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Dynamic conceptual framework to investigate adoption of healthy diet through agent-based modelling

British Food Journal

Abstract

Purpose: The purpose of this research is to develop a dynamic conceptual framework depicting factors related to the adoption of a healthy diet, which will underpin the development of an agent-based model to uncover the dynamic interplay between these factors.

Design/methodology/approach: The conceptual framework was developed in three steps using available empirical data from semi-structured in-depth interview qualitative study, a comprehensive systematic literature searches, existing theories and models, and expert opinions from across the world.

Findings: The conceptual framework explicitly presents intention as the key determinant of the tendency to adopt a healthy diet. Intention is determined by demographic, psychological and behavioural factors, and individual dietary mind-set factors, and dynamically affected by social environment and the person's past behaviour. The relationship between intention and behaviour is dynamically moderated by perceived control factors (price and accessibility of healthy food, and time).

Originality: The conceptual framework developed in this study is well supported by evidence and experts' opinions. This conceptual framework will be used to design our agent-based model, and it can be used in future investigations on the tendency to adopt healthy diet and food choices.

Keywords: Agent-based model, Conceptual framework, Food choices, Healthy diet.

Introduction

Unhealthy eating has been identified by the World Health Organization (WHO) as a significant risk factor for non-communicable diseases (NCDs) including cancer, cardio-metabolic diseases and obesity (Organization, 2016). A Lancet report indicated strong links between poor diet and mortality, accounting for 1 in 5 deaths globally (Afshin, et al., 2019). In 2015, NCDs accounted for 40 million deaths worldwide, 80% of which could be prevented (Organization, 2016).

A healthy diet is usually defined as a diet that is high in plant-based foods such as whole grains, fruits, vegetables, nuts, legumes, and fish and low in high-fat and processed animal-based food (Organization, 2019). Basic principles of healthy eating include variety, caloric control, reduced salt, sugars, saturated and trans-fats consumption. Despite the large amount of research on factors influencing healthy eating, only small improvements in health diet are observed at the population level worldwide (Ng, et al., 2014). Furthermore, the dynamic interaction between these factors and sustained effects are poorly understood. Understanding the factors influencing the adoption of a healthy diet and their dynamic relationships is essential to promote health and prevent diseases.

The inter-relations between the factors influencing the adoption of a healthy diet are complex. Recently, the use of computational models to simulate the effect and interactions of factors influencing health outcomes- such as the adoption of a healthy diet- has received growing attention. For example, there is an increased interest in applying agent-based model (ABMs) better to understand complex public health matters (Tracy, et al., 2018). The use of ABM allows a holistic understanding of dynamic interactions between factors at different levels (i.e., personal, behavioural, social, economic, and environmental factors) (Tracy, et al., 2018). ABM has been applied to public health understand the multiple drivers of population patterns of health

behaviours related to the risk of NCDs such as smoking cessation (Beheshti & Sukthankar, 2014), alcohol drinking (Gorman, et al., 2006), and physical activity(L. M. Garcia, et al., 2018).

There are several other ABMs that have addressed the issue of a healthy diet (Auchincloss, et al., 2011; Beheshti, et al., 2016; Langellier, 2016; Orr, et al., 2014; Rice, 2012). But limited number of them provide a conceptual framework for their study. So it is needed to a developable conceptual framework in the context of a healthy diet. Furthermore, each of the previous studies examined a specific aspect of the factors that influence and shape the diet such as social networks(Langellier, 2016; Orr, et al., 2014), spatial disparities(Rice, 2012), price per calorie(Beheshti, et al., 2016), and income (Auchincloss, et al., 2011). Studies have not paid enough attention to personal factors such as psychological and demographic factors and have paid less attention to dietary-mind factors such as dietary knowledge, attitude and self-efficacy. Our work tries to fill this gap by designing a comprehensive conceptual framework combining, in a structured way, a comprehensive review of literature and expert opinions. This design includes psychological and behavioural factors, dietary-mind, demographic, perceived control and social environment factors that affected healthy dietary choices. This paper reports the development of the dynamic conceptual framework depicting the factors related to the adoption of a healthy diet that underpin our ABM.

Methods

Our endpoint is to construct an ABM of the determinants and mechanisms that shape the tendency to make healthy food choices as well as the decision-making involved during this process in the context of community-dwelling healthy individuals. To underpin the ABM, a conceptual framework was developed in a three-stage approach (Figure 1), as proposed by Garcia et al.(L. M. T. Garcia, et al., 2017). An initial model was developed based on the authors' expertise and a

qualitative study that was carried out by authors, details of which have been reported elsewhere (Haghighian Roudsari, et al., 2017; Haghighian Roudsari, et al., 2019). As a second step, an intermediary conceptual framework was developed by updating the conceptual framework using new information obtained from a comprehensive literature search in MEDLINE, Scopus and Web of Science. Subsequently, a panel of international expert researchers in this field assessed the intermediary conceptual framework, and a final revised version of the conceptual framework was formulated.

Initial conceptual framework

The initial model was developed using the Theory of Planned Behaviour (TPB) (Ajzen, 1991), a widely applied theory in food choices and healthy eating behavioural research (Canova, et al., 2020; Ehrlinger, et al., 2017; Petrovici, et al., 2004; Vilaro, et al., 2016). We applied TPB as a foundation of our model and developed it using the expertise of the study authors and a qualitative study of determinants of food choice that was carried out by authors using a semi-structured in-depth interview, details of which have been reported elsewhere (Haghighian Roudsari, et al., 2017; Haghighian Roudsari, et al., 2019). Briefly, 33 adults living in Tehran took part in in-depth semi-structured interviews that explored factors influencing food choice with a focus on perception, attitude, and eating practices (Haghighian Roudsari, et al., 2017; Haghighian Roudsari, et al., 2019).

Intermediary model of conceptual framework

An intermediary conceptual framework was subsequently developed by updating the initial model using additional information derived through a systematic search of the literature. This stage aimed to consolidate, remove or include elements and relationship into the initial conceptual framework. Following recommendations for evidence-based practice (Evans, 2003; Murad, et al., 2016), we limited our literature search to meta-analysis and systematic reviews to ensure findings on efficacy were used to inform the design of our framework. We conducted a comprehensive systematic search without language, location, or time restrictions in PubMed/MEDLINE, Scopus and Web of Science databases up to the 10th February of 2020. We used MeSH and non-MeSH keywords in titles, abstracts, and keywords for literature search limited to systematic reviews and meta-analysis (Table S1). Furthermore, in an attempt to avoid exclusion of other relevant studies, reference lists of included studies were screened, and an email alert was put in place to detect studies of interest after the date of the search. Finally, the intermediary conceptual framework was developed by reviewing selected original empirical studies and theories that helped to define constructs and delimit the elements, relations, and mechanisms.

Final model of conceptual framework

The final version of the conceptual framework was developed considering opinions of expert from around the world. To achieve an adequate volume of responses, we set out to obtain the opinions of at least twenty experts in different fields. The response rate was anticipated to be around 20%, thus 100 experts were invited to evaluate the intermediary model. Invited experts were mostly identified and selected during the literature review step and were from multiple fields such as community nutrition, epidemiology, sociology and psychology. The professional webpage or curriculum vitae of invited experts were searched to obtain information to describe the

participants, such as gender, country, and fields of expertise. An electronic link containing the intermediary framework alongside a description of the project’s purpose, goals and delimitations was sent by email to experts. Four questions were posed to experts to evaluate the intermediary model:

One question was presented with response options in a five-point Likert scale from 1 (completely disagree) to 5 (completely agree):

I) *How much do you agree with the current intermediary conceptual model?*

The other three questions had an open-ended format:

- I. *Are there any variables or mechanisms not included in the current intermediary conceptual model that should be added?*
- II. *Are there any variables or mechanisms included in the current intermediary conceptual model that should be excluded?*
- III. *Do you have any additional comments or suggestions about the current intermediary conceptual model?*

Four weeks were given for experts to express their opinions, and a reminder email was sent to them at the end of the third week. The first author reviewed, categorised and coded all experts’ responses based on content similarity. Suggestions on elements and process were used to help decide whether variables and mechanisms should be kept, added or ignored from the intermediary conceptual framework. We ranked and prioritised the frequencies of suggestions on elements and process. Those that were outside the scope of our ABM or the aim of this study were not incorporated in the model.

The expert consultation was approved by the Ethics in Research Committee of the National Nutrition & Food Technology Research Institute, Iran (# IR.SBMU.NNFTRI.REC.1398.069).

Results

The initial conceptual framework is shown in Supplementary Figure S1. It incorporated individual, social, food, and environmental factors. Besides the TPB, features and elements of social practice theories(Ortner, 2006), social cognitive theory(Bandura, 2001), random utility models(Baltas & Doyle, 2001), and food choice process model (T. Furst, et al., 1996) were also taken into account in the design of this initial conceptual framework. The structure of the initial conceptual framework builds on the TPB. In the first step, we listed affective variables according to author's knowledge and classified them into categories of final behaviour, intention, perceived behaviour control related to food, subjective norms and environmental factors, and attitude containing socio-economic, psychological and knowledge factors.

The systematic literature search conducted to build the intermediary version of the framework yielded 2589 papers, of which 1007 were duplicates and 1524 irrelevant records were excluded following title, abstract or full-text review (Figure 2). Fifty-eight studies were eligible and underwent in-depth review (see Table S2 for main findings of each paper). Elements and process identified within the 58 eligible studies were used to change and improve our initial conceptual framework (Supplementary Figure S2). We identified food price (Andreyeva, et al., 2010; Bennett, et al., 2020; Mogendi, et al., 2016) and food access (Abeykoon, et al., 2017; Akande, et al., 2015; Gittelsohn, et al., 2017; Pitt, et al., 2017) as key perceived controls in determining healthy dietary behaviours, while individual factors (McDermott, et al., 2015; Nardi,

et al., 2019; Riebl, et al., 2015), social environment (Allan, et al., 2017; McDermott, et al., 2015), and past behaviour (Nardi, et al., 2019) were identified as determinants of intention. Past behaviour appears to have an effective role in determining intention (Nardi, et al., 2019), while the social and physical environments have different roles in the framework (Clohessy, et al., 2019; Fletcher, et al., 2011; Pitt, et al., 2017; Vecchio & Cavallo, 2019; Wright & Bragge, 2018). Physical environment (access) in the perceived control box has a modifying role on the effect of intention upon behaviour function (Abeykoon, et al., 2017; Akande, et al., 2015; Pitt, et al., 2017), whereas social environment is affected by past behaviour and have direct effect on intention (Nardi, et al., 2019). In developing the intermediary conceptual framework, economic level (De Irala-Estevéz, et al., 2000; Kamphuis, et al., 2015) and influence of past behaviour (Nardi, et al., 2019) were added to the model.

Of the 100 invited experts, 23 completed the survey form, of which 43% were male. Experts were from a variety of fields: Nutritional Epidemiology, Public Health and Nutrition (Community nutrition), Epidemiology, Consumer Behavior, Food Policy, Psychology, Marketing, Health Economics, Public Health, Sociology, Chronic Disease Care, and Social Anthropology. Their regions of practice were the US, the UK, Denmark, Australia, Brazil, Canada, Italy, Qatar, China, France, India, New Zealand, Iran, and Kenya. The mean score of agreement with the conceptual framework was 3.70 ± 0.82 , and three of the experts were entirely in agreement with the proposed conceptual framework.

The feedback provided by experts on the intermediary conceptual framework is outlined in Table S3. The most common comments were about: 1) adding self-efficacy as an important factor in food choice and following a healthy diet; 2) considering the effect of advertising; 3) the effect of food choice on disease and health status of family members; 4) attention to health literacy,

self-esteem and knowledge, and 5) time as a perceived control factor. The frequency of proposed comments is provided in supplementary Figure S3. Attention to social environment and norms was emphasized by 30% of participants. Furthermore, 26% of the experts proposed to add self-efficacy to the conceptual framework. Intention was mentioned by 26% of participants. Past behaviour, health status, and economic level were proposed by 13%, and time to providing a healthy diet by 9% of researchers. Only 4% of the experts suggested the addition of self-esteem.

In the last stage, the conceptual framework was updated to incorporate the experts' opinions. We included time and self-esteem in the final conceptual framework. Also, we added healthy diet-related knowledge, attitude, and self-efficacy (individual dietary mind-set factors) to the model, which encompass health literacy and advertising. In fact, advertising can indirectly change the intention of behaviour by affecting dietary mind-set factors. There were no many suggestions to exclude elements or relationships. All changes in the elements and relationships through each iteration of the conceptual framework are displayed in Table S4.

The resulting conceptual framework is presented in Figure 3, and the relevant operational definition of the elements included is provided in Table 1. The meanings and assumptions of the relationships in the conceptual framework are presented in Table 2. In this conceptual framework, the influence of an individual's past behaviour and social environment on intention is considered to have an inverted U shape. That is to say that the closer the intention is to its upper or lower limit, the weaker the influence of the individual's past behaviour and the social environment on his or her current intention. Furthermore, perceived controls are deemed to have a moderating effect on the relationship between intention and behaviour (i.e., likelihood of adopting a healthy diet) (Figure 4).

Discussion

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This study aimed to construct a dynamic conceptual framework of healthy eating behaviour, which will form the foundations for and inform an ABM. This framework was derived from a three-stage development process involving a qualitative study of healthy eating behaviours, a systematic overview of published systematic reviews, and finally, refinement of proposed factors and relationships through the incorporation of expert opinion. The framework identifies key personal, environmental, and perceived control which dictate the likelihood of an individual to adopt a healthy diet. Furthermore, we attempted to define and describe the direction and nature of each relationship; all of which is intended to inform the creation of an ABM and allow in-depth interrogation of the determinants and their associations.

The conceptual framework we developed contains important elements, and mechanisms of existing theories on food choice such as (a) economic (household and random utility) models (Baltas & Doyle, 2001; Bonke, 1992), (b) food choice process model (Tanis Furst, et al., 1996) and (c) TPB (Ajzen, 1991; Conner & Armitage, 2006; Fishbein & Ajzen, 1980; McCarthy, et al., 2003). This conceptual framework contains important features of complex systems approaches such as dynamic mechanisms linking between elements, dynamic perspective on the phenomenon, feedback loops behaviour and its causes , emergent behaviours, limited predictability, dynamic actions between interdependent individuals, and fundamental uncertainty (Bar-Yam, 2002; Cameron & Larsen-Freeman, 2007; Grimm, et al., 2005). Interestingly, Sobal and Bisogni, employing constructionist social definition perspectives to promote a food choice process model, linked food choice strategies to intuitive responses that establish factors and dynamics involved in food behaviours(Sobal & Bisogni, 2009). More specifically, for this food choice process, the authors considered life course events and experiences, cultural ideals, personal factors, resources, social factors, and food choice strategies in the individual routine(Sobal & Bisogni, 2009).

In 1996, Furst et al. proposed one step toward an more complete understanding of food choice, suggesting that a constructionist approach can positively impact the food choice (Tanis Furst, et al., 1996). In 1999, Shepherd highlighted the importance of TPB as a model from social psychology for predicting behaviour as well as a tool to determine the relevance of various factors in influencing food choice (Shepherd, 1999). Among the plethora of extensions of this model, the moral obligation is a way to expanding factors related to food choices in specific scenarios (Shepherd, 1999). Taking into account these proposals, further consideration should be given to emotional and feeling elements fundamental in food choice, instead of trivially considering food choice as a rational cognitive problem (Shepherd, 1999). Indeed, TPB formed the basis for this framework, as well as the relationship between intention and behavior is among the highlights (Ajzen, 1991; Conner & Armitage, 2006). Herein, such a relationship was deemed to be moderated by perceived controls such as healthy food price, accessibility, and time available to the individual. This perceived role may make such factors amenable to intervention and can be explored further through ABM. This interaction is highlighted in Figure 4, which demonstrates the potential beneficial or harmful modulatory effects of these perceived controls on the relationship between intention and behavior.

The process involved in developing this framework is a relatively novel one. It has been previously used to study patterns of leisure-time physical activity among community dwelling adults (L. M. T. Garcia, et al., 2017). In this study, each stage of the process resulted in a significant modification in the subcomponents of the framework, although without major shifts in key themes (*i.e.*, environmental, individual, *etc.*) or their relationships. Evidence from the systematic review was incorporated into the framework, but no significant changes were made. We explicitly defined perceived controls as a category and confined their effect as solely on the transition from intention to behaviour. Finally, we incorporated the most common recommendations of experts, and further sub-classified individual factors into demographics, individual dietary mind-set factors, and psychological aspects in the final iteration of the framework. Although a range of additional factors were suggested and considered at each stage of the framework development, we aimed to create a

highly parsimonious conceptual model. This meant that several potentially valid elements and relationships were excluded based on their relevance to the questions we expect to investigate with our ABM. However, excluded factors have been catalogued for consideration in future versions of the framework and ABM.

The findings of this article may provide a better understanding of the complex relationship between socio-economic and psychological factors and mechanisms that affect the adoption of a healthy diet. This paper provides a comprehensive conceptual model that takes into account the knowledge base of different fields that can bridge the gap between theory and practice in investigating the adoption of a healthy diet through ABM simulation.. As this model is a multi-field conceptual framework developed with ABM in mind, researchers and policymakers can use it for simulating scenarios in an attempt to find the best policy to be implemented in the community and improve government policy in the prevention of NCDs. Insofar policies that improve community food habits and changing harmful eating habits and lifestyles are adopted, the risk of NCDs decreases. .

This work provides a framework that can assist in the adoption of healthy eating behavior, which is a dynamic and multifaceted problem that cannot be addressed satisfactorily through single-component strategies. While recognizing the scale of this problem, previous efforts to address a restricted number of factors or levels of influence independently have demonstrated significant shortcomings and failed to acknowledge the entire dynamic relationship. The application of a socio-ecological methodology should lead to a broader consideration and ultimately a complete assessment of different levels of influence, such as intrapersonal, interpersonal, environmental and policy factors, as well as the nature of their respective contributions. In addition, it should be empathized that global obesity trends continue to rise

without effective, sustainable, or promising interventions for management (Ng, et al., 2014). We hope that this conceptual framework and subsequent ABMs can contribute with in the primary prevention of obesity and related comorbidities (i.e., hypertension, metabolic syndrome, diabetes, and dyslipidemia), which is a key course of action against the mortality rates caused by these global concerns (Hoelscher, et al., 2015; Lutfiyya, et al., 2008; Padwal & Sharma, 2010; van Grieken, et al., 2012).

Strengths and Limitations

In designing this framework, we drew upon lay-person, stakeholder and expert opinion, alongside up-to-date evidence from a comprehensive systematic review of published reviews. The integration of this diverse set of information is a significant strength of the current study and the resulting framework, which ensures its accuracy and generalizability. Also, the heterogeneity between the fields of the experts improved the comprehensiveness of the final conceptual framework. Furthermore, this conceptual framework provides a good basis for future work by other researchers to expand and modify accordingly. More importantly, our multilevel framework was designed to be suitable for the development of ABMs, while other existent models are neither multilevel nor appropriate for ABM.

On the other hand, there were some limitations that should be pointed out. First, the low response rate of experts contacted suggests that non-responder bias may affect the quality of the opinions. However, the broad range of sub-specialties represented by the respondents is reassuring, indicating that the expert input was diverse and comprehensive. Another limitation is that the thematic synthesis of survey findings was performed by a single author without input from independent coding. Lastly, some relevant elements and mechanisms were not considered or included because there was no review about them yet.

Conclusion

This study combined evidence from qualitative and quantitative sources to create a dynamic conceptual framework which aims to inform and support the creation of an ABM of healthy eating behaviour. Once validated through external data, we will be able to explore population patterns and various scenarios, thereby informing potential population-wide interventions for healthy eating behaviours.

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Figure 1. Steps for developing the conceptual framework.

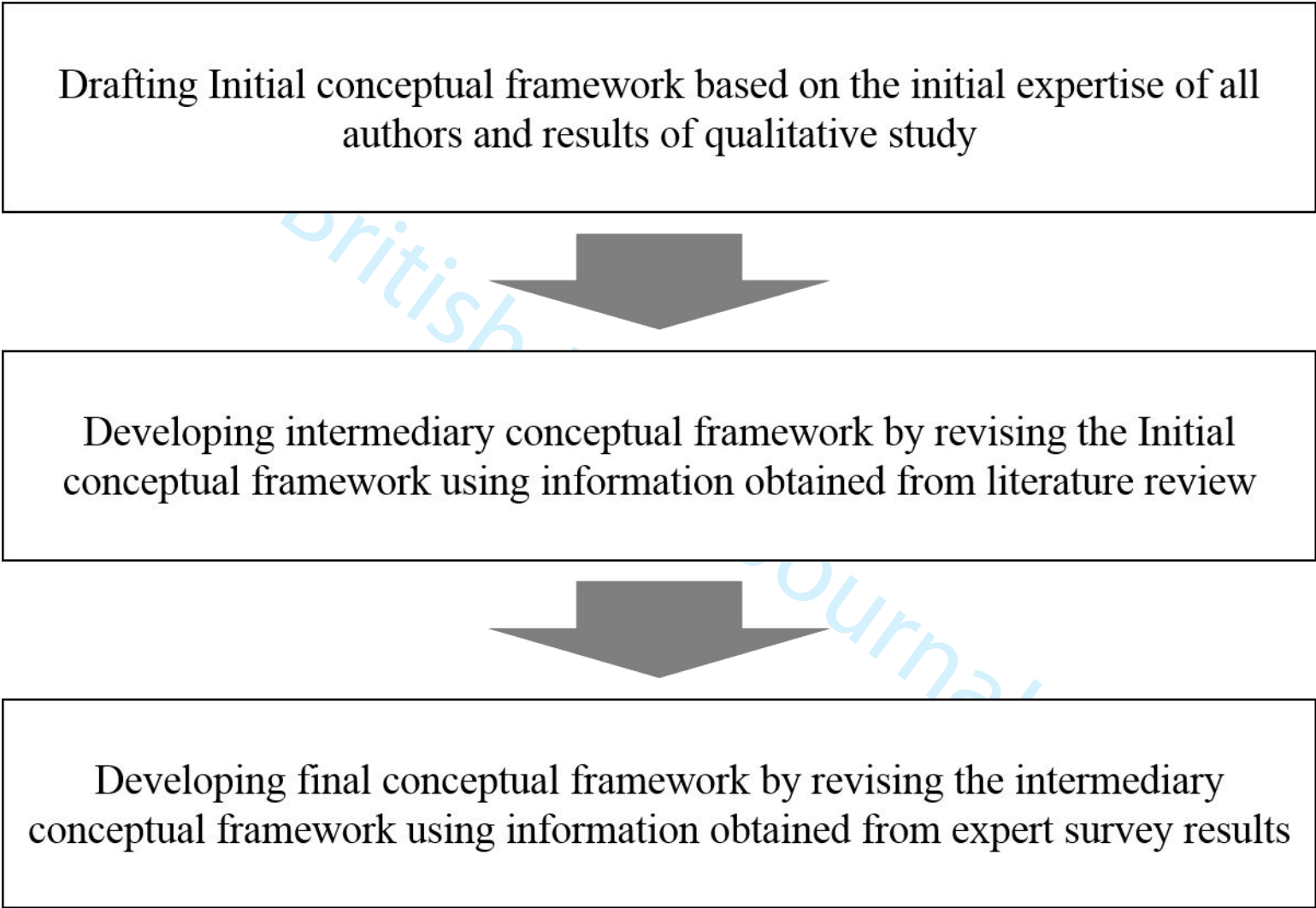


Figure 2. Flow chart of included studies identified in the literature search.

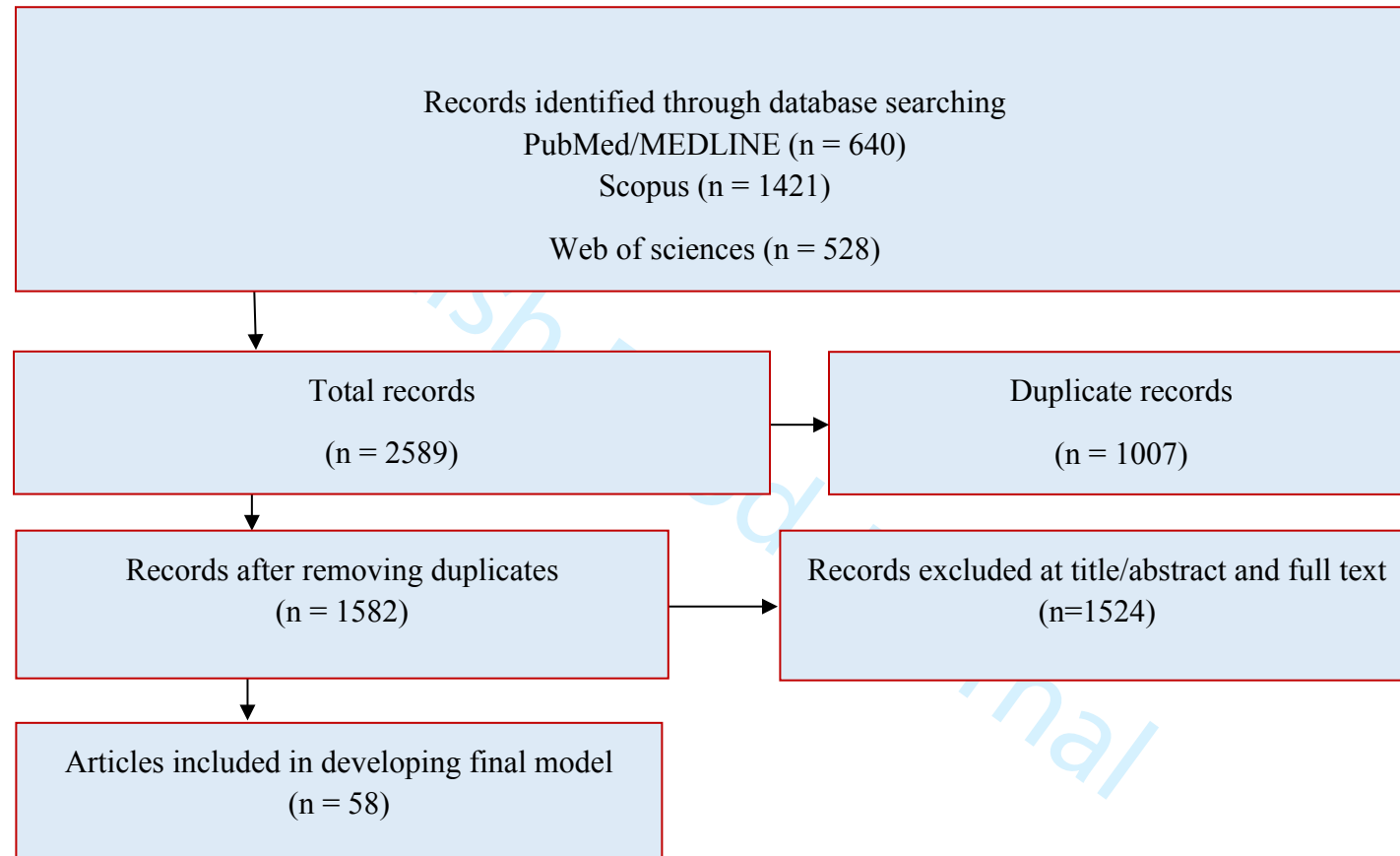


Figure 3. Dynamic conceptual framework of factors affecting the adoption of healthy diet.

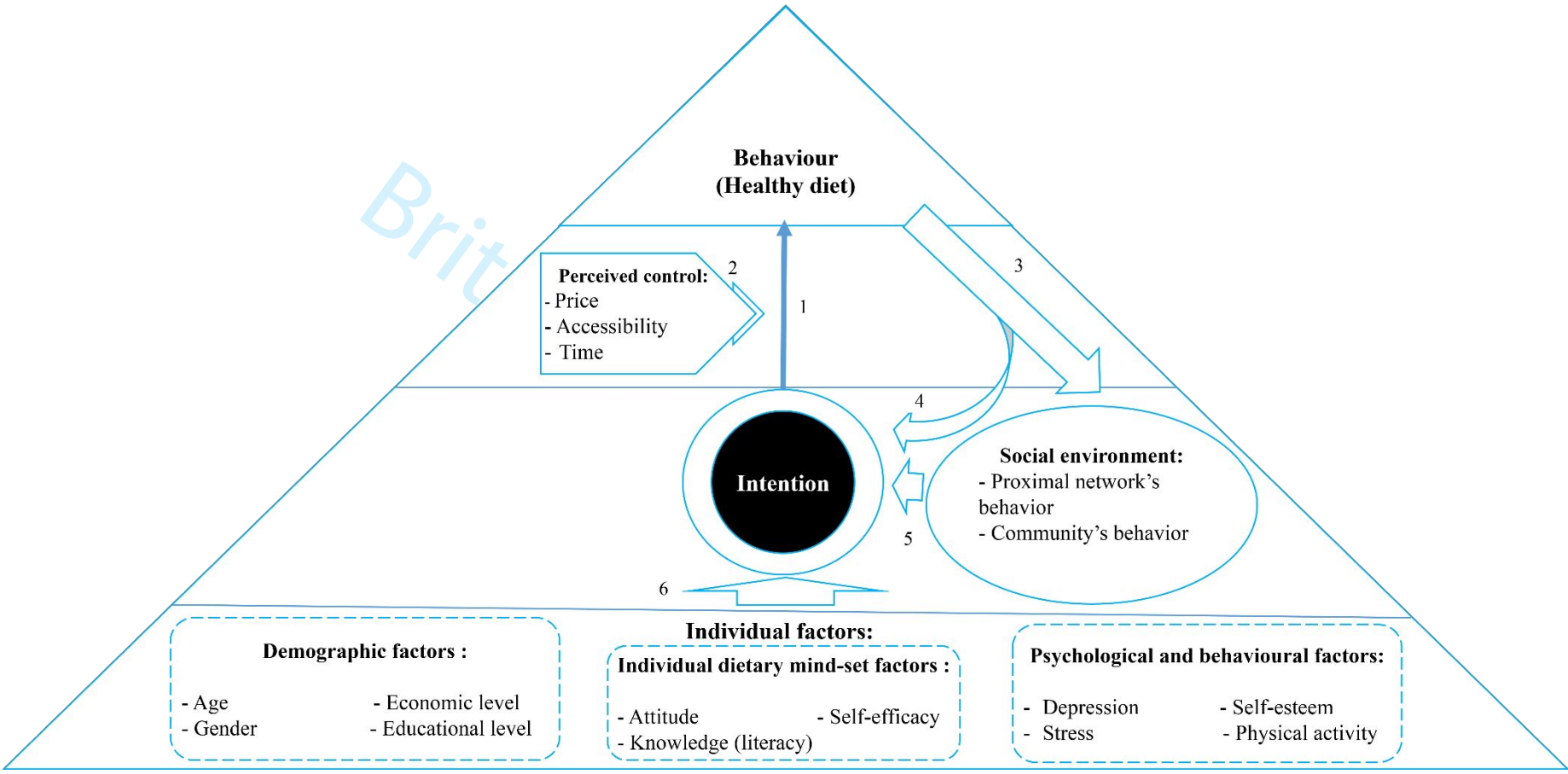


Figure 4. Example of the moderating effect of the perceived controls on the relationship between intention to adopt a healthy diet and the likelihood of following a healthy diet (Continuous line: relationship with no modification effect. Dotted and dashed lines: are relationships moderated by positive (dotted) or negative (dashed) perceived levels of control (Adapted from Garcia et al.2017)

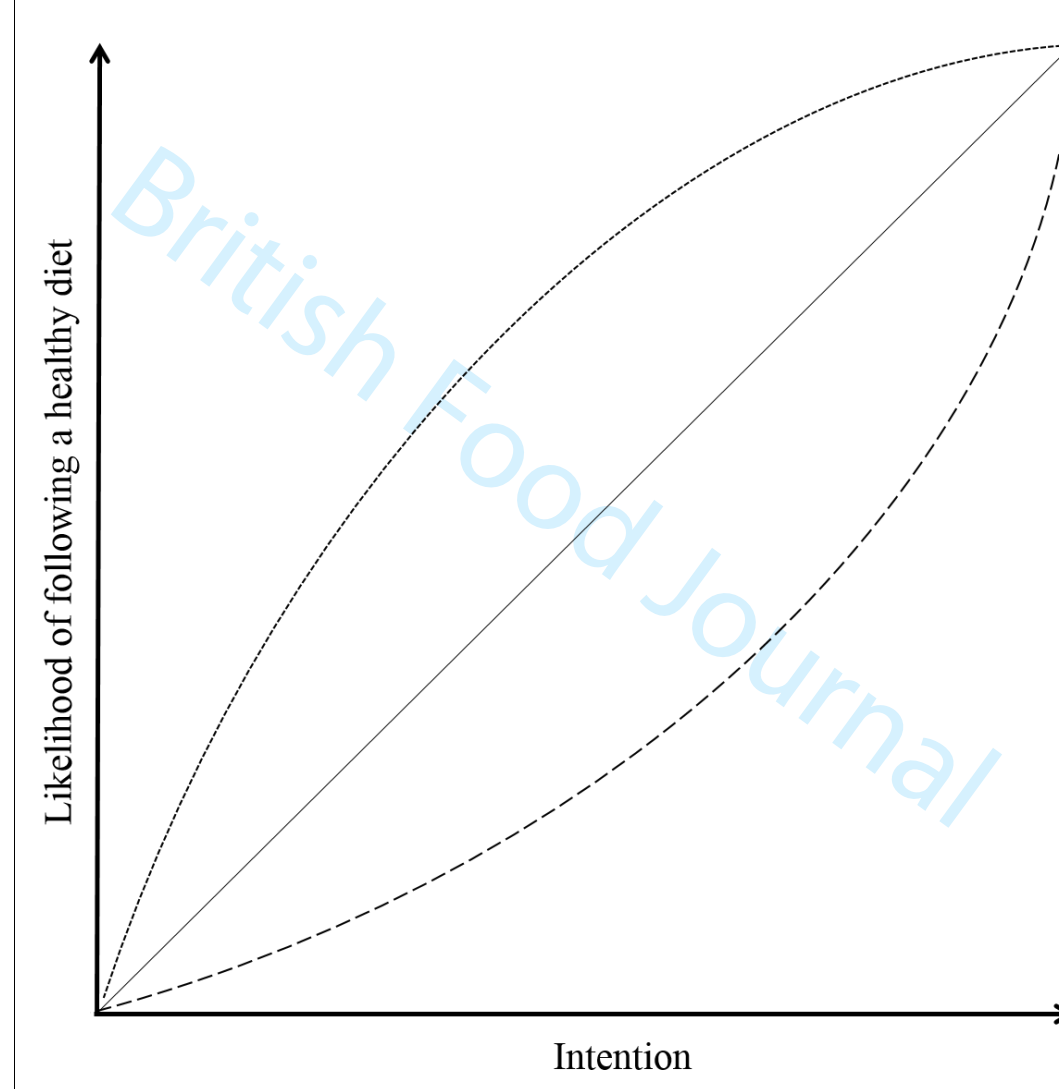


Table 1. Operational definition of the elements in the conceptual framework.

Domain	Construct	Operational definition	
Individual attributes	Behaviour	Individual’s healthy diet during a certain period of time	
	Intention	Effort of an individual to having a healthy diet	
	Demographic	Age	
		Gender	
		Educational level	
		Economic level	
	Individual dietary mind-set factors	Attitude	A feeling or opinion about having a healthy diet
		Knowledge (nutritional literacy)	Knowledge of concepts and processes related to nutrition and health including knowledge of diet and health, diet and disease, foods representing major sources of nutrients, and dietary guidelines and recommendations
		Self-efficacy	One's ability to manage a healthy diet
	Psychological and behavioural factors	Depression	Mood disorder that causes a persistent feeling of sadness and loss of interest.
		Stress	Feeling of strain and pressure.
		Self-esteem	An individual's subjective evaluation of their own worth
Physical activity			
Perceived control	Price	Price of foods	
	Accessibility	How easily people can access and purchase healthy foods	
	Time	Having enough time to follow a healthy diet	
Social environment	Proximal network’s behaviour	Adherence to healthy diet of the people within the person’s proximal network (friends, relatives etc.)	
	Community’s behaviour	Adherence to healthy diet of people living in a relatively large and geographically limited area	

Table 2. Meanings and assumptions of relationships contained in the conceptual framework.

Relationship	Meanings and assumptions
1	The intention of an individual determines his/her adoption of a healthy diet. The greater the intention, the more likely is to adopt a healthy diet.
2	Moderating effect of the perceived controls on the relationship between intention and the likelihood of following a healthy diet. Perceived controls strongly influence the relationship between intention and behaviour (see Figure 4).
3	The behaviour of the social environment (proximal network and community) are influenced by the individual's behaviour.
4	The intention of an individual is influenced by his/her past behaviour. This relationship has an inverted U shape, i.e., the closer the intention is to its upper or lower limit, the weaker the influence of the individual's past behaviour on his/her current intention.
5	The intention of an individual is influenced by his/her social environment (proximal network and community). This relationship has an inverted U shape, i.e., the closer the intention is to its upper or lower limit, the weaker the influence of the social environment on his/her current intention.
6	The intention of an individual is influenced by his/her intrinsic individual factors.

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Supplementary material

Table S1. Keywords used in the literature search.

PubMed/MEDLINE	Scopus	Web of sciences
((((((("Food Preferences"[Mesh] OR "Diet, Healthy"[Mesh]) OR "eating behaviour"[Title/Abstract]) OR "Food Preferences"[Title/Abstract]) OR "food choice*"[Title/Abstract]) OR "food selection"[Title/Abstract]) OR "healthy diet"[Title/Abstract]) OR "healthy eating"[Title/Abstract]) OR "eat healthier"[Title/Abstract]) AND (((("meta analysis"[Title/Abstract] OR "meta-analysis"[Title/Abstract]) OR "systematic review"[Title/Abstract]) OR "systematic-review"[Title/Abstract]))	(((TITLE-ABS-KEY ("meta-analysis") OR TITLE-ABS-KEY ("meta analysis") OR TITLE-ABS-KEY ("systematic review") OR TITLE-ABS-KEY ("systematic-review"))) AND ((TITLE-ABS-KEY ("eating behaviour") OR TITLE-ABS-KEY ("Food Preferences") OR TITLE-ABS-KEY ("food choice*") OR TITLE-ABS-KEY ("food selection") OR TITLE-ABS-KEY ("healthy diet") OR TITLE-ABS-KEY ("healthy eating") OR TITLE-ABS-KEY ("eat healthier"))))	TS=("eating behaviour" OR "Food Preferences" OR "food choice*" OR "food selection" OR "healthy diet" OR "healthy eating" OR "eat healthier") AND TS=("meta analysis" OR "meta-analysis" OR "systematic review" OR "systematic-review")

Table S2: Summary of findings from systematic reviews and meta-analysis retrieved from the literature search.

Reference	Main findings
(Robson et al., 2020)	Positive association between <i>family meal frequency</i> and Healthy Eating Index.
(Bennett et al., 2020)	<i>Price promotions</i> of unhealthy foods may shift consumer purchasing ability towards cheaper choices.
(Yang et al., 2019)	<i>Training and education</i> may influence eating behaviour.
(Vecchio et al., 2019)	<i>Nudging approaches</i> redirect consumer choice towards a healthier outcome and was successful in over 80% of studies. Nudging involves modifying the <i>physical or social context</i> .
(Tørris et al., 2019)	<i>Traffic-light labelling</i> may be a promising strategy in selecting healthy food.
(Tan et al., 2019)	<i>Stimulating sensory functions</i> are negatively associated with food intake. Dietary behaviours are more related to <i>preferred appearance</i> compared to <i>sensitivity and intensity measures (taste)</i> .
(Strahler, 2019)	Similar tendencies to a healthy diet between <i>genders</i> , although healthful eating is more pronounced in women.
(Shaw et al., 2019)	Environmental interventions such as <i>health promotion education</i> and labelling improve dietary behaviours.
(Sala et al., 2019)	<i>Mindfulness</i> (bringing one's attention to present moment) is associated with eating health behaviours (rs=0.14, 95% CI: 0.08-0.19).
(Perez-Cueto, 2019)	Providing information such as <i>nutrition education, labelling, nutrition information on foods</i> for a healthy diet promotes healthy choices in consumers. Healthier food choices are related to <i>food literacy</i> .
(Panao et al., 2019)	Autonomous motivations for exercising such as <i>pleasure, health, and wellbeing</i> are associated with healthy eating behaviours, but <i>appearance-related exercising</i> and other controlled reasons were inversely related to healthy eating behaviours.
(Oostenbach et al., 2019)	Propensity to select healthier foods is related to <i>nutritional claims</i> , which sometimes led to an increase in energy intake and food consumption by consumers.
(Nardi et al., 2019)	<i>Past behaviour</i> had an effect on food choice intentions (r=0.341; p=0.001) and behaviour (r=0.386; p=0.291). This relation was weaker in <i>higher age</i> (MLowAGE=0.505; MHighAGE=0.344, p=0.05). The relationship between PBC and behaviour was weaker among <i>women</i> (MLowGEN=0.304; MHighGEN=0.13, p=0.05).
(McGowan et al., 2019)	<i>Oral health</i> has a positive relationship with healthy diet/nutrition outcome.
(Li et al., 2019)	<i>Nutritional education</i> improves dietary behaviours.
(Devonport et al., 2019)	<i>Stress, depression, and sadness</i> increase unhealthy eating behaviours.

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(Clohessy et al., 2019)	<i>Job role, workplace food environment, and social aspects of the office</i> influence eating behaviours at the workplace.
(Zorbas et al., 2018)	<i>Diet affordability and availability</i> of healthy food stores had an effect on a healthy diet especially in lower socio-economic groups.
(Yeung, 2018)	<i>Men and women</i> have different brain responses to food, driving differences in eating behaviour.
Wright et al., 2018	<i>Social identity</i> affects policies or interventions that aim at improving healthy choices. Reduction of <i>portion size</i> may be effective.
(Woodruff et al., 2018)	<i>New retailers</i> selling healthy food may result in modest short-term improvements in healthy diet behaviour among adults
(Steinhauser et al., 2018)	Relationship between <i>knowledge of nutrition, familiarity, and socio-demographic characteristics</i> and health.
(Rahimi-Ardabili et al., 2018)	<i>Self-compassion</i> may be beneficial for improving nutritional or eating behaviours and body image.
(Hill et al., 2018)	Relationship between <i>stress</i> and unhealthy eating behaviours among children (younger than 12 years old: Hedge's $g = 0.283$, $p < 0.001$) and older than 12 years old: Hedge's $g = 0.274$, $p = 0.001$).
(Hartmann-Boyce et al., 2018)	<i>Availability of foods</i> plays an important role in improving health.
(Garcia et al., 2018)	<i>Availability and adequacy</i> of healthy food have a positive impact on practices of healthy food choice and food perceptions.
(Blaga et al., 2018)	<i>Traffic-light labels</i> promote healthy food choices; furthermore, use of <i>incentives + education</i> decreases unhealthy food consumption and reduce waste.
(Appleton et al., 2018)	<i>Exposure to healthy food and the use of rewards</i> increase healthy dietary behaviours (exposure 0.23, CI: 0.07-0.39; reward 0.32, CI: 0.15-0.50).
(Amireault et al., 2018)	Interventions that <i>last ≥ 17 weeks</i> (≥ 4 months) are more likely to improve healthy eating behaviours.
(Pitt et al., 2017)	<i>Availability, accessibility and affordability</i> were identified as key determinants of healthy food choice within community nutrition environments.
(Kaur et al., 2017)	<i>Foods health claims</i> have an important effect on dietary choices (OR 1.75, CI: 1.60–1.91).
(Broers et al., 2017)	<i>Nudging</i> aimed at increasing healthy diet behaviour have a moderate significant effect ($d = 0.30$).
Allan et al., 2017	<i>Environmental change</i> seemed to affect eating behaviour successfully.
(Abeykoon et al., 2017)	<i>Improving food access at retailers</i> does not show strong evidence of enhancing health-related behaviour.

(Mogendi et al., 2016)	Key determinants of consumer evaluation were: (1) <i>information and nutrition knowledge</i> ; (2) <i>attitudes, beliefs, perceptions and behavioural determinants</i> ; (3) <i>price, process and product characteristics</i> ; and (4) <i>socio-demographics</i> .
Fernandes et al., 2016	<i>Labelling</i> in menus was not effective to promote healthier food choices.
Cecchini et al., 2016	<i>Labelling</i> empowers consumers in choosing healthier foods.
Bucher et al., 2016	<i>Food position or order</i> have positive effect on food choice.
(Boyland et al., 2016)	Exposure to <i>food advertising</i> increases food intake among children but had no effect among adults.
(Riebl et al., 2015)	<i>Attitude</i> has the strongest relationship to dietary behavioural intention (mean $r=0.52$; $p=0.001$), while <i>dietary behavioural intention</i> was the strongest predictor of behaviour performance (mean $r=0.38$; $p=0.001$).
(McDermott et al., 2015)	<i>Attitudes</i> showed the strongest relationship with intention ($r=0.54$), followed by <i>Perceived Behavioural Control</i> ($r=0.42$) and <i>Subjective norm</i> ($r=0.37$). The association between intention and behaviour was $r=0.45$ and between <i>Perceived Behavioural Control</i> and behaviour was $r=0.27$. Age moderated the intention-behaviour among the ≤ 17 age group, differing significantly from the $30+$ age group ($B=-0.21$), but <i>gender</i> was not a moderator for associations within the <i>theory of planned behaviour</i> .
(Kamphuis et al., 2015)	People of <i>Low socio-economic class</i> were more likely to eat more unhealthy bread products (OR: 3.22, 95% CI: 1.77–5.84), and unhealthy meat products (OR: 1.96, 95% CI: 1.37–2.80) than people of higher socio-economic status; age and sex adjusted.
Cardi et al., 2015	<i>Negative mood</i> is related to higher food intake.
(Bull et al., 2015)	Among people of <i>low-income groups</i> , behaviour change interventions have small positive effects on healthy eating (SMD: 0.22, 95% CI: 0.14 to 0.29).
(Akande et al., 2015)	<i>Low socio-economic status</i> and <i>high transportation cost</i> which affects food accessibility are associated with poor dietary choices.
(Robinson et al., 2014)	High intake norms ($Z=3.84$; $P=0.0001$; SMD 0.41, 95% CI 0.20 - 0.63) and low intake norms ($Z=2.78$; $P=0.005$; SMD -0.35, 95% CI -0.59 to -0.10) have moderate influence on amounts of food eaten. This finding show <i>norms</i> influence food choices.
(van 't Riet, 2013)	<i>Product health information</i> affect actual purchase behaviour. Interventions with <i>higher length</i> are more effective.
Skov et al., 2013	<i>Health labelling</i> and <i>payment option manipulation</i> were associated with healthier food choice
(Eyles et al., 2012)	<i>Raising taxes</i> on unhealthy food (carbonated drinks and saturated fat) and <i>subsidising</i> healthy food (fruits and vegetables) were associated with beneficial dietary change.

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(Fletcher et al., 2011)	<i>School friendships</i> may be critical in eating behaviours and <i>social-network based</i> health promotion interventions in schools are important.
(Diaz Ramirez et al., 2011)	Relationship between <i>exposure to food advertising</i> and food consumption.
(Adriaanse et al., 2011)	<i>Intention</i> is an effective tool for promoting healthy food items (Cohen's $d = 0.51$), but it is not a good tool for reducing unhealthy eating patterns (Cohen's $d = 0.29$).
(Andreyeva et al., 2010)	<i>Reduction in income or dramatic increases in food prices</i> can lead to changes in food purchasing behaviours.
(De Irala-Estevez et al., 2000)	Higher <i>Socio-economic and educational status</i> is associated with a healthy diet. The difference in fruit intake was 24.3 g/person/day (95% confidence interval (CI) 14.0–34.7) between men in the highest and lowest level of <i>education</i> . Similarly, the difference was 33.6 g/person/day for women (95% CI: 22.5–44.8). The differences regarding vegetables were 17.0 g/person/day (95% CI: 8.6–25.5) for men and 13.4 g/person/day (95% CI: 7.1–19.7) for women. The results were still significantly different when <i>occupation</i> instead of education was used as an indicator of socio-economic status.
(Spronk et al., 2014)	Significant, positive, but weak ($r < 0.5$) association between higher <i>nutritional knowledge</i> and dietary intake, especially with intake of fruit and vegetables.
(Escaron et al., 2013)	Supermarket and grocery store interventions (such as <i>point-of-purchase, pricing, and promotion and advertising</i>) for promoting healthful eating is effective.
(Gittelsohn et al., 2017)	<i>Pricing interventions</i> that sought to improve access to healthy food increased stocking, sales, purchasing, and consumption of these types of food.
(Liberato et al., 2014)	Short-term <i>monetary incentives</i> increased purchase of healthier food.

Footnotes: SMD: standardized mean difference

Table S3: Results of concepts from expert survey based on the intermediary conceptual framework

No	Level of agreement with the intermediary model	Concepts added to the intermediary conceptual model	Concepts removed from the intermediary conceptual model	Other comments
1	4	Health literacy	Not evident what attitude means	No
2	4	Subjective and moral norms, self-identity, self-efficacy, self-esteem	Perceived behavioural control and social environment can influence intention and behaviour directly	-
3	3	Food industry environment, obesogenic environment, socio-economic factors as part of the social environment	It is not only about the intention and behaviour, and it is about accessibility, which does not only influence perceived control, as it also impacts access to healthier or less healthy foods beyond control.	-
4	3	Cooking skills (within perceived control); habits and heuristics (as food choices rely mostly on prior experience). In the social environment, you can address choice architecture and obesogenic facilitators.	I think that your variable for perceived control may not be the best. Both are more about food security.	Your model seems to be an adaptation of the theory of planned behaviour. You could enrich your model with thinking of the dual-process theory and how it may add instrumental variables to your model.
5	4	Wonder about personal food preference, hunger, appetite, taste preferences, social support, self-efficacy, media and advertising? They may fall under some of the existing categories, but I think I need to be included.	No	This is a good source of info although Europe focused - https://www.eufic.org/en/healthy-living/article/the-determinants-of-food-choice

6	3	Many food environments and food system drivers, commercial influences etc.	No	-
7	2	Self-efficacy in cooking and eating healthy; weight/body fat	No	I believe that individual factors should be divided into modifiable and not (i.e. personal characteristics and variables that can be changed). Moreover, there are unperceived attitudes, such as pleasantness, the habit of eating in a certain way, familiarity. It is hard to properly evaluate the conceptual model without reading the literature in which it is based.
8	2	Preference, background, body image, self-efficiency	No	-
9	5	Self-efficacy, healthy diet-related skills	No	No
10	4	Intrinsic motivation; Cultural factors	No	-
11	3	I think that human behaviour could also be influenced by mental representation and cognitive schemes of interpretation of reality.	No	-
12	3	Not just social environment, but culture (cf. vast differences between countries); behavioural biases (often not conscious: cf. Pierre 'Chandon's articles)	No	It is a good basis to explain it. It can probably never be exhaustive, but surely it can help.

13	4	Maybe the current health status of the individual as well as the health status of family members. For example, knowing that my father had diabetes, I might follow a more healthy diet to avoid getting diabetes.	No	No
14	3	Occupation, income	No	The perceived control factors would require further digging. It can gather more variables that are relevant
15	4	Familial aggregation and genetic predisposition, co-morbidities	No	No
16	4	Does the model consider whether or not individuals are motivated (by health or other?) to make healthy choices? Health status? Background interests (e.g. a high performing athlete might be more likely to choose wisely). Impact of media/advertising to influence? Impact of peer pressure (all friends going to McDonald's...)	No	No other
17	4	Time management as an individual factor, and quality and social status as perceived control	What is the minimum age included in this conceptual framework? If it is 18 years, then you have left out factors that influence this age group? Yes, they are also influenced by (social, economic, physical, biological and attitudes, belief and knowledge) But most importantly taste hunger and convenience. The prevalence of	I would classify the factors in a group (social, economic, physical, biological and attitudes, belief and knowledge). All the best.

			obesity in this age group is increasing rapidly.	
18	4	Perhaps something around physical health. You have mental health, but there are many physical conditions the dictate how a diet should be or be adapted.	No	Just the consideration of "physical health."
19	5	Diseases, drugs. Also, intermediate results could significantly improve the adherence to the diet.	No	Some diseases can influence adherence, as well as smoking habits
20	5	One aspect I think you missed is "the power of advertisement"; It is the principle behind of television and its mechanism to condition us into buying some products over the other. This is served upon us by our modern society's consumerism logic	No, actually it is a well-performing model. It highlights the majority of the factors that may affect a man	-
21	4	Maybe cultural and economic capital as Bourdieu mentioned	Maybe physical activities	-
22	4	Not seemingly	-	Family environment or childhood behaviour or similar variable also might contribute to diet behaviour.
23	4	You may add time to the "Perceived Control" box - eating a healthier diet may take more time (shopping, cooking) than eating an unhealthy diet. Even if someone wants to eat healthier, he/she may have limited time.	No	-

Table S4. Changes made between conceptual frameworks

Versions of models	Type of change	Change
Primary to intermediary	Elements	Environmental factors (Social and physical): change to Social Environment Intention to a healthy diet: change to intention Adherence to a healthy diet: change to the behaviour Access to healthy foods: change to access knowledge of a healthy diet: change to knowledge Economic level: added Perceived control: added Food factors: removed Quality (safety): removed Taste: removed
	Relations	Past behaviour influencing intention: added Past behaviour influencing social environment: added Perceived control influencing intention to behaviour: added Food factors influencing intention: removed Food factors influencing intention to behaviour: removed
Intermediary to Final model	Elements	Access: change to accessibility Time: added Self-efficacy: added Self-esteem: added
	Relations	Individual factors: divided into Demographic factors, individual dietary mind-set factors, and Psychological and behavioural factors.

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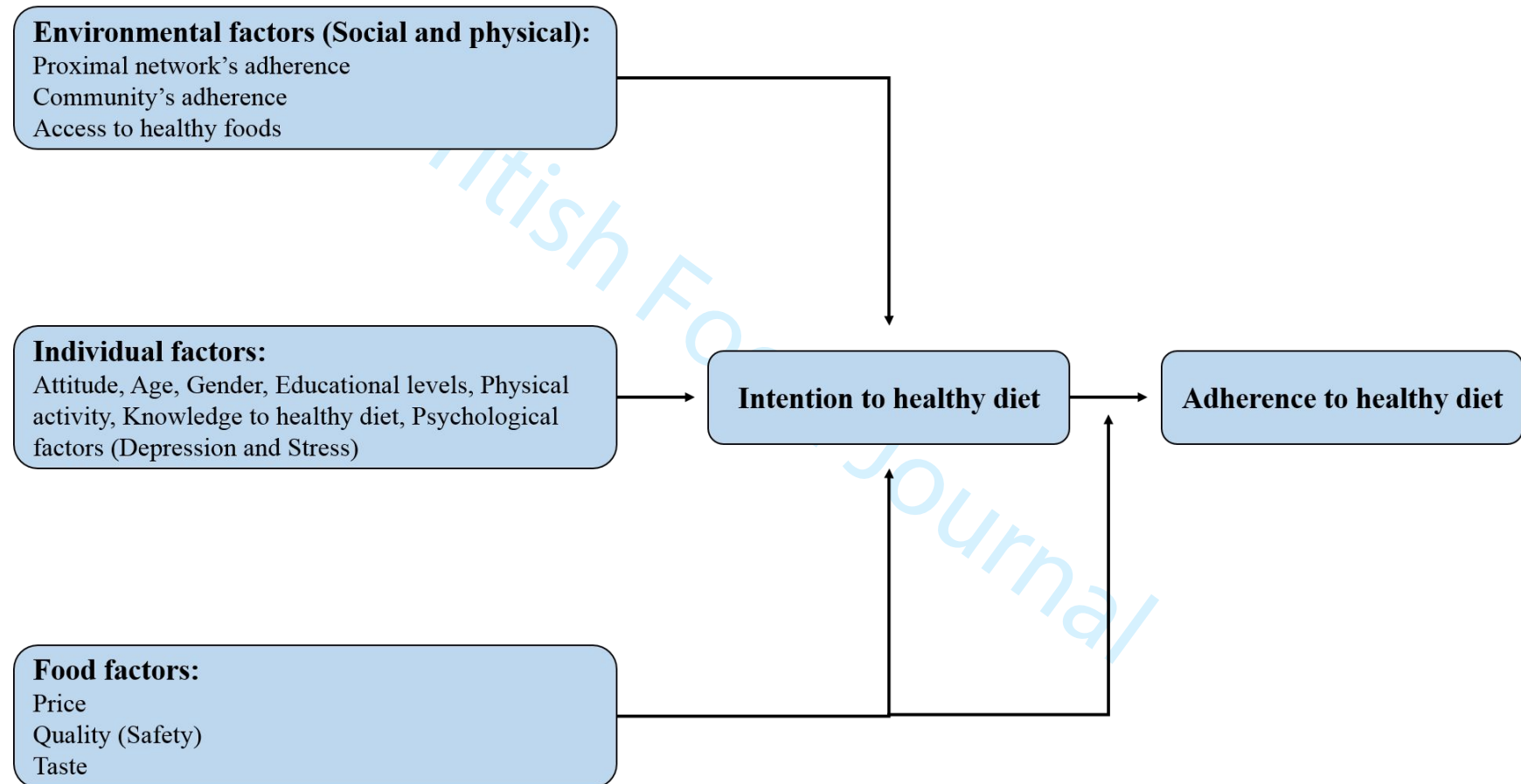
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Supplementary material

Figure S1. Initial conceptual framework.



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Figure S2. Intermediary conceptual framework.

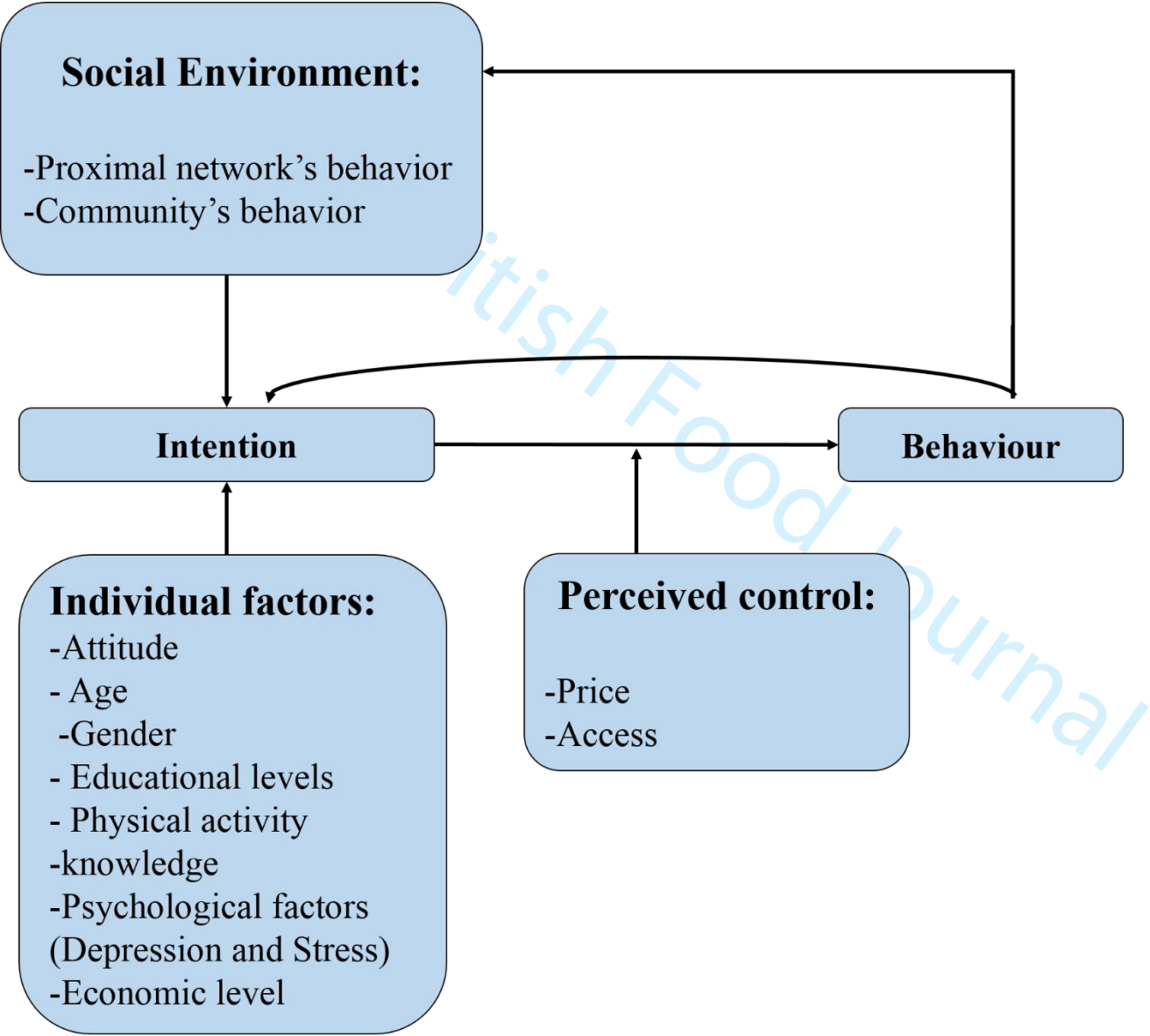


Figure S3. Frequency (%) of variables proposed by expert researchers.

