foods (Coffino et al., 2020; Coffino & Hormes, 2018) and in total fats (Coffino et al., 2020) was reported when comparing prefilled grocery carts with nutrition education alone. Altering the default order of products in ascending order of SFA reduced percentage energy from SFA in (Koutoukidis et al., 2019). In addition, the proportion of products that contained less than 1.5% SFA in the shopping basket was higher when altering the default order, compared with control or offering swaps (Koutoukidis et al., 2019).

Similar findings were shown when researchers offered swaps to reduce SFA of the grocery basket. Three studies found that offering an explicit swap either at the point of selection (Koutoukidis et al., 2019) or at the online checkout (Bunten et al., 2021; Huang et al., 2006) resulted in a reduction of SFA content.

3.1.5. Other nutrients

Two studies reported an effect of using prefilled grocery carts as a default option on sodium and cholesterol reduction (Coffino et al., 2020; Coffino & Hormes, 2018) compared to nutrition education alone. Additionally, changes in grams of salt in the total shopping basket content were not significantly different when offering swaps (Bunten et al., 2021). Furthermore, prefilled grocery cart increased the mean fibre content of purchases (Coffino et al., 2020).

Five studies reported on sugar content. One study altered the default order of foods or combined it with swaps, and found that the percentage of energy from total sugars increased by approximately 2%, compared with the control group or swap only intervention group (Koutoukidis et al., 2019). Similarly, increased proportion of lower-ED products lead to increased energy from sugar of the shopping basket (Marty et al., 2020). In contrast, two studies found that applying labels can lead to a reduction of purchased sugar; DFLF label decreased the amount of sugar per serving and total sugar per purchase (Shin et al., 2020), and MTL label reduced total sugar purchased for beverages only (Finkelstein et al., 2019). One study did not find any significant changes in sugar contained in the total shopping basket content when swaps were offered (Bunten et al., 2021). Interesting, MTL labelling led to a reduction in protein content when analysing food and beverages and beverages only, compared with the control condition (Finkelstein et al., 2019).

3.1.6. Diet quality, healthiness and purchases of specific food groups

Overall diet quality was reported in three studies and all of them applied labels to the UI. Two studies measured diet quality by the weighted average Nutri-Score (Santé publique France, 2022); either of the grocery basket when applying MTL and NS labels (Finkelstein et al., 2019) or per serving when implementing DFLF (Shin et al., 2020). In addition to average Nutri-Score, one study (Finkelstein et al., 2019) also measured overall diet quality using a modified version of the Alternative Healthy Eating Index-2010 (AHEI-2010). Both studies found that implementing labels (MTL, NS, DFLF) significantly improved diet quality measured by modified AHEI-2010 or average Nutri-Score. Contrary, the HCS label did not improve overall diet quality, as measured by the Grocery Purchase Quality Index-2016 (Finkelstein et al., 2021).

Two studies reported the 'healthiness' or 'healthfulness' of purchases when applying labels to the grocery store's UI, and the results were mixed. In one study healthiness was measured by classifying products based on their number of 'red' labels (no-label vs. at least one label) and by calculating healthiness score based on the colours of the product's traffic-light indicators (Sacks et al., 2011). Researchers found that the addition of traffic-light nutrition information did not have an effect on *healthy* and *less healthy* product sales. Whereas in the study conducted by Blitstein et al., 2020, the overall healthfulness of the shopping basket was measured by the Healthy purchase index (HPI), calculated using the nutrient profiling model score (derived from the standard nutrition label). In this study all three different types of labels (nutrient-specific, summary and hybrid) scored higher HPI scores compared to no-label

Table 4
Study outcomes and main findings organised by the nudging type.

Author, Year	Nudging type	Effectiveness of nudges	Measured outcomes	Key findings
Shin et al. (2020)	Label	Dynamic food labels improved the nutritional quality of food purchases measured by a Nutri-Score per serving and lowered sugar content of purchased products, but had no effects on energy or other nutrients. Which label features were most effective was not assessed.	The average weighted Nutri-Score per serving; total calories (kcal) and sugar (g) purchased; average per serving of calories (kcal), sugar (g), sodium (mg), total fat (g), SFA (g).	The mean weighted Nutri-Score was 0.4 (95% CI: 0.2, 0.6) higher, sugar per serving decreased by 0.85g (95% CI: −1.7, −0.0) and total sugar by 169.5g (95% CI: −284.5, −54.5) in the intervention condition for purchased foods and beverages.
Blitstein et al. (2020)	Label	Summary, nutrient-specific and hybrid labels improved overall healthfulness of the shopping basket.	The overall healthfulness of the shopping basket measured by Healthy purchase index (HPI).	All 3 labels resulted in significantly higher HPI scores compared to no-label. In the hybrid label group, the mean HPI score was the highest (37.1 points), followed by the summary label (36.1 points), the nutrient-specific label (33.6 points), and no-label (31.1 points).
Finkelstein et al. (2019)	Label	Multiple Traffic Lights (MTL) and Nutri-Score (NS) labels improved diet quality measured by modified AHEI-2010. NS was more effective than MTL and no label when diet quality was measured by average Nutri-Score, but MTL was more effective in reducing calories per serving.	Diet quality per shopping trip measured by AHEI-2010; average Nutri-Score of the shopping basket weighted by serving size; calories, SFA, total fat, sodium, sugar (per serving (mg or g/serving) and total (mg or g)).	MTL (1.16; $p = 0.04$) and NS (1.09; $p = 0.04$) labels significantly increased the modified AHEI-2010 scores, compared to control. The effect was not significantly different between labels. Nutri-Score was increased by 0.33 points ($p < 0.01$) in NS compared to control and by 0.31 points ($p < 0.01$) compared to MTL. The difference in average Nutri-Score between MTL and control was not statistically significant ($p = 0.06$). MTL decreased calories (19.75kcal; $p = 0.01$), fat (1.03g; $p = 0.03$) and protein (0.83g; $p = 0.01$) per serving, compared to control. NS decreased total SFA per order (29.29g; $p = 0.01$), relative to control. Food items only: NS improved average Nutri-Score (0.21; $p = 0.02$) and total SFA (−29.79g; $p = 0.01$), and MTL decreased calories per serving by 20.56kcal/serving ($p = 0.02$) and fats per serving by 1.02g/serving ($p = 0.03$) relative to control. For beverages only: NS (0.72; $p < 0.01$) and MTL (0.52; $p = 0.01$) improved average Nutri-Score. MTL reduced calories (15.48kcal; $p = 0.01$), fats (−0.55g; $p = 0.03$) and protein (−0.76g; $p = 0.01$) per serving, and total sugar purchased (−66.83g; $p = 0.03$), relative to control.
Finkelstein et al. (2020)	Label	No significant difference was observed in the effectiveness of the within and across category strategies when applied to total basket. Neither of the labels were effective at reducing calories purchased when applied to total basket, but both reduced in beverage calories purchased.	The proportion of 'Lower Calorie' products purchased; total calories purchased (kcal); calories per serving (kcal/serving).	The proportion of labelled products purchased was 3 percentage points higher in the Within-category group compared to control ($p = 0.01$). The proportion was not statistically significant different in the Across-category group compared to control ($p = 0.71$), and between the Across-category and Within-category groups ($p = 0.15$). For beverages only, the proportion of labelled products purchased was 4 percentage points higher ($p = 0.02$) in the Across-category group compared to control, but was smaller and not significantly different when comparing Within-category to control ($p = 0.52$) or between the Across-category and Within-category groups ($p = 0.16$). For beverages only, total calories purchased were 398 lower ($p = 0.01$) in Within-category and 438 lower ($p < 0.01$) in Across-category compared to control.
Finkelstein et al. (2021)	Label	Healthier Choice Symbol (HCS) label was not effective at improving diet quality or total calories purchased. Providing HCS and Physical Activity Equivalent (PAE) labels simultaneously reduced the effectiveness of each. While, HCS was effective at increasing purchases of labelled products, adding PAE next to HCS diluted this effect.	The average calories per serving purchased (kcal/serving); total calories per shopping trip (kcal); diet quality per shopping trip as measured by GQPI-2016 and weighted average Nutri-Score; sugar (g), sodium (mg), SFA (g) per serving.	HCS increased the proportion of labelled products purchased by 5 percentage points (95% CI: 1%, 9%), relative to control. PAE+HCS undid this effect, as the point estimate is reduced to 2 percentage points (95% CI: 2%, 5%) and the difference between control and HCS+PAE is not statistically significant. No other statistically significant differences in nutrients purchased or in other measures of diet quality across the three conditions.

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Table 4 (*continued*)

Author, Year	Nudging type	Effectiveness of nudges	Measured outcomes	Key findings
Sacks et al. (2011)	Label	The presence of online traffic-light nutrition information (TLNI) did not have an impact on changes in sales by the relative healthiness of the products.	Change in sales by relative healthiness of the products.	The changes in sales of products with 'red' labels were not significantly different to the changes in sales of products without 'red' labels. The same was seen when products were classified as 'healthier' and 'less-healthy'. No observed relationship between changes in sales and the relative healthiness of products was observed in the pre-trial period to the trial period in the intervention store compared to the comparison store.
Marty et al. (2020)	Label/ increasing availability	Labelling and markedly increasing the proportion of lower- energy density (ED) products was effective strategy to reduce the ED of the shopping basket. But only increased proportion was effective at reduced total energy.	ED of the shopping basket; total energy (kcal); energy from sugar (%); energy from SFA (%); salt (g/100 g); the percentage of lower-ED food items in the shopping basket.	Labelling of lower-ED products decreased (−4.2kcal/100g; 95% CI: −7.8 to −0.6) the ED of the shopping basket and increasing the proportion of lower-ED products decreased the ED of the shopping basket (−17kcal/100g; 95% CI: −21 to −14). The proportion intervention increased the energy from sugar (0.57%; 99% CI: 0.36 to 0.79) and decreased total energy (−852 kcal; 99% CI: −1519 to −184), and the energy from SFA (−0.60%; 99% CI: −0.79 to −0.41) of the shopping basket. Significant effect of labelling on ED was found for 3/10 categories (ready meals, sausages and crisps) and of proportion on ED for all except jam and spread.
Coffino & Hormes (2018)	Default option	The default option was significantly more effective in targeting healthy decision-making than nutrition education.	Nutritional quality of food selections between shopping tasks; whole grains (%), fruits (%), vegetables (%), the average total daily calories (kcal), fat (g/day), SFA (g/day), sodium (mg/day), cholesterol (mg/day), milk (servings), meat/beans (servings), grains (servings), carbohydrates (%), protein (%), fibre (g/day).	Significant decrease of daily grams of calories (m = −852.50, SD = 640.85), SFA (m = −16.67, SD = 12.54), sodium (m = −1538.61, SD = 1463.04) and cholesterol (m = −306.44, SD = 290.67), and increase of the percentages of wholegrain and fruits in the default condition compared with the education condition.
Coffino et al. (2020)	Default option	Prefilling an online grocery shopping cart with healthy food effectively nudged individuals facing financial constraints to purchase healthier foods.	Food (whole grains (servings/day), fruits (servings/day), vegetables (servings/day)) and nutrient content (average calories (kcal/day), fat (g/day), SFA (g/day), sodium (mg/day), cholesterol (mg/day), fibre (mg/day)) of food purchased.	Grams of SFA (Mdiff = 26.20; 95% CI:14.07, 38.34; $p < 0.001$), total fats (Mdiff = 75.42; 95% CI: 42.81, 108.03; $p < 0.001$), cholesterol (mg, Mdiff = 463.86; 95% CI: 198.76, 728.96; p = 0.001), sodium (mg; Mdiff = 1642.66; 95% CI: 660.85, 2624.48; p = 0.002), and daily energy (M = −852.50kcal, SD = 640.85) decreased, while servings of wholegrain increased for 4.05 serve/day (95% CI: 1.96, 6.14; $p < 0.001$), fruits for 1.51 serve/day (95% CI: 0.59, 2.51; p = 0.00) and vegetables for 2.21 serve/day (95% CI: 0.41, 4.01; p = 0.02) in the default condition, compared with nutrition education intervention.
Koutoukidis et al. (2019)	Swap/default order	Altering the default order to show foods in ascending order of SFA was significantly more effective than offering a swap with lower SFA, and no evidence were found that providing swaps in addition to altering the order increased the effect. Both strategies were effective in reducing percentage energy from SFA and ED. Altering order and combined interventions also resulted in a reduction of total energy.	The difference in the SFA (% of energy) content of the basket; the proportion of products with less than 1.5 g of SFA per 100 g of product; total energy (kcal); ED (kcal/100 g); sugar (% of total energy); salt (g/100 g).	Altering the order of foods (%; Mdiff = −5.0; 95% CI: −6.3 to −3.6) and offering swaps (%; Mdiff = −2.0%; 95% CI: −3.3 to −0.6) reduced SFA. Altering the default order reduced the percentage energy from SFA significantly more than offering swaps (−3.0% (95% CI: −4.3 to −1.6), and the combined intervention was more effective than swaps alone (−3.4% (−4.7 to −2.1)), but not different than altering the order alone (−0.4% (−1.8 to 0.9); p = 0.04). The proportion of products containing less than 1.5% SFA in the shopping basket was higher in each of the interventions compared to control. Altering the default order of foods alone or in combination with swaps significantly reduced the total energy and ED compared to control or swaps alone. Altering the order and the combination of the interventions increased the percentage energy from total sugars compared to swaps alone or control.
Stuber et al. (2022)	Swap/ information nudge	No overall statistically significant intervention effects were observed for all three intervention groups (swaps, information nudge or a combination of them).	The total percentage of healthy grams purchased (calculated based on the sum of healthy grams purchased relative to all grams purchased); which food groups drove	No overall statistically significant intervention effects were observed for information nudge (Mdiff = 0.4%; 95% CI: − 0.7, 1.6), position nudge (Mdiff = −1.1%; 95% CI: − 2.2, 0.0), nor combination of both

(*continued on next page*)

Table 4 (*continued*)

Author, Year	Nudging type	Effectiveness of nudges	Measured outcomes	Key findings
			the overall differences; differential effects of nudging strategies across food groups.	(Mdiff = −1.1%; 95% CI: − 2.2, 0.0). Shoppers from deprived areas, in information nudge condition purchased a 2.4% (95% CI: 0.8, 4.0) higher percentage of healthy products compared to control. Shoppers from non-deprived areas, in information nudge condition (Mdiff = −1.6%; 95% CI: − 3.2, −0.1) and combination condition (Mdiff = −2.1%; 95% CI: − 3.6, −0.6) purchased a significantly lower percentage of healthy products, whereas this difference was non-significant in position nudge condition.
Huang et al. (2006)	Swap	Offering an explicit swap with lower SFA content products at checkout is effective in reducing SFA content of the basket.	The mean percent of SFA in the purchased items among the 524 foods studied.	The amount of SFA in the foods purchased by the intervention group was 0.66% lower (95% CI: 0.480.84 $p < 0.001$) than in the corresponding foods purchased by the control group. Equivalent to an approximate 10% reduction in SFA content of foods purchased.
Bunten et al. (2021)	Swap	Offering swaps is overall effective, but message framing had no significant effect of on swap acceptance. Framing lower-energy food swaps in terms of cost benefits or social norms was not more effective at encouraging participants to accept swaps compared to a health message.	The energy content (kcal) of individual products involved in the swaps, the energy content (kcal) of the total shopping baskets; the acceptance of the swap offered.	On average, each swap offer led to a mean reduction of 9.69kcal (SD = 35.14) in energy purchased across all intervention groups, when comparing kcal of original choices against final purchases. Total energy content of the whole shopping baskets was on average reduced by 30.48kcal between original choices (M = 3622.85kcal, SD = 747.80) and final purchases (M = 3594.68, SD = 748.64). Swaps significantly reduced grams of saturated fat (MChange = −1.09, SD = 5.52; t712 = −5.27; $p < 0.001$), but no significant changes in grams of sugar (MChange = 0.14, SD = 6.12; t712 = 0.59; p = 0.555) or grams of salt (MChange = 0.28, SD = 6.89; t712 = 1.08; p = 0.281) were observed. Across all groups, 12.91% swap offers were accepted by 28.3% of participants.
Forwood et al. (2015)	Swap	Offering swaps at selection is more effective than offering them at checkout.	The ED difference between the base food and the alternative food (kJ/100 g); total ED (kJ/100 g) of the basket.	The ED of the food purchased was not significantly different between the intervention groups and control. Each accepted swap led to a not significant ED reduction of 24kJ/100g (95% CI: 4.04, −52.23). Swaps offered at selection were significantly more likely to be accepted than swaps offered at checkout ($p < 0.0001$). Consented swaps were not more likely to be accepted than imposed ones. Swaps offering larger reductions in ED resulted in lower levels of acceptance. Different food categories led to different levels of swap acceptance.
Blom et al. (2021)	Increased salience	Increasing the salience was effective at increasing the number of healthy food choices (nudged and unnudged). The effect of nudging on healthy food choice did not differ based on whether people were under low or high time pressure.	The number of nudged healthy products chosen; total number of healthier products chosen (nudged or unnudged).	More of the healthier nudged products and more healthy options (unnudged) were chosen in the nudges present condition compared to the nudges absent condition. Time pressure manipulation did influenced participants shopping time (in high time pressure condition participants finished the shopping task faster).

SFA = saturated fats; ED = energy density; SD = standard deviation; CI = confidence interval; M = mean; Mdiff = mean difference; MChange = mean changes; HPI = Healthy purchase index; TLNI = Traffic-light nutrition information; MTL = Multiple Traffic Lights; NS = Nutri-Score; AHEI-2010 = Alternative Healthy Eating Index-2010; HCS = Healthier Choice Symbol; PAE = Physical Activity Equivalent; GQPI-2016 = Grocery Purchase Quality Index-2016

condition.

One study reported the number of healthier products chosen in virtual reality supermarkets (Blom et al., 2021). It found that applying a salience nudge, in the form of a frame around a healthy item, not only increased the number of nudged healthy food choices, but also increased the total number of healthy food choices (unnudged). Interesting, measuring the percentage of healthy food by weight purchased, identified that information nudges to promote healthier purchasing behaviours can lead to a higher percentage of healthy food purchases only among shoppers from deprived areas (based on area-level status scores). While adverse effects were found among shoppers from non-deprived area exposed to information or/and unhealthy-to-healthy product swaps, as those shoppers purchased lower percentage of healthy products (Stuber et al., 2022). Three studies reported specific food groups as an outcome and found that nudging can have different effects across food groups in an online supermarket. As reported by Coffino & Hormes, 2018, an online cart prefilled with healthy food increased the serves/-percentages of whole grains and fruits. Similarly, the use of the default

shopping cart resulted in purchase of more whole grains, fruits and vegetables, compared with a nutrition education intervention alone (Coffino et al., 2020). Whereas, shoppers from deprived area, purchased more healthy breads, milk and yogurt, and fish when exposed to information nudges, and more healthy pasta and rice, healthy breads, bread substitutes, milk and yogurt, and fish when exposed to information nudges and swaps. In addition, shoppers from non-deprived areas, purchased less healthy fish, legumes, nuts, and fats when exposed to information nudges alone, and less fruits, vegetables, and bread substitutes when exposed to the combination of nudges (Stuber et al., 2022).

4. Discussion

The current scoping review summarises current research on the use of digital nudging strategies within online grocery stores and its impact on making healthier food choices. Four strategies were frequently used within the reviewed studies, namely, application of different label(s), healthy swap offers, adding default options, increasing product salience, or a combination of strategies.

Despite the existing definitions of nudging (Thaler & Sunstein, 2008) and digital nudging (Weinmann et al., 2016), inconsistent use of terms creates challenges in synthesizing the literature. Overall, papers frequently failed to explicitly explain or report the designed visual UI elements. This has consequences for synthesis and interpretation of results. A potential solution to address this is for authors to annotate texts and corresponding datasets using a field specific ontology, which defines the relationships between taxonomic terms to structure the description of shared data, such as ONE recently proposed by Yang et al., 2019. Given that different UI elements, such as colour, can attract consumer attention and influence consumer behaviour and decision making (Aslam, 2006), these elements need to be taken into account when designing UIs. Among reviewed studies implementing different labels in online grocery stores, the majority used previously established food labels and so the design process was not further described. One study highlighted the use of two existing online stores with completely different UIs, which sold the same products and compared sales (Sacks et al., 2011). This needs to be acknowledged since this review is focusing on digital nudges and any change of the UI is part of it. Using different UI's may have an impact on people's perception of the online grocery store, therefore, findings may not be directly comparable with other study designs.

In the current literature, nudging strategies have had varied effects on lowering total energy or ED in online grocery stores, hence manipulations to future nudging strategies need to be designed and implemented attentively. Studies implementing a default option or order, identified that this strategy can successfully nudge participants to select foods lower in calories (Coffino et al., 2020; Coffino & Hormes, 2018; Koutoukidis et al., 2019). Conversely, overall swap nudges does not appear to be effective for reducing total energy content of shopping baskets, with only one study (Bunten et al., 2021) showing an energy reduction in the final purchases. However, each swap accepted by participants did reduce the energy content of the purchased food, with swaps offered at the point of selection rather than at the checkout, more likely to be accepted (Forwood et al., 2015). In addition, combining swap offers with altering the default order of products appears promising (Koutoukidis et al., 2019). Similarly, while labels are likely to increase purchases of labelled products, they might not have an impact on decreasing calories of the shopping basket (Finkelstein et al., 2019, 2020, 2021; Shin et al., 2020), or the impact may be limited to beverages only (Finkelstein et al., 2020). It may be that information on multiple nutrients may confuse consumers and lead to incorrect judgement of a product's healthiness. However, additional research is required due to the diversity of nutrition information and outcomes assessed in available studies.

Findings were similarly mixed for micro-and macronutrient contents of foods, with labels used to nudge lower fat and SFA of shopping baskets showing mixing results. This might be because implemented labels did not focus solely on fat and/or SFA content of foods and drinks (Finkelstein et al., 2019, 2021; Marty et al., 2020; Shin et al., 2020). On the other hand, adding a default option (Coffino et al., 2020; Coffino & Hormes, 2018), altering the default order (Koutoukidis et al., 2019) or offering an explicit swap (Huang et al., 2006; Koutoukidis et al., 2019) successfully nudged selection of foods lower in SFA and fat in all studies implementing these strategies. A default option successfully reduced sodium, and cholesterol content, while increasing fibre content of grocery baskets (Coffino et al., 2020; Coffino & Hormes, 2018). However, changing UI does not always lead to positive outcomes; potentially due to the increased information costs of health claims. For example, labels need to be carefully applied as a nudging strategy, if lower protein intake among consumers is to be avoided (Finkelstein et al., 2019). Further, altering the default order of foods alone or combined with swaps and increasing the proportion of foods can increase energy from sugars (Koutoukidis et al., 2019; Marty et al., 2020).

It has also been proposed that salience nudges (attracting consumers) capture attention and consequently the products in proximity to the nudge stand out (Blom et al., 2021). Therefore, even if participants did not select the specific nudged healthy product, they selected one of the nearby (healthier) options positioned next to it. This implies that with the right design, a UI which subtly leads consumers to focus on targeted products or screen area may encourage them to select healthier options.

4.1. Future research

Findings of the current review on digital nudging in online grocery stores are similar to a recent review that found different type of a nudges have varying effects and that digital nudges can effectively influence online users towards healthier food, either by attracting them or guiding them away (Jesse et al., 2021). Given the promising results of digital nudging, future research should examine whether the positive benefits of different nudging strategies applied in an online grocery shop would be sustained or continued over repeated online shopping experiences. UIs can easily be modified in an online environment, and potentially could be personalized for consumers. Future research should seek to address this. For example, allowing consumers to choose which nudging type is most appropriate for them and their dietary needs (e.g., which label decreases sodium content, offering swaps based on specific nutrient contents, etc.). In addition, as results were mixed and effects varied in regards to the content of foods or on total energy, future research in this field needs to strategically apply nudging strategies to specific dietary aspects to avoid adverse effects. Furthermore, it has been noted that only experimental study designs have been identified in this scoping review, future research could consider the use of other study designs, e.g., observational studies, longitudinal designs and/or stakeholder interviews to investigate current implementation, long term effects and key stakeholder opinions on digital nudging, and should clearly describe them.

The review findings should be considered with respect to its limitations. Inconsistencies in describing nudging strategies and distinguishing between digital nudging and nudging in digital settings exist. Authors from different research fields use different terms to describe nudging strategies (Piper et al., 2021), hence differing terminologies may not have been captured, despite the broad search strategy employed. Online food environments are a fast emerging field and as such do not currently have a standardised terminology or research approaches. Furthermore, only 33.3% of included studies used existing grocery shops. Therefore, results should be interpreted with caution, because the majority of studies were situated within a simulated online supermarket where results may differ from real-life experiences. Moreover, it is important to acknowledge that different platforms, such as web-based online stores, 3-dimensional virtual supermarket, and web-based virtual supermarket, were included in the current review.

Hence, the implementation and interpretation of the overall results needs to be interpreted with caution. Additionally, the included studies measured and assessed a variety of nutritional outcomes while investigating different nudging strategies alone or in combination with other strategies (e.g., nutrition education). This diversity in nutritional outcomes assessed and use of different measurement methods limits the ability to compare results or synthesise the evidence. Furthermore, there may be a publication bias with studies on nudging strategies potentially not being effective or not published. Lastly, as the goal was to scope the literature to identify trends and research gaps, we did not evaluate the quality of the evidence.

5. Conclusion

This is the first review to summarise the evidence of the digital nudging application in online groceries. We conclude, firstly most studies have changed the grocery store's UI by incorporating different label(s), a default option, a pop-up swap suggestion, increased salience, or a combination of strategies, while reporting different nutritional outcomes. Secondly, the lack of a well-designed description of UI features and general details of UIs, means insights in to the most impactful UI elements cannot be identified at this time. Therefore, future studies need to address and clearly explain implemented UI features, to investigate and quantify the effect on consumers' food choices. Thirdly, to avoid publication biases, gaining insights into which digital nudging approaches are not effective, is very important. Fourthly, investigating personalized nudging approaches as a strategy to promote healthier food choices at the individual level, as well at the population level is warranted. In physical environments, effort changes, social references, (re) placement, resizing the products, product presentation, etc. have been shown to be effective (Harbers et al., 2020; Hollands et al., 2017, 2019; Vecchio & Cavallo, 2019), but no studies that tested these approaches in an online store were identified. Future research should address this gap and investigate strategies such as: colour, imagery exposure, the effort to obtain a food (e.g., number of clicks), on-screen (re)placement/positioning, etc., while considering a variety of study designs. Lastly, current frameworks or taxonomies that structure nudging interventions do not consider the digital context, and thus may not be applicable to online settings. Additionally, inconsistencies in describing the term digital nudging, along with food choice studies performed in digital environments call for a unified terminology, with a theoretical framework for online environments and use of ontologies to standardize research outputs.

Contributions

EV and TB designed the study. EV performed the searches, title and abstract screening, and full text screening. EV extracted and coded the data. EB, CEC, BKS and TB provided critical manuscript feedback. The authors read and approved the final manuscript.

Funding

This research was supported by the Australian Research Council (ARC DP210100285) and the Hunter Medical Research Institute. Additionally, this work was undertaken within the OPKP ('Upgrade of the Open platform for clinical nutrition with a mobile app') project, which has received funding from the Ministry of Health of Slovenia under Grant Agreement No.C2711-19-185021 and from the Slovenian Research Agency [P2-0098: Computer Structures and Systems].

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

No data was used for the research described in the article.

Acknowledgments

The authors wish to thank Dr. Nienke de Vlieger, Melanie Cockbain, Ludwina Eugenia and Jessica Piper for their contribution in assisiting in screening of this study.

References

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Aslam, M. M. (2006). Are you selling the right colour? A cross-cultural review of colour as a marketing cue. *Journal of Marketing Communications, 12*(1), 15–30. https://doi.org/10.1080/13527260500247827

Austin, C. (2013). How square register's UI guilts you into leaving tips. https://www.fastcompany.com/3022182/how-square-registers-ui-guilts-you-into-leaving-tips. (Accessed March 2022).

Azman, N., & Sahak, S. Z. (2014). Nutritional label and consumer buying decision: A preliminary review. *Procedia-Social and Behavioral Sciences, 130*, 490–498. https://doi.org/10.1016/j.sbspro.2014.04.057

Bell, R., Meiselman, H. L., Pierson, B. J., & Reeve, W. G. (1994). Effects of adding an Italian theme to a restaurant on the perceived ethnicity, acceptability, and selection of foods. *Appetite, 22*(1), 11–24. https://doi.org/10.1006/appe.1994.1002

Blitstein, J. L., Guthrie, J. F., & Rains, C. (2020). Low-income parents' use of front-of-package nutrition labels in a virtual supermarket. *Journal of Nutrition Education and Behavior*. https://doi.org/10.1016/j.jneb.2020.04.003. Scopus.

Blom, S. S. A. H., Gillebaart, M., De Boer, F., van der Laan, N., & De Ridder, D. T. D. (2021). Under pressure: Nudging increases healthy food choice in a virtual reality supermarket, irrespective of system 1 reasoning. In *Appetite* (Vol. 160)N.PAG-N.PAG. ccm. https://doi.org/10.1016/j.appet.2021.105116.

Bucher, T., Collins, C., Rollo, M. E., McCaffrey, T. A., De Vlieger, N., Van der Bend, D., … Perez-Cueto, F. J. (2016). Nudging consumers towards healthier choices: A systematic review of positional influences on food choice. *British Journal of Nutrition, 115*(12), 2252–2263. https://doi.org/10.1017/S0007114516001653

Bucher, T., Siegrist, M., & van der Horst, K. (2014). Vegetable variety: An effective strategy to increase vegetable choice in children. *Public Health Nutrition, 17*(6), 1232–1236. https://doi.org/10.1017/S1368980013002632. Cambridge Core.

Bunten, A., Porter, L., Sanders, J. G., Sallis, A., Payne Riches, S., Van Schaik, P., … Forwood, S. (2021). A randomised experiment of health, cost and social norm message frames to encourage acceptance of swaps in a simulation online supermarket. *PLoS One, 16*(2), Article e0246455. https://doi.org/10.1371/journal.pone.0246455

Cadario, R., & Chandon, P. (2020). Which healthy eating nudges work best? A meta-analysis of field experiments. *Marketing Science, 39*(3), 465–486. https://doi.org/10.1287/mksc.2018.1128. Scopus.

Coffino, J. A., & Hormes, J. M. (2018). A default option to enhance nutrition within financial constraints: A randomized, controlled proof-of-principle trial. *Obesity, 26*(6), 961–967. https://doi.org/10.1002/oby.22151. Scopus.

Coffino, J. A., Udo, T., & Hormes, J. M. (2020). Nudging while online grocery shopping: A randomized feasibility trial to enhance nutrition in individuals with food insecurity. *Appetite, 152*, Article 104714. https://doi.org/10.1016/j.appet.2020.104714. Scopus.

Demarque, C., Charalambides, L., Hilton, D. J., & Waroquier, L. (2015). Nudging sustainable consumption: The use of descriptive norms to promote a minority behavior in a realistic online shopping environment. *Journal of Environmental Psychology, 43*, 166–174. https://doi.org/10.1016/j.jenvp.2015.06.008

Finkelstein, E. A., Ang, F. J. L., & Doble, B. (2020). Randomized trial evaluating the effectiveness of within versus across-category front-of-package lower-calorie labelling on food demand. *BMC Public Health, 20*(1), 1–10. https://doi.org/10.1186/s12889-020-8434-1

Finkelstein, E. A., Ang, F. J. L., Doble, B., Wong, W. H. M., & van Dam, R. M. (2019). A randomized controlled trial evaluating the relative effectiveness of the multiple traffic light and nutri-score front of package nutrition labels. *Nutrients, 11*(9), 2236. https://doi.org/10.3390/nu11092236

Finkelstein, E. A., Doble, B., Ang, F. J. L., Wong, W. H. M., & van Dam, R. M. (2021). A randomized controlled trial testing the effects of a positive front-of-pack label with or without a physical activity equivalent label on food purchases. *Appetite, 158*, Article 104997. https://doi.org/10.1016/j.appet.2020.104997

Forwood, S. E., Ahern, A. L., Marteau, T. M., & Jebb, S. A. (2015). Offering within-category food swaps to reduce energy density of food purchases: A study using an experimental online supermarket. *International Journal of Behavioral Nutrition and Physical Activity, 12*(85), 1–10. https://doi.org/10.1186/s12966-015-0241-1

Harbers, M. C., Beulens, J. W. J., Rutters, F., de Boer, F., Gillebaart, M., Sluijs, I., & van der Schouw, Y. T. (2020). The effects of nudges on purchases, food choice, and energy intake or content of purchases in real-life food purchasing environments: A systematic review and evidence synthesis. *Nutrition Journal, 19*(1), 103. https://doi.org/10.1186/s12937-020-00623-y

Hollands, G. J., Bignardi, G., Johnston, M., Kelly, M. P., Ogilvie, D., Petticrew, M., Prestwich, A., Shemilt, I., Sutton, S., & Marteau, T. M. (2017). The TIPPME intervention typology for changing environments to change behaviour. *Nature Human Behaviour, 1*(8). https://doi.org/10.1038/s41562-017-0140. Scopus.

Hollands, G. J., Carter, P., Anwer, S., King, S. E., Jebb, S. A., Ogilvie, D., Shemilt, I., Higgins, J. P. T., & Marteau, T. M. (2019). Altering the availability or proximity of food, alcohol, and tobacco products to change their selection and consumption, 2019 *Cochrane Database of Systematic Reviews*, (8)https://doi.org/10.1002/14651858.CD012573.pub2. Scopus.

Huang, A., Barzi, F., Huxley, R., Denyer, G., Rohrlach, B., Jayne, K., & Neal, B. (2006). The effects on saturated fat purchases of providing internet shoppers with purchase-specific dietary advice: A randomised trial. *PLoS Clinical Trials, 1*(5), e22. https://doi.org/10.1371/journal.pctr.0010022

Hummel, D., & Maedche, A. (2019). How effective is nudging? A quantitative review on the effect sizes and limits of empirical nudging studies. *Journal of Behavioral and Experimental Economics, 80*, 47–58. https://doi.org/10.1016/j.socec.2019.03.005

Insider Intelligence. (2022). Digital grocery industry trends and forecast. https://www.insiderintelligence.com/insights/digital-grocery-industry/. (Accessed 13 June 2022).

Jesse, M., Jannach, D., & Gula, B. (2021). Digital nudging for online food choices. *Frontiers in Psychology, 12*(101550902), Article 729589. https://doi.org/10.3389/fpsyg.2021.729589

Kahn, B. E., & Wansink, B. (2004). The influence of assortment structure on perceived variety and consumption quantities. *Journal of Consumer Research, 30*(4), 519–533. https://doi.org/10.1086/380286

Keller, C., Markert, F., & Bucher, T. (2015). Nudging product choices: The effect of position change on snack bar choice. *Food Quality and Preference, 41*, 41–43. https://doi.org/10.1016/j.foodqual.2014.11.005

Koutoukidis, D. A., Jebb, S. A., Ordóñez-Mena, J. M., Noreik, M., Tsiountsioura, M., Kennedy, S., Payne-Riches, S., Aveyard, P., & Piernas, C. (2019). Prominent positioning and food swaps are effective interventions to reduce the saturated fat content of the shopping basket in an experimental online supermarket: A randomized controlled trial. *International Journal of Behavioral Nutrition and Physical Activity, 16*(1). https://doi.org/10.1186/s12966-019-0810-9. Scopus.

Marty, L., Cook, B., Piernas, C., Jebb, S. A., & Robinson, E. (2020). Effects of labelling and increasing the proportion of lower-energy density products on online food shopping: A randomised control trial in high-and low-socioeconomic position participants. *Nutrients, 12*(12), 3618. https://doi.org/10.3390/nu12123618

Metcalfe, J. J., Ellison, B., Hamdi, N., Richardson, R., & Prescott, M. P. (2020). A systematic review of school meal nudge interventions to improve youth food behaviors. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1). https://doi.org/10.1186/s12966-020-00983-y. Scopus.

Piper, J., Adam, M. T. P., De Vlieger, N., Collins, C. E., Bucher, T., et al. (2021). A Bibliometric Review of Digital Nudging within Digital Food Choice Environments. *ACIS 2021 Proceedings, 63*. https://aisel.aisnet.org/acis2021/63.

PwC. (2020). *Lockdown, shake up: The new normal for shopping in Europe*. https://www.pwc.de/en/retail-and-consumer/european-consumer-insights-series-2020-new-normal.html.

Rolls, B. J., Morris, E. L., & Roe, L. S. (2002). Portion size of food affects energy intake in normal-weight and overweight men and women. *The American Journal of Clinical Nutrition, 76*(6), 1207–1213. https://doi.org/10.1093/ajcn/76.6.1207

Rumrill, P. D., Fitzgerald, S. M., & Merchant, W. R. (2010). Using scoping literature reviews as a means of understanding and interpreting existing literature. *Work, 35*(3), 399–404. https://doi.org/10.3233/wor-2010-0998

Sacks, G., Tikellis, K., Millar, L., & Swinburn, B. (2011). Impact of 'traffic-light' nutrition information on online food purchases in Australia. *Australian & New Zealand Journal of Public Health, 35*(2), 122–126. https://doi.org/10.1111/j.1753-6405.2011.00684.x

Santé publique France. Nutri-score. https://www.santepubliquefrance.fr/en/nutri-score. (Accessed 27 March 2022).

Schiffman, L., O'Cass, A., Paladino, A., & Carlson, J. (2013). *Consumer behaviour*. Pearson Higher Education AU.

Shin, S., van Dam, R. M., & Finkelstein, E. A. (2020). The effect of dynamic food labels with real-time feedback on diet quality: Results from a randomized controlled trial. *Nutrients, 12*(7), 1–16. https://doi.org/10.3390/nu12072158. Scopus.

Starke, A. D., Willemsen, M. C., & Trattner, C. (2021). Nudging healthy choices in food search through visual attractiveness. *Frontiers in Artificial Intelligence, 4*(101770551), Article 621743. https://doi.org/10.3389/frai.2021.621743

Stöckli, S., Stämpfli, A. E., Messner, C., & Brunner, T. A. (2016). An (un) healthy poster: When environmental cues affect consumers' food choices at vending machines. *Appetite, 96*, 368–374. https://doi.org/10.1016/j.appet.2015.09.034

Stok, F. M., Hoffmann, S., Volkert, D., Boeing, H., Ensenauer, R., Stelmach-Mardas, M., Kiesswetter, E., Weber, A., Rohm, H., Lien, N., Brug, J., Holdsworth, M., & Renner, B. (2017). The DONE framework: Creation, evaluation, and updating of an interdisciplinary, dynamic framework 2.0 of determinants of nutrition and eating. *PLoS One, 12*(2), Article e0171077. https://doi.org/10.1371/journal.pone.0171077

Stuber, J. M., Lakerveld, J., Kievitsbosch, L. W., Mackenbach, J. D., & Beulens, J. W. J. (2022). Nudging customers towards healthier food and beverage purchases in a real-life online supermarket: A multi-arm randomized controlled trial. *BMC Medicine, 20*(1), 10. https://doi.org/10.1186/s12916-021-02205-z

Sunstein, C. R., & Thaler, R. H. (2003). Libertarian Paternalism. *American Economic Review, 93*(2), 175–179. https://doi.org/10.1257/000282803321947001

Thaler, R. H., & Sunstein, C. R. (2008). Nudge: Improving decisions about health, wealth, and happiness. *Penguin*.

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., … Weeks, L. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine, 169*(7), 467–473. https://doi.org/10.7326/M18-0850

Vecchio, R., & Cavallo, C. (2019). Increasing healthy food choices through nudges: A systematic review. *Food Quality and Preference, 78*. https://doi.org/10.1016/j.foodqual.2019.05.014. UNSP 103714.

Veritas Health Innovation. (2022). Covidence systematic review software. www.covidence.org.

Waxman, A. (2004). WHO global strategy on diet, physical activity and health. *Food and nutrition bulletin, 25*(3), 292–302. https://doi.org/10.1177/156482650402500310

Weinmann, M., Schneider, C., & Brocke, J. vom (2016). Digital nudging. *Business & Information Systems Engineering, 58*(6), 433–436. https://doi.org/10.1007/s12599-016-0453-1

Yang, C., Ambayo, H., De Baets, B., Kolsteren, P., Thanintorn, N., Hawwash, D., Bouwman, J., Bronselaer, A., Pattyn, F., & Lachat, C. (2019). An ontology to standardize research output of nutritional epidemiology: From paper-based standards to linked content. *Nutrients, 11*(6). https://doi.org/10.3390/nu11061300

Chapter 3

SnackTrack: An App-Based Tool to Assess the Influence of Digital and Physical Environments on Snack Choice

Published: Valenčič E., Beckett E., Collins C.E., Koroušić Seljak B., Bucher T., (2022). Nutrients, 15(2), 349.

Eating patterns have changed in the last years [15]. Consumers are now eating a higher proportion of meals away-from-home [53], alone [54], or on the go than ever before. As the frequency of snacking is also increasing [55], snacks became an important part of the diet, and can significantly impact diet quality. Research shows that energy-dense foods, such as sweets, desserts, salty foods and sugar-sweetened beverages often represent the majority of snacks consumed [56]–[58]. Conversely, the consumption of nutrient-dense foods has also been reported [59], [60]. The prudent selection of snacks can potentially have a positive impact on overall diet by contributing important nutrients and promoting satiety. Therefore, selecting healthful snacks could benefit consumer's overall health.

Further, investigating the connection between environment and snack composition is needed to fully understand the contribution of environmental factors to snack choice. Determining the triggers for nutrient-dense and nutrient-poor snack choices would be beneficial for the understanding of modern dietary patterns and could be used to encourage consumption of more nutrient-dense snacks. Moreover, it could assist in promoting strategies to improve public health outcomes and update dietary recommendations and guidelines.

The aim of this study was to investigate the impact of physical and digital environment on snack choices. For this purpose an open-source mobile application with variable UI – background images, was designed and developed. The aim of this study was to test whether different background images can be used to nudge app users. Five different backgrounds were implemented and randomised, two of them depicted healthy snacks, two displayed unhealthy snacks, and a control background. The development of a mobile app for tracking food choices with a variable background was an innovative approach. As the tool is open source, other nudging strategies can easily be implemented and more experiments can be conducted on this topic.

Among other findings, this study found that users exposed to an unhealthy background image, submitted photos containing the healthiest foods (as measured by the Nutri-Score).

This finding is surprising, as it shows the opposite of what is suggested by the nudging theory, which suggests that changing the environment leads to predictable changes in consumer's behaviours.

Moreover, it is important to note that this study was conducted during COVID-19 pandemic, therefore findings need to be interpreted accordingly. Further, as this was a feasibility trial, repeating it on a bigger sample size, would be beneficial to confirm the results. Nevertheless, findings confirmed that consumer's choices can be influenced and that digital environment can impact your choices. However, combining these findings with the existing food composition D&K could have even greater implications for food choices. Thus, replicating these findings would be a sensible next step.

With this work goal **O2** – To design and test a research mobile app for testing environmental influences and investigating the impact of different UIs on people's snacking choices, and the hypotheses **H1b** - The presence of a background image within the UI influences food choices, were addressed.

Permission to include the publication "SnackTrack: An App-Based Tool to Assess the Influence of Digital and Physical Environments on Snack Choice" in this doctoral dissertation was confirmed by the publisher MDPI in an email exchange on May 5, 2023.

nutrients

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Article

SnackTrack—An App-Based Tool to Assess the Influence of Digital and Physical Environments on Snack Choice

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Abstract: As food choices are usually processed subconsciously, both situational and food environment cues influence choice. This study developed and tested a mobile app to investigate the association between physical and digital environments on snack choices. SnackTrack was designed and used to collect data on the snack choices of 188 users in real-life settings during an 8-week feasibility trial. The app asks users to take a photo of the food they are planning to consume and to provide additional information regarding the physical environment and context in which this food was eaten. The app also displayed various user interface designs (i.e., different background images) to investigate the potential effects of images on snack choice. Preliminary results suggest that the time of snack obtainment did not have a significant effect on the healthfulness of the snacks chosen. Conversely, it was found that unhealthy background images appeared to encourage healthier snack choices. In conclusion, despite consumers having the knowledge to make healthy choices, environmental cues can alter food choices. SnackTrack, a novel tool to investigate the influence of physical and digital environments on consumers' food choices, provides possibilities for exploring what encourages (un)healthy eating behaviours.

Keywords: digital nudging; user interface; food environment; choice behaviour; snacks; snack choice; food choice

Citation: Valenčič, E.; Beckett, E.; Collins, C.E.; Koroušić Seljak, B.; Bucher, T. SnackTrack—An App-Based Tool to Assess the Influence of Digital and Physical Environments on Snack Choice. *Nutrients* **2023**, *15*, 349. https://doi.org/10.3390/nu15020349

Academic Editor: Jose M. Miranda

Received: 13 December 2022
Revised: 2 January 2023
Accepted: 3 January 2023
Published: 10 January 2023

1. Introduction

Consumer behaviour, including food and nutrition choices, is influenced by factors at the individual and environmental levels. However, the DONE interactive framework [1] demonstrates that environmental factors have the greatest influence on food choices, and importantly, they can be modified. Therefore, strategies to improve dietary habits that are linked with food choices need to focus not only on individual behaviours but also on the food environment and the conditions in which people live and make food choices [2].

Some environmental factors shown to influence food choice and amounts consumed include availability, the effort required for consumption [3], the variety [4] and portion sizes [5] of food presented. Hence, strategically restructuring physical and digital food choice environments appears to be a promising avenue to improve dietary habits and promote population health [6,7]. Modifying the environment by making healthier choices easier and more accessible may have a positive influence on consumers' food choices. This approach has been described as nudging, which is defined as "any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives." [6].

An individual's health behaviour is determined by conscious and systematic intentions, as well as by automatic, nonintentional and subconscious processes [8]. While habits, including eating habits, can be difficult to change at the individual level, they are affected by environmental cues, such as the visibility of food, which are frequently processed unconsciously. Thus, environmental cues, which are processed outside of conscious awareness, could help in targeting automatic, effortless and spontaneous processes and therefore nudge healthier food choices [9–12]. One such potential cue is imagery, which carries messages which viewers decode and react to [13]. Food imagery, particularly, may increase food-related thoughts, cravings, hunger, guilt, appetitive appeal, and motivation to eat [11]. It has been shown that images influence consumers' trust and ease of use of websites [14]. However, to date, few studies have investigated if and how imagery influences food choices [15–19].

In recent years, the consumers' everyday food choice environments shifted, with food choices now regularly conducted in digital settings, such as online grocery stores, pre-ordering systems, food delivery services, etc. In contrast to traditional food choice environments, the perception of visual cues in a digital setting is entirely mediated through a user interface (UI). As such, UI design may play an important role in consumer perception and food selection. This raises the importance of research in digital nudging, which is defined as "the use of user-interface design elements to guide people's behaviour in digital choice environments" [20]. A recent review showed that digital nudging is a rapidly growing field, increasingly investigated in food and health contexts [21]. Therefore, the scope of a feasibility study presented in this paper pertains specifically to the imagery used in digital UI and its influence on users.

To date, little is known about how people make food choices within digital environments and which key elements of the UI influence food perception, selection and purchase [7]. Although information and communication technologies are commonly used in the healthy-eating context, research on online tools for guiding consumers' decision-making processes in the context of healthy food choices is lacking [22]. Additionally, the lack of empirical evidence limits our understanding of how imagery could be used to nudge healthy food choices and if it may even lead to unhealthy food choices.

The frequency of snacking [23] and the contribution of snacks to total energy intake has increased. Research shows that more than 30% of energy comes from snack occasions among Australian children [24] and that snacking contributes to almost one-quarter of total energy intake among Canadian adults [25]. Since the impact of snacking on the overall diet quality depends on their nutritional composition [26], in this study, we specifically focused on snack choices. Snacking is typically defined as the consumption of food or drink between main meals [27]. However, the interpretation of the terms 'snacks' and 'snacking' may vary by country [28].

In order to understand the contribution of environmental factors and determine the triggers for snack choices, we were interested in tools allowing participants to repeatedly report their experiences in real-time and real-world settings. This kind of report is called Ecological Momentary Assessment [29]. As we could not find a publicly available tool to efficiently investigate environmental and nudging impacts on food choices, the aim of this study was to develop and test a mobile app [30] to assess the contribution of physical and digital environments (i.e., digital nudging). The app allows users to track their snacks while exposing them to different UI designs (implemented as mobile app backgrounds).

2. Materials and Methods

2.1. Study Design

The feasibility study aimed to design, test and assess a mobile application, and to investigate associations between the digital and the physical environment with snack choices. A mobile app called SnackTrack was designed and developed by the University of Newcastle, Australia, in collaboration with the Computer Systems Department, Jožef Stefan Institute (JSI). SnackTrack was used to collect data on consumers' snack choices in

real-life settings, and the study involved an 8-week feasibility trial to investigate which environmental factors are associated with snack choices. The app enables users to take a photo of the food they are planning to consume via the phone's camera and allows individuals to provide additional information regarding the physical environment and context in which the food was consumed by selecting pre-set options (e.g., when and how was it obtained, where was eaten, etc.). The whole process of submitting photo(s) and additional information was developed to be as intuitive as possible and not too demanding for app users. For example, participants did not have to enter text or write the answers; they only had to select the most appropriate ones.

The development of SnackTrack focussed on designing a mobile app with a variable UI (in this case, background images) to investigate whether UIs can be used to nudge consumers/app users. In the present study, the goal was to create an app which could be used to investigate whether different mobile backgrounds could nudge consumers towards selecting healthier snack options. Four different backgrounds were implemented and randomised to participants in the intervention conditions. The backgrounds were real-life photos related to either healthy (fruits, vegetables) or unhealthy (sweets, salty snacks) foods (See Figure S1 in Supplementary Materials). These photos were selected because if we wanted to ensure primes will influence consumers and encourage healthy behaviours, environmental cues need to be congruent with health-relevant concepts and products and need to complement the other components in the triggered environment [11]. As nudging should be subconscious, there was no mention of or emphasis on the presence of the backgrounds. Participants allocated to the Control condition used the app without an image background (grey plain-coloured background).

Ethical approval for this study was obtained from the University of Newcastle Human Research Ethics Committee (Approval number H-2020-0267).

2.2. Participants and Procedure

Participants were recruited in the period from February to April 2022 via social media and printed posters (displayed at JSI and on campus at the University of Newcastle). Individuals interested in participating in the study scanned a QR code on the recruitment material to download the mobile app SnackTrack from either the Apple App store or Google Play. SnackTrack was only available in the app stores in Australia (English version) and Slovenia (Slovenian version). After downloading the app, participants received a study information statement, and consent was obtained online prior to the data collection. Each participant received a unique code to protect their privacy; thus, no information on identity was recorded during the research study. Before being able to use the app, participants provided information about their sex and year of birth. Only participants aged 18 years or older were eligible to participate.

Participants were randomised into 5 conditions (4 intervention conditions; mobile background containing photos of either (i) fruits, (ii) vegetables, (iii) salty snacks or (iv) sweets, and a Control condition (v); grey-coloured background). Randomisation was performed directly in the app, using an algorithmic approach for randomisation to avoid any subjective decision. Each background was assigned once per cycle; therefore, each 5th participant downloading the app was allocated to the Control condition. Participants were asked to take photos of the snacks they consumed or were planning to consume throughout the day. Participants were instructed to capture the photo of the foods as close as possible and to make sure that the food was clearly visible. Photos could be taken of the snacking occasion (e.g., multiple food items on one photo,) or each food item could be captured separately. Photos submitted at the same time were treated as one snacking occasion. Together with photos of snacks, additional data about snacking choices, such as how and when the snack was obtained and where and in the company of how many people the snack was consumed, were collected. A screenshot of the additional data screen with the vegetable background is shown in Figure S2 in Supplementary Material. Participants were asked to upload at least 15 photos over 15 days between February and April 2022. Therefore, they were

asked to use the app at least once a day for at least 15 days (no need to be consecutive). Participants who submitted at least 15 photos of actual foods were eligible to be included in a prize draw for either a $50AUD gift card (Australian participants) or a €10 gift card (Slovenian participants).

2.3. Sample Size

We aimed to recruit 500 participants (250 from each country, 50 in each condition), which is the number needed to detect medium to large effect sizes. We anticipated recruiting as many participants as possible within the eight weeks of the intervention.

2.4. Measures

After data collection was completed, we checked all the photos and removed duplicates. Duplicates could have been uploaded if the internet connection was lost while submitting the photo (this resulted in uploads of multiple of the same photos on the server). In some cases, the photos were not uploaded to the server correctly, and we could not open and see the photos. These photos were also removed from the analysis. After the removal of duplicates and 'broken' photos, we annotated and described each photo (snack). We annotated the name of the food on the photo (e.g., chocolate bar), the Nutri-Score (NS) [31] of the foods, and the food group the food corresponds to. The food groups used, together with examples based on submitted photos, are shown in Table 1.

Table 1. Food groups with examples of foods corresponding to them.

Food Group	Examples of Foods in the Food Group
Fruits	Fresh fruits, fruit-only containing smoothies, dried fruits
Vegetables	Fresh and pickled vegetables
Salty snacks	Chips, tortilla chips, popcorn, salty crackers, salty sticks/pretzels
Sweets	Chocolate bars, cookies, candy, granola/muesli/protein/nut/fruit bar, sweet pastries, cakes, waffles, etc.
Grains	Bread bun, sour pastries, rice cakes, etc.
Dairy and dairy substitutes	Yoghurt (natural or flavoured), quark, puddings, plant-based yoghurt
Meat, fish & egg	Cold cuts, jerky, salmon, eggs
Beverage	Juices, coffee/tea (with milk), carbonated drinks, energy drinks, alcoholic beverages
Nut	Nuts (plain, roasted, salted), nuts with dried fruits
Mixed dishes and other foods	Sandwich, toast with spread, soup, pizza, fries, porridge, breaded vegetables, pancakes with spreads, peanut butter, honey, etc.

The primary outcome variable was the average NS [31–33], which is a colour-coded index of overall diet quality ranging from A (healthiest) to E (least healthy) based on the British Food Standard Agency Nutrient Profiling System. For each snack (photo), we applied the standard Nutri-Score algorithm to assign a score from A to E based on nutritional quality. Later, we recorded the scores as numbers from 5 (A: the healthiest) to 1 (E: the least healthy). We calculated an average score for the snacking occasion in the following cases: when the photo contained multiple foods (e.g., mandarins and chocolate bar) as a part of one snacking occasion or if participants submitted more than 1 photo, but it was clear that the photos were part of one snacking occasion (e.g., on 1 photo a hot cross bun, and on the other a handful of nuts; both photos were submitted together).

In addition, two independent accredited dietitians (one from Slovenia and one from Australia) were asked to assess the healthiness of the photos. They assigned a score from 1 (very unhealthy) to 5 (very healthy). The dietitian's holistic assessment score (DA) was needed because NS could not be applied to all of the snacks, as some photos did not contain the information needed to assign the score. For example, foods prepared and self-packed

in advance did not contain the dietary labels needed to calculate the NS (e.g., we could not distinguish the fat content of dairy products).

2.5. Data Analysis

Descriptive statistics were used to describe the properties of participants and the additional data about snacking choices (when and where the snacks were obtained, where they were eaten and with whom) using Microsoft Excel and R software [34] (v. 4.2.0, for iOS). Demographic details were summarised with frequencies, means, and standard deviations (SD) as appropriate. The time of the photo submission was considered as the time of the snack consumption. For data analysis, time was corrected to correspond to either CEST or AEST time zone (Daylight saving time change was taken into consideration), depending on the participant's location.

Data were tested for normality with the Shapiro–Wilk test, and the homogeneity of variances was tested using Levene's test, using R software; p-values <0.05 were considered statistically significant. Statistical comparison of the differences in NS and DA between conditions was performed using a Kruskal–Wallis test, followed by Dunn's posthoc test (p-value adjustment method; Benjamini and Hochberg). A chi-squared test was used to compare the proportions of food groups in the 5 conditions.

3. Results

3.1. Participants

A total of 284 adults downloaded the app; of those, 80 were from Australia and 204 from Slovenia. Of the 284, 95 people had not submitted any photo, and one person entered invalid data for their year of birth. Therefore, data from 188 people (52 from Australia and 136 from Slovenia) were included in the final analysis. Out of those, 64 people submitted 15 photos or more, and the average number of days participants were using the app was 5.02. Participants were randomised in Control (n = 36), 'Fruit' (n = 47), 'Vegetable' (n = 34), 'Salty snacks' (n = 36), and 'Sweets' condition (n = 35). Participants in the Control condition submitted 353 photos; in the 'Fruit' condition, 441 photos; in the 'Vegetable' condition, 297 photos; in the 'Salty snacks' condition, 354 photos; and in the 'Sweets' condition, they submitted 318 photos.

The mean age of the participants was 35.5 years (±12.8); of those, 72.3% identified themselves as female (n = 135), 25% as male (n = 47), 2.1% as other (n = 4), and 1.1% declined to answer (n = 2).

3.2. Feasibility Outcomes

During the intervention, participants submitted a total of 1763 (1297 from Slovenia and 466 from Australia) photos of snacks. Of those, 76.1% (n = 1343) were obtained at the moment of consumption (80.3% (n = 1042) from Slovenia and 64.6% (n = 301) from Australia) and 23.8% (n = 420) were obtained more than one-hour prior consumption (19.7% (n = 255) from Slovenia and 35.4% (n = 165) from Australia). Most snacks were purchased by the participants themselves (66.3%; n = 1169), whereas 33.7% (n = 594) of snacks were purchased by someone else, or participants got them for free. The majority of snacks were consumed when participants were by themselves (74.9%; n = 1322), followed by when they were accompanied by one additional person (14.5%; n = 257), more than two people (6.5%; n = 114), or by exactly two people (4.0%; n = 70). Overall, the most snacks were consumed at the dining table (26.6%; n = 469), followed by on the sofa (21.6%; n = 382), at the working desk (21.3%; n = 375), in the workplace (15.0%; n = 265), on the go (7.3%; n = 129), in restaurants/cafés (1.2%; n = 22), and "other" was selected for 6.9% of the snacks. The majority of snacks consumed by Australian participants were eaten at the working desk (35%; n = 163), while Slovenian participants consumed the most snacks at the dining table (31.8%; n = 412). See Figure 1 for more details.

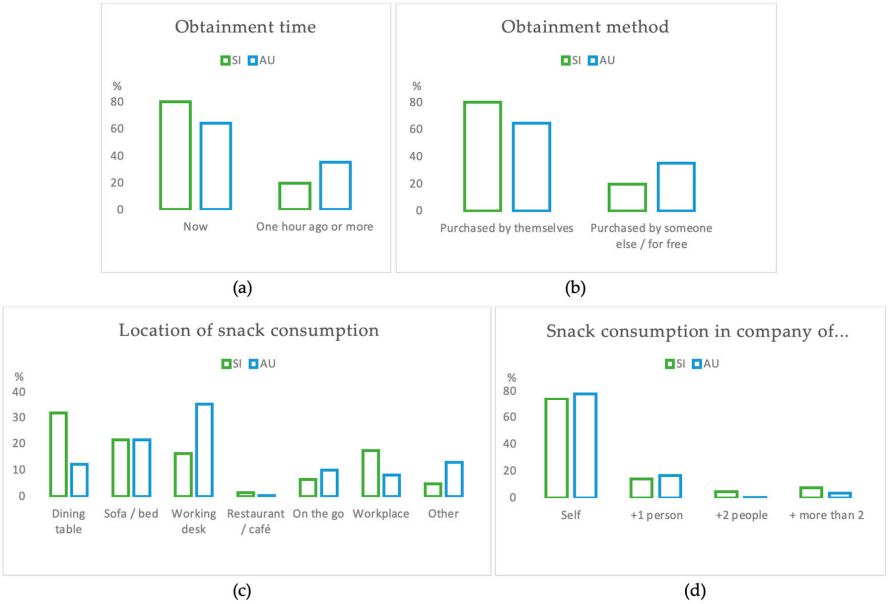

Figure 1. Results on the context of snack consumption: (**a**) Time of snack obtainment; (**b**) Method of snack obtainment; (**c**) Location of snack consumption; (**d**) How many people participants were with while eating the snacks.

When the time of the day of the snacking occasion was considered, it was found that 37.6% (n = 663) of reported snacks were consumed in the morning (from 5 a.m. to 12:59 p.m.), 36.9% (n = 652) in the afternoon (from 1 p.m. to 5:59 p.m.), and 25.4% (n = 448) in the evening/at night (from 6 p.m. to 4:59 a.m.). Slovenian participants submitted the most pictures of snacks between 5–6 p.m., while Australian participants between 4–5 p.m. We found that photos of snacks submitted by men are more likely to be consumed in the evening (24.9%) than those of women (18.1%).

The mean NS of all submitted snacks was 2.7 ± 1.6 out of five, and the mean DA was 2.5 ± 1.6 out of five. The nutritional quality of snacks among men was slightly poorer (NS: 2.5 ± 1.7 and DA: 2.4 ± 1.6) compared to women (NS: 2.7 ± 1.6 and DA: 2.5 ± 1.6) but not statistically different (NS: p = 0.66; DA: p = 0.32). Additionally, the difference in NS and DA between Australians (NS: 3.1 ± 1.6; DA: 2.6 ± 1.6) and Slovenians (NS: 2.5 ± 1.6; DA: 2.4 ± 1.5) was significant (NS: $t(763) = 6.0612$, $p < 0.001$; DA: $t(785) = 2.6708$, $p = 0.008$), meaning that Australians consumed healthier snacks. In addition, the results showed that the difference in NS and DA between snacks obtained at the moment of consumption (NS: 2.7 ± 1.6 and DA: 2.5 ± 1.5) and the ones obtained more than 1 hour before consumption (NS: 2.7 ± 1.7 and DA: 2.5 ± 1.6) was not significant (NS: $t(697) = 0.45216$, $p = 0.65$; DA: $t(673) = -0.10023$, $p = 0.92$), which means that the time of snack obtainment did not affect healthfulness of snacks. Moreover, snacks eaten when participants were alone were significantly healthier that when participants were in company with others (NS: $t(759) = -7.3674$, $p < 0.001$; DA: $t(885) = -7.9996$, $p < 0.001$).

Regarding the time of snacking, a Kruskal–Wallis H-test showed that there was a statistically significant difference in NS and DA between the times of day the snacks were consumed (NS: $\chi^2_{(2)} = 23.85$, $p < 0.001$; DA: $\chi^2_{(2)} = 51.29$, $p < 0.001$) with a mean

NS/DA score of 2.9/2.7 for morning snacks, 2.7/2.5 for afternoon snacks and 2.4/2.1 for evening snacks.

As the purpose of the app is to assess whether UI design (background) has an impact on the healthfulness of the snacks consumed, we first checked the mean NS and DA for all five backgrounds. The mean NS and DA scores were the lowest in the Control condition (NS: 2.4 ± 1.5; DA: 2.2 ± 1.5) and the highest in the 'Sweets' condition (NS: 2.9 ± 1.7; DA: 2.7 ± 1.6) as seen in Table 2. When analysing differences between the conditions (data were not normally distributed ($p < 0.001$) and did not have equal variance (NS: $p < 0.001$; DA: $p < 0.005$)) results showed that there was a statistically significant difference in NS ($\chi^2_{(4)} = 21.418$, $p = 0.0003$) and DA ($\chi^2_{(4)} = 18.392$, $p = 0.001$) as presented in Table 2. The posthoc test indicated significant differences in NS of snacks between Control and 'Fruit' ($p = 0.04$), Control and 'Salty snack' ($p = 0.004$), Control and 'Sweets' ($p = 0.0002$), and between 'Vegetable' and 'Sweets' ($p = 0.04$). See Table 2 for more details and for the condition differences between DA scores.

Table 2. Nutri-Score and Dietitian's Assessment Score per condition.

			Nutri-Score (NS)					**Dietitian's Assessment Score (DA)**				
Conditions		*n*	Mean (SD)	*df*	χ^2	*p*	Comparison condition	Mean (SD)	*df*	χ^2	*p*	Comparison condition
				4	21.418	**<0.001**			**4**	18.392	**0.001**	
Healthy conditions	Fruit	441	2.7 (1.6)			0.59	Vegetable	2.4 (1.5)			0.39	Vegetable
						0.34	Salty snacks				0.30	Salty snacks
						0.06	Sweets				0.29	Sweets
	Vegetable	297	2.6 (1.7)			0.17	Salty snacks	2.4 (1.6)			0.10	Salty snacks
						0.04 *	Sweets				0.10	Sweets
Unhealthy conditions	Salty snacks	354	2.8 (1.7)			0.30	Sweets	2.6 (1.6)			0.98	Sweets
	Sweets	318	2.9 (1.7)					2.7 (1.6)				
Control condition	Control	353	2.4 (1.5)			**0.04** *	Fruit	2.2 (1.5)			**0.03** *	Fruit
						0.16	Vegetable				0.25	Vegetable
						0.004 **	Salty snacks				**0.003** **	Salty snacks
						<0.001 ***	Sweets				**0.002** **	Sweets
	Total	1763	2.7 (1.6)					2.5 (1.6)				

SD, standard deviation; χ^2, results from Kruskal-Wallis test; *df*, degree of freedom; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

In addition, which food groups were most represented among the conditions was evaluated. Interestingly, among all five conditions, the majority of photos of snacks corresponded to the sweets food group, followed by fruits. See Table 3 for more details. This indicated that the majority of snacks consumed were chocolate, cookies, candy, fruit/nut/granola/protein bars or similar, followed by different types of fresh fruits, fruit-only smoothies or dried fruits. When comparing between countries, the Slovenian participants submitted more sweet snacks (46.7%) than Australian participants (35%). In addition, one-quarter of Slovenians and over 22% of Australians had fruits as a part of their snacking occasions, and less than 3% of Australians and less than 2% of Slovenians consumed vegetables as snacks. Moreover, background images had a significant effect on snack choices ($\chi^2_{(45)} = 100.95$, $p < 0.001$), and from the visual presentation in Figure S3 in Supplementary Materials, it can be seen that in the 'Fruit' condition, more photos of 'Mixed meals and other' were submitted, and in 'Sweets' condition more photos of 'Beverages' were submitted. Post-hoc analysis indicated that only the proportion of snacks within the 'Mixed meals and other' condition (Table 1 for more details) food group is significant ($p = 0.02$). There was no significant difference between other intervention groups.

Table 3. Food groups of snacks per condition.

		Healthy Conditions		**Unhealthy Conditions**		**Control Condition**
All photos *n* (%)		Fruit *n* (%) n^p = 47 (AU = 13; SI = 34)	Vegetable *n* (%) n^p = 34 (AU = 11; SI = 23)	Salty snacks *n* (%) n^p = 36 (AU = 9; SI = 27)	Sweets *n* (%) n^p = 35 (AU = 9; SI = 26)	Control *n* (%) n^p = 36 (AU = 10; SI = 26)
Fruits	412	103 (25)	67 (16.3)	92 (22.3)	82 (19.9)	68 (16.5)
Vegetables	35	5 (14.3)	8 (22.9)	5 (14.3)	13 (37.1)	4 (11.4)
Dairy	169	50 (29.6)	25 (14.8)	44 (26.0)	35 (20.7)	15 (8.9)
Grains	41	11 (26.8)	6 (14.6)	13 (31.7)	4 (9.8)	7 (17.1)
Meat, fish and eggs	18	4 (22.2)	1 (5.6)	7 (38.9)	0 (0.0)	6 (33.3)
Nut	130	26 (20.0)	16 (12.3)	27 (20.8)	38 (29.2)	23 (17.7)
Salty snacks	158	33 (20.9)	40 (25.3)	31 (19.6)	15 (9.5)	39 (24.7)
Sweets	770	190 (24.7)	129 (16.8)	136 (17.7)	141 (18.3)	174 (22.6)
Beverages	94	23 (24.5)	7 (7.4)	15 (16.0)	31 (33.0)	18 (19.1)
Mixed meals and other	166	64 (38.6)	21 (12.7)	28 (16.9)	20 (12.0)	33 (19.9)

n = number of submitted photos; n^p = number of participants from Australia or Slovenia.

We also investigated whether background images were associated with the selection of foods present in this image. For example, whether fruity background images stimulate fruit consumption. We found only in the 'Sweets' condition that the percentage of sweets containing photos was the highest (41.2%) compared to other conditions. For this purpose, all photos containing food(s) corresponding to the background foods were considered. This means that if fruit and cookies were consumed as a part of one snacking occasion, the cookies were considered in the 'Sweets' condition, even if not solely cookies were in the photo.

4. Discussion

Innovative interventions are needed to understand how people make food choices within digital environments and which (if any) UI features influence the selection the most. This study explored the feasibility of an app-based tool to investigate (physical and digital) environmental influences on snack choice.

In the existing literature [35], it is seen that monitoring dietary intake can be very demanding for people; thus, we wanted to develop an easy-to-use and intuitive app. Hence, we intentionally removed the burden of taking pictures of separated foods or ingredients when consuming a composite dish (e.g., all the ingredients used to prepare the sandwich) and providing additional information by typing. Instead, the app allows selecting pre-set options.

Contrary to the studies suggesting that meal planning and food prepared at home is healthier (e.g., [36–38]), in our study, we found that the average NS or DA did not significantly change between snacks obtained immediately prior to consumption and the ones obtained more than one hour before consumption. This may be due to the fact that the intervention was performed during the COVID-19 pandemic when people worked remotely or mainly from home. This would also justify that more than 75% of snacks were obtained at the moment of consumption, as participants did not need to prepare the foods in advance. Similarly, it would explain the fact that the majority of snacks were eaten at the dining table (Slovenians) or at the working desk (Australian). In addition, 75% of snacks were consumed when participants were by themselves, which can again be a consequence of the working-from-home requirement. However, in contrast to a study by Chae et al. [39],

we found that the food quality of these shacks was higher compared to snacks eaten in the company of others (either one, two, or more people).

We found that among participants from both countries, the majority of snack photos contained some sort of sweets, but photos submitted by Slovenians contained more of these compared to photos from Australians. This might be due to the holiday season in Slovenia, which took place during the data collection when fried sweet pastries are traditionally consumed. In addition, surprisingly, one-quarter of Slovenians and a bit more than 22% of Australians had fruits as a part of their snacking occasions. In contrast, only less than 3% of Australians and less than 2% of Slovenians consumed vegetables as a part of the snacking occasions. A very recent study showed that the majority of Polish adults are aware of the importance of vegetable and fruit intake, the negative effects of the consumption of sugar and salt, and the related dietary risk factors [40]. Nevertheless, many people still do not meet the recommended fruit and vegetable intakes (e.g., [41–43]), even though research is consistent that fruits and vegetables have beneficial effects on our overall physical and mental health [44–46]. This calls for innovative strategies to promote nutritious snacks and overall food consumption, which can be challenging as people have difficulties assessing snacks' nutritiousness when snacks contain healthy and less healthy components (e.g., fruit yoghurt containing large amounts of sugar or nuts with high energy and/or salt content) [47]. Despite the widespread knowledge about the impact of diet on health, people still have difficulties consuming and selecting nutritious foods. Hence, promoting nutritious snack consumption of, for example, snack-sized vegetables (such as mini carrots, which can be found in any well-stocked Australian store) and making them more accessible could increase vegetable intake and reduce health-related risks.

In addition, findings here are consistent with results from other studies suggesting that women make healthier food choices than men (e.g., [48]). Moreover, in agreement with previous studies on adults in France and Australia, our findings suggest that snacks consumed in the morning are healthier than the ones consumed later in the day [49,50]. Further research needs to investigate what drives these behaviours to promote healthier snacking behaviours and choices.

The nudging theory suggests that manipulating the consumer's environment can change behaviour in a predictable way. Hence, it could be expected that people who are exposed to healthy images would be nudged to choose healthier food [51]. However, our results showed that NS and DA were the highest (i.e., more healthful) in the 'Sweets' condition. Moreover, the DA score was the lowest in the 'Fruit' and 'Vegetable' conditions. This suggests that presenting images containing healthy foods can encourage unhealthy food choices and vice versa; images of unhealthy foods (sweets) may nudge consumers towards healthier food choices. While this is inconsistent with the previous results of other studies conducted in real-life settings (not online) (e.g., [15]), there is literature supporting our findings that healthy cues can lead to unhealthy choices (e.g., [52,53]). In the study by Wilcox et al. [52], consumers that saw a healthy food option on a menu were more likely to choose the least healthy option compared to when a healthy option was not included. This effect is called vicarious goal fulfilment, where the mere presence of healthy options fulfils the need to make healthy food choices and provides the individual with a rationale for unhealthy choices. Therefore, it may be possible that seeing unhealthy foods fulfilled participants' desire to indulge and select unhealthy snack and thus they felt satisfied enough to make a healthy choice. However, the small sample size within each condition may have influenced these results, which should be interpreted with caution. Additional studies are warranted to determine whether these findings can be repeated in a larger sample size, and our findings provide a rationale for investigating this.

Moreover, results here showed that participants in the 'Sweets' condition submitted more than 40% of snacks that corresponded to the sweet confectionary food group. These conflicting results need further investigation, and future research should examine whether the positive benefits of nudging strategies used in real-life settings have the same effect in online settings. For example, can repositioning foods in online settings influence food

choices the same as it does in field studies [3]? In addition, as UIs can easily be modified in an online environment, it may be beneficial for our understanding of UI impact on consumers to test different types of imagery. In our study, we used food imagery; however, the potential impact of using nature imagery or warning graphic images (as seen on cigarette packages) in an online setting still needs to be addressed. Hence, SnackTrack is an open-source mobile app, and its source code is freely available (See Computer Codes S1–S3 in Supplementary Materials) for use and modification required for any research purposes (CC-BY-NC, i.e., the Creative Commons Attribution-NonCommercial).

Limitations

The current study has some limitations that need to be acknowledged. Firstly, the small sample size prevented us from detecting small effects. Participants overall submitted fewer photos per person than anticipated, impacting the ability to assess the overall impacts of the image-based nudging. This feasibility study confirmed that food intake monitoring could be a burden to consumers, as participants were struggling with tracking their snack intakes for 15 days. This might also be due to the fact that 25% of apps are used only once after being downloaded [54]. Furthermore, sending reminders to participants to encourage them to track food intake would be advisable, although this cannot guarantee photo acquisition, as reminders are sent automatically and not necessarily immediately before snacking occasion. In addition, the NS nutrient profiling system, as well as the developed app, did not consider the portion size of foods. Since SnackTrack is not a dietary assessment application, portion size estimation was beyond the scope of the study, which was to assess the impact of the UI on food choices. Future research should incorporate portion size into a nutrient profiling system and/or the app and compare nutrient profile scores relative to nudging strategies.

Another limitation may be the understanding of the definition of snacking and the perception of what is considered a snack. For example, in Slovenia, a lot of companies offer warm meals for employees during working hours. Therefore, people frequently eat a multi-course meal (e.g., soup, potatoes with meat and salad) between breakfast and lunchtime. Even though we did not receive many photos of meals like this, we do have to emphasise that 'a meal between main meals' might mean different things for different people, cultures, etc.

Lastly, investigating the ability of imagery to nudge consumers over time is warranted. As environmental cues affect eating habits and are processed subconsciously, consumers might have been nudged the first time using the app. Currently, there is no strong evidence of how much time it takes to influence consumers to change their dietary behaviours; therefore, future research should seek to address this. For example, investigating how long the exposure should be for (food) imagery to target and increase cravings and motivation to eat certain foods (e.g., healthy foods) and if the exposure time is different for different types of foods (e.g., healthy vs unhealthy) or during the day. In addition, how the healthfulness of foods or diet quality changes over time while exposed to nudges (e.g., if more and more unhealthy choices were made in the unhealthy condition) needs further investigation. In order to investigate this, monitoring dietary intake and tracking behavioural changes or nutritional quality of the snacks over a period of time is needed. Hence, finding a solution to motivate participants to track their food intake is warranted. A potential solution could be automatic food image recognition [55,56], which can further contribute to the development of automated dietary assessment. Future research should seek to address this. Lastly, we would like to emphasise that during the recruitment period, COVID-19 lockdown restrictions were in place in both countries.

5. Conclusions

This pilot study demonstrates that food (online) environments play an important role, and innovative strategies are needed for behavioural changes. Since promoting healthy foods can impact consumer choices and have the opposite effect than intended, our findings

suggest that future research needs to address this, especially in an online context. Further, a clear description of implemented UI elements to investigate and quantify the effect on consumers' food choices is needed. In addition, while consumers have the knowledge to make a healthy choice, the plethora of environmental stimuli influencing them is evidently altering food choices. Although the current study has a relatively small sample size, it still provides some interesting findings, such as insights into the healthy cues leading to unhealthy choices and the time of food obtainment not having an effect on the healthfulness of selected foods.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/nu15020349/s1. Figure S1: Background images used in four conditions; Figure S2: A screenshot of Take a photo screen and the additional info screen with the vegetable background; Figure S3: Visual presentation of standard residuals; Source code S1: SnackTrack–iOS version; Source code S2: SnackTrack–Android version and Source code S3: SnackTrack–Server.

Author Contributions: Conceptualisation, E.V., E.B., C.E.C., B.K.S. and T.B.; methodology, E.V., E.B., C.E.C., B.K.S. and T.B.; formal analysis, E.V., E.B. and T.B.; writing—original draft preparation, E.V.; writing—review and editing, E.V., E.B., C.E.C., B.K.S. and T.B.; supervision, E.B., C.E.C., B.K.S. and T.B.; funding acquisition, B.K.S. and T.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Australian Research Council (ARC DP210100285) and the Hunter Medical Research Institute. Additionally, this work was undertaken within the OPKP ('Upgrade of the Open platform for clinical nutrition with a mobile app') project, which has received funding from the Ministry of Health of Slovenia under Grant Agreement No. C2711-19-185021, from the COMFOCUS project, which has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 101005259, and from the Slovenian Research Agency [P2-0098: Computer Structures and Systems]. Lastly, C.E.C. is supported by an NHMRC Leadership Research Fellowship (L3, APP2009340).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by The University of Newcastle Human Research Ethics Committee (H-2020-0267).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request. The data are not publicly available due to privacy and ethical restrictions.

Acknowledgments: The authors wish to thank Matevž Ogrinc, Andraž Simčič, Robert Modic, Gordana Ispirova, Simon Mezgec and Peter Novak for their contribution to the design and development of SnackTrack. In addition, we would like to thank Tammie Jakstas and Julija Repolusk for their contribution to the study.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Stok, F. Marijn; Renner Britta; Hoffmann Stefan; Volkert Dorothee DONE (Determinants of Nutrition and Eating) Framework. Available online: https://www.uni-konstanz.de/DONE/ (accessed on 3 January 2020).
2. Story, M.; Kaphingst, K.M.; Robinson-O'Brien, R.; Glanz, K. Creating Healthy Food and Eating Environments: Policy and Environmental Approaches. *Annu. Rev. Public Health* **2008**, *29*, 253–272. [CrossRef] [PubMed]
3. Bucher, T.; Collins, C.; Rollo, M.E.; McCaffrey, T.A.; De Vlieger, N.; Van der Bend, D.; Truby, H.; Perez-Cueto, F.J. Nudging Consumers towards Healthier Choices: A Systematic Review of Positional Influences on Food Choice. *Br. J. Nutr.* **2016**, *115*, 2252–2263. [CrossRef] [PubMed]
4. Bucher, T.; van der Horst, K.; Siegrist, M. Improvement of Meal Composition by Vegetable Variety. *Public Health Nutr.* **2011**, *14*, 1357–1363. [CrossRef] [PubMed]
5. Steenhuis, I.H.; Vermeer, W.M. Portion Size: Review and Framework for Interventions. *Int. J. Behav. Nutr. Phys. Act.* **2009**, *6*, 58. [CrossRef] [PubMed]

6. Thaler, R.H.; Sunstein, C.R. *NUDGE: Improving Decisions about Health, Wealth, and Happiness*; Yale University Press: New Haven, CT, USA; London, UK, 2008; ISBN 9780300122237.
7. Valenčič, E.; Beckett, E.; Collins, C.E.; Seljak, B.K.; Bucher, T. Digital Nudging in Online Grocery Stores: A Scoping Review on Current Practices and Gaps. *Trends Food Sci. Technol.* **2022**, *131*, 151–163. [CrossRef]
8. Papies, E.K. Health Goal Priming as a Situated Intervention Tool: How to Benefit from Nonconscious Motivational Routes to Health Behaviour. *Health Psychol. Rev.* **2016**, *10*, 408–424. [CrossRef] [PubMed]
9. Evans, J.S.B. Dual-Processing Accounts of Reasoning, Judgment, and Social Cognition. *Annu. Rev. Psychol.* **2008**, *59*, 255–278. [CrossRef]
10. Cohen, D.A.; Babey, S.H. Contextual Influences on Eating Behaviours: Heuristic Processing and Dietary Choices. *Obes. Rev.* **2012**, *13*, 766–779. [CrossRef]
11. Phillips, M. Store Atmospherics as a Prime to Nudge Shoppers toward Healthier Food Choices. Ph.D. Thesis, Auckland University of Technology, Auckland, New Zealand, 2017.
12. Vermeir, I.; Roose, G. Visual Design Cues Impacting Food Choice: A Review and Future Research Agenda. *Foods* **2020**, *9*, 1495. [CrossRef]
13. Geise, S.; Baden, C. Putting the Image Back Into the Frame: Modeling the Linkage Between Visual Communication and Frame-Processing Theory. *Commun. Theory* **2015**, *25*, 46–69. [CrossRef]
14. Rendell, A.; Adam, M.; Eidels, A. Towards Understanding the Influence of Nature Imagery in User Interface Design: A Review of the Literature. In Proceedings of the 52nd Hawaii International Conference on System Sciences, Maui, HI, USA, 8–11 January 2019.
15. Stöckli, S.; Stämpfli, A.E.; Messner, C.; Brunner, T.A. An (Un) Healthy Poster: When Environmental Cues Affect Consumers' Food Choices at Vending Machines. *Appetite* **2016**, *96*, 368–374. [CrossRef] [PubMed]
16. Lee, D.; Moon, J.; Rhee, C.; Cho, D.; Cho, J. The Effect of Visual and Auditory Elements on Patrons' Liquor-Ordering Behavior: An Empirical Study. *Int. J. Hosp. Manag.* **2016**, *55*, 11–15. [CrossRef]
17. Papies, E.K.; Hamstra, P. Goal Priming and Eating Behavior: Enhancing Self-Regulation by Environmental Cues. *Health Psychol.* **2010**, *29*, 384. [CrossRef] [PubMed]
18. Bell, R.; Meiselman, H.L.; Pierson, B.J.; Reeve, W.G. Effects of Adding an Italian Theme to a Restaurant on the Perceived Ethnicity, Acceptability, and Selection of Foods. *Appetite* **1994**, *22*, 11–24. [CrossRef] [PubMed]
19. Adams, J.M.; Hart, W.; Gilmer, D.O.; Lloyd-Richardson, E.E.; Burton, K.A. Concrete Images of the Sugar Content in Sugar-Sweetened Beverages Reduces Attraction to and Selection of These Beverages. *Appetite* **2014**, *83*, 10–18. [CrossRef]
20. Weinmann, M.; Schneider, C.; Brocke, J. vom Digital Nudging. *Bus. Inf. Syst. Eng.* **2016**, *58*, 433–436. [CrossRef]
21. Piper, J.; Adam Marc, T.P.; De Vlieger, N.; Collins, C.E.; Bucher, T. A Bibliometric Review of Digital Nudging within Digital Food Choice Environments. In Proceedings of the 32nd Australasian Conference on Information Systems, Sydney, Australia, 6–10 December 2021; Volume 63, pp. 1–12.
22. Bucher, T.; Keller, C. The Web-Buffet–Development and Validation of an Online Tool to Measure Food Choice. *Public Health Nutr.* **2015**, *18*, 1950–1959. [CrossRef]
23. Hunter, S.R.; Mattes, R.D. The Role of Eating Frequency and Snacking on Energy Intake and BMI. In *Handbook of Eating and Drinking*; Springer: Cham, Switzerland, 2020; pp. 659–678.
24. Wang, D.; Van der Horst, K.; Jacquier, E.F.; Afeiche, M.C.; Eldridge, A.L. Snacking Patterns in Children: A Comparison between Australia, China, Mexico, and the US. *Nutrients* **2018**, *10*, 198. [CrossRef]
25. Vatanparast, H.; Islam, N.; Patil, R.P.; Shafiee, M.; Smith, J.; Whiting, S. Snack Consumption Patterns among Canadians. *Nutrients* **2019**, *11*, 1152. [CrossRef]
26. Myhre, J.B.; Løken, E.B.; Wandel, M.; Andersen, L.F. The Contribution of Snacks to Dietary Intake and Their Association with Eating Location among Norwegian Adults—Results from a Cross-Sectional Dietary Survey. *BMC Public Health* **2015**, *15*, 369. [CrossRef]
27. Chaplin, K.; Smith, A.P. Definitions and Perceptions of Snacking. *Curr. Top. Nutraceuticals Res. Coppell* **2011**, *9*, 53–59. [CrossRef]
28. Potter, M.; Vlassopoulos, A.; Lehmann, U. Snacking Recommendations Worldwide: A Scoping Review. *Adv. Nutr.* **2018**, *9*, 86–98. [CrossRef] [PubMed]
29. Shiffman, S.; Stone, A.A.; Hufford, M.R. Ecological Momentary Assessment. *Annu. Rev. Clin. Psychol.* **2008**, *4*, 1–32. [CrossRef] [PubMed]
30. Valenčič, E.; Novak, P.; Ogrinc, M.; Simčič, A.; Modic, R.; Ispirova, G.; Mezgec, S.; Koroušić-Seljak, B. *Design, Implementation and Validation of the SnackTrac Mobile Application*; JSI Technical Report: Boston, Mam USA, 2022.
31. Nutri-Score. Available online: https://www.santepubliquefrance.fr/en/nutri-score (accessed on 30 May 2022).
32. Chantal, J.; Hercberg, S.; World Health Organization. Development of a New Front-of-Pack Nutrition Label in France: The Five-Colour Nutri-Score. *Public Health Panor.* **2017**, *3*, 712–725.
33. Julia, C.; Etilé, F.; Hercberg, S. Front-of-Pack Nutri-Score Labelling in France: An Evidence-Based Policy. *Lancet Public Health* **2018**, *3*, e164. [CrossRef]
34. Field, A.; Miles, J.; Field, Z. *Discovering Statistics Using R*; Sage publications: London, UK; Thousand Oaks, CA, USA; New Delhi, India; Singapore, 2012; ISBN 1-4462-0046-9.
35. Burke, L.E.; Wang, J.; Sevick, M.A. Self-Monitoring in Weight Loss: A Systematic Review of the Literature. *J. Am. Diet. Assoc.* **2011**, *111*, 92–102. [CrossRef]

36. Ducrot, P.; Méjean, C.; Aroumougame, V.; Ibanez, G.; Allès, B.; Kesse-Guyot, E.; Hercberg, S.; Péneau, S. Meal Planning Is Associated with Food Variety, Diet Quality and Body Weight Status in a Large Sample of French Adults. *Int. J. Behav. Nutr. Phys. Act.* **2017**, *14*, 12. [CrossRef]
37. Hanson, A.J.; Kattelmann, K.K.; McCormack, L.A.; Zhou, W.; Brown, O.N.; Horacek, T.M.; Shelnutt, K.P.; Kidd, T.; Opoku-Acheampong, A.; Franzen-Castle, L.D.; et al. Cooking and Meal Planning as Predictors of Fruit and Vegetable Intake and BMI in First-Year College Students. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2462. [CrossRef]
38. Laska, M.N.; Hearst, M.O.; Lust, K.; Lytle, L.A.; Story, M. How We Eat What We Eat: Identifying Meal Routines and Practices Most Strongly Associated with Healthy and Unhealthy Dietary Factors among Young Adults. *Public Health Nutr.* **2015**, *18*, 2135–2145. [CrossRef]
39. Chae, W.; Ju, Y.J.; Shin, J.; Jang, S.-I.; Park, E.-C. Association between Eating Behaviour and Diet Quality: Eating Alone vs. Eating with Others. *Nutr. J.* **2018**, *17*, 117. [CrossRef]
40. Żarnowski, A.; Jankowski, M.; Gujski, M. Public Awareness of Diet-Related Diseases and Dietary Risk Factors: A 2022 Nationwide Cross-Sectional Survey among Adults in Poland. *Nutrients* **2022**, *14*, 3285. [CrossRef]
41. Charlton, K.; Kowal, P.; Soriano, M.M.; Williams, S.; Banks, E.; Vo, K.; Byles, J. Fruit and Vegetable Intake and Body Mass Index in a Large Sample of Middle-Aged Australian Men and Women. *Nutrients* **2014**, *6*, 2305–2319. [CrossRef]
42. Vandevijvere, S.; De Ridder, K.; Fiolet, T.; Bel, S.; Tafforeau, J. Consumption of Ultra-Processed Food Products and Diet Quality among Children, Adolescents and Adults in Belgium. *Eur. J. Nutr.* **2019**, *58*, 3267–3278. [CrossRef] [PubMed]
43. Dietary Guidelines Advisory Committee. *Scientific Report of the 2015 Dietary Guidelines Advisory Committee: Advisory Report to the Secretary of Health and Human Services and the Secretary of Agriculture*; U.S. Department of Agriculture, Agricultural Research Service: Washington, DC, USA, 2015; p. 421.
44. World Health Organization. *Healthy Diet*; No. WHO-EM/NUT/282/E; World Health Organization: Nasr City, Egypt, 2019.
45. Głąbska, D.; Guzek, D.; Groele, B.; Gutkowska, K. Fruit and Vegetable Intake and Mental Health in Adults: A Systematic Review. *Nutrients* **2020**, *12*, 115. [CrossRef] [PubMed]
46. World Health Organization. *Diet, Nutrition, and the Prevention of Chronic Diseases: Report of a Joint WHO/FAO Expert Consultation*; World Health Organization: Geneva, Switzerland, 2003; Volume 916, ISBN 92-4-120916-X.
47. De Vlieger, N.M.; Collins, C.; Bucher, T. What Is a Nutritious Snack? Level of Processing and Macronutrient Content Influences Young Adults' Perceptions. *Appetite* **2017**, *114*, 55–63. [CrossRef] [PubMed]
48. Hartmann, C.; Siegrist, M.; Horst, K. van der Snack Frequency: Associations with Healthy and Unhealthy Food Choices. *Public Health Nutr.* **2013**, *16*, 1487–1496. [CrossRef]
49. Si Hassen, W.; Castetbon, K.; Tichit, C.; Péneau, S.; Nechba, A.; Ducrot, P.; Lampuré, A.; Bellisle, F.; Hercberg, S.; Méjean, C. Energy, Nutrient and Food Content of Snacks in French Adults. *Nutr. J.* **2018**, *17*, 33. [CrossRef]
50. McNaughton, S.A.; Leech, R.; Worsley, A. Does the Nutrient Profile of Snacks Vary According to the Time of Day of Consumption? *FASEB J.* **2016**, *30*, 677.20. [CrossRef]
51. Sunstein, C.R.; Thaler, R. Libertarian Paternalism. *Am. Econ. Rev.* **2003**, *93*, 175–179. [CrossRef]
52. Wilcox, K.; Vallen, B.; Block, L.; Fitzsimons, G.J. Vicarious Goal Fulfillment: When the Mere Presence of a Healthy Option Leads to an Ironically Indulgent Decision. *J. Consum. Res.* **2009**, *36*, 380–393. [CrossRef]
53. Chiou, W.-B.; Yang, C.-C.; Wan, C.-S. Ironic Effects of Dietary Supplementation: Illusory Invulnerability Created by Taking Dietary Supplements Licenses Health-Risk Behaviors. *Psychol. Sci.* **2011**, *22*, 1081–1086. [CrossRef] [PubMed]
54. BuildFire Mobile App Download Statistics & Usage Statistics (2022). Available online: https://buildfire.com/app-statistics/ (accessed on 30 November 2022).
55. Mezgec, S.; Koroušić Seljak, B. NutriNet: A Deep Learning Food and Drink Image Recognition System for Dietary Assessment. *Nutrients* **2017**, *9*, 657. [CrossRef] [PubMed]
56. Mezgec, S.; Eftimov, T.; Bucher, T.; Koroušić Seljak, B. Mixed Deep Learning and Natural Language Processing Method for Fake-Food Image Recognition and Standardization to Help Automated Dietary Assessment. *Public Health Nutr.* **2019**, *22*, 1193–1202. [CrossRef] [PubMed]

Chapter 4

FoodMapper: Management System for the Integration and Interoperability of Food- and Nutrition-related Data and Knowledge

Submitted: Valenčič E., Beckett E., Collins C.E., Bucher T., Koroušić Seljak B.

Food- and nutrition-related D&K are widely used in different research fields focusing on human health. In addition, new D&K are produced an accumulated on a daily basis. This calls for innovative strategies, which allow experts to be able to synthesise specific information of interest to them. Moreover, as D&K is produced so fast, the harmonisation and standardisation of them is necessary for humans and information systems to easily use them. There exists many different standardisation and harmonisation frameworks and flowcharts describing the process. However, they are not interconnected, which limits their use for both, humans and information systems. Therefore, to overcome these limitations, the goal was to design and develop a DKBMS to compile a distributed database and link it with evidence-based information. DKBMS is intended for experts, as its use requires an understanding of food and nutrition D&K. For instance, understanding how data was produced or analysed and compiled is of great importance for the assessment of its quality, which presents a substantial baseline for further data management and dissemination.

Moreover, the DKBMS is implemented as web-based tool, that allows easy access and traceability of interconnected D&K. This is important, as is eases the process for choice architects to select and design nudging strategies, and to further implement them. In addition, consumers are enabled to make more informed food choices when they are provided with relevant and reliable nutrition information [61].

To demonstrate its feasibility, Slovenian D&K were reviewed and imported. They were then complemented with D&K from six publicly available FCDBs. In addition, relevant food and nutritional knowledge from national and international resources, was reviewed, collected and compiled it into a KB. When compiling FCDB, the main goal was to achieve an optimal linking of DK, which enabled borrowing data and reduced missing DK.

The developed tool is useful to investigate gaps and errors in data production, compilation or management. Therefore, the tool can easily be used to identify globally

missing D&K. Moreover, it allows comparison of different D&K, which allows food compilers to accurately and quickly assess the quality of them. Additionally, DKBMS reduced missing data by allowing users to borrow them from other evidence-based resources. This developed tool takes what has been done in the past one step further by, not linking just FCD, but also allowing knowledge incorporation. This can further be used to inform and educate consumers (e.g., via digital platforms). Instead of providing consumers with just FCD, the incorporated knowledge offers multiple opportunities for choice architects to deliver personalised strategies to them.

With this work goal **O3** - Design and test a DKBMS in the form of a web-based tool where experts can easily search through different FCDBs and KBs, compile them and further link different types of evidence-based food information, and **O4** - was addressed. In addition, the hypothesis **H2** - Combining food- and nutrition-related data and knowledge into a single database, and enabling its connectivity with other systems, leads to easily accessible source of evidence-based food and nutrition data, information and knowledge, was confirmed.

FoodMapper: Management System for the integration and interoperability of food- and nutrition-related data and knowledge

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Abstract

Contemporary data and knowledge (D&K) management, and exploration are due to regular release and updates, and different types and formats. In the food and nutrition domain, solutions for integrating D&K with respect to FAIR (Findability, Accessibility, Interoperability, and Reusability) principles are lacking. Therefore, we have developed a D&K management system, called FoodMapper, with the aim of compiling a food composition database and link it with evidence-based information. Here, we present resources and methodology developed to support FoodMapper. This web-based tool is modifiable, and newly generated D&K can continuously be added as interoperability with other systems is enabled. Moreover, the traceability of the D&K origin is enabled, which allows compilation of a trustworthy management system. We demonstrate feasibility of FoodMapper on Slovenian D&K that is further linked with international resources. Additionally, outputs such as matched food components and groups have been integrated into semantic resources, currently under development in various international projects.

Keywords: Database management system, Food data compilation, Food composition data, Food composition database, Knowledge database.

1. Introduction

Food and nutrition-related data and knowledge (D&K) are essential for research domains, such as dietary and health assessments, public health surveillance and promotion, disease prevention, nutrition education, consumer protection, food safety and authenticity, agriculture, food policy, and food labelling [1, 2]. D&K are also necessary for other stakeholders representing food industry, retailers, non-government organisations, policymakers, and consumers. Consumers rely on D&K when making informed food and nutrition decisions, and other stakeholders use various types of food and nutrition-related D&K to obtain accurate scientific evidence needed to design and promote strategies required to improve public health and well-being.

However, D&K are complex, covering different areas, such as food composition, safety/toxicity, authenticity, consumption. This paper focuses on food composition data (FCD) and knowledge for dietary assessment and advising. This is of great importance to food and nutrition experts and policy makers in order to inform contemporary nutrition recommendations, as well as citizens including patients and consumers. While FCD carries detailed compositional, biochemical and physiological data regarding different foods (e.g., how much Vitamin C do apples contain), knowledge provides additional complex food information (e.g., what is the recommended intake of Vitamin C). Contemporary, FCD and knowledge are compiled in various databases, however, their integration and interoperability are lacking [3]. For example, better integration would allow us to easily access the latest evidence-based D&K from different research fields within one system.

1.1 Related work

1.1.1 Food composition data

Today, FCDs are compiled online in the form of a food composition database (FCDB). FCDBs are usually compiled at the national level, but are often used at an international level to conduct public health studies [2]. Examples include European FCDBs (available through the EuroFIR FoodExplorer tool [4]), USDA's FoodData [5], FAO/INFOODS databases [6], Canadian FooDB [7], etc. In general, FCDBs contain data on traditional, ethnic and local foods and dishes, with some combining generic and branded foods (e.g., Serbian [8]) and others having separate databases for different food types (e.g., Dutch branded food database [9]). Besides the institutional databases, numerous company-owned FCDBs also exist, such as the Edamam's food, grocery and (restaurant) database composed using

Natural Language Processing (NLP) techniques [10], GS1 branded foods and barcode databases maintained through the Global Data Synchronisation Network (GDSN) [11].

There are two main challenges with existing FCDBs. Firstly, they may contain data of different quality, due to differing approaches to data production (food sampling, analyses or estimation, (re)calculation, borrowing) or compilation (collection, aggregation, compilation and dissemination) and management. The challenge of data harmonisation has been addressed by the Food CEN standard [12], which defines requirements on the structure and semantics of food datasets and of interchange of food data for various applications. Another initiative contributing to the development of aligned metrology services in food and nutrition is the ESFRI research infrastructure Metrofood [13]. There are several additional frameworks, such as LanguaL [14], INFOODS [6] and FoodEx2 [15], which enable unified data classification and description to be considered when harmonising various FCDB [2, 16, 17]. While these standards and frameworks solve the problem of food- and nutrition- related data harmonisation, there is a problem linking this type of data with other data types (e.g., medical, environmental, consumption-related) remains unresolved. Therefore, semantic resources like the ontologies FoodOn [18], ISO-FOOD [19], FNS-Harmony [20], COMFOCUS [21] are being developed to formally describe knowledge, as a set of concepts within a domain and the relationships between them. These resources enable interoperability of data from various domains. However, to link data with selected semantic resources, data needs to be annotated with metadata. Standardised metadata in machine-readable formats are important as they enable a search based on matches of specific terms across different data sources.

The second challenge relates to missing data in FCDBs, which distorts data integrity. Analysing all components of specific foods is a major financial burden for any institution, thus no FCDB is complete and updates can be performed only once every few years or decades. The challenge of missing FCD is being resolved in various ways, either by borrowing data from other databases, by performing tedious manual work, or using computer-supported methods for (semi-) automated data imputation [22, 23].

1.1.2 Food- and nutrition-related knowledge

By definition, a knowledge base (KB) is an easily accessible online library of collected and organized information and documentation about certain topics [24]. In the food and nutrition domain, such knowledge is required not only for compiling high-quality FCD, but also for supporting developers of

differing tools in dietary assessment and treatment. Thus, important parts of a food and nutrition KB should be: (i) standardised classification and description of coding systems (e.g., FoodEx2 [15], LanguaL [14]), (ii) standardised thesauri for value documentation (acquisition type, matrix, method type, value type, unit) [16], (iii) measurement units, (iv) chemical databases of molecular entities–ChEBI [25], (v) retention and yield factors used to calculate nutrient content of composite dishes or recipes [26], (vi) dietary reference values based on an individual's age group, gender, physical activity level, health condition, life stage, (vii) dietary guidelines providing evidence-based recommendations on types and amounts of foods people need to eat to meet nutrient requirements, (viii) physical activity standards, (ix) knowledge about food components' bioavailability, (x) food-drug interactions.

As knowledge accumulates quickly, creation and maintenance of a KB is tedious work, currently usually done manually by domain experts. However, semantic resources (e.g., ontologies, knowledge graphs (KGs)) complement KBs and allow better and easier connectivity of D&K from different research areas. Recently, methodology for creating KGs describing complex relationships between food, chemicals and drugs was developed to support further developments in collecting and structuring knowledge required for personalised dietary advice [27].

Regardless of all research efforts, applicable KBs providing integrated knowledge on food and nutrition are still lacking. There are few KBs that focus on specific subdomains of knowledge, e.g., FoodKG for food recommendation based on diet-relating knowledge conceptualised as a KG [28], TasteAtlas, a world atlas of traditional dishes, local ingredients, and authentic restaurants [29].

1.1.3 Integrated FCD and knowledge

As reviewed above, the food and nutrition community has created many FCDBs as well as some KBs, but their integration and interoperability are warranted but missing currently. Even when limited to the integration of FCD, there are many obstacles, such as using different coding or classification systems, following different documentation or standards. Some excellent tools have harmonised some FCD, e.g., FoodExplorer [4], FoodCASE [30], FoodData Central [5], Glycemic Index Research and GI News [31]. These tools enable searching, and in some cases also comparison of FCD from multiple countries [4]. This is important as with increasing globalisation, the availability of international foods and dishes is increasing, and obtaining datasets of non-local foods is necessary. Having FCDBs composed on national level is important, however at the application level it would be beneficial for compilers and

developers to be able to connect and integrate not only FCD with each other, but also FCDBs with KBs. This is something that we believe does not yet exist in food and nutrition domain, or that is not publicly available.

In the current paper, we introduce a new management system, called FoodMapper for integrating FCD from different databases, with knowledge in a database. The integration is performed in a transparent way and enables, together with harmonisation, a major reduction in missing data. In Section 2, we explain how publicly available D&K resources which (currently) represent the basis of the new database management system were identified and collected. Next, we introduce the FoodMapper and describe its functionality. In Section 3, we describe the compilation process of the Slovenian FCDB and KB, identify issues that have arisen and possible solutions FoodMapper offers. We conclude in Section 4 with plans for upgrading the tool and for future work.

2. Materials and Methods

2.1 Data and knowledge collection

To demonstrate the feasibility of FoodMapper, Slovenian D&K were collected, starting with the import of analytical compositional data on generic foods from the Slovenian FCDB composed in 2006 and updated in 2012 [32]. The Slovenian FCDB also contains recipes, which were imported separately, as they require different data handling. When working with recipes, yield and retention factors, and standards on how to calculate recipes [33, 34] need to be considered. Moreover, information regarding preparation processes, cooking method(s), removed water or fat, nesting recipes, were addressed. In addition, branded foods that can be purchased in Slovenia currently, were uploaded through an application programming interface (API) from the Composition and Labelling Information System (CLAS) [35]. To complete the Slovenian FCDB for generic foods, six publicly available and recently updated FCDBs, together with associated documentation, were either downloaded from the web or linked with through an API in late 2020 or 2021 (Table 1). The FCDBs were used to create a database composed of the selected datasets having different formats, noting that few of them have applied the Food CEN standard [12].

Various FCDBs were imported as they provide different types of data. For example, FoodData Central (US in Table 1) [5] also provides data for units of measure and household units (e.g., tablespoon, cup, dash) which cannot be found in other imported FCDBs and can be used for most generic foods.

Additionally, different components are collected or analysed across FCDBs. For instance, some datasets contain data for total carbohydrates (digestible and indigestible, including dietary fibre), whereas others contain only data for carbohydrates digested and absorbed in the intestine. From the FCDBs currently imported only three provide data for total carbohydrate. Nevertheless, all of them contain data for carbohydrate and total dietary fibre, thus calculating total carbohydrate is possible. Moreover, relevant evidence-based food and nutrition documentation was systematically reviewed and collected from publicly available national and international resources and was further compiled into the FoodMapper KB (Table 1).

Table 1: Included FCDBs and other resources to be included in the FoodMapper KB.

CURRENTLY IMPORTED FCDBs				
Country code	No. of components available for allocation	No. of food group by levels‡	No. of foods / dishes	Source file format
SI	773*	15 48 149	993	.CSV/.XSL
FR	60	10 58 83	2807	.CSV/.XSL
NL	133	27	2152	.CSV/.XSL
DK	197	18 127	1186	.CSV/.XSL
UK	178	14 71 54	2910	.CSV/.XSL
AU	249	22 97	1534	.CSV/.XSL
US	235	28	7793†, 210¨	API

RESOURCES USED in KB			
Resource name/type and reference	Knowledge type	Description	No. of entities
Standardised classifications and description coding system	FoodEx2 [15] classification	A food classification and description system developed by EFSA - includes different hierarchies and facets for different food safety domains. (e.g., A00KR#F27.A00KV$F27.A00LN $F27.A00LB$F27.A00LG; mixed leafy vegetables)	4445
Standardised value documentation [16]	Component type	Component identifiers and descriptors (e.g., CHO; carbohydrate; use for total of those carbohydrates digested and absorbed in the intestine; total accessible carbohydrates include	660 (9 of these are for backward compatibility only) 56 classification identifiers (not used for new indexing)

Table 1 (continued)

		free sugars, polyols and dextrins, starch, and glycogen).	
	Unit	E.g., grams, millimoles, alpha-tocopherol equivalent, per cent.	19 Additional 20 added (IU, g/kg body mass, etc.)
	Matrix unit	E.g., per 100g of total food, per 100ml food volume, per unit, per 100g edible portion.	20 matrixes
	Value type	E.g., arithmetic mean, best estimate, average, below limit of detection, trace.	20 types
	Method type	Reporting if the value was analysed, calculated or imputed (e.g., calculated as recipes, calculated from related food, analytical result).	20 types
	Method indicator	Providing details for the analytical method or formulas used for calculation (e.g., chromatography, difference, ash calculated as sum of minerals).	214 indicators
	Acquisition type	Describes the origin of the value (e.g., laboratory, food composition table, authoritative document).	12 types
	Reference type	E.g., article in journal, file or database, product label, software.	14 types
LanguaL thesaurus [14]	Cooking methods	E.g., griddled, cooked by microwave, deep fried.	47 methods
FoodData Central at US Department of Agriculture (USDA) [5]	Measurement Units	E.g., tea spoon, slice, fillet, cup, could be used for volume to weight conversions.	115 (currently in use) out of 1923
ChEBI - a chemical database and ontology of molecular entities [25], which is part of the Open biomedical ontologies at the EBI, and European ELIXIR infrastructure	Dictionary of molecular entities	Providing detailed data of chemical entities of biological interest (e.g., definitions, formulars, ontologies, chemical reactions, IUPAC names and identifiers)	210 linked to added components
SciName Finder [36].	Search tool for scientific and common names of plants and animals	Providing precise identify plants and animals Allows precise identification of plants and animals, and searching the information on scientific and common names provided by authoritative resources (and not from secondary sources)	More than 1,000,000 scientific and common names
Culinary groups (adapted from [26, 33])	Culinary groups / subgroups related to retention and yield factors.	Providing the basics for obtaining nutrient content of foods by calculation methods (as recipe calculation), based on the amount of ingredients given in a recipe, nutrient composition of ingredients and factors that consider changes in nutrient content (retention factors), and weight (yield factors) during preparation.	31 groups and subgroups related to yield factors, and 38 related to retention factors

Table 1 (continued)

Slovenian dietary reference values (DRVs) [37] based on the D-A-CH reference values adopted by the Ministry of Health of the Republic of Slovenia	DRVs	Reference values for energy and nutrient intake for children (at least 1-year old), adolescents, adults, elderly, pregnant women and nursing mothers.	34 references for energy, macro- and micronutrients, for men and women (10 different age groups)
Latest dietary guidelines and recommendations	National and international dietary guidelines and recommendations	Relevant evidence-based guidelines and recommendations for different consumers (athletes, pregnant women and nursing mothers, healthy individuals from different age groups).	Currently defined for biomarkers (blood cholesterol and glucose) and endurance sports.
Physical activity related standards	Metabolic equivalent of task (METS)	E.g., basketball, swimming, mopping, walking, sitting.	541 tasks
	Physical activity level (PAL)	E.g., sedentary or light activity lifestyle.	5 levels per sex

*651 from EuroFIR Thesauri document and 122 subsequently added (own); ‡ = the top number is the first level, the bottom number is the last level (sub-level); † = SR Legacy Foods; ¨ = Foundation Foods

The approaches applied and described in the current paper can be used for D&K from any country. Slovenian datasets are used as an example only. Unlimited publicly available FCDBs and/or KBs can be uploaded or linked with via an API to create a database.

2.2 FoodMapper Management System

FoodMapper is designed to enable easy integration with other KBs and semantic resources conceptualizing the health, environmental, general consumer domains and food and nutrition domains in particular. This data- and knowledge base management system (DKBMS) has been implemented as a web-based tool for food compilers to easily explore and compile and link FCDBs and KBs. The main goal of this process (Figure 1) is achieving an optimal linking of D&K, which enables borrowing data respecting the FAIR (Findability, Accessibility, Interoperability, and Reusability) guiding principles for data management [38] and reduces missing D&K.

As food composition depends on its geographical origin, it is important to consider where the data comes from and which are most closely related to the local foods. Therefore, the tool takes into account a pre-set priority list where other European datasets are prioritised before non-EU datasets, (e.g., AU). This allows experts to compile datasets that are as complete as possible and also transparent in regard to where the specific data came from. The pre-set priority list can easily be amended or set for different countries.

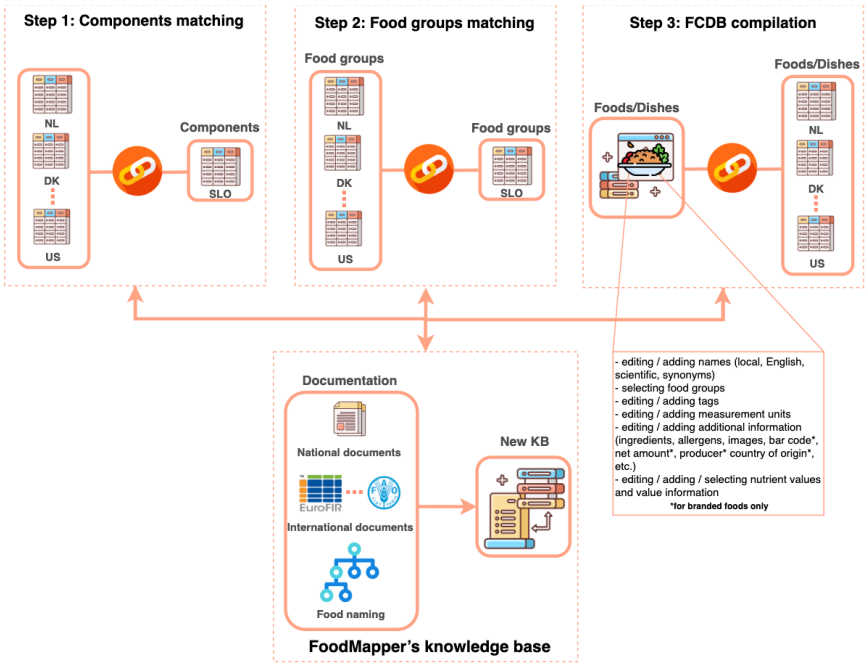

Figure 1: Flowchart of compilation process to link foods from different FCDBs.

FoodMapper supports this work in process with Slovenian FCDB (Figure 1; Step 3). This module is used to address basic food information (metadata), compositional values (analytical, calculated or imputed from the food label) and food images. Within this module a comparison of a local dataset, in the current case, Slovenian with other foreign datasets is enabled. This feature allows compiling a compositional value for a selected food, by borrowing data from other FCDBs. Together with food composition data, compilers can also check additional value information, such as value type and method type, if this data is provided. Being able to check value standards, allows compilers to assess the quality of the data and select the most appropriate or accurate one.

To ease and speed up component and food group matching as well as food compilation, knowledge resources (Table 1, Documentation in Figure 1) can be considered. The module *Thesaurus* presents a KB baseline, and it is a KB front-end for compilers. In this module, knowledge about relevant food- and nutrition topics can be collected and maintained. The KB, implemented within the DKBMS, is

198 connected with all three steps of the workflow. Thus, it can easily be updated and the updates will have
199 an immediate impact on data linked or matched in one of the steps. That means whenever new D&K
200 is published it can easily be imported and linked to existing D&K, or it can automatically substitute
201 existing D&K with the latest findings.
202
203 An important part of implemented KB is food naming, by using tags. The module *Tags* provide
204 functionality for unique food naming and metadata annotation. While much work has already been
205 conducted on unified food description and classification, food naming is still an open issue. Therefore,
206 we have implemented a new food-tagging approach to unify and standardise food naming in the food
207 and nutrition domain. FoodMapper supports an easy implementation of tags and rules for food naming.
208 This strategy to unify food naming is especially useful when different people are working on a FCDB,
209 as it enables unambiguous communication between all users involved in the working process. In
210 addition, together with using tags, setting rules for food naming has been proposed as an addition
211 solution.

212 **3. Results and Discussion**

213 **3.1 The Slovenian FCDB and KB compilation**

214 Data and knowledge maintained through the working process (Figure 1) are stored in a database
215 respecting the FAIR principles [38]. Managing D&K so that the format of foreign FCDBs and KBs
216 remains unchanged from the original sources has been an essential requirement for FoodMapper.

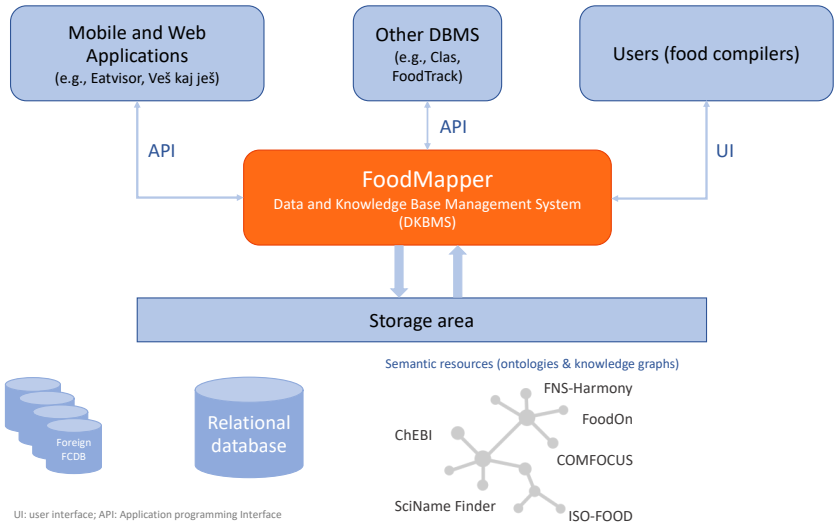

Figure 2: Overview of FoodMapper structure.

3.1.1 Components matching

To create and link the Slovenian database, the working progress was initiated by performing Step 1 (components matching; Figure 1). As the Slovenian FCDBs comply with the CEN Food standard [12], the components (n=660) specified with respect to the EuroFIR thesaurus for components [16] had to be matched with components from the foreign FCDB (Table 1). Although most of them also comply with the CEN Food standard, there were still mismatched components (i.e., different names for the same components) as presented in Table 2.

Components were matched manually to be provided as input to the FNS-Harmony ontology [20], which has been developed in the FNS-Cloud project to support interoperability of food- and nutrition-related data in the ecosystem of the European Open Science Cloud (EOSC). Once FoodMapper is integrated with FNS-Harmony that reuses or integrates several ontologies including FoodOn, we will be able not only to provide but also to use new knowledge about semantic integration with other systems (e.g., GS1 GDSN [11]).

Table 2: An example of component matching of Slovenian components with components from foreign datasets.

Component names among different FCDBs						
SI	**FR**	**NL**	**DK**	**UK**	**AU**	**US**
Carbohydrate, total (CHOT)	/	/	Carbohydrate by difference; g	/	/	Carbohydrate, by difference; Unit: G
Carbohydrate (CHO)	Carbohydrate (g/100g)	CHO_g	Carbohydrates, available; g, Carbohydrate, declaration; g	Carbohydrate (g); CHO	Available carbohydrate, with sugar alcohols; (g)	Carbohydrate, by summation; Unit: G
Fibre, total dietary (FIBT)	Fibres (g/100g)	FIBT_g	Dietary fiber; g	AOAC fibre (g); AOACFIB	Total dietary fibre; (g)	Total dietary fiber (AOAC 2011.25); Unit: G, Fiber, total dietary; Unit: G
Fat, total (FAT)	Fat (g/100g)	FAT_g	Fat, total; g	Fat (g); FAT	Total Fat; (g)	Total lipid (fat); Unit: G
Fatty acids, total saturated (FASAT)	FA saturated (g/100g)	FASAT_g	Sum saturated; g	Satd FA /100g FA (g); SATFAC, Satd FA /100g fd (g); SATFOD	Total saturated fatty acids;(%), Total saturated fatty acids; (g)	Fatty acids, total saturated; Unit: G
Fatty acids, total monounsaturated (FAMS)	FA mono (g/100g)	/	Sum monounsaturated; g	Mono FA /100g food (g); MONOFOD, Mono FA/ 100g FA (g); MONOFAC	Total monounsaturated fatty acids; (g), Total monounsaturated fatty acids; (%)	Fatty acids, total monounsaturated; Unit: G
Fatty acids, total polyunsaturated (FAPU)	FA poly (g/100g)	FAPU_g	Sum polyunsaturated; g	Poly FA /100g food (g); POLYFOD, Poly FA /100g FA (g); POLYFAC	Total polyunsaturated fatty acids; (g), Total polyunsaturated fatty acids; (%)	Fatty acids, total polyunsaturated; Unit: G

3.1.2 Food groups matching

In Step 2 (Food groups matching; Figure 1) food groups were designed considering classification of foods being used by relevant information systems in Slovenia as well as the EuroFIR standard [16], which is aimed for generic foods. Since Slovenian FCDB also includes branded foods, classification systems for these need to be considered as well. However, we found out that different Slovenian

institutions use different systems, meaning that even within one country it may be necessary to follow and comply with several standards. For example, the 'e-catalogue' classification system which is based on public procurement and is determined by law, or the Dunford classification system [39] specifically developed for branded foods. Currently, Slovenian FCDB includes three hierarchical classification levels; 15 groups on the first, 48 on the second and 160 on the third level.

Together with matching national food classification systems among each other, Slovenian food groups were matched with the food groups used in the foreign FCDBs. An example of a matching food group, *Fresh vegetables*, among FCDBs is presented in Table 3. We found this task was especially challenging, as different countries use different numbers of classification levels. For example, in France and the UK foods are classified to up to three levels, in Australia and Denmark to two levels, and in the Netherlands and USA to just one level. Moreover, food groups are variously detailed. As seen in Table 3, some countries combine all vegetables together, while the others may have sub-classified them (e.g., root vegetables, fruiting vegetables, etc.). To ensure that foods are classified correctly, we implemented a feature allowing experts to add examples of foods for each food group to the main classification system (in our case Slovenian), which was found to be very beneficial for the users. Also in this case, manually matched food groups have been provided as inputs into FNS-Harmony.

3.1.3 FCDB compilation

FCD compilation (Step 3 in Figure 1) started with an initial dataset of manually checked and corrected 14,064 data for 443 foods analysed by the Biotechnical Faculty of the University of Ljubljana in 2006 and 2012 [32]. For each food, composition data were annotated with metadata (e.g., method type, acquisition type, etc.). We also reviewed to ensure that the right components are used throughout the FCDB. For example, that data for total digestible and indigestible carbohydrates (CHO) is marked as such, and differs from data for total carbohydrates digested and absorbed in the intestine (CHOT). This process is in accordance with the first 12 steps of the generic compilation process described by Westenbrink et al. [2], currently excluding Step 5 (attribution of quality index) and Step 11 (physical storage).

Next, we assigned each food item a Slovenian name, a scientific name (when possible), an English name and synonyms considering the new food-tagging approach. For this aim, we have sensibly defined tags and set rules for their use within each food group. We found that similar foods might have

different names. This can make it harder for compilers to search for a specific food, and for consumers accessing publicly available FCDBs. For example, ‘Baked eggplant with added cheese and tomato

Table 3: An example of matching one Slovenian food group with different foreign FCDBs.

Classification level	SI	FR	NL	DK	UK	AU	US
L1	Vegetables	Fruits, vegetables, legumes and nuts	Vegetables	Vegetables and vegetable products	Vegetables	Vegetable products and dishes	Vegetables and Vegetable Products
L2	Vegetables, mushrooms and algae	Vegetables	/	- Leaf and stem vegetables; - Root and tuber vegetables; -"Fruit" vegetables; - Other vegetables	Vegetables, general undefined	- Wild harvested vegetables, and vegetable dishes; - Cabbage, cauliflower and similar brassica vegetables; - Carrot and similar root vegetables; - Leaf and stalk; - Tomato and tomato products; - Other fruiting vegetables; - Other vegetables and vegetable combinations	/
L3	Fresh vegetables	- Vegetables raw; - Vegetables, cooked	/	/	/	/	/

L1 = level 1 (the highest level in the hierarchy); L2 = level 2; L3 = level 3 (the lowest level in the hierarchy).

sauce’ or ‘Aubergine prepared in tomato sauce and cheese, frozen’. The only difference between them is that one is baked and the other is frozen, but the names are very different. Therefore, using tags for

food naming, unifies the FCDB and makes it easier to search for specific foods. Moreover, during this process, rules for food naming were checked or new rules were added. As we found that lay people can find it difficult to comprehend a foods condition (e.g., how it was processed), we wanted to make sure the naming is clear to all users. For example, meat can be analysed as raw (e.g., Beef, fillet) or heat treated (e.g., Beef, fillet, grilled). However, by experience, it is seen that lay people do not consider 'Beef, fillet' as raw, but rather as ready-to-eat steak. Therefore, adding tag 'raw' to all raw meat seemed reasonable. On the other hand, it is clear to consumers that 'Banana' is raw, and they do not expect the tag added. Thus, tag 'raw' is used within one food group, but not another. In addition, tag 'peeled' is used only when it makes sense (e.g., 'Apple, peeled', but not 'Banana, peeled'). Currently, within the tool each food group on the third hierarchical level has on average 15.4 tags added.

Next, the initial Slovenian dataset was linked with the same or similar food items from the selected foreign FCDBs, so that the scientific and English names could be harmonised, if needed. FoodMapper allows linking one food with multiple foods within one database or across multiple databases. For example, the Slovenian average white bread can be linked with white baguette and white loaf from one FCDB, and with white breads from all the other FCDBs. However, linked data will be displayed based on the pre-set priority list of FCDBs. In our case, when a food item is linked with food items from across different FCDBs, data from European datasets were prioritised before non-EU datasets. However, compilers can manually change this and select non-EU data to be displayed if appropriate. We found this approach to be very convenient, as it provides compilers with data most closely related to the local foods, but it still gives them freedom to select another dataset. Moreover, the manually matched foods present a valuable asset that can be used to construct a gold standard corpus, i.e., a corpus of text annotated with food entities required for NLP, such as CafeteriaFCD [40].

As for generic foods, branded foods are also linked with similar foods from other FCDBs. In this case, original data is added from NIP, and other data not provided on the NIP can be imputed from other FCDBs and transparently marked as such. This is especially beneficial when collecting data for the national food consumption survey. As seen in the EU Menu project it is easier for lay people to provide only the brand or production line of the food item when reporting food intake. For example, instead of reporting consumption of 'full fat milk', they have reported a producer's name of such milk. Since on food labels usually only provide information on the average quantity of energy and six other nutrients, the quantities of micronutrients are unknown. To reduce missing data, branded foods can be linked with generic foods to compose the complete dataset, which would provide the opportunity to more

accurately assess food intake of individuals and overall populations. Table 4 presents an example of the number of imputed data for *Fresh vegetables* food group from a specific FCDB. As seen from the Table 4, only one value for total carbohydrates had to be borrowed from US FCDB, the rest were from national FCDB. Whereas, values for cystine are missing in Slovenian FCDB, therefore they had to be borrowed from Danish and US FCDB (the other FCDBs do not contain data for cystine).

Table 4: Number of data imputed from a specific FCDB for Fresh vegetables food group.

Component	SI	FR	NL	DK	UK	AU	US
Carbohydrate, total (CHOT)	42	-	-	0	-	-	1
Carbohydrate (CHO)	24	15	3	1	1	0	0
Fibre, total dietary (FIBT)	36	4	0	1	1	0	0
Fat, total (FAT)	42	0	0	0	1	0	0
Fatty acids, total saturated (FASAT)	28	12	1	0	1	0	2
Fatty acids, total monounsaturated (FAMS)	26	12	-	1	1	0	1
Fatty acids, total polyunsaturated (FAPU)	26	12	1	0	1	0	1
Protein (PROT)	42	0	0	0	1	0	0
Energy, gross (ENERA)	5	4	0	0	1	0	0
Energy, total metabolizable (ENERC)	33	1	5	0	0	0	5
Water (WATER)	41	1	0	0	1	0	0
Ash (ASH)	41	1	0	0	-	0	1
Polyols (POLYL)	0	10	22	0	-	-	0
Alcohol (ALC)	0	31	4	2	2	0	1
Sodium (NA)	39	2	0	0	1	0	0
Salt (NACL)	12	31	-	-	-	-	-
Organic acids (OA)	22	3	0	1	-	-	-
Alanine (ALA)	10	-	-	11	-	3	11
Arginine (ARG)	24	-	-	6	-	0	7
Asparagine (ASN)	0	-	-	-	-	-	-
Cysteine (CYSTE)	15	-	-	-	-	-	0
Cystine (CYS)	0	-	-	18	-	-	13
Glutamic acid (GLU)	10	-	-	11	-	3	11
Glutamine (GLN)	10	-	-	-	-	-	0
Histidine (HIS)	23	-	-	7	-	0	7
Isoleucine (ILE)	25	-	-	5	-	0	7
Leucine (LEU)	24	-	-	6	-	0	7
Lysine (LYS)	25	-	-	5	-	0	7
Methionine (MET)	25	-	-	5	-	0	7
Phenylalanine (PHE)	25	-	-	5	-	0	7
Proline (PRO)	10	-	-	11	-	3	11
Serine (SER)	9	-	-	12	-	3	11
Taurine (TAU)	0	-	-	-	-	-	0
Threonine (THR)	24	-	-	6	-	0	7
Tryptophan (TRP)	20	-	-	8	-	2	8
Tyrosine (TYR)	17	-	-	7	-	2	9
Valine (VAL)	24	-	-	6	-	0	7

- = the component is not in the FCDB.

Finally, yet importantly, internationally accepted algorithms to avoid errors were selected and applied to produce aggregated data (e.g., recipe calculations) (Steps 14 and 15 according to Westenbrink et. al. [2]). Moreover, all data within the database were verified (and corrected if needed) (Steps 16 and 17, according to Westenbrink et al. [2]) to prevent hazards related to data validation. The majority of the FCD validation has been done manually (e.g., checking for outliers within each component), however the tool automatically performs consistency checks for some components (e.g., the sum of macronutrients is ≤100, quantity of saturated fatty acids is not larger than total fats) or metadata. The validated data is then stored and disseminated (Steps 18 to 22, according to Westenbrink et al. [2])

3.1.4 Knowledge base creation

Using FoodMapper, we have created a KB required for the food compilation process, as well as for data quality assessment, traceability, calculations and validation (resources are listed in Table 1). The KB implemented within FoodMapper tool is meant to be used by experts, as it collects the latest scientific evidence and standards required for data and data source management. It also consists of the reference list and it allows publication metadata to be imported in standardised formats. These references can be further linked to specific data, which allows traceability of data and metadata. Moreover, the information within KB can be added or edited, and therefore upgraded. For instance, units listed in EuroFIR value documentation [16] can be supplemented or extended with other units (e.g. IU, ABV) to meet compilers needs.

3.1.5 FCDB and knowledge linking

FoodMapper enables FCD and knowledge linking. For instance, a specific component (e.g., vitamin C) can be easily linked with relevant and specific dietary recommendations, such as Slovenian dietary guidelines and DRVs for specific age group, gender, and physical activity level [37]. Therefore, we were able to interconnect and complement data (component; vitamin C) with knowledge (dietary requirements for vitamin C for different groups of consumers, and/or chemical details) which allows access to combined information in one place. This approach takes what has been done in the past a step further by allowing knowledge incorporation, which can be useful to further inform and educate consumers (e.g., via mobile apps). Instead of providing consumers or app users just with FCD, the incorporated knowledge can also be provided, meaning delivery of a personalised approach. Additionally, direct links to publicly available documents from foreign FCDBs have been implemented

throughout the tool. This means that with one click, users can be redirected to the specific document, and they do not have to manually search for it.

FoodMapper was evaluated throughout the whole compilation process of the Slovenian FCDB and KB. Six food compilers of different skills have performed various tasks (component matching, food linking) depending on their user profile role. For example, less skilled compilers have only edited D&K, whereas experts have approved and published the edited D&K.

3.2. Strengths and Limitation of DKBMS

While reviewing analytical data from the past Slovenian FCDB and importing it into the DKBMS, some errors and gaps were identified and further discussed with compilers. The analytical data review was performed using spreadsheets and found that errors were difficult to be identified. However, when using FoodMapper to review and edit the FCD, compilers agreed that it is a useful and reliable tool. Although spreadsheets are very popular when researchers are handling data, similar observation was found by Presser et al. [30].

To be able to access the quality of D&K, it is crucial to create and maintain a quality management system [2]. Currently available FCDBs contain data of varying quality, which reflects different resources and different ways of obtaining the data. The metadata used to describe them, as well as the quantity of data differ among FCDBs. Usage of FCDBs may further be significantly restricted due to the incomplete coverage of food components, which leads to missing data [41]. It has been proposed that it is better to include imputed data, transparently identified as such, than no data at all [41]. However, data should only be borrowed or imputed among the same or similar foods. Several computer methods for missing data imputation in electronic-FCDBs have been previously researched [22, 23]. All of them concluded, that to be able to ‘borrow’ data, that as many details about the source (food) as possible are needed. In addition, when borrowing data, it is necessary to check if the values for at least the macronutrients contributing to energy are similar. If the values deviate too much, then foods should not be linked, and a better match should be identified. Deviations may occur for various reasons, such as; different food origin, different analytical methods used or outdated data. The developed DKBMS may ease the process of comparing FCD among different datasets or resources and help finding the best matches.

Even though linking just two FCDBs would be the easiest for compilers, it is not always feasible, because different FCDBs consists of different data. For example, all of the imported FCDBs contain data for total protein content, but only three provide data for specific amino acids. However, research suggests that emphasis should be given not only to overall protein intake, but also to specific amino acids (i.e. leucine in older adults, as it is proposed to prevent and treat sarcopenia [42]). For experts to be able to prepare dietary guidelines, and to further communicate this with lay people, FCDBs need to provide this data. Among the FCDBs currently imported, only Danish, Australian and American FCDBs provide data for leucin. As analysing specific components is costly and time consuming, it is not affordable for all laboratories. Therefore, it can again be seen that borrowing data between FCDBs is a suitable solution. The DKBMS can easily be used to identify globally missing D&K.

FoodMapper follows all relevant documentation and allows compilers to complete their datasets with imputed data, and therefore minimises missing data. However, when linking data, all relevant additional food information should be taken into account, to avoid incorrect data to be interconnected. For example, linking foods analysed for different matrix materials (e.g., per 100g of edible portion or per 100g of dry weight). Hence, within the tool, compositional values are differentiated according to the matrix.

Currently, many websites and mobile applications allow adding or editing FCD without considering data standards and documents. This may lead to imprecise data, which can further lead to incorrect dietary intake assessment. This is a concern; in that it raises the question of how can users be assured that the data is of high quality or is actually correct? Hence, it is recommended that FCDs from approved FCDBs (e.g. FoodExplorer [4]) be used, as they guarantee that the data is harmonised, scientifically collected and reviewed by experts. Within FoodMapper data origin is clearly displayed and traceability of it is enabled, which allows compilation of a trustworthy FCDB. Combining such FCDB with all relevant KBs provides a baseline for other systems (e.g., mobile apps, web-based tools, online grocery stores) to innovate and is an extension of what has been done before.

In addition, FoodMapper allows collection of different knowledge resources into one place to compile its own KB. Currently, some documentations (see Table 1) are included within the tool. However, many more can be added and implemented, either as direct links to relevant resources or as baseline to quick information access and to further inform and educate consumers. Some examples of KBs and knowledge resources that could be added to the system are; the international network of food data

systems - INFOODS [6], the Global Dietary Database [43], the chemical hazard database [44], different EFSA guidelines, standards and tools [45], etc. Uniting, linking and updating all these resources within one tool, could help manufacturers and experts from different fields to obtain access to important scientific evidence. Moreover, it could be used as a baseline system providing consumers with transparent, detailed and evidence-based food and nutrition D&K relevant for their well-being. Thus, the newly developed tool, is an extension of what has already been done in this research area.

4. Conclusion

The development of FoodMapper demonstrates how complex the food compilation is and how many activities need to be performed to develop and maintain high-quality FCD and related knowledge, and to construct semantic resources needed for the automation of specific steps. Results of the manually performed work presented in the current paper serve as input to FNS-Harmony [20]. Additionally, new computer-based methodologies to support our further work have been developed, and some solutions have already been implemented that are now openly available web services (e.g., through the FNS-Cloud catalogue [46]). In order to speed up the compilation process, Ispirova et al. [47] developed the methodology for automatic identification of different names of the same foods or dishes (e.g., 'Baked eggplant with added cheese and tomato sauce' and 'Aubergine prepared in tomato sauce and cheese').

To enable rapid upgrades of D&K, the current tool will be integrated within existing or developing KG (e.g., FoodKG on food recommendations [28], FooDB [7], KGs on food-disease and food-chemical relations [27], a KG on food consumer knowledge being developed within the COMFOCUS project [21]). Most of these resources are still under development. Furthermore, for branded foods and recipes using branded foods as ingredients, values for components that are not mandatory to be included on the NIP, will be calculated using the food matching web services developed within FNS Cloud [46].

Moreover, complementing FCDBs with food images would be beneficial, however a database of unified images of generic foods is currently lacking. Having such a database, and linking it with FCDBs would ease food identification within the FCDBs, and contribute to research related to automated food image recognition [48]. This could further be used to assist in dietary intake assessment, and portion size estimation, especially if measurement aids (e.g., [49]) were included.

The DKBMS system presented in the current paper is a comprehensive system that is currently available and includes not only multiple FCDBs, but also KBs. Moreover, all D&K included are

harmonized and compiled with respect to various well-established standards. FoodMapper can also help to create and maintain a QMS needed to assure data quality. Combining quality systems with data production, compilation managing allows better monitoring and assessment of FCDBs, which further increases credibility of FCDB among consumers, experts, policy makers and other stakeholders. Moreover, using FoodMapper reduces the time required to review FCD, by allowing people to add, edit, link, and combine data with knowledge, all in one place. In addition, as the use of FCDBs can be limited by missing data with in FCDBs, FoodMapper provides an important step to include imputed data that is transparently identified as such. Lastly, the implementation of some tasks was especially challenging, as not all data is provided in the same format and requirements differ among users, leading to multiple possible solutions. However, FoodMapper is highly modifiable and can be further customized to meet different requirements at the national or international level. Existing and newly generated D&K can continuously be added as connectivity with other systems is enabled, and can therefore strengthen the tool even more.

List of abbreviations

API – Application Programming Interface
D&K – Data and knowledge
DKBMS – Data- and knowledgebase management system
FCD – Food composition data
FCDB – Food composition database
KB – Knowledge base
NIP – Nutrition information panel
NLP – Natural Language Processing

Contributions

Eva Valenčič: Conceptualization, Methodology, Investigation, Writing- original draft preparation
Barbara Koroušić Seljak: Conceptualization, Methodology, Software, Investigation, Writing—original draft preparation, Writing- Reviewing and Editing, Supervision, Funding acquisition
Emma Beckett: Writing- Reviewing and Editing
Tamara Bucher: Writing- Reviewing and Editing
Clare E. Collins: Writing- Reviewing and Editing.
All authors have read and agreed to the published version of the manuscript.

Funding

475 This research was supported by the Ministry of Health of Slovenia [Grant Agreement No. C2711-19-
476 185021] within the OPKP ('Upgrade of the Open platform for clinical nutrition with a mobile app')
477 project, and by the Slovenian Research Agency (research core grant number P2-0098). CEC is
478 supported by an NHMRC Leadership Research Fellowship (L3, APP2009340).

479 **Declaration of competing interest**

480 The authors declare no conflict of interest.

481 **Acknowledgments**

482 The authors gratefully acknowledge the work of Matevž Ogrinc, Andraž Simčič, Robert Modic, Tina
483 Kondić, Gregor Novak, Anemari Voršič, Gordana Ispirova and Peter Novak for their contribution to
484 the design and development of the tool. We would also like to thank Erika Jesenko, Julija Repolusk,
485 Jernej Ogrin, Kaja Kranjc and Emanuela Čerček Vilhar for their contribution to editing and
486 supplementing the database. In addition, we would like to thank Blaž Ferjančič, Anja Bolha and Mojca
487 Korošec, Tanja Pajk Žontar, Jasna Bertoncelj and Saša Piskernik from the Biotechnical Faculty of the
488 University of Ljubljana for their contribution to the development, review and the update of Slovenian
489 food composition data.

490 **References**

491 1. Harrington RA, Adhikari V, Rayner M, Scarborough P (2019) Nutrient composition databases in
492 the age of big data: foodDB, a comprehensive, real-time database infrastructure. BMJ open
493 9:e026652

494 2. Westenbrink S, Oseredczuk M, Castanheira I, Roe M (2009) Food composition databases: The
495 EuroFIR approach to develop tools to assure the quality of the data compilation process. Food
496 Chemistry 113:759–767

497 3. Emara Y, Koroušić Seljak B, Gibney ER, Popovski G, Pravst I, Fantke P (2022) Workflow for
498 building interoperable food and nutrition security (FNS) data platforms. Trends in Food Science
499 & Technology 123:310–321

500 4. EuroFIR (2022) EuroFIR - FoodEXplorer. https://www.eurofir.org/our-tools/foodexplorer/.
501 Accessed 15 Nov 2022

502 5. U.S. DEPARTMENT OF AGRICULTURE (2022) FoodData Central, food composition
503 database. In: FoodData Central, food composition database. https://fdc.nal.usda.gov. Accessed 12
504 Apr 2022

505 6. FAO - Food and Agriculture Organization (FAO) INFOODS - International Network of Food
506 Data Systems. https://www.fao.org/infoods/en/. Accessed 20 Nov 2022

507 7. TMIC FooDB. https://foodb.ca. Accessed 20 Nov 2022

8. Gurinović M, Milešević J, Kadvan A, Djekić-Ivanković M, Debeljak-Martačić J, Takić M, Nikolić M, Ranković S, Finglas P, Glibetić M (2016) Establishment and advances in the online Serbian food and recipe data base harmonized with EuroFIR™ standards. Food Chemistry 193:30–38

9. Westenbrink S, van der Vossen-Wijmenga W, Toxopeus I, Milder I, Ocké M (2021) LEDA, the branded food database in the Netherlands: Data challenges and opportunities. Journal of Food Composition and Analysis 102:104044

10. Edamam: Food and Grocery Database. https://developer.edamam.com/food-database-api. Accessed 27 Dec 2022

11. GS1. https://www.gs1.org. Accessed 27 Dec 2022

12. CEN (2022) European Standard. Food Data – Structure and Interchange Format. EN 16104:2012. https://www.en-standard.eu/bs-en-16104-2012-food-data-structure-and-interchange-format/. Accessed 12 Apr 2022

13. METROFOOD: Infrastructure for promoting Metrology in Food and Nutrition. https://www.metrofood.eu. Accessed 5 May 2022

14. Langual (2014) Langual - The International Framework for Food Description. https://www.langual.org/default.asp. Accessed 15 Nov 2022

15. European Food Safety Authority (EFSA) (2015) The food classification and description system FoodEx2 (revision 2). Wiley Online Library

16. European Food Information Resource (2022) The EuroFIR Thesauri 2008 Technical report D1.8.22. https://www.eurofir.org/our-resources/eurofir-thesauri/. Accessed 15 Nov 2022

17. CEN/TC 387. Food data – Data structure. https://www.eurofir.org/food-information/how-are-fcdbs-made/quality-and-standards/common-standard/. Accessed 12 Apr 2022

18. Dooley DM, Griffiths EJ, Gosal GS, Buttigieg PL, Hoehndorf R, Lange MC, Schriml LM, Brinkman FSL, Hsiao WWL (2018) FoodOn: a harmonized food ontology to increase global food traceability, quality control and data integration. npj Science of Food 2:23

19. Eftimov T, Ispirova G, Potočnik D, Ogrinc N, Koroušić Seljak B (2019) ISO-FOOD ontology: A formal representation of the knowledge within the domain of isotopes for food science. Food Chemistry 277:382–390

20. FNS Harmony. In: Application ontology for the H2020 FNS-Cloud project. https://github.com/panovp/FNS-Harmony. Accessed 3 Apr 2023

21. COMFOCUS: Comunity on Food Consumer Science. https://comfocus.eu. Accessed 3 Apr 2023

22. Ispirova G (2022) Exploiting Domain Knowledge in Predictive Learning from Food and Nutrition Data: Doctoral Dissertation. [G. Ispirova]

23. Gjorshoska I, Eftimov T, Trajanov D (2022) Missing value imputation in food composition data with denoising autoencoders. Journal of Food Composition and Analysis 112:104638

24. Atlassian What is a knowledge base? https://www.atlassian.com/itsm/knowledge-management/what-is-a-knowledge-base. Accessed 30 Nov 2022

25. EMBL-EBI ChEBI. https://www.ebi.ac.uk/chebi/. Accessed 20 Apr 2022

26. Machackova M, Giertlova A, Porubska J, Roe M, Ramos C, Finglas P (2018) EuroFIR Guideline on calculation of nutrient content of foods for food business operators. Food Chemistry 238:35–41

27. Cenikj G, Seljak BK, Eftimov T (2021) FoodChem: A food-chemical relation extraction model. In: 2021 IEEE Symposium Series on Computational Intelligence (SSCI). IEEE, pp 1–8

28. FoodKG FoodKG: A Semantics-Driven Knowledge Graph for Food Recommendation. https://foodkg.github.io. Accessed 27 Dec 2022

29. AtlasMedia Ltd TasteAtlas: World Food Atlas. In: Travel Global, Eat Local. https://www.tasteatlas.com. Accessed 6 Jan 2023

30. Presser K, Weber D, Norrie M (2018) FoodCASE: A system to manage food composition, consumption and TDS data. Food Chemistry 238:166–172

31. The University of Sydney (2022) GI Search. https://glycemicindex.com/gi-search/. Accessed 27 Dec 2022

32. Korošec M, Golob T, Bertoncelj J, Stibilj V, Seljak BK (2013) The Slovenian food composition database. Food Chemistry 140:495–499

33. Grande F. Food Composition Explained. https://www.foodcomponline.info. Accessed 28 Dec 2022

34. Reinivuo H, Bell S, Ovaskainen M-L (2009) Harmonisation of recipe calculation procedures in European food composition databases. Journal of Food Composition and Analysis 22:410–413

35. Pravst I, Hribar M, Žmitek K, Blažica B, Koroušić Seljak B, Kušar A (2022) Branded Foods Databases as a Tool to Support Nutrition Research and Monitoring of the Food Supply: Insights From the Slovenian Composition and Labeling Information System. Frontiers in Nutrition. https://doi.org/10.3389/fnut.2021.798576

36. Møller A, Ireland J (2013) SciName Finder™. Procedia Food Science 2:113–116

37. National Institure for Public Health Reference values for energy and nutrient intake Tabular recommendations for children (from 1 year of age), adolescents, adults, older adults, pregnant women and nursing mothers.

38. GO FAIR FAIR Principles. https://www.go-fair.org/fair-principles/. Accessed 5 Apr 2023

39. Dunford E, Webster J, Metzler AB, Czernichow S, Mhurchu CN, Wolmarans P, Snowdon W, L'Abbe M, Li N, Maulik PK (2012) International collaborative project to compare and monitor the nutritional composition of processed foods. European journal of preventive cardiology 19:1326–1332

579 40. Ispirova G, Cenikj G, Ogrinc M, Valenčič E, Stojanov R, Korošec P, Cavalli E, Koroušić Seljak
580 B, Eftimov T (2022) CafeteriaFCD Corpus: Food Consumption Data Annotated with Regard to
581 Different Food Semantic Resources. Foods. https://doi.org/10.3390/foods11172684

582 41. Greenfield H, Southgate DA (2003) Food composition data: production, management, and use.
583 Food & Agriculture Org.

584 42. Bauer J, Biolo G, Cederholm T, et al (2013) Evidence-Based Recommendations for Optimal
585 Dietary Protein Intake in Older People: A Position Paper From the PROT-AGE Study Group.
586 Journal of the American Medical Directors Association 14:542–559

587 43. Global Dietary Database. In: Global Dietary Database. https://www.globaldietarydatabase.org.
588 Accessed 20 May 2022

589 44. EFSA OpenFoodTox. https://www.efsa.europa.eu/en/data-report/chemical-hazards-database-
590 openfoodtox. Accessed 20 Apr 2022

591 45. EFSA - European Food Safety Authority. In: Publications.
592 https://www.efsa.europa.eu/en/publications. Accessed 20 May 2022

593 46. Presser K., Kapela W., Astley S., Roe M., Finglas P.
594 (https://zenodo.org/record/6966070#.Y66RKS8w1Bx) Catalogues for Data Sources and
595 Services. Accessed 2 Jan 2023

596 47. Ispirova G, Eftimov T, Koroušić Seljak B (2021) Domain Heuristic Fusion of Multi-Word
597 Embeddings for Nutrient Value Prediction. Mathematics. https://doi.org/10.3390/math9161941

598 48. Mezgec S, Eftimov T, Bucher T, Koroušić Seljak B (2019) Mixed deep learning and natural
599 language processing method for fake-food image recognition and standardization to help
600 automated dietary assessment. Public Health Nutr 22:1193–1202

601 49. Bucher T, Weltert M, Rollo ME, Smith SP, Jia W, Collins CE, Sun M (2017) The international
602 food unit: a new measurement aid that can improve portion size estimation. Int J Behav Nutr Phys
603 Act 14:124

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Chapter 5

Changing the Order of Food Items in an Online Grocery Store May Nudge Healthier Food Choices

Submitted: Valenčič E., Beckett E., Collins C.E., Koroušić Seljak B., Bucher T.

This last study incorporated all the insights from the previous studies that have shown that digital environments are a useful platform to investigate behavioural drivers. Moreover, strategically changing digital environment can have an impact on food choices. In addition, experts need to have access to relevant and trustworthy D&K, so that they can design appropriate strategies to support consumers and help them making informed food choices. Therefore, an experimental online grocery store was designed, where digital nudging knowledge was combined with food composition D&K. Specifically, the aim was to investigate whether repositioning foods based on fibre content within an experimental online grocery store can nudge healthier choices. Two experimental stores were designed, where the only difference was the position of higher-fibre foods. They were either positioned at top of the webpage within each food category (intervention group) or at the bottom (comparator condition). By re-positioning, the products were obtainable with minimal effort. Moreover, the study focused on the dietary fibre content, which has shown to have important benefits on gastrointestinal health and on the lowering of the risk of chronic diseases [62]. Moreover, in many countries, declaring dietary fibre on nutrition labels is not mandatory. Therefore, to be able to sort the products in the experimental online grocery store, dietary fibre content data from a valid FCDB had to be obtained.

The study found that changing product order within an experimental online grocery store can influence food selection. In particular, the intervention influenced the total amount of fibre in the purchased, the fibre content per 100 kcal, and the fibre per dollar spent. Furthermore, the total energy per cart and the total price per cart were not statistically different between conditions. Especially the last finding is of major importance as it shows that consumers' overall budget and supermarket revenue may not be affected when incorporating sensible strategies to nudge healthier choices.
This work fulfills the dissertation goal **O5** - Use the FCDB and KB to design an experimental web grocery store and identify effective digital nudging strategies to promote healthier choices. It also confirmed the hypothesis **H3** - Well-structured, detailed and interoperable FCDBs and KBs are useful and effective for experts to create healthier (digital) food environments.

Changing the default order of food items in an online grocery store may nudge healthier food choices

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Abstract

The environment influences food choices. Therefore, applying environmental nudging strategies could potentially improve consumer's eating behaviours and overall health. Given consumers increasingly buy food through online grocery stores, they present an avenue to nudge healthier food choices. The aim of this study was to investigate whether repositioning foods within an experimental online grocery store can be used to nudge healthier choices. Specifically, we investigated whether repositioning based on fibre content, will influence selection. Adults residing in Australia (n = 175) were randomised to either intervention (high-fibre foods on top) or comparator condition (high-fibre foods on the bottom). Participants completed a shopping task using the experimental online grocery store, and were asked to

spend up to AU$100 to purchase weekly groceries they would typically buy for one person. The results of this study show that the total fibre content per 100 kcal per cart ($p < 0.001$) and total fibre content per cart ($p < 0.036$) was higher in the intervention compared to comparator condition. The total energy per cart ($p = 0.17$) and total price per cart ($p = 0.70$) were not significantly different between conditions. Participants (48%) reported that they would like to have the option to reposition foods based on a specific nutrient criterion when shopping online. The study shows that repositioning products within an online grocery store may influence food choices towards healthier decisions. Specifically, changing the position of foods based on dietary fibre content influenced total fibre content per cart and per 100 kcal per cart. These findings have important implications for consumers, digital platform operators, researchers in health and food domains, and for policy makers.

Trial registration: AsPredicted (#114183) (25/11/2022)

Keywords: digital nudging, online grocery store, experimental store, repositioning, choice behaviour, food choice, dietary fibre.

1 Background

Environments have a major influence on what, and how much people eat [1], which in turn impacts overall health and wellbeing [2]. Attempts to promote healthy eating by focusing on educating consumers had have a limited success [3]. While nutrition education and nutrition information can provide consumers with knowledge to make informed food choices, this does not generally translate into action [3]. Although nutrition and eating behaviours are influenced by innate factors, many learned and modifiable factors also shape nutrition and eating behaviour, making the behaviour highly adaptive. The Determinants of Nutrition and Eating (DONE) interactive framework [4] emphasises that environmental factors have the greatest influences on food choices, and are the most highly

influential and modifiable. Therefore, environmental factors should be key targets for interventions and policy changes.

Most food choices have traditionally occurred in physical environments, such as supermarkets and restaurants. However, increasing technology capability and accessibility are shifting food choices to digital environments. This shift to online shopping includes online grocery shopping, technology-facilitated delivery services, pre-ordering systems and services. Following the recent COVID-19 pandemic, online food purchasing increased drastically, and consumers are now even more accustomed to ordering food online [5]. For example, in Australia almost one-quarter (23%) of the household food budget was spent ordering food online in 2022 [6]. In addition, advances in information and communication technology using user interfaces (UIs), through websites and mobile applications are making online grocery shopping and meal ordering easy. While factors, such as proximity to the checkout, are important determinants in physical environments [7] they may not be relevant within online stores. In digital environments, other factors, such as the effort needed to place an item into a basket or cart, or the colour scheme and design of the online store, might impact food choices. However, research into how different UI variables online influence consumers' decision-making processes is currently lacking.

Since food and eating environments have such a profound influence on food choices, strategically modifying them can be an effective strategy to promote healthy eating and healthy choices [8, 9]. The term *nudging* describes a strategic environmental change that alters people's behaviour in a predictable way, without forbidding any options in a paternalistic manner or directly changing economic incentives [8]. This knowledge can be strategically exploited, for example by depleting consumers cognitive resources and triggering impulse purchases, or by saliently placing products to increase sales. While it has been shown that retailers can strategically influence consumers to promote sales [10], little is

known on how to strategically improve food environments to encourage healthier choices in digital environments [11]. Since online services could provide opportunities to promote healthier food choices and eating habits, *digital nudging*, defined as "the use of UI design elements to guide people's behaviour in digital choice environments" [12], is becoming more relevant.

A recent bibliometric analysis confirmed that digital nudging is a rapidly growing field with strong historical roots in psychology [13]. However, what is not well understood is how different UI elements influence product perception and choice. A scoping review identified only 15 studies on digital nudging in online grocery stores. To date research has focused on applying different (already established) label(s), healthier swap suggestions, default options, increasing salience, or a combination of strategies [14]. Additionally, there is a lack of research focusing on the effect of repositioning food items within an online grocery store. This is surprising as studies in physical store environments have shown that placing healthy foods closer to the checkout can increase healthy food purchases [15, 16].

Therefore the aim of the current study was to investigate whether reordering healthier foods by making them obtainable with minimal effort encourages selection of healthier foods within an experimental online grocery store. In this study, this focus is on repositioning the order of foods presented online according to their dietary fibre content. This nutrient was selected because dietary fibre has been shown to have important benefits on gastrointestinal health and higher intakes are also associated with a lower risk of chronic diseases such as cardiovascular diseases, type II diabetes, specific cancers, and all-cause mortality [17]. However, current intakes do not meet recommended daily dietary fibre intake targets [18] and on average adults worldwide consume less than 20 g of dietary fibre per day [19], instead of the recommended 25–35 g per day (depending on the country) [17].

Previous studies in physical food choice environments [11] have shown that 'effort' targeted nudges can influence food choice. We therefore hypothesised that reordering products within an online grocery store according to fibre content, and thereby making them obtainable with less effort, could lead to healthier choices and increase the amount of fibre per online shopping occasion. Specifically, we hypothesised that the nudge would result in shopping carts having a higher total fibre content per 100 kcal. In addition, energy content (kcal) of the cart was hypothesised to be reduced. Nevertheless, we are aware that high fibre foods, such as whole grain bread are not necessarily lower in energy. While high fibre containing foods have less energy that is biologically available, this is not acknowledged in nutrient databases and on food labels.

2 Methods

2.1 Participants

Participants aged 18 years or older residing in Australia were recruited online via a QuestionPro research panel [20]. Participants were randomised to either intervention (higher-fibre foods positioned at top of the webpage within each food category) or comparator condition (higher-fibre foods at the bottom of the webpage within each food category). Randomisation was performed by QuestionPro, and links to two different experimental online grocery stores were sent to each research panel. Participants and researchers were blinded to group allocation. Ethical approval for the current study was obtained from the University of Newcastle Human Research Ethics Committee (Approval number H-2022-0240).

Participants completed a pre-task survey, a shopping task and a post-task survey. The shopping task required them to use the experimental online grocery store and spend up to AU$100 to shop online for weekly groceries they would typically purchase for one person (minimum order amount AU$60). No

information on identity was recorded during the research study. Participants were excluded if they completed the study (both online surveys and shopping task) in less than half the median time (i.e., 300 seconds); purchased less than 5 products from less than two food group categories; spent less than AU$50 or more than AU$150; had a body mass index (BMI) less than 15 or more than 35. In addition, participants whose 'Purchasing order number' could not be linked to a survey number were also excluded.

2.2 Experimental online grocery store

An experimental online grocery store was designed for the purpose of this study, using the Wix.com Ltd software, which provides templates for online stores that can relatively easily be ‘stocked’ with products. Previous studies have shown that using an experimental store is a valid method for investigating consumer behaviours and food choices [21, 22]. The experimental online grocery store designed for the current study contained 188 commonly purchased Australian food and beverage products and was designed to resemble an actual online grocery store (See Figure 1), but it did not take any payment nor arrange delivery of the purchased foods. Products were grouped into six categories: (i) Fruits and Vegetables, (ii) Bakery, (iii) Pantry, (iv) Freezer and Ready-to-eat, (v) Meat, Fish, Dairy, Eggs and Fridge, and (vi) Drinks and Liquor. All products included a picture of the item, item name, price in Australian dollars and quantity or unit size (e.g. 4 pack, 120g). Images on generic non-branded products were used to avoid breaching copy right and exclude effects of branding. For products where no suitable images were available, synthetic images were generated via the AI tool, DALL-E 2 [23]. Participants could add and remove products from their cart, and review the order summary before proceeding to checkout.

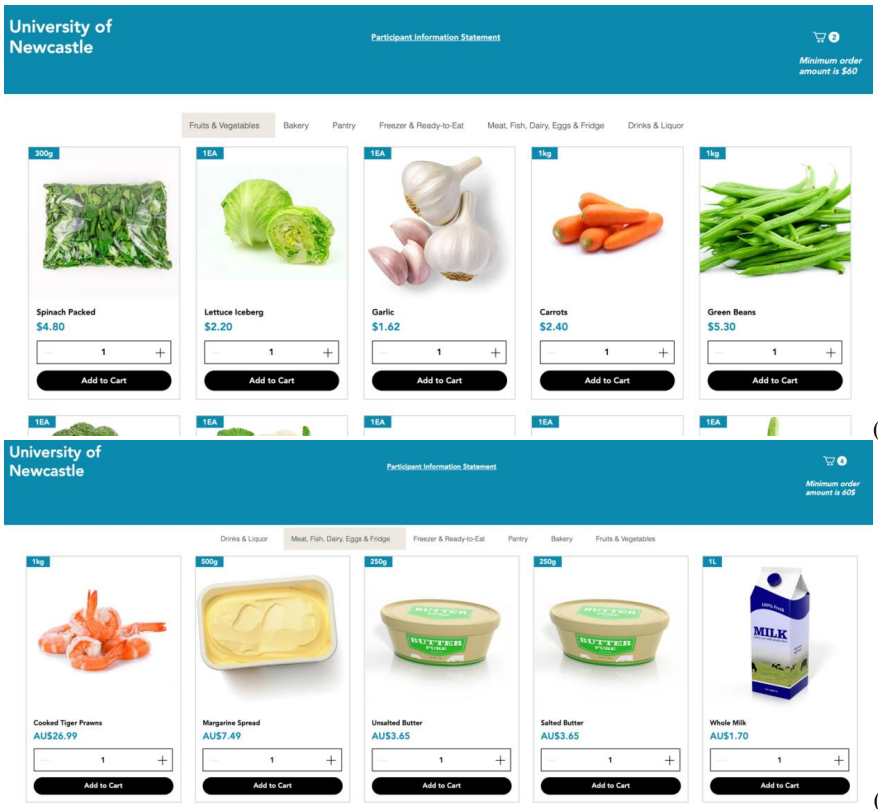

Figure 1: An example of the Fruits and Vegetables group as it appeared in the intervention experimental online store (A) and of the Meat, Fish, Dairy, Eggs and Fridge group as it appears in the comparator experimental online store (B). In the upper left corner of each item, product quantities were tied to product price (e.g., EA means 'each') are indicated.

2.3 Procedure

153 **2.3.1 Pre-task survey**

154 At the beginning of the survey, participants received a personal information statement and consent was
155 obtained online prior to data collection. Participants were asked to provide information on gender
156 ("Woman", "Man", "Non-binary", "Prefer not to say" or "Other (specify)"), year of birth, height
157 (centimetres), weight (kilograms), highest educational level or qualification ("Postgraduate degree",
158 "Bachelor's degree", "Trade certificate / TAFE qualification", "Year 8-12 or equivalent", "Did not
159 attend school") obtained and lastly their typical eating pattern ("Omnivore", "Vegetarian", "Vegan" or
160 "Other (specify)").

161 **2.3.2 Online shopping task**

162 After finishing the pre-task survey, participants had to read the instructions regarding the shopping
163 task. They were made aware that the online grocery store website was not a real commercial website,
164 and that they would not be required to spend any money and would not receive the groceries. They
165 were instructed to spend up to AU$100 by purchasing groceries that they would typically buy each
166 week, and to choose a similar item if something they wanted was not available. As the experimental
167 store resembles a real online store, participants had to provide shipping details, but were advised to
168 enter dummy data (e.g., mockup@gmail.com as an email address). Additionally, they were instructed
169 to remember or copy the order number received after placing their order, as they needed to enter it into
170 the post-task survey for verification of completion. Lastly, they were given a link which redirected
171 them to either intervention or comparator experimental online grocery store.
172
173 In both versions of the experimental stores the categories, as well as the products within categories
174 were reordered. In the intervention store, categories were ordered as followed: Fruits and Vegetables;
175 Bakery; Pantry; Freezer and Ready-to-eat; Meat, Fish, Dairy, Eggs and Fridge; and Drinks and Liquor.
176 The products within each of these categories were reordered ascendingly based on the dietary fibre

content per 100 kcal. That means that the foods with the highest content of dietary fibre per 100 kcal within each category were placed on top of the screen and the lowest dietary fibre content foods at the bottom. Participants had to scroll and/or go to the next page to locate items. For example, wholegrain products within the category 'Bakery' were at the top, whereas white-flour products and baked sweets were located at the bottom. In the comparator store, the order of categories and products was inverted. That means that the first category was Drinks and Liquor, followed by Meat, Fish, Dairy, Eggs and Fridge; Freezer and Ready-to-eat; Pantry; Bakery; and Fruits and Vegetables. The products with the lowest content of dietary fibre per 100 kcal within each category were placed at the top, while the products with the highest dietary fibre content were at the bottom. The exact order of all products within each category for both stores is presented in the Additional File 1: S1 and Additional File 1: S2.

2.3.3 Post-task Survey

Upon finalising the shopping task, participants were asked to complete the post-task survey by firstly entering their order number, that they had received at checkout. After entering a valid order number, participants were asked to indicate how often they had purchased groceries online over the past year ("Not at all in the last year", "Less than once a month", "1–3 times a month", "Once a week", "More than once a week"), what proportion of their groceries they shopped for online (0-100%), whether they were the main person responsible for grocery shopping in the household, how many people currently lived in their household and what their average total household income per month was before tax. Additionally, they were asked to indicate how they found the online shopping experience (from poor to excellent) and to indicate the level of agreement regarding following statement: "*The possibility to reorder foods based on a certain nutrient is something I would like to have when I do my usual online shopping.*" (from strongly disagree to strongly agree). They were also asked to choose their three top criteria for food choices and purchases (price, appearance, taste, habits, healthiness,

environmental impact, convenience, special offers, special diet or to specify other). Lastly, they had the opportunity to provide additional comments.

2.4 Outcomes

The primary outcomes were the differences (mean/median) between the two conditions for total fibre content per 100 kcal and number of foods containing fibre within shopping carts. Secondary outcomes were differences (mean/median) between the two conditions in total energy (kcal) per shopping cart, total fibre (g) per cart and total price (AU$) of the shopping cart between the two conditions.

2.5 Analysis

Declaring dietary fibre on nutrition labels is currently not mandatory in Europe [24] or Australia (unless a nutrition claim about fibre is made on the label) [25]. Therefore, to be able to sort the products the dietary fibre data was obtained from food composition database. For analysis, all products used in the experimental store were linked with the Australian food composition database (AUSNUT 2011-13) [26]. In the database nutrient values were presented per 100g edible portion, and energy was presented in kilojoules (kJ). These values were used to calculate kilocalories (kcal) per 100 g, kcal per unit, dietary fibre per unit and fibre per 100 kcal. Each product was coded as containing fibre or not, based on the Codex Alimentarius: Guidelines for use of Nutrition and health claims [27], where foods containing at least 1.5 g/100kcal of dietary fibre were considered as being a ‘source of fibre’.

Descriptive statistics were used to describe the properties of participants using Microsoft Excel and R software [28] (v. 4.2.0, for iOS). Demographic details were summarised with frequencies, means/medians, and standard deviations (SD) as appropriate. Data was tested for normality using the Shapiro–Wilk test, and the homogeneity of variances was tested using Levene’s test, using R software; p-values < 0.05 were considered statistically significant. Chi-square tests and Wilcoxon rank-sum test

were performed to check whether the conditions were well matched for baseline characteristics. Since data was non-parametric, statistical comparison of total fibre content per 100 kcal, total number of fibre-source foods, total energy (kcal) per shopping cart and total price of shopping cart contents between conditions was performed using a Wilcoxon rank-sum test.

The hypothesis was that reordering products according to dietary fibre content would result in shopping carts containing more total fibre content per 100 kcal, and a lower energy content. All hypotheses and methods for data cleaning and analysis were registered on the AsPredicted platform [29] prior to study commencement (trial registration number: #114183).

3 Results

3.1 Participants

A total of 303 adults completed the study. Of those, 128 were excluded based on the exclusion criteria described in section 2.1 (31 participants completed the study in less than 300 seconds, 54 reported a BMI less than 15 or more than 35, and 43 participants purchased less than five products from less than two food group categories or spent less than AU$50 or more than AU$150). Therefore, data from 175 adults were included in the final analysis. Participants were randomised into the intervention (n = 82) and the comparator (n = 93) condition. On average participants needed 17.3 minutes to complete the study.

The mean age of participants was 38.6 years (±15.3) and 72.6% identified as female (n = 127), 26.3% as male (n = 46) and 1.1% as non-binary (n = 2). The majority (90.3%) of participants were the main person responsible for grocery shopping in their household. The average BMI of the sample was 25.0 kg/m^2 (±4.6). In addition, the greatest proportion of participants had a trade certificate or TAFE

246 qualification (29.7%), were omnivores (89.7%), lived in a household of two people (30.9%) and had a
247 mean total household income per month before tax of less than AU$5'000 (44.6%). Participants on
248 average purchased 33.6% of their groceries online, and over the past year the greatest proportion
249 (27.4%) purchased groceries online less than once a month. When asked about the top three factors
250 that affect their decisions when purchasing foods online, most participants selected price (86.9%), taste
251 (66.3%) and healthiness (33.1%), whereas environmental factors were the least important (5.7%). See
252 Table 1 for more details. There was no significant difference between groups in terms of demographics.

253 **Table 1: Sample characteristics.**

Variable		Condition	
	Total (*n* = 175)	Intervention (*n* = 82)	Comparator (*n* = 93)
Age in years M (SD)	38.6 (15.3)	39.6 (15.4)	37.7 (15.2)
BMI M (SD)	25.0 (4.6)	25.5 (4.3)	24.7 (4.9)
Gender *n* (%)			
Woman	127 (72.6)	57 (32.6)	70 (40.0)
Man	46 (26.3)	25 (14.3)	21 (12.0)
Non-binary	2 (1.1)	0 (0.0)	2 (1.1)
Education *n* (%)			
Postgraduate degree	34 (19.4)	16 (9.1)	18 (10.3)
Bachelor's degree	50 (28.6)	29 (16.7)	21 (12.2)
Trade certificate / TAFE qualification	52 (29.7)	25 (14.3)	27 (15.4)
Year 8-12 or equivalent	39 (22.3)	12 (6.9)	27 (15.4)
Did not attend school	0 (0.0)	0 (0.0)	0 (0.0)
Eating patterns *n* (%)			
Omnivore	157 (89.7)	72 (41.1)	85 (48.6)
Vegetarian	12 (6.9)	7 (4.0)	5 (2.9)
Vegan	2 (1.1)	2 (1.1)	0 (0.0)
Other	4 (2.3)	1 (0.6)	3 (1.7)
Household size *n* (%)			
1 person	30 (17.1)	6 (3.4)	24 (13.7)
2 people	54 (30.9)	34 (19.4)	20 (11.4)
3 people	30 (17.1)	16 (9.1)	14 (8.0)
4 people	28 (16.0)	13 (7.4)	15 (8.6)
5 people	20 (11.4)	7 (4.0)	13 (7.4)
6 or more people	13 (7.4)	5 (3.4)	7 (4.0)
Income *n* (%)			
Less than AU$5000	78 (44.6)	34 (19.4)	44 (25.1)
AU$5000-10.000	64 (36.6)	35 (20.0)	29 (16.6)
More than AU$10.000	33 (18.9)	13 (7.4)	20 (11.4)

Frequency of online purchases in the last year *n* (%)			
Never	44 (25.1)	24 (13.7)	20 (11.4)
Less than once a month	48 (27.4)	18 (10.3)	30 (17.1)
1-3x a week	41 (23.4)	18 (10.3)	23 (13.1)
Once a week	35 (20.0)	19 (10.9)	16 (9.1)
More than once a week	7 (4.0)	3 (1.7)	4 (2.3)
Proportion of groceries purchased online %	33.6	32.6	34.5
Factors affecting purchasing decision *n* (%)			
Price	152 (86.9)	71 (40.6)	81 (46.3)
Taste	116 (66.3)	55 (31.4)	61 (34.9)
Healthiness	58 (33.1)	22 (12.6)	36 (20.6)
Special offers	57 (32.6)	30 (17.1)	27 (15.4)
Convenience	39 (22.3)	17 (9.7)	22 (12.6)
Appearance	37 (21.1)	18 (10.3)	19 (10.9)
Habits	36 (20.6)	13 (7.4)	23 (13.1)
Special diet	18 (10.3)	11 (6.3)	7 (4.0)
Environmental factors	10 (5.7)	7 (4.0)	3 (1.7)
Other	2 (1.1)	2 (1.1)	0 (0.0)

3.2 Primary outcome

As hypothesised the total fibre content per 100 kcal per cart was higher in the intervention shopping cart compared to the comparator condition ($p < 0.001$). The total number of fibre-source foods (defined as containing at least 1.5 g/100kcal [30]) added to shopping carts was not significantly different between groups ($p = 0.67$). See Table 2 for more details.

3.3 Secondary outcomes

The total fibre content per cart was significantly higher in the intervention compared to comparator condition ($p < 0.036$). The total energy per cart was not statistically different ($p = 0.17$) between conditions. Results also indicated that the total grocery price per cart was not statistically different between conditions ($p = 0.70$). In addition, total fibre content per dollar was significantly higher in the intervention compared to comparator condition ($p = 0.016$), whereas total energy per dollar was not statistically different between conditions ($p = 0.15$). See Table 2 for more details.

Table 2: Outcomes.

Condition	Total (*n* = 175)			Intervention (*n* = 82)			Comparator (*n* = 93)			Wilcoxon
	Mdn	*IQR*	*CI*	*Mdn*	*IQR*	*CI*	*Mdn*	*IQR*	*CI*	*W*
Fibre content g/100 kcal	1.45	0.8	1.4;1.6	1.62	0.91	1.5; 1.9	1.34	0.73	1.2;1.4	2487***
Fibre g/cart	245.9	166.8	212;273	270.3	176.6	212;312	219.9	150.4	190;264	3111*
Number of fibre-source foods/cart	15	15.5	13;18	15	14.8	12;20	15	17	12;20	3668.5
Energy kcal/cart	16’280	6’817	15’411; 17’083	15’840	6’654	14’194; 17’627	16’689	7’262	15’411; 18’131	4271
Price $AU/cart	99.0	7.8	98.2; 99.6	98.9	7.2	97.4; 99.7	99.1	7.9	97.7; 100	3943
Fibre g/$AU	2.48	1.44	2.3;2.7	2.78	1.63	2.2;3.1	2.37	1.3	2.0;2.6	3003*
Energy kcal/$AU	164.5	66.0	156.7; 172.4	158.5	65.0	139.9; 174.0	170.3	64.8	159.4; 185.6	4300

*$p<0.05$, **$p<0.01$, ***$p<0.001$, *Mdn* = Median, *IQR* = Inter quartile range, *CI* = 95% Confidence interval.

In the post-task survey participants were debriefed by telling them that the foods were arranged according to their fibre content, which may have increased or decreased their effort in locating a particular food. Next, they were asked to indicate their level of agreement regarding preference regarding a possibility to reorder foods based on a certain nutrient when shopping online. Results indicated that 48% of participants agreed or strongly agreed with the statement, and 39% neither agreed nor disagreed (Figure 2).

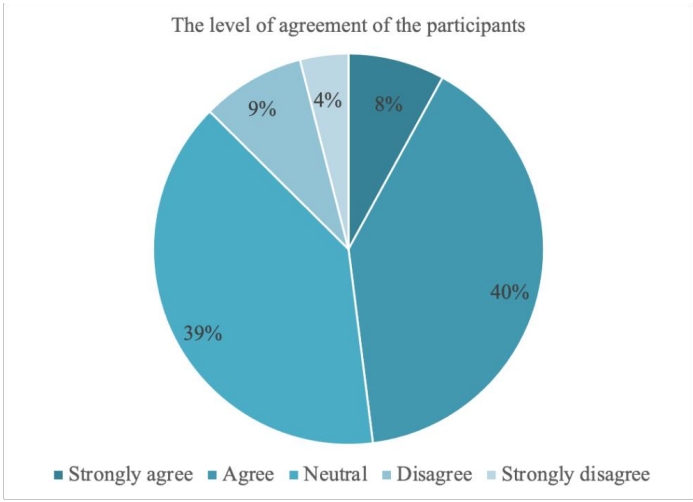

Figure 2: Level of agreement with the statement: *'The possibility to reorder foods based on a certain nutrient is something I would like to have when I do my usual online shopping.'*

4 Discussion

The current study found that changing product order within an online grocery store could influence which foods people added into their shopping cart. Specifically, changing the order of foods based on dietary fibre content influenced the total amount of fibre in the foods chosen (increase of 50.4 g), the fibre content per 100 kcal per cart (increase of 0.28 g per 100 kcal) and the fibre per dollar spent (increase of 0.41 g per AU$). These results are promising and potentially of high impact in influencing population intake and health risks, particularly as research indicates that for every 10 g/day increase in dietary fibre, the risk of coronary heart disease is reduced by 14%, and the risk of coronary mortality by 27% as reported in a pooled analysis of prospective cohort studies [31]. Additionally, Howarth et al. [32] summarised the effects of dietary fibre on hunger, satiety, energy intake and body composition in healthy people, and found that a 10% decrease in total energy intake was associated with body weight reduction of 1.9 kg over 3.8 months when consuming an additional 14 g of dietary fibre per day.

290

291 Previous studies found that positional changes in real-life settings (e.g., cafeteria) had a positive
292 influence on food choice overall, and that nudging healthier food choices was successful [33–36]. In a
293 systematic review by Bucher et al. [11], it was concluded that food positioning influences food choice
294 if it alters the levels of effort to obtain the food, i.e., if there is a reduced effort to obtain healthy foods,
295 people selected more healthy food. To date, very little is known about how strategic changes within
296 online grocery stores (i.e., digital nudges) influence food choice [14], and there is a lack of research on
297 the effect of positioning food products. However one other study, which also used an experimental
298 online store, found that repositioning products based on lower saturated fat content, leads to overall
299 less saturated fat purchased [37]. The current study adds to the evidence that modification of product
300 order and food category arrangement based on nutrient criteria can be to support and encourage
301 healthier food choices in online purchasing environment. In general UI changes in online grocery stores
302 can easily be customised, compared with real life grocery store settings.

303

304 In the future, UIs could potentially be personalized for specific consumer need. Reordering products
305 based on differing nutrient criteria (including sodium, saturated fat, free sugars, not just dietary fibre)
306 could help personalise grocery purchasing to optimise nutrient intakes and assist in meet their needs.
307 Whether individuals have specific dietary needs, follow special diets, environmental factors, or
308 financial constraints, etc. The results of the current study indicated that most consumers (almost 90%)
309 wanted the option (48%) to reorder foods presented online based on specific nutrients when shopping
310 online or were neutral (39%) regarding this option. A recent study implemented dynamic food labels
311 with real-time feedback in an experimental online grocery store [38] where participants were able to
312 switch between different nutrition information panel nutrient displays and then access products
313 according to specific nutritional content (total fat, saturated fat, sugar, Calories per serving, etc.), and
314 to sort products within a category. The researchers found that nutritional quality improved and sugar

315 content of purchased products decreased, compared to the control condition, with the features
316 implemented found to be useful and user-friendly [38]. Therefore, future online grocery stores should
317 offer the option to consumers to sort or reorder products according to their individual (dietary) needs.
318 This offers multiple possibilities for online stores to encourage positive dietary changes that potentially
319 influence, not only population health, but also the overall environment, for example by adding
320 environmental impact score as one of the options.
321
322 However, the current results highlighted that price was the most important factor individual reported
323 affecting their purchasing decisions, which is in agreement with other marketing research [39, 40].
324 Since online stores commonly make decisions regarding product arrangement without consumer's
325 approval or awareness, it is likely that products are arranged to maximise sales or let brands pay for
326 positioning within their stores. Future research should therefore investigate whether regulating the
327 order of products presented is warranted or that it be mandated to offer consumers the option to choose
328 how products are presented to them. Results from the current study indicate that the total median cost
329 of foods purchased per shopping cart was not significantly different between conditions. This may be
330 because price is generally the most important shopping decision criteria, and that consumers are more
331 conscious about price compared to other factors. Of major importance is that it also indicates that
332 nudges related to the order in which items are shown online may be a simple way to nudge healthy
333 food or sustainable choices without affecting consumers' overall budget, or supermarket revenue.
334
335 Clearly, (online) stores can impact purchasing behaviours, by using strategic design and marketing to
336 increase sales. The WHO report on obesity and overweight [2] indicates that industry should restrict
337 marketing of foods high in sugars, salt and fats, and ensure that healthy and nutritious choices are
338 available and affordable. However, research shows that food marketing is still mainly used to promote

339 foods with less favourable nutritional composition [41–45]. Since promoting healthy eating is
340 challenging, implementing regulations regarding food marketing strategies is necessary.
341
342 Considering the rapid global growth rate in online grocery markets, [46] digital nudges promoting
343 healthy and sustainable food choices have enormous potential to support for public health. However,
344 there is also the risk that companies abuse strategic changes to increase profits, without considering
345 effects on diet, individual- and planetary health outcomes. This raises ethical questions, which should
346 be addressed through corporate responsibility and embedded in policy. Currently, access to transparent
347 information about which nudging strategies are being used in online stores is limited. This means
348 understanding of the impact of individual (or a combination of) nudging strategies on purchasing
349 choices is also limited. Hence, gaining access to such information could assist researchers to further
350 investigate how to personalised UIs to benefit consumers and encourage them to make healthier food
351 choices.

352 **4.1 Strengths and Limitations**

353 There is a debate on the effectiveness of nudging to alter behaviour [47, 48] and hence a call for better
354 study design and trial registration. Hypotheses were pre-registered and data is publicly available for
355 future research and comparison purposes. Despite the contributions of the current study the research
356 limitations need acknowledgment. Firstly, there was no condition with a random order of products.
357 Thus, future studies should include and intervention arm that randomly present foods within food
358 categories. In addition, future studies should validate choices from the experimental store by comparing
359 them to actual online purchases. This would confirm whether choices in the experimental store translate
360 to real-life situations by validating what consumers have actually purchased when spending their own
361 money. However, other online studies have shown that choices made in experimental stores are a valid
362 proxy for real consumer choices [49].

Additionally, a relatively large number of participants did not complete the full survey. This was likely because the participant burden was relatively high. Future studies should reduce burden by removing the need to enter 'checkout details' and automatically redirect participants back to the post-task survey. However, working with a prebuild platform allowed us to design a realistic experimental online store environment with relatively little effort. Lastly, the current study used a limited set of generic non-branded products. Future studies could use more foods and could further investigate how brands, loyalty and familiarity with products moderate nudging effects. Despite these limitations, the current study is one of the first to investigate a product order 'nudge' based on nutrient information not commonly available on food labels, and has implications for practice and scope for further research.

5 Conclusion

The current study indicates that repositioning food products in an experimental online grocery store could influence food choice towards healthier purchase decisions. For consumers, this research provides insight regarding how UIs related to what people see when ordering food online, can consciously or unconsciously affect food choice decisions, both positively and negatively. For digital platform operators (i.e., online grocery stores) this research could inform UI design guidelines. For researchers in health promotion, nutrition and dietetics, this project provides important theoretical knowledge that advances the field and may inform the development of interventions to promote healthy food choices. Given people are not meeting recommended daily intakes for many nutrients (e.g., iron, protein, etc.), opportunities exist to implement repositioning of food products to optimise food and/or nutrient intake based on individual needs or preferences. Lastly, for policy makers, result could inform whether regulations and/or codes of practice regarding design changes (digital nudges) within online food choice settings are needed to protect consumers (e.g., in food delivery apps, online school meal

ordering systems). Additionally, policies that allow access to transparent data and information from food industry and digital platform operators that could assist when designing UI, are warranted.

6 List of abbreviations

UI: user interface

BMI: body mass index

7 Supplementary material

Supplementary file S1: The exact order of categories and products within intervention condition;

Supplementary file S2: The exact order of categories and products within comparator condition.

8 Availability of data and materials

The datasets used and analysed during this study is available on (*Zenodo link to the dataset to be added after acceptance*).

9 Acknowledgments

The authors wish to thank Irma Dupuis for her contribution to the development of the experimental store. In addition, we would like to thank QuestionPro team for their help with the recruitment of participants.

10 Author's Contributions

EV prepared and analysed the data, and was responsible for the first drafting of the manuscript. EB, CEC, BKS and TB provided critical manuscript feedback. All authors read and approved the final manuscript.

Declaration of interest: None

11 Funding

407 This research was supported by the Australian Research Council (ARC DP210100285) and the Hunter
408 Medical Research Institute, Food and Nutrition Group. Additionally, this work was undertaken within
409 the OPKP ('Upgrade of the Open platform for clinical nutrition with a mobile app') project, which has
410 received funding from the Ministry of Health of Slovenia under Grant Agreement No. C2711-19-
411 185021, and by the Slovenian Research Agency (research core grant number P2-0098: Computer
412 Structures and Systems). CEC is supported by an NHMRC Leadership Research Fellowship (L3,
413 APP2009340).

414 **12 References**

415 1. Hill JO, Wyatt HR, Reed GW, Peters JC (2003) Obesity and the environment: where do we go
416 from here? Science 299:853–855

417 2. WHO Obesity and overweight facts sheet: World Healtth Organization.

418 3. Bucher T, Van der Horst K, Siegrist M (2013) Fruit for dessert. How people compose healthier
419 meals. Appetite 60:74–80

420 4. Stok FM, Hoffmann S, Volkert D, et al (2017) The DONE framework: Creation, evaluation, and
421 updating of an interdisciplinary, dynamic framework 2.0 of determinants of nutrition and eating.
422 PLOS ONE 12:e0171077

423 5. OJ Digital Solutions Online Grocery Shopping Statistics. https://ojdigitalsolutions.com/online-
424 grocery-shopping-statistics/. Accessed 23 Jan 2023

425 6. Spryker Online Grocery Report 2022. https://spryker.com/press-release-australian-online-
426 grocery-report-2022/. Accessed 30 Jan 2023

427 7. Maas J, de Ridder DTD, de Vet E, de Wit JBF (2012) Do distant foods decrease intake? The effect
428 of food accessibility on consumption. Psychology & Health 27:59–73

429 8. Thaler RH, Sunstein CR (2008) Nudge: Improving decisions about health, wealth, and happiness.
430 Penguin

431 9. Marteau TM, Ogilvie D, Roland M, Suhrcke M, Kelly MP (2011) Judging nudging: can nudging
432 improve population health? Bmj 342:

433 10. Roschk H, Loureiro SMC, Breitsohl J (2017) Calibrating 30 years of experimental research: a
434 meta-analysis of the atmospheric effects of music, scent, and color. Journal of Retailing 93:228–
435 240

11. Bucher T, Collins C, Rollo ME, McCaffrey TA, De Vlieger N, Van der Bend D, Truby H, Perez-Cueto FJ (2016) Nudging consumers towards healthier choices: a systematic review of positional influences on food choice. British Journal of Nutrition 115:2252–2263

12. Weinmann M, Schneider C, Brocke J vom (2016) Digital nudging. Business & Information Systems Engineering 58:433–436

13. Piper J., Adam Marc T.P., De Vlieger N., Collins C.E., Bucher T. (2021) A Bibliometric Review of Digital Nudging within Digital Food Choice Environments. Sydney, Australia, pp 1–12

14. Valenčič E, Beckett E, Collins CE, Seljak BK, Bucher T (2022) Digital nudging in online grocery stores: A scoping review on current practices and gaps. Trends in Food Science & Technology. https://doi.org/10.1016/j.tifs.2022.10.018

15. Huitink M, Poelman MP, Seidell JC, Kuijper LDJ, Hoekstsra T, Dijkstra C (2020) Can Healthy Checkout Counters Improve Food Purchases? Two Real-Life Experiments in Dutch Supermarkets. International Journal of Environmental Research and Public Health. https://doi.org/10.3390/ijerph17228611

16. Sigurdsson V, Larsen NM, Gunnarsson D (2014) Healthy food products at the point of purchase: An in-store experimental analysis. Journal of Applied Behavior Analysis 47:151–154

17. Gill SK, Rossi M, Bajka B, Whelan K (2021) Dietary fibre in gastrointestinal health and disease. Nature Reviews Gastroenterology & Hepatology 18:101–116

18. Koroušić Seljak B, Valenčič E, Hristov H, Hribar M, Lavriša Ž, Kušar A, Žmitek K, Krušič S, Gregorič M, Blaznik U (2021) Inadequate Intake of Dietary Fibre in Adolescents, Adults, and Elderlies: Results of Slovenian Representative SI. Menu Study. Nutrients 13:3826

19. Mayor S (2019) Eating more fibre linked to reduced risk of non-communicable diseases and death, review finds. BMJ 364:l159

20. QuestionPro QuestionPro: Survey respondents. https://www.questionpro.com/audience/. Accessed 28 Feb 2023

21. Forwood SE, Ahern AL, Marteau TM, Jebb SA (2015) Offering within-category food swaps to reduce energy density of food purchases: a study using an experimental online supermarket. International Journal of Behavioral Nutrition and Physical Activity 12:1–10

22. Finkelstein EA, Ang FJL, Doble B, Wong WHM, van Dam RM (2019) A randomized controlled trial evaluating the relative effectiveness of the multiple traffic light and nutri-score front of package nutrition labels. Nutrients 11:2236

23. Open AI Dall-e. https://openai.com/dall-e-2/. Accessed 15 Nov 2022

24. Regulation (Eu) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers.

25. Food Standards Australia New Zealand Nutrition information panels. https://www.foodstandards.gov.au/consumer/labelling/panels/Pages/default.aspx. Accessed 28 Feb 2023

26. AUSNUT: Food Composition Database. In: Food Nutrient Database. https://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/foodnutrient/Pages/default.aspx. Accessed 15 Nov 2022

27. Codex Committee on Food Labelling (2013) Guidelines for use of nutrition and health claims (CAC/GL 23-1997). 8

28. Field A, Miles J, Field Z (2012) Discovering statistics using R. Sage publications

29. Wharton Credibility Lab, University of Pennsylvania AsPredicted. https://aspredicted.org. Accessed 27 Feb 2023

30. Food Standards Australia New Zealand Qualifying criteria for nutrition content claims about dietary fibre in Standard 1.2.7 – Nutrition, Health and Related Claims. https://www.foodstandards.gov.au/industry/labelling/Documents/Qualifying%20criteria%20for%20dietary%20fibre%20claims%20post%20board.pdf. Accessed 28 Feb 2023

31. Pereira MA, O'Reilly E, Augustsson K, Fraser GE, Goldbourt U, Heitmann BL, Hallmans G, Knekt P, Liu S, Pietinen P (2004) Dietary fiber and risk of coronary heart disease: a pooled analysis of cohort studies. Archives of internal medicine 164:370–376

32. Howarth NC, Saltzman E, Roberts SB (2001) Dietary Fiber and Weight Regulation. Nutrition Reviews 59:129–139

33. Romero M, Biswas D (2016) Healthy-left, unhealthy-right: Can displaying healthy items to the left (versus right) of unhealthy items nudge healthier choices? Journal of Consumer Research 43:103–112

34. Dayan E, Bar-Hillel M (2011) Nudge to nobesity II: Menu positions influence food orders. Judgment and Decision making 6:333–342

35. van Kleef E, Seijdell K, Vingerhoeds MH, de Wijk RA, van Trijp HCM (2018) The effect of a default-based nudge on the choice of whole wheat bread. Appetite 121:179–185

36. Baskin E, Gorlin M, Chance Z, Novemsky N, Dhar R, Huskey K, Hatzis M (2016) Proximity of snacks to beverages increases food consumption in the workplace: A field study. Appetite 103:244–248

37. Koutoukidis DA, Jebb SA, Ordóñez-Mena JM, Noreik M, Tsiountsioura M, Kennedy S, Payne-Riches S, Aveyard P, Piernas C (2019) Prominent positioning and food swaps are effective interventions to reduce the saturated fat content of the shopping basket in an experimental online supermarket: A randomized controlled trial. International Journal of Behavioral Nutrition and Physical Activity. https://doi.org/10.1186/s12966-019-0810-9

38. Shin S, van Dam RM, Finkelstein EA (2020) The effect of dynamic food labels with real-time feedback on diet quality: Results from a randomized controlled trial. Nutrients 12:1–16

39. DiSantis KI, Grier SA, Odoms-Young A, Baskin ML, Carter-Edwards L, Young DR, Lassiter V, Kumanyika SK (2013) What "Price" Means When Buying Food: Insights From a Multisite Qualitative Study With Black Americans. Am J Public Health 103:516–522

40. Steenhuis IH, Waterlander WE, de Mul A (2011) Consumer food choices: the role of price and pricing strategies. Public Health Nutrition 14:2220–2226

41. Lavriša Ž, Pravst I (2019) Marketing of Foods to Children through Food Packaging Is Almost Exclusively Linked to Unhealthy Foods. Nutrients. https://doi.org/10.3390/nu11051128

42. Harris JL, Fleming-Milici F (2019) Food marketing to adolescents and young adults: Skeptical but still under the influence. In: The Psychology of Food Marketing and (Over) Eating. Routledge, pp 25–43

43. Grigsby-Toussaint DS, Rooney MR (2013) Food Marketing Targeting Youth and Families: What Do We Know about Stores Where Moms Actually Shop? Journal of Environmental and Public Health 2013:674181

44. Folkvord F, Hermans RCJ (2020) Food Marketing in an Obesogenic Environment: a Narrative Overview of the Potential of Healthy Food Promotion to Children and Adults. Current Addiction Reports 7:431–436

45. van der Bend DLM, Jakstas T, van Kleef E, Shrewsbury VA, Bucher T (2022) Making sense of adolescent-targeted social media food marketing: A qualitative study of expert views on key definitions, priorities and challenges. Appetite 168:105691

46. Precedence research Online Grocery Market - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2022 – 2030. https://www.precedenceresearch.com/online-grocery-market. Accessed 8 Feb 2023

47. Marchiori DR, Adriaanse MA, De Ridder DTD (2017) Unresolved questions in nudging research: Putting the psychology back in nudging. Social and Personality Psychology Compass 11:e12297

48. Congiu L, Moscati I (2022) A review of nudges: Definitions, justifications, effectiveness. Journal of Economic Surveys 36:188–213

49. Waterlander WE, Jiang Y, Steenhuis IHM, Mhurchu CN (2015) Using a 3D virtual supermarket to measure food purchase behavior: a validation study. Journal of medical Internet research 17:e3774

Chapter 6

Discussion

6.1 Main Findings of the Dissertation

Poor food choices can contribute to various health problems, whereas making healthy choices can be a key factor in preventing and managing such conditions. Promoting healthier choices is therefore of great importance. However, despite consumers' awareness of the importance and benefits of healthy food choices, they are still struggling with following dietary guidelines and meeting recommended intakes for specific food groups and nutrients. This might also be, because of the complexity of the decision-making process [63], [64] caused by a range of reasons, such as lack of knowledge, emotional, social and cultural factors, as well as accessibility and financial constraints. Moreover, providing consumers with multiple complex information, or not providing complete information, may confuse them and lead to incorrect judgment of a food's healthiness. Therefore, facilitating decision-making process by emphasizing better food and food choices, can help consumers to more easily make appropriate decisions about their health. Furthermore, it has been proposed that the role of conscious/cognitive determinants has been overestimated and that the connection between environments and behaviours needs to be considered [65]. This is in contrast with the prevailing theories about health behaviour, such as the theory of planned behaviour [66], the social cognitive theory [67] or self-determination theory [68]. Focusing on promotion of actions instead of motivation might have a positive effect on behaviour changes [69]. That might also be the reason nutrition interventions focusing on consciously changing consumer behaviours have not been the most successful.

Novel solutions to address the unconscious effect of the environment on consumers' behaviours are required. One could be to strategically create food choice environments, which will direct consumers attention towards healthier food choices. As the decision-making process is increasingly transitioning into digital environments, there is a growing need for in depth exploration of these environments in connection with food choices. In particular, there is still an open question regarding how to strategically implement digital nudging strategies. Therefore, the digital food environment requires new approaches that have not yet been sufficiently explored.

The overarching purpose of my dissertation was to investigate the research questions regarding whether and what types of digital nudging strategies can effectively promote healthier food choices in a digital setting. First, a scoping review was conducted to synthesize the types of nudges currently investigated in online grocery shops, and to synthesise effects and identify gaps and limitations within studies conducted on nudging healthier food choices in this setting. Based on the review, it was concluded that it is important to continue the research in this area. Secondly, a study to investigate whether specific UI design elements of a mobile app, designed for tracking snack consumption, could

influence consumers' snack choices, was conducted. This study highlighted the need for innovative design approaches involving food and nutrition D&K to effectively promote healthier food choices. However, it was found that although many resources of food and nutrition D&K exist, an integrated solution that provides structured information to meet the specific goals is still missing. To address this, a new management system that integrates food and nutrition-related D&K in accordance with the FAIR principles, was developed. To finally prove the effectiveness of the integration of D&K into the development process of UI design elements, an experimental online grocery store, where food products were sorted and presented to the consumer, based on dietary fibre content, was designed and tested. These findings can further lead to promoting better food choices with respect to the amount of dietary fibre.

6.1.1 Review on Digital Nudging in Grocery Stores

Findings of the scoping review suggest that consumers can be approached and influenced via different nudging strategies. However, it was found that the inconsistent use of digital nudging definitions impacts literature synthesis. Thus, clearly describing, classifying, understanding and testing nudging strategies is key to gaining insights into which are effective and whether positive outcomes can be expected. As highlighted by the review, the inconsistency in nudging descriptions and terminology used in the literature may limit the conducted study, as some papers might not have been captured and included in the analysis. Specifically, based on the literature search, it is important to emphasise that the meaning of ‘digital nudging’ and ‘applying nudges in a digital setting’ are not the same. For example, sending e-mails to remind (and therefore nudge) consumers to have a glass of water, might increase their water intake. However, it does not fit into digital nudging definition.

Digital nudging strategies that target subconscious processes may make consumers more receptive to nudges and may therefore be more effective. As consumers are usually not paying attention to the specific UI design features (e.g., colours, the position of buttons), they could be modified to positively influence food choice behaviours on a subconscious level. At this point it is also important to emphasise the ethical considerations related to nudging [70]. The findings about digital nudging and how UI alterations might influence consumer behaviour, could potentially also be misused to promote higher sales or the sales of unhealthy food. It is important to note that 'neutral' design does not exists, and often a choice architect has to make a choice intentionally. Therefore, it is especially important for choice architects to be aware of the potential that nudging may hold, and hence it needs to be implemented accordingly. Moreover, nudging should be transparent, or at least consumers should be aware of it, and subject to public scrutiny to avoid ethical objections.

As mentioned in the previous paragraph, researchers need to be aware that UI can be a powerful tool to influence consumers. For example, placing a button on the left- or right-hand side of the screen may impact consumers. Hence, according to the results of the review, UIs need to be designed with purpose and based on knowledge of their effects. Further, they also need to be described in detail to specifically identify potential effect(s). Currently, as observed also in the document from World Health Organisation [71], a lack of theoretical understanding and empirical evidence limits our comprehension of the impacts of digital environments and how can they support healthier food choices. Therefore, developing a theoretical framework and taxonomies for digital nudges is warranted. Together with well-defined taxonomic terms, logical relationships between them need to further be described. This will allow linking and comparability of research findings. Thus, developing and using ontologies and knowledge graphs (semantic resources) to annotate and standardise data, is of importance and can be impactful [72]. Currently, there

exist ontologies providing knowledge about food. Their purpose is to provide data standardisation, interoperability, reusability and quality control, and to facilitate traceability, which is becoming critical due to increasing globalization. For example, FoodOn – a global farm-to-fork ontology about food [73] or ISO-FOOD which describes isotopic data [74]. However, in the consumer science field these are still lacking, although one (COMFOCUS) is currently under development [75]. In addition, information extraction is largely investigated within the biomedical domain, likely due to large collections of annotated biomedical data. However, the food and nutrition research field still lacks semantic resources, and would benefit from additional resources such as CafeteriaFCD Corpus developed based on food composition data [76]. Such resources can further be used for different purposes, for example, they can contribute to improve the automation of systematic literature reviews. Commonly, systematic reviews are not conducted quickly enough to support the rapid implementation, mainly because of the length of the process, review cost and the expertise needed to conduct a comprehensive review. Therefore, systems to ease the process of conducting a systematic review or its specific tasks, are desirable. Clearly, developing taxonomies and other semantic resources for digital nudges would be beneficial for choice architects when developing nudging strategies, as it can ease the process of reviewing the literature, as well as standardised the outcomes.

Moreover, while summarising the literature, it was observed that different nudging strategies can have mixed effects on nutrition-related outcomes. For example, as discussed in the review, inclusion of different labels may be effective, if the goal is to select foods that contain a label. However, they seem not to be effective when goals were to lower total energy content of the shopping carts. Furthermore, they can have the opposite effect, as they may reduce the likelihood of choosing foods containing the desired nutrients (e.g., proteins). Clearly, manipulation of digital environments must be done in a controlled manner, to avoid unwanted results. However, this is currently not well investigated, and interventions testing the relative impact of different nudging strategies are needed.

6.1.2 Mobile Application to Assess the Influence of the Environments

Based on the learnings of the literature review, the second study to investigate the impact of background imagery on consumers' food choices was conducted. Specifically, the goal of the study was to investigate whether modifying background imagery within mobile digital environments can influence food selection. Thus, an innovative mobile tool developed specially for this purpose was tested. The developed open-source mobile app is modifiable allowing UI to be easily adapted to specific goal [77], [78]. As imagery was the subject of the study, the influence of adding a background image to the food-tracking mobile application was investigated in regard to app-users' food choices. Users were not aware of the intentionally selected background being tested. The study showed that digital nudging might have effects that were the opposite to that intended. One of the most interesting results was that healthier foods were consumed when users were exposed to an unhealthy image. Even though this result was unexpected, it might be explained with the vicarious goal fulfillment theory, a phenomenon in which individuals fulfill the need to make a healthy choice by just the mere presence of it [79], [80]. A study conducted by Wilcox *et al.* [79] found that when consumers see a healthy food option in a menu, they are more likely to choose the least healthy option compared to when a healthy option was not included. In addition, they also found that people with high self-control are less likely to make an unhealthy choice when no healthy options are available compared to people with low self-control. The results from the *SnackTrack* study suggest that vicarious goal fulfilment theory might work both ways. App users might have selected healthier foods, because by seeing image of unhealthy foods they fulfilled their need to indulge and select

a healthy snack. This finding opens new opportunities for researchers to further investigate in which situations this theory holds and which ones it does not, and how it can be implemented to promote health.

In addition, it is important to point out that individuals' snacking habits and perception of the concept of 'snacking', together with cultural specificities and personal preferences, need to be considered, as these can impact single snacking occasions. Further, it should be emphasised that the study was conducted on a small sample and did not monitor changes over time using a longitudinal study design. Hence, repeating it on a larger sample, and perhaps even in multiple countries, could further contribute to this research field. Because the newly developed mobile tool is openly available, it offers opportunities to repeat the study or upgrade it and investigate the influence of other UI design elements.

6.1.3 Experimental Online Grocery Store to Test Digital Nudging Effects

While people often use mobile apps to make food choices, online grocery shopping via websites is also common. Therefore, an experimental online grocery store was designed to investigate whether nudging consumers, based on a specific nutrient profile, could increase the selection of foods containing this nutrient. This was the first study exploring if repositioning foods can support consumers' food choices in a digital setting. When deciding which criteria to select for nudging, dietary fibre was chosen for various reasons. Firstly, higher dietary fibre intakes have multiple beneficial effects on people's health [62]. However, people struggle to meet the recommended daily intake targets [81], Secondly, in it is not mandatory to include dietary fibre values on the nutrition information panel of labels of food products. Therefore, despite the fact that it is an extremely favourable nutrient, consumers may not (be able to) pay attention to it. This might contribute to the fact that they are not meeting recommended daily values [82]. However, the data about fibre content can be accessed via national and international FCDBs. As the study was conducted in Australia, and the experimental store contained foods typically consumed in Australia, it was logical to link the food products with the Australian FCDB. As a result, the products within the experimental online store were sorted according to fibre content, and further provide consumers with easy access to fibre-rich foods (or the opposite in the comparator condition). Moreover, as re-positioning foods in a real-life setting (not online) has previously shown promising results [83]–[86], this nudging strategy was tested in a digital setting.

However, it needs to be acknowledged that there is a difference between the default product order and giving the consumers an option to sort products based on the nutritional content such as dietary fibre. The possibility of product sorting is a type of decision aid which can be implemented only in a digital setting. While product sorting was not an available feature for participants in the current experimental store, it was assessed if it is something that consumers would like to have as an option or be in control of when shopping online. Since the position of the food products and categories seem to have an effect on choice, future research should further explore this, because a sorting function is a unique digital decision aid.

The finding of this study suggests that re-positioning food products is an advantageous welfare-oriented nudging strategy. Not only did it lead to an increased amount of fibre added to the shopping carts, it also proposes that consumers' budgets, and supermarket revenue might not be adversely impacted. This finding is important for stakeholders such as policy makers, choice architects, food industry, retailers and consumers. Knowing that food choices can be positively influenced, and consumers can be supported by implementing

relatively straight forward digital solutions that promote healthful, cost-neutral choices, may motivate them creating better digital food environments.

In addition, similar nudges may offer further options for retailers to positively influence sustainability, reduce waste, reduce the carbon footprint, or promote locally produced or organic foods. However, these topics still need further investigation. Effective collaboration between retailers and researchers could lead to positive changes supporting consumers' food choices without negatively impacting their business. The framework of Middel *et al.* [87], suggested how different stakeholders could collaborate to create healthy food environments. Similar collaborations might also be effective for creating healthy digital environments.

However, it needs to be acknowledged that

6.1.4 Data- and Knowledge Base Management System

To date, different nudging strategies show varying effects, which confirms that applying appropriate nudging strategies is a complex and challenging task, as it can result in unpredicted results. Therefore, choice architects (i.e., experts) need to be provided with relevant evidence-based D&K to create appropriate nudging strategies that lead to positive changes. As stated above, it was observed that currently no system allows interoperability of D&K. Thus, a comprehensive information system to link D&K in a database, intended to be used by experts, was developed. Contemporary, new D&K are generated and released on a daily basis. Hence, many different resources exist containing relevant information, but that also means that it is hard to follow the state-of-the-art findings. Storing all this information is crucial, but data storage alone is no longer enough. Due to the amount of already existing and newly generated data, it is extremely important to be able to link these D&K together.

Connecting relevant resources (and therefore information) makes it easier to work with them. Therefore, having a system that transparently unites and links the relevant information into one base, can make D&K access and management more efficient. Moreover, due to advances in ICTs and digitalisation, the D&K has to be compiled and provided in a format suitable for choice architects as well as for information systems. The developed system (Chapter 4) enables the connection of resources with relevant information from various research areas of food and nutrition, for the creation and acquisition of new knowledge. In terms of food and nutrition-related D&K that means connecting data such as compositional contents, isotope data, and volatile compounds data with food and nutrition knowledge and data sources, such as dietary guidelines, food standards, documents of toxic substances, findings from food consumer science or food psychology. Specifically, for the study conducted within an experimental online grocery store, dietary fibre content data was linked, with knowledge about the recommended daily intake targets and contemporary intake data, showing how people do not meet these targets, which foods are rich in fibre and the fact that the content values are not present on food labels. Moreover, information in addition to being digitised, must also be standardized. That means that among all different research areas the same terminology is used. One good example in obtaining data using standardised methods is the Metrofood infrastructure [88], contributing to the development of aligned metrology services in food and nutrition field. Metrology is the science of measurement focusing on the improvement of the reliability and comparability of analytical results, and on the definition of internationally accepted units of measurement and the metrological traceability. Therefore, metrology allows for the measurement results to be reliable and comparable. In the context of food and nutrition, this can enhance food data quality, and safety [89]. Moreover, the Metrofood infrastructure allows the integration and harmonization of food quality and safety D&K.

Further, when working with food and nutrition D&K, the methods used should also be transparent and described in detail. For example, in terms of compositional analysis of food it is important to know which parameters were tested/analysed, how the sample was prepared, which chemicals were added and how the sample was analysed. This is also important for integration of food quality legislation and regulations, which often differ between countries. In terms of UI design, it is important to know if specific elements were deliberately added or positioned or if they were unintentionally placed. Only after standardisation and transparent data acquisition, will quality data be obtained, and harmonisation of information be possible. This will further allow information comparison and interchange. Considering this, the design of the DKBMS was made to allow easy adaptation to new standards, documentation and information through the KB.

Therefore, the DKBMS can easily be upgraded to include the latest findings, and it was shown to be a useful tool for experts to design supportive food choice environments. It was demonstrated that combining knowledge from different research areas, namely digital nudging and food and nutrition related D&K, within an experimental online grocery store, can be a promising strategy to nudge consumers toward healthier choices. Moreover, this work also highlights how important and beneficial is the collaboration of a multidisciplinary team of researchers from different research areas. Since researchers from a single research area do not have all the knowledge and/or necessary skills to solve complex tasks by themselves, people from different research areas need to collaborate to develop and create new outcomes.

6.2 Contribution to Theoretical Frameworks

As mentioned in the first chapter, food and nutrition choices are influenced by factors at the individual and environmental level, and finding which factors have the greatest impact on consumers' behaviours is very important. However, current frameworks demonstrating the importance of factors at the environmental level lack the inclusion of a digital category. Therefore, a modification of the DONE framework [11] by including this category to the factors at the environmental level, is proposed (Figure 3).

Specifically, based on the scoping review and experimental work it is suggested to include a digital 'Stem-category', which contains 'Leaf-categories', such as the effort to obtain a product, product swapping, adding a default option, increasing product salience and adding labels or badges. Based on other literature about influence on food choice in digital settings, the category should also include 'Leaf-categories' such as the exposure to targeted marketing [90]. Moreover, the product price, customer reviews (e.g., star ratings of products) and comparator products might also be relevant in the digital setting.

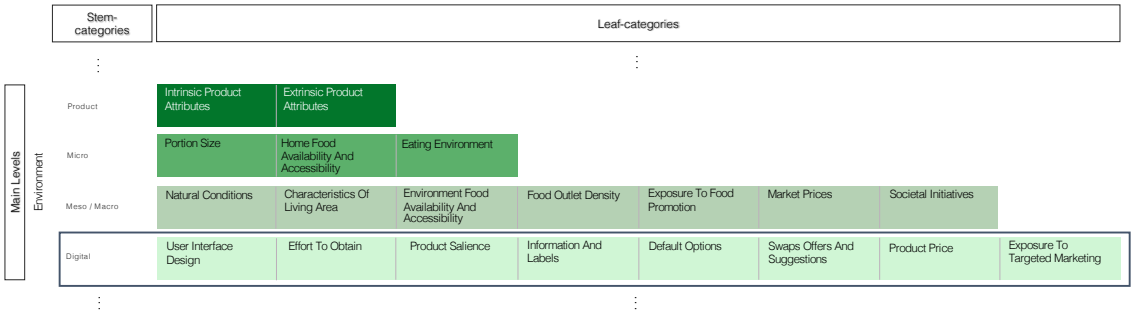

Figure 3: The DONE framework structure [11], with an environmental level containing a digital category. The 'Leaf categories' contain user interface design elements and other factors such as targeted marketing.

6.3 Limitations and Strengths

Lastly, within this dissertation all the hypotheses were confirmed. However, some weaknesses need to be acknowledged. Firstly, the first experimental study on snacking was conducted during COVID-19 lockdown and might have impacted the results, which need to be interpreted with caution. At the time of the study, people still worked remotely or mainly from home which might have influenced their snacking choices. Next, the study focused only on assessing the healthfulness of the snacks and did not consider the portion size. Nevertheless, the open-source mobile app is an important tool to further investigate different digital nudging strategies and UI influences on users or consumers. Future versions of *SnackTrack* could even be upgraded to include automated methods for portion size estimation once they will be fully developed [91].

Moreover, different research fields use different terminologies to describe nudging strategies, therefore some studies might not have been included in the scoping review. Additionally, publication bias might exist with the ineffective nudging strategies not being published. To avoid these limitations, future studies need to clearly describe the implemented UI design elements, to investigate the effect on consumers' food choices. In addition, future studies need to clearly distinguish between digital nudging strategies and the strategies used in digital setting. As defined by Weinmann *et al.* [30] digital nudging involves specific UI design elements in contrast to the digital setting, where an ICT is involved in the nudge. Moreover, to avoid publication bias, researchers need to use trial registration tools to register and publish details about their studies, and provide the overall plan, study design and the measuring outcomes of the research study.

Further, the study about re-positioning of food products based on dietary fibre was conducted in an experimental online grocery store. Therefore, the results might differ from real-life experiences where consumers have to spend their own money. However, research suggests that choices made in experimental setting are representative for real-life choices. Therefore, the developed experimental store presents a valid tool to test the effectiveness of nudging strategies and the promotion of better food choices. Furthermore, the store only included a set of products and intentionally avoided the addition of branded products, which might have had an influence on final choices. Nevertheless, this is the first study to investigate re-positioning of food products based on a specific nutrient content in an experimental online grocery store. Moreover, this study lacks a condition with random order of products based on dietary fibre. Comparing products re-positioned based on dietary fibre (high to low) with the random order would be useful. However, as this was the first study to investigate re-positioning of food products based on certain nutrient, comparing high fibre content products to low fibre content products was initially investigated.

In addition, the newly developed DKBMS has not yet incorporated a data quality index, which is a score to evaluate the quality of original data, that further allows better data comparison. Further, some food and nutrition related semantic resources (e.g., FoodKG [92], FooDB [93]), are still under development, and are therefore not yet included within the DKBMS. However, as the tool is highly adaptable and is designed to allow easy integration, relevant publicly available semantic resources can be added to the KB in the future.

6.4 Future Work

Findings of this dissertation highlight possibilities for future research that could build on our work. Firstly, investigating whether findings can be translated into an actual online

grocery store is warranted. Collaborating with an online store and validating our results within such a setting would potentially be impactful and of great potential public health importance, as results could provide choice architects with additional knowledge on behavioural drivers in a real-life setting and public health and policy makers with evidence to inform regulation.

In addition, our work should be extended with research that focuses on the maintenance of behavioural change over a longer period of time. Investigating whether exposure to the same nudging strategy over time leads to a decay or increase of effectiveness, would be an important to understand. Specifically, data on how long or how many times consumers need to be exposed to the same nudge in order to influence their purchasing habits, usual eating habits and dietary intake is warranted.

Next, future studies should test the effect of strategically sorted food products (re-positioning) against a random order of food products. Our study compared favourably sorted (high content of dietary fibre) with unfavourably sorted (low content of dietary fibre) food products. It remains unclear, if effects would still be present when a favourable product order would be compared to a 'random' food product order. It would be important to introduce random order at category level and at the product level. Future studies should further entangle the effect of order. Finding out if re-positioning is effective at category level and/or at the product level is warranted. Ideally, random orders should be included at both levels to have a true control condition. However, it could be debated whether a random sequence really is unbiased. For example, a random order of food products within an online grocery store could appear chaotic and may not represent a real-life choice scenario.

In addition, future studies should test weather product sorting implemented as a type of decision aid (e.g., the possibility for consumers to re-order product based on a specific nutrient), could be effective. This was not tested in the current study; however future research could focus on this as it is a unique opportunity for digital environments.

Moreover, testing other digital nudging strategies is warranted. Our work focused on food product re-positioning and on imagery. However, other promising strategies shown to be effective in real-life settings still need to be investigated within digital settings. For example, it could be tested if imagery exposure, on-screen positioning (left versus right side), re-sizing of the product images, UI colours used or customer product reviews are influencing choice. Furthermore, it is warranted to investigate how strategies, specific to the digital environment, perform. For example, when evaluating the influence of 'effort' as nudging strategy, evaluating whether there is any difference if users have to scroll instead of clicking to locate the desirable products.

Furthermore, our work gives rise to questions related to UI design personalisation. Since, digital environments and UIs can be relatively quickly and easily modified, implementing the same strategy targeting different nutrients, might be worth investigating. This approach seems promising also because in our experimental online store, participants indicated that they would like to have the option to sort products based on specific nutrients. Therefore, UIs could be personalised or adapted to the specific needs of consumers. Next, this dissertation highlights the need for UI guidelines and provides some initial evidence related to the use of images and product positioning.

In addition, investigating the implementation of a combination of multiple, promising nudging strategies, is warranted. For example, combining imagery with re-positioning. In our studies, it was found that imagery might have the opposite effect to that predicted. However, re-positioning food products based on a single nutrient influences food choices in a predictable way. Therefore, combining them and investigating whether one has a greater effect than the other, or whether they have a synergistic effect, is warranted.

Furthermore, the mobile tool developed to investigate environmental impact on food choices could also present a starting point collecting real-life photos for automated food image recognition (FIR), which can help with the automatization of dietary assessment. As the app collects real-life photos, it can help with the testing and training phase of the FIR process, which is based on machine learning, where the learning algorithms require training, validation and testing [94], [95]. In addition, not only can *SnackTrack* provide photos for FIR, it could also be upgraded into a mobile app with an integrated automated FIR feature. Future versions which automatically recognise food items from the taken photos and provide users with its nutritional value or nutritional profile (e.g., Nutri-Score, Health Star Rating) related to evidence-based criteria could be created. This may increase consumers interest in using the app and make it more effective research tool.

Lastly, the developed DKBMS offers multiple opportunities for integration of new computer-based methods for semi-automatization. For example, it could integrate automatic methods for missing data imputation [46], [96], or methods to calculate missing values based on the ingredient lists of branded food, which have already been developed but are not yet implemented within the system. Moreover, our study shows the importance of interconnecting and integrating multiple relevant resources within one system. As the DKBMS facilitate linking and integration of different online resources, latest scientific evidence could be available to experts immediately, when discovered. Moreover, it could provide experts with insights into relevant connections not yet investigated. However, for experts to be able to investigate this and to make conclusions, data and datasets need to be standardised and annotated. Moreover, D&K from different research fields, such as food consumption, food psychology, behavioural economics, agriculture, etc. need to be integrated, for researchers to easily access them and further use them.

Chapter 7

Conclusions

This doctoral dissertation bridges gaps between research areas and creates new knowledge beneficial for differing fields across consumer science, nutrition and dietetics and ICT. It indicates that appropriately designed digital nudging strategies can influence food choices towards healthier purchase decisions. In addition, it can present a baseline for choice architects (i.e., digital platform operators) to develop UI design guidelines. Furthermore, it provides important knowledge that advances different research fields (e.g., health promotion, human-computer interaction, data management) and may further inform the development of interventions to promote healthy food choices. Next, findings could inform policy makers whether new regulations about the usage of digital nudges within online food choice settings are needed to protect consumers.

Moreover, new D&K are constantly created across different research fields. Therefore, it is almost impossible for choice architects to follow all the latest findings. Therefore, an information system allowing the collection and linking of D&K relevant for a specific research field, can represent a fundamental information source for choice architects. In addition, such a comprehensive system can also assure harmonisation and high-quality of D&K, which further increases traceability and credibility among consumers, choice architects and other stakeholders.

Lastly, health behaviours change is complex, thus innovative interdisciplinary collaboration between research areas are warranted to enable the design of supportive (digital) environments for consumers. Linking existing and newly generated D&K regarding the environmental impact on consumers' food choices, can provide important insights for choice architects to design health-promoting environments. These may make decision-making process easier for consumers and can further facilitate the formation of healthy eating behaviours.

References

[1] F. Fayet-Moore, V. Peters, A. McConnell, P. Petocz, and A. L. Eldridge, "Weekday snacking prevalence, frequency, and energy contribution have increased while foods consumed during snacking have shifted among Australian children and adolescents: 1995, 2007 and 2011-12 National Nutrition Surveys," *Nutr J*, vol. 16, no. 1, pp. 65–65, Oct. 2017, doi: 10.1186/s12937-017-0288-8.

[2] M. Story, K. M. Kaphingst, R. Robinson-O'Brien, and K. Glanz, "Creating Healthy Food and Eating Environments: Policy and Environmental Approaches," *Annual Review of Public Health*, vol. 29, no. 1, pp. 253–272, 2008, doi: 10.1146/annurev.publhealth.29.020907.090926.

[3] B. Wansink, "Environmental factors that increase the food intake and consumption volume of unknowing consumers," *Annu. Rev. Nutr.*, vol. 24, pp. 455–479, 2004, doi: 10.1146/annurev.nutr.24.012003.132140.

[4] C. Bos, I. A. Van der Lans, F. J. Van Rijnsoever, and H. C. Van Trijp, "Understanding consumer acceptance of intervention strategies for healthy food choices: a qualitative study," *BMC Public Health*, vol. 13, no. 1, p. 1073, Nov. 2013, doi: 10.1186/1471-2458-13-1073.

[5] T. Bucher *et al.*, "Nudging consumers towards healthier choices: a systematic review of positional influences on food choice," *British Journal of Nutrition*, vol. 115, no. 12, pp. 2252–2263, 2016.

[6] T. Bucher, K. van der Horst, and M. Siegrist, "Improvement of meal composition by vegetable variety," *Public Health Nutrition*, vol. 14, no. 8, pp. 1357–1363, 2011.

[7] I. H. Steenhuis and W. M. Vermeer, "Portion size: review and framework for interventions," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 6, no. 1, p. 58, Aug. 2009, doi: 10.1186/1479-5868-6-58.

[8] R. H. Thaler and C. R. Sunstein, *NUDGE: Improving Decisions About Health, Wealth, and Happiness*. New Haven & London: Yale University Press, 2008.

[9] T. Bucher, K. Van der Horst, and M. Siegrist, "Fruit for dessert. How people compose healthier meals," *Appetite*, vol. 60, pp. 74–80, 2013.

[10] R. W. Belk, "The objective situation as a determinant of consumer behavior," *ACR North American Advances*, 1975.

[11] F. M. Stok *et al.*, "The DONE framework: Creation, evaluation, and updating of an interdisciplinary, dynamic framework 2.0 of determinants of nutrition and eating," *PLOS ONE*, vol. 12, no. 2, p. e0171077, Feb. 2017, doi: 10.1371/journal.pone.0171077.

[12] S. Stöckli, A. E. Stämpfli, C. Messner, and T. A. Brunner, "An (un) healthy poster: When environmental cues affect consumers' food choices at vending machines," *Appetite*, vol. 96, pp. 368–374, 2016.

[13] J. Maas, D. T. D. de Ridder, E. de Vet, and J. B. F. de Wit, "Do distant foods decrease intake? The effect of food accessibility on consumption," *Psychology & Health*, vol. 27, no. sup2, pp. 59–73, Oct. 2012, doi: 10.1080/08870446.2011.565341.

[14] T. Bucher *et al.*, "Nudging consumers towards healthier choices: a systematic review of positional influences on food choice," *British Journal of Nutrition*, vol. 115, no. 12, pp. 2252–2263, 2016.

[15] C. Hawkes, "Promoting healthy diets through nutrition education and changes in the food environment: an international review of actions and their effectiveness," *Nutrition Education and Consumer Awareness Group, Rome: FAO. Available at: www. fao. org/ag/humannutrition/nutritioneducation/69725/en*, 2013.

[16] E. K. Papies, "Health goal priming as a situated intervention tool: how to benefit from nonconscious motivational routes to health behaviour," *Health Psychology Review*, vol. 10, no. 4, pp. 408–424, 2016.

[17] J. A. Bargh and T. L. Chartrand, "The unbearable automaticity of being," *American Psychologist*, vol. 54, no. 7, pp. 462–479, 1999, doi: 10.1037/0003-066X.54.7.462.

[18] C. Loersch and B. K. Payne, "The Situated Inference Model: An Integrative Account of the Effects of Primes on Perception, Behavior, and Motivation," *Perspect Psychol Sci*, vol. 6, no. 3, pp. 234–252, May 2011, doi: 10.1177/1745691611406921.

[19] J. S. Blumenthal-Barby and H. Burroughs, "Seeking Better Health Care Outcomes: The Ethics of Using the 'Nudge,'" *The American Journal of Bioethics*, vol. 12, no. 2, pp. 1–10, Feb. 2012, doi: 10.1080/15265161.2011.634481.

[20] A. L. Wilson, E. Buckley, J. D. Buckley, and S. Bogomolova, "Nudging healthier food and beverage choices through salience and priming. Evidence from a systematic review," *Food Quality and Preference*, vol. 51, pp. 47–64, Jul. 2016, doi: 10.1016/j.foodqual.2016.02.009.

[21] N. Shea and C. D. Frith, "Dual-process theories and consciousness: the case for 'Type Zero' cognition," *Neuroscience of Consciousness*, vol. 2016, no. 1, p. niw005, Jan. 2016, doi: 10.1093/nc/niw005.

[22] J. S. B. Evans, "Dual-processing accounts of reasoning, judgment, and social cognition," *Annu. Rev. Psychol.*, vol. 59, pp. 255–278, 2008.

[23] D. Kahneman, "A perspective on judgment and choice: mapping bounded rationality.," *American psychologist*, vol. 58, no. 9, p. 697, 2003.

[24] K. E. Stanovich and R. F. West, "Individual differences in reasoning: Implications for the rationality debate?," *Behavioral and Brain Sciences*, vol. 23, no. 5, pp. 645–665, 2000, doi: 10.1017/S0140525X00003435.

[25] D. A. Cohen and S. H. Babey, "Contextual influences on eating behaviours: heuristic processing and dietary choices," *Obesity Reviews*, vol. 13, no. 9, pp. 766–779, 2012, doi: 10.1111/j.1467-789X.2012.01001.x.

[26] Powell E.M., Frankel L.A., Umemura T., and Hazen N., "The relationship between adult attachment orientation and child self-regulation in eating: The mediating role of persuasive-controlling feeding practices," *Eating Behav.*, vol. 26, no. (Powell,

Frankel) University of Houston, Department of Psychological, Health and Learning Sciences, 491 Farish Hall, Houston, TX 77204, United States, pp. 121–128, 2017, doi: 10.1016/j.eatbeh.2017.02.006.

[27] M. Phillips, "Store atmospherics as a prime to nudge shoppers toward healthier food choices," Auckland University of Technology, 2017.

[28] PwC, "Lockdown, Shake Up: The New Normal for Shopping in Europe," 2020. [Online]. Available: https://www.pwc.de/en/retail-and-consumer/european-consumer-insights-series-2020-new-normal.html

[29] E. I. T. Food, "COVID-19 impact on consumer food behaviours in Europe," *Covid-19 Study: European Food Behaviours*, 2020.

[30] M. Weinmann, C. Schneider, and J. vom Brocke, "Digital nudging," *Business & Information Systems Engineering*, vol. 58, no. 6, pp. 433–436, 2016.

[31] R. Brooks *et al.*, "Use of artificial intelligence to enable dark nudges by transnational food and beverage companies: analysis of company documents," *Public Health Nutrition*, vol. 25, no. 5, pp. 1291–1299, 2022, doi: 10.1017/S1368980022000490.

[32] A. Rendell, M. Adam, and A. Eidels, "Towards Understanding the Influence of Nature Imagery in User Interface Design: A Review of the Literature," in *Proceedings of the 52nd Hawaii International Conference on System Sciences*, 2019.

[33] D. Hummel and A. Maedche, "How effective is nudging? A quantitative review on the effect sizes and limits of empirical nudging studies," *Journal of Behavioral and Experimental Economics*, vol. 80, pp. 47–58, Jun. 2019, doi: 10.1016/j.socec.2019.03.005.

[34] T. Bucher and C. Keller, "The web-buffet–development and validation of an online tool to measure food choice," *Public health nutrition*, vol. 18, no. 11, pp. 1950–1959, 2015.

[35] R. A. Harrington, V. Adhikari, M. Rayner, and P. Scarborough, "Nutrient composition databases in the age of big data: foodDB, a comprehensive, real-time database infrastructure," *BMJ open*, vol. 9, no. 6, p. e026652, 2019.

[36] S. Westenbrink, M. Oseredczuk, I. Castanheira, and M. Roe, "Food composition databases: The EuroFIR approach to develop tools to assure the quality of the data compilation process," *Food Chemistry*, vol. 113, no. 3, pp. 759–767, Apr. 2009, doi: 10.1016/j.foodchem.2008.05.112.

[37] M. A. Martínez Burgos *et al.*, "Building a unified Spanish food database according to EuroFIR specifications," *Food Chemistry*, vol. 113, no. 3, pp. 784–788, Apr. 2009, doi: 10.1016/j.foodchem.2008.10.024.

[38] European Food Information Resource, "The EuroFIR Thesauri 2008 Technical report D1.8.22.," Apr. 2022. https://www.eurofir.org/our-resources/eurofir-thesauri/ (accessed Nov. 15, 2022).

[39] European Food Safety Authority (EFSA), "The food classification and description system FoodEx2 (revision 2)," Wiley Online Library, 2015.

[40] Langual, "Langual - The International Framework for Food Description," 2014. https://www.langual.org/default.asp (accessed Nov. 15, 2022).

[41] "CEN/TC 387. Food data – Data structure." https://www.eurofir.org/food-information/how-are-fcdbs-made/quality-and-standards/common-standard/ (accessed Apr. 12, 2022).

[42] GS1 Standards, "GS1," Apr. 2022. https://www.gs1.org/standards (accessed Apr. 12, 2022).

[43] CEN, "European Standard. Food Data – Structure and Interchange Format. EN 16104:2012," Apr. 2022. https://www.en-standard.eu/bs-en-16104-2012-food-data-structure-and-interchange-format/ (accessed Apr. 12, 2022).

[44] M. Machackova, A. Giertlova, J. Porubska, M. Roe, C. Ramos, and P. Finglas, "EuroFIR Guideline on calculation of nutrient content of foods for food business operators," *Food Chemistry*, vol. 238, pp. 35–41, Jan. 2018, doi: 10.1016/j.foodchem.2017.03.103.

[45] G. Ispirova, T. Eftimov, and B. K. Seljak, "Evaluating missing value imputation methods for food composition databases," *Food and Chemical Toxicology*, vol. 141, p. 111368, Jul. 2020, doi: 10.1016/j.fct.2020.111368.

[46] I. Gjorshoska, T. Eftimov, and D. Trajanov, "Missing value imputation in food composition data with denoising autoencoders," *Journal of Food Composition and Analysis*, vol. 112, p. 104638, Sep. 2022, doi: 10.1016/j.jfca.2022.104638.

[47] G. Ispirova, T. Eftimov, P. Korošec, and B. Koroušić Seljak, "MIGHT: Statistical Methodology for Missing-Data Imputation in Food Composition Databases," *Applied Sciences*, vol. 9, no. 19, 2019, doi: 10.3390/app9194111.

[48] I. Castanheira *et al.*, "Establishing quality management systems for European food composition databases," *Food Chemistry*, vol. 113, no. 3, pp. 776–780, 2009.

[49] S. M. Church, "EuroFIR synthesis report No 7: Food composition explained," *Nutrition Bulletin*, vol. 34, no. 3, pp. 250–272, 2009.

[50] E. Valenčič, E. Beckett, C. E. Collins, B. K. Seljak, and T. Bucher, "Digital nudging in online grocery stores: A scoping review on current practices and gaps," *Trends in Food Science & Technology*, Oct. 2022, doi: 10.1016/j.tifs.2022.10.018.

[51] E. Valenčič, E. Beckett, C. E. Collins, B. Koroušić Seljak, and T. Bucher, "SnackTrack—An App-Based Tool to Assess the Influence of Digital and Physical Environments on Snack Choice," *Nutrients*, vol. 15, no. 2, p. 349, 2023.

[52] GO FAIR, "FAIR Principles." https://www.go-fair.org/fair-principles/ (accessed Apr. 05, 2023).

[53] Y. Li, T. Du, and J. Peng, "Understanding Out-of-Home Food Environment, Family Restaurant Choices, and Childhood Obesity with an Agent-Based Huff Model," *Sustainability*, vol. 10, no. 5, p. 1575, 2018.

[54] W. Chae, Y. J. Ju, J. Shin, S.-I. Jang, and E.-C. Park, "Association between eating behaviour and diet quality: eating alone vs. eating with others," *Nutrition journal*, vol. 17, no. 1, p. 117, 2018.

[55] J. Wardle, "Eating behaviour and obesity," *Obes Rev*, vol. 8 Suppl 1, pp. 73–75, Mar. 2007, doi: 10.1111/j.1467-789X.2007.00322.x.

[56] K. J. Duffey, R. A. Pereira, and B. M. Popkin, "Prevalence and energy intake from snacking in Brazil: analysis of the first nationwide individual survey," *European journal of clinical nutrition*, vol. 67, no. 8, p. 868, 2013.

[57] A. K. Kant and B. I. Graubard, "40-year trends in meal and snack eating behaviors of American adults," *Journal of the Academy of Nutrition and Dietetics*, vol. 115, no. 1, pp. 50–63, 2015.

[58] C. Piernas and B. M. Popkin, "Snacking increased among US adults between 1977 and 2006," *The Journal of nutrition*, vol. 140, no. 2, pp. 325–332, 2009.

[59] J. B. Myhre, E. B. Løken, M. Wandel, and L. F. Andersen, "Meal types as sources for intakes of fruits, vegetables, fish and whole grains among Norwegian adults," *Public health nutrition*, vol. 18, no. 11, pp. 2011–2021, 2015.

[60] C. A. Zizza, D. D. Arsiwalla, and K. J. Ellison, "Contribution of snacking to older adults' vitamin, carotenoid, and mineral intakes," *Journal of the American Dietetic Association*, vol. 110, no. 5, pp. 768–772, 2010.

[61] G. Cowburn and L. Stockley, "Consumer understanding and use of nutrition labelling: a systematic review," *Public Health Nutrition*, vol. 8, no. 1, pp. 21–28, 2005, doi: 10.1079/PHN2004666.

[62] S. K. Gill, M. Rossi, B. Bajka, and K. Whelan, "Dietary fibre in gastrointestinal health and disease," *Nature Reviews Gastroenterology & Hepatology*, vol. 18, no. 2, pp. 101–116, Feb. 2021, doi: 10.1038/s41575-020-00375-4.

[63] J. Sobal and C. A. Bisogni, "Constructing Food Choice Decisions," *Annals of Behavioral Medicine*, vol. 38, no. suppl_1, pp. s37–s46, Dec. 2009, doi: 10.1007/s12160-009-9124-5.

[64] H. Willman-Iivarinen, "The future of consumer decision making," *European Journal of Futures Research*, vol. 5, no. 1, p. 14, Dec. 2017, doi: 10.1007/s40309-017-0125-5.

[65] R. W. Jeffery, "How can Health Behavior Theory be made more useful for intervention research?," *International journal of behavioral nutrition and physical activity*, vol. 1, pp. 1–5, 2004.

[66] I. Ajzen, "The theory of planned behavior," *Organizational Behavior and Human Decision Processes*, vol. 50, no. 2, pp. 179–211, Dec. 1991, doi: 10.1016/0749-5978(91)90020-T.

[67] A. Bandura, "Health promotion from the perspective of social cognitive theory," *Psychology & Health*, vol. 13, no. 4, pp. 623–649, Jul. 1998, doi: 10.1080/08870449808407422.

[68] R. M. Ryan and E. L. Deci, *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Publications, 2017.

[69] J. Brug, A. Oenema, and I. Ferreira, "Theory, evidence and Intervention Mapping to improve behavior nutrition and physical activity interventions," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 2, no. 1, pp. 1–7, 2005.

[70] C. R. Sunstein, "Nudging and choice architecture: Ethical considerations," *Yale Journal on Regulation, Forthcoming*, 2015.

[71] World Health Organisation, "Digital food environments: Factsheet." 2021. Accessed: Apr. 16, 2023. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/342072/WHO-EURO-2021-2755-42513-59052-eng.pdf?sequence=1&isAllowed=y

[72] C. Yang *et al.*, "An Ontology to Standardize Research Output of Nutritional Epidemiology: From Paper-Based Standards to Linked Content," *Nutrients*, vol. 11, no. 6, 2019, doi: 10.3390/nu11061300.

[73] D. M. Dooley *et al.*, "FoodOn: a harmonized food ontology to increase global food traceability, quality control and data integration," *npj Science of Food*, vol. 2, no. 1, p. 23, Dec. 2018, doi: 10.1038/s41538-018-0032-6.

[74] T. Eftimov, G. Ispirova, D. Potočnik, N. Ogrinc, and B. Koroušić Seljak, "ISO-FOOD ontology: A formal representation of the knowledge within the domain of isotopes for food science," *Food Chemistry*, vol. 277, pp. 382–390, Mar. 2019, doi: 10.1016/j.foodchem.2018.10.118.

[75] "COMFOCUS: Comunity on Food Consumer Science." https://comfocus.eu (accessed Apr. 03, 2023).

[76] G. Ispirova *et al.*, "CafeteriaFCD Corpus: Food Consumption Data Annotated with Regard to Different Food Semantic Resources," *Foods*, vol. 11, no. 17, 2022, doi: 10.3390/foods11172684.

[77] M. Ogrinc, "Source code for iOS mobile app SnackTrack." 2023. [Online]. Available: https://repo.ijs.si/matevzog/snacktrack

[78] A. Simčič and M. Ogrinc, "Source code for Android mobile app SnackTrack." 2023. [Online]. Available: https://repo.ijs.si/andrazsimcic/snack-track-android

[79] K. Wilcox, B. Vallen, L. Block, and G. J. Fitzsimons, "Vicarious Goal Fulfillment: When the Mere Presence of a Healthy Option Leads to an Ironically Indulgent Decision," *Journal of Consumer Research*, vol. 36, no. 3, pp. 380–393, Oct. 2009, doi: 10.1086/599219.

[80] W.-B. Chiou, C.-C. Yang, and C.-S. Wan, "Ironic effects of dietary supplementation: illusory invulnerability created by taking dietary supplements licenses health-risk behaviors," *Psychological science*, vol. 22, no. 8, pp. 1081–1086, 2011.

[81] B. Koroušić Seljak *et al.*, "Inadequate Intake of Dietary Fibre in Adolescents, Adults, and Elderlies: Results of Slovenian Representative SI. Menu Study," *Nutrients*, vol. 13, no. 11, p. 3826, 2021.

[82] N. M. McKeown, G. C. Fahey, J. Slavin, and J.-W. van der Kamp, "Fibre intake for optimal health: how can healthcare professionals support people to reach dietary recommendations?," *BMJ*, vol. 378, p. e054370, Jul. 2022, doi: 10.1136/bmj-2020-054370.

[83] M. Romero and D. Biswas, "Healthy-left, unhealthy-right: Can displaying healthy items to the left (versus right) of unhealthy items nudge healthier choices?," *Journal of Consumer Research*, vol. 43, no. 1, pp. 103–112, 2016, doi: 10.1093/jcr/ucw008.

[84] E. Dayan and M. Bar-Hillel, "Nudge to nobesity II: Menu positions influence food orders," *Judgment and Decision making*, vol. 6, no. 4, pp. 333–342, 2011.

[85] E. van Kleef, K. Seijdell, M. H. Vingerhoeds, R. A. de Wijk, and H. C. M. van Trijp, "The effect of a default-based nudge on the choice of whole wheat bread," *Appetite*, vol. 121, pp. 179–185, 2018, doi: 10.1016/j.appet.2017.11.091.

[86] E. Baskin *et al.*, "Proximity of snacks to beverages increases food consumption in the workplace: A field study," *Appetite*, vol. 103, pp. 244–248, Aug. 2016, doi: 10.1016/j.appet.2016.04.025.

[87] C. N. Middel, T. J. Schuitmaker-Warnaar, J. D. Mackenbach, and J. E. Broerse, "Designing a healthy food-store intervention; a co-creative process between interventionists and supermarket actors," *International Journal of Health Policy and Management*, vol. 11, no. 10, pp. 2175–2188, 2022.

[88] A. Sorbo, E. Pucci, C. Nobili, I. Taglieri, D. Passeri, and C. Zoani, "Food Safety Assessment: Overview of Metrological Issues and Regulatory Aspects in the European Union," *Separations*, vol. 9, no. 2, 2022, doi: 10.3390/separations9020053.

[89] M. Rychlik *et al.*, "Ensuring Food Integrity by Metrology and FAIR Data Principles," *Frontiers in Chemistry*, vol. 6, 2018, doi: 10.3389/fchem.2018.00049.

[90] D. L. M. van der Bend, T. Jakstas, E. van Kleef, V. A. Shrewsbury, and T. Bucher, "Making sense of adolescent-targeted social media food marketing: A qualitative study of expert views on key definitions, priorities and challenges," *Appetite*, vol. 168, p. 105691, Jan. 2022, doi: 10.1016/j.appet.2021.105691.

[91] F. E. Thompson and A. F. Subar, "Dietary assessment methodology," *Nutrition in the Prevention and Treatment of Disease*, pp. 5–48, 2017.

[92] FoodKG, "FoodKG: A Semantics-Driven Knowledge Graph for Food Recommendation." https://foodkg.github.io (accessed Dec. 27, 2022).

[93] TMIC, "FooDB." https://foodb.ca (accessed Nov. 20, 2022).

[94] S. Mezgec, T. Eftimov, T. Bucher, and B. Koroušić Seljak, "Mixed deep learning and natural language processing method for fake-food image recognition and standardization to help automated dietary assessment," *Public Health Nutr*, vol. 22, no. 7, pp. 1193–1202, May 2019, doi: 10.1017/S1368980018000708.

[95] S. Mezgec and B. Koroušić Seljak, "NutriNet: A Deep Learning Food and Drink Image Recognition System for Dietary Assessment," *Nutrients*, vol. 9, no. 7, Jun. 2017, doi: 10.3390/nu9070657.

[96] G. Ispirova, "Exploiting Domain Knowledge in Predictive Learning from Food and Nutrition Data: Doctoral Dissertation," [G. Ispirova], Ljubljana, 2022.

Bibliography

Publications Related to the Thesis

Journal Articles

E. Valenčič, E. Beckett, C. E. Collins, B. Koroušić Seljak, and T. Bucher, "Digital nudging in online grocery stores: A scoping review on current practices and gaps," *Trends in Food Science & Technology*, Oct. 2022, doi: 10.1016/j.tifs.2022.10.018.

E. Valenčič, E. Beckett, C. E. Collins, B. Koroušić Seljak, and T. Bucher, "SnackTrack—An App-Based Tool to Assess the Influence of Digital and Physical Environments on Snack Choice," *Nutrients*, vol. 15, no. 2, p. 349, 2023.

E. Valenčič, E. Beckett, C. E. Collins, B. Koroušić Seljak, and T. Bucher. "Changing the order of food items in an online grocery store may nudge healthier food choices" – *submitted*

E. Valenčič, E. Beckett, C. E. Collins, T. Bucher, and B. Koroušić Seljak. "FoodMapper: Management System for the integration and interoperability of food- and nutrition-related data and knowledge " – *submitted*

Other Publications

G. Cenikj, E. Valenčič, G. Ispirova, M. Ogrinc, R. Stojanov, P. Korošec, *et al.*, "CafeteriaSA corpus: scientific abstracts annotated across different food semantic resources," *Database*, vol. 2022, p. baac107, Jan. 2022, doi: 10.1093/database/baac107.

G. Ispirova, G. Cenikj, M. Ogrinc, E. Valenčič, R. Stojanov, P. Korošec, *et al.*, "CafeteriaFCD Corpus: Food Consumption Data Annotated with Regard to Different Food Semantic Resources," *Foods*, vol. 11, no. 17, 2022, doi: 10.3390/foods11172684.

B. Koroušić Seljak, E. Valenčič, H. Hristov, M. Hribar, Ž. Lavriša, A. Kušar, *et al.*, "Inadequate Intake of Dietary Fibre in Adolescents, Adults, and Elderlies: Results of Slovenian Representative SI. Menu Study," *Nutrients*, vol. 13, no. 11, p. 3826, 2021.

G. Ispirova, G. Popovski, E. Valenčič, N. Hadzi-Kotarova, T. Eftimov, and B. Koroušić Seljak, "Food Data Normalization Using Lexical and Semantic Similarities Heuristics," in *Biomedical Engineering Systems and Technologies: 13th International Joint Conference, BIOSTEC 2020, Valletta, Malta, February 24–26, 2020, Revised Selected Papers 13*, Springer, 2021, pp. 468–485.

E. Molina-Montes, I. Uzhova, V. Verardo, R. Artacho, B. García-Villanova, E. J. Guerra-Hernández *et al.*, "Impact of COVID-19 confinement on eating behaviours across 16 European countries: The COVIDiet cross-national study," *Food Quality and Preference*, vol. 93, p. 104231, 2021.

A. Biasizzo, B. Koroušić Seljak, E. Valenčič, M. Pavlin, M. Santo Zarnik, B. Blažica *et al.*, "An open-source approach to solving the problem of accurate food-intake monitoring," *IEEE Access*, vol. 9, pp. 162835–162846, 2021.

T. Eftimov, G. Popovski, E. Valenčič, and B. Koroušić Seljak, "FoodEx2vec : new foods' representation for advanced food data analysis," in press 2020. [Online]. Available: doi:10.1016/j.fct.2020.111169

G. Popovski, G. Ispirova, N. Hadzi-Kotarova, E. Valenčič, T. Eftimov, and B. Koroušić Seljak, "Food Data Integration by using Heuristics based on Lexical and Semantic Similarities.," in *HEALTHINF*, 2020, pp. 208–216.

Biography

Author of this thesis Eva Valenčič started her higher education at the Biotechnical Faculty, University of Ljubljana, Slovenia, studying Food Science and Nutrition. She finished her academic bachelor's degree in 2015 with a thesis entitled " Electronic tongue and perception of sweet taste". The same year she started her master's studies in Nutrition at the Biotechnical Faculty, University of Ljubljana, Slovenia. During her master's studies she went on an Erasmus^{+} exchange at the Faculty of Bioscience Engineering, Ghent University, Belgium. She received her Master of Science in Nutrition in 2018, under the supervision of Assoc. Prof. Dr. Mojca Korošec. In 2019 she received The Faculty Prešeren Award for best master's thesis entitled "Optimization of the Slovenian food basket using linear programming".

In October 2018 she started her dual awarded doctoral degree studies in Nutrition and Dietetics at the Jožef Stefan International Postgraduate School in Ljubljana, Slovenia, and at the University of Newcastle, Australia, under the primary supervision of Prof. Dr. Barbara Koroušić Seljak and Assoc. Prof. Dr. Tamara Bucher, and co-supervision of Dr. Emma Beckett and Laureate Prof. Clare E. Collins. Over the course of her doctoral studies, she has been employed as a research assistant at the Computer System Department at the Jožef Stefan Institute and has taken part in several national and international projects. Moreover, she has received the Higher Degree Research Scholarship at the School of Health Sciences, College of Health, Medicine and Wellbeing at The University of Newcastle, Australia. In addition, she has been affiliated with the Hunter Medical Research Institute, Food and Nutrition Program, Australia.

In her PhD, she explored environmental impacts on consumer's food choices in digital settings. Further, throughout her doctoral studies she has been closely collaborating with the team of computer scientist working on different projects focused on food- and nutrition related data and knowledge, where she has assisted with data collection and provided nutrition expert knowledge.