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Strategies for online personalised nutrition advice employed in the development of the eNutri web app

Rodrigo Zenun Franco[1], Rosalind Fallaize[2], Faustina Hwang[1] and Julie A. Lovegrove[2]*
[1]*Biomedical Engineering Section, School of Biological Sciences, University of Reading, Reading RG6 6AY, UK*
[2]*Hugh Sinclair Unit of Human Nutrition, University of Reading, Reading RG6 6AH, UK*

The internet has considerable potential to improve health-related food choice at low-cost. Online solutions in this field can be deployed quickly and at very low cost, especially if they are not dependent on bespoke devices or offline processes such as the provision and analysis of biological samples. One key challenge is the automated delivery of personalised dietary advice in a replicable, scalable and inexpensive way, using valid nutrition assessment methods and effective recommendations. We have developed a web-based personalised nutrition system (eNutri) which assesses dietary intake using a validated graphical FFQ and provides personalised food-based dietary advice automatically. Its effectiveness was evaluated during an online randomised controlled trial dietary intervention (EatWellUK study) in which personalised dietary advice was compared with general population recommendations (control) delivered online. The present paper presents a review of literature relevant to this work, and describes the strategies used during the development of the eNutri app. Its design and source code have been made publicly available under a permissive open source license, so that other researchers and organisations can benefit from this work. In a context where personalised diet advice has great potential for health promotion and disease prevention at-scale and yet is not currently being offered in the most popular mobile apps, the strategies and approaches described in the present paper can help to inform and advance the design and development of technologies for personalised nutrition.

FFQ: Internet: Software: EatWellUK

The general recommendations for addressing non-communicable diseases are related to lifestyle changes, mainly encouraging healthy diets and physical activity[1]. The majority of face-to-face nutritional consultation in public services is available only to people with a diagnosed condition such as diabetes or obesity. For people without a diagnosed condition, preventive initiatives are focused on generalised public guidelines only, such as the five-a-day campaign in the UK, which aims to encourage a minimum consumption of five portions of fruit or vegetables daily[2]. Internet technologies offer considerable potential for delivering online personalised nutrition advice at-scale, however, they need to fulfil a number of requisites in order to foster wide uptake: reproducibility, scalability, security and usability.

Background

We have developed a web-based personalised nutrition system (eNutri) which assesses dietary intake using a validated graphical FFQ and provides personalised food-based dietary advice automatically[3]. The next subsections present a review of technologies used for nutrition assessment and recommendation, how they were used in previous online nutrition interventions and the rationale behind the eNutri app development.

Nutrition assessment methods

Valid dietary intake recording is key for nutritional intervention. The methods used for collecting food intake

Abbreviations: AHEI, alternative healthy eating index; RCT, randomised controlled trial; 24HR, 24-h recall.
***Corresponding author**: Julie A. Lovegrove, fax +44 1189310080, email j.a.lovegrove@reading.ac.uk

data can be classified in a number of ways. Based on the time of the collection, retrospective methods, such as the 24-h recall (24HR), require memory for recollection of foods eaten. In contrast, prospective methods require diet reporting as food is consumed, acting as food diaries.

An important and long-established retrospective nutrition assessment method is the FFQ. A FFQ is based on a list of popular food items in a specific region, and typically contains about 100 items[4]. FFQ have some accuracy limitations (e.g. energy estimation) but are more appropriate for initial dietary assessment for the purposes of personalised nutrition, because this method captures longer-term patterns in the diet. It has been used in epidemiological studies for decades, for example, the European Prospective Investigation into Cancer and Nutrition (EPIC) study, one of the largest cohort studies in the world with more than half a million participants recruited across ten European countries. The UK version of this FFQ is known as the EPIC-Norfolk FFQ[5], which was adapted for use in the Food4me project[6], the largest study (*n* 1540) on personalised nutrition at the time of writing this review.

Diet quality scores

Most public nutrition campaigns aim to improve diets at population level through qualitative or simplified quantitative approaches, such as the Eatwell guide in the UK[7]. Similarly, food pyramid guides have been used to indicate the relative proportions of food groups (e.g. vegetables, salad and fruit *v.* fats, spreads and oils) that make up a balanced diet[8]. These tools are important but mainly designed to offer a visualisation of a balanced diet, and do not easily lend themselves to a computational analysis of the diet. In order to propose a more quantitative analysis of a dietary intake, indexes of diet quality have been developed over the past decades. Some focus on local guidelines and others on specific target groups or diseases. A comprehensive report containing existing indexes of diet quality was published in 2005[9].

The Healthy Eating Index (HEI), revised in 2010[10], was developed by the United States Department of Agriculture. In some cases, specific indexes have been created to address particular diseases, such as the alternative HEI (AHEI) that predicts the risk of chronic diseases[11]. The AHEI calculations are clearly defined and quantitative[11], making them well-suited for implementation in software. Furthermore, this index can be used with the data derived from different dietary assessment methods such as 24HR or FFQ.

Online personalised nutrition

Tailoring plays an important role in health interventions[12,13] and there is an interest amongst end-users in receiving personalised nutrition advice[14,15]. Some studies are investigating how to personalise nutritional guidance for more effective behaviour change[16]. The Food4Me study was designed to determine the efficacy of different levels of personalised nutrition: based on diet intake alone; diet and phenotypic biomarkers; and diet, phenotype and genotype. Results showed that personalisation of food-based dietary advice based on an individual's dietary intake was more effective than generic public health advice, although in that study, no further benefit resulted from the addition of phenotypic or genetic advice[17,18]. The Food4Me dietary advice was based on a decision tree executed manually by researchers during the study to create a report that was sent via e-mail. This decision tree was subsequently automated[19], but their details have not been published. The lack of transparency in reporting nutrition interventions makes the reproducibility and comparison between studies more challenging and the improvements in this field slower. This difficulty was reported in 2017 by Warner *et al.* in a systematic review of telehealth-delivered dietary intervention trials[20].

Technologies for recording dietary intake

Nutrition assessment methods are traditionally paper-based, and their administration and analysis are time consuming and more expensive than digital methods[21]. Besides the faster and easier processing of data input, computerised methods bring the advantage of immediate results. However, the interest for digitalising the recording of dietary intake is not recent. An overview of computerised dietary assessment programmes published in 2005 discussed twenty-nine programmes designed to be used by health professionals or in research[22]. They used one or two of the following nutrition assessment methods: food record (*n* 13), diet history (*n* 8), FFQ (*n* 5) and 24HR (*n* 5).

Prospective nutrition assessment methods (e.g. estimated food diary), usually offer a feature to search for the food items in a database. Although more convenient for the user than inserting the information manually from paper, these repetitive searches are still time consuming. Besides the fact that a single food diary may contain more than twenty food items, the recording of dietary intake using these methods still require logging of the quantity (e.g. two bananas) and the weight. Depending on the food item, the weight may be derived from typical household portions, for example a teaspoon of sugar. However, some items present greater challenges for weight estimation. The end user (i.e. citizen/patient) normally does not know the weight of a banana and the text-based units (e.g. small, medium, large) may not be enough to accurately assess portion weight without food images. Furthermore, in order to increase the successful response rate during food searches, system designers may want to increase the size of the food database, so that a more specific search may be conducted (e.g. a specific pizza brand), but this may decrease the quality of the food composition database supporting the nutrient analysis (i.e. incomplete or less reliable nutrient data for these very specific items, especially branded foods). This is due to the fact that typical food composition tables do not contain all the food items available in a specific country, but only generic versions (e.g. soft drink) of popular items (e.g. coke)[23].

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These systems started to gain popularity in the internet age and are now very popular not only among nutrition professionals[24] but also among the general population[25]. Due to this burden of data input and in an attempt to make these systems more acceptable, some emerging technologies have been considered in order to replace the textual search, mainly using image recognition and natural language processing. There are some open challenges in terms of accuracy of these technologies in this field, and the next subsections will discuss some systems using traditional technologies (food selection and search) and also how more advanced technologies can bring improvement, increasing the convenience of dietary intake recording.

Established technologies

In terms of online FFQ, the first online versions presented simple tables with food names in the rows and frequencies in the columns[26], very similar to the paper-based versions[27]. Some paper-based FFQ present images for the participants to select the portion sizes. This same strategy was replicated in the digital domain during the development of the Graphical Food Frequency System[28].

The presentation of many frequency options and a few images to the users is challenging on small screen devices such as smartphones. The completion process is very repetitive, which may decrease the user satisfaction with the system. Another potential usability challenge is the presentation of the frequency options, since they do not necessarily all use the same units (e.g. two monthly, three weekly, one daily), making the decision-making process more difficult. The online Food4Me FFQ presented three food images together with seven radio buttons for the user to select the portion size (i.e. very small, small, small/medium, medium, medium/large, large, very large)[6]. Both the small radio buttons and the number of options presented simultaneously on the screen are not appropriate for smartphones. In addition, the Food4Me web design was not responsive, that is, it did not adapt to the screen size of the device. The visual design and layout of the FFQ options and their impact on usability was a research gap explored during the current project.

One project using 24HR is the ASA24[29], an automated self-administered system developed by the American National Cancer Institute. Three UK-based projects also used the 24HR method: Oxford WebQ[30], Intake24[31] and MyFood24[32,33]. This method is able to capture how a dietary intake is distributed across meals but does not contain much information about food patterns and frequencies over a longer time period. A 24HR system can be adapted to work as a food diary, collecting dietary intake prospectively. For instance, MyFood24 can be used either retrospectively or prospectively.

A number of popular nutrition-related mobile apps, currently available for download, use a nutrition assessment strategy based on food diaries[25]. The aim of collecting detailed information about food consumption sounds promising, but it also demands time and discipline from users[34]. In order to simplify this process, some investigators have proposed alternatives such as the POND (pattern-oriented nutrition diary), which is a Food Index-Based Nutrition Diary[35]. This study explored some alternatives to the food lookup (text search), using for example the ' + 1 button' for items previously inserted (i.e. common items).

Different nutrition assessment methods can be combined during dietary intake recording, in order to increase the nutrient accuracy and also collect different aspect of the information needed (e.g. time of the meals and consumption patterns). A recent publication (2017) shows a new web-based tool (Foodbook24) which combines a 24HR, a FFQ and a supplementary questionnaire[36]. To improve the food and drink search, tags were applied in 484 out of the 751 items, so that brand names and misspellings could be linked to a similar food item. With these searchable tags, a specific food item may return in the search even if its name was not inserted correctly. For instance, the tag 'Coca-Cola' could be attached to coke, making both terms indexed in the search.

Inclusivity is another important aspect to be considered in public nutrition strategies. The NANA (Novel Assessment of Nutrition and Ageing) project included older adults in the design of a system specific for this population. The existing version of this system was successfully tested with older adults and validated from a nutritional perspective. It was a custom software app intended to be used off-line, and it involved the use of a camera and was not designed to provide feedback or advice to the users[37–39].

These studies propose some alternatives to established digital methods that still face many usability challenges. Most of the published studies in this field concentrate on the nutritional validity (accuracy against a gold standard method), but there is a lack of studies exploring how to increase the user acceptance of these digital methods. The amount of effort required to use these tools in relation to the perceived benefit from the user (self-monitoring or personalised nutrition advice) is one of the trade-offs that motivates this current work.

Emerging technologies

The need for technological innovation in dietary assessment has been reported in academic publications[34]. The main challenges are combining improvement in accuracy of assessment and user acceptance. One possible way to make progress in this trade-off is to propose more pervasive technologies, to improve user acceptability, decreasing the burden for users. A comprehensive review of digital methods was published in 2013 and may serve as a reference for the main emerging technologies applied in this field in recent years[40].

Food image recognition is perhaps the most promising technology for bringing convenience to dietary recording in a very scalable way since smartphones with cameras have become widespread. Some studies are focused on food recognition[41,42] and Google has recently

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announced a research project named Im2calories in this area[43]. These experiments train the systems based on limited menus, from restaurants or schools, and try to expand their applicability to new contexts, but they still have unsatisfactory accuracy. To design and develop a system that could recognise foods and estimate their weights in any context, including home-made meals, is still an open challenge.

Some of the difficulties in food recognition are related to hidden foods on the plates as well as depth and volume estimation. Some projects have used laser beams to overcome this difficulty[40], although the use of extra hardware makes the scalability of these solutions less promising for the immediate future. Similar scalability challenges occur with solutions proposing to use wearables for automatic dietary monitoring[44].

Natural language processing has also been used[45–47], but still without significant results as a stand-alone input method and without evidence from experiments with end users recording food diaries, for example. This technology could potentially be combined with image recognition in order to increase its accuracy. For instance, a smartphone user could take a food image and record the name of the food items in the meal, perhaps with some estimation of portion sizes. As mentioned in the previous section, new assessment methods have to be validated against independent methods (e.g. weighed food records). No validation study using natural language processing was found in the literature.

Another proposal for addressing the lack of trained professionals for dietary assessment utilised crowdsourcing of untrained workers to estimate energy and macronutrients of photographs[48]. This strategy could increase the scalability of nutrition assessment solutions, but probably not enough to support free or low-cost applications to the final users due to the number of manual transactions.

Technologies for nutrition recommendation

After collecting information on dietary intake, a system would need to have a basis (e.g. a set of rules or a knowledge base) for a recommendation decision engine. One of the main challenges in this field is how to train these systems without databases of clinical nutrition recommendations being available. This might be the main reason for the scarcity of tools for nutrition recommendations. Because of this, the following subsections present a diversity of tools applied in the nutrition field, not only directly to online personalised nutrition advice.

Menu and meal planning

The use of computational methods for supporting nutritional planning has been investigated for some time. The need of meeting nutritional requirements via a vast number of possible combinations of foods opens an opportunity for the use of computers. Mixed integer linear programming was proposed as a possible solution for this in 1993, based on the Simplex algorithm, considering nutrients and prices[49]. Besides meeting the nutritional guidelines, it is imperative to recommend meals that individuals will find acceptable. This challenge was presented by Buisson *et al.* in 2003[50] and further elaborated upon in a paper presenting Nutri-Educ software in 2008[51]. Based on the nutrition literature, they were aware that a solution would need to propose a well-balanced diet that was not very different from a person's current diet. Improvements would need to be introduced gradually, in order to have good user acceptance. With this in mind, they stated that the current meal is linked to similar meals via addition, deletion or portion modifications. Their solution was to consider this state space as a graph, in which nodes were possible meals and edges between nodes the acceptable transformations. The search strategy consisted of finding an acceptable meal, meeting the nutritional recommendations, as close as possible to the initial meal[51].

Artificial intelligence approaches, such as case-based reasoning, have also been proposed for planning menus[52–54]. Some of these systems were designed to be used by dietitians[52,53] who predefined the menus to be selected via CBR based on a number of variables such as age and sex. Khan *et al.* proposed to use ripple-down rules to create the knowledge base through a direct system interaction while the domain expert is accomplishing their tasks of constructing a diet for a given client[53]. However, in consultations between patients/individuals and dietitians/nutritionists the decision-making process for dietary change advice is more complex, with consideration of usual dietary habits in the context of the patient's/individual's preferences are used for optimum advice. Yet, user preference is not necessarily the optimal goal in nutrition recommender systems, as the preferred diets are often unhealthy. That is a limitation of recommender systems which are based on recipes collected from the internet and their reviews[55].

The usual nutritional recommendations provided by nutrition professionals take into account a number of important variables, such as age, sex, dietary restrictions and lifestyle. Some specific groups (e.g. older adults, vegans) need to receive specialised advice. Hence, technology based systems also need to have similar levels of personalisation. An example of such a system is described in the paper 'Nutrition for Elder Care: a nutritional semantic recommender system for the elderly', whose recommendations take into account participants' preferences[56]. This paper, published in April 2016, describes the system design and the ontology supporting the recommender system. The system takes into account demographic data (e.g. sex), physical characteristics (e.g. weight and height), nutritional state (e.g. malnourished) and also some responses from an FFQ without portion sizes. The aim of their system is to recommend variations of pre-defined diet plans, instead of modifications to the person's current diet.

These approaches are very useful when there are predefined meals and diets (e.g. hospitals), but they can result in proposed diets that are very different from the current diet, making the goal harder to achieve by users. These techniques applied to tailoring daily menus

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are not directly applicable to creating personalised nutrition advice that is comparable to a nutritional consultation. The next subsection will present dietary modelling tools, which were closer to the final aim of this project.

Dietary modelling tools

For modelling well-balanced diets, the target is generally to balance the food groups (fruit, vegetables, etc.) and distribution of nutrients. A recent study used nonlinear constraint optimisation techniques to design a tool for standardising the background diet of participants during a dietary randomised controlled trial (RCT)[57]. A constraint is a function resulting in a Boolean output (i.e. true/false), which is true if the combination of all values is allowed and false otherwise. An objective function results in a set of solutions that are optimal with respect to the objectives, during the constraint optimisation process. The users of this tool (likely dietitians) enter the macronutrients (fat, carbohydrate and protein) and food groups serving targets (e.g. five servings of vegetables) and participant details (height, weight, age and sex) so that the tool can calculate the estimated energy requirement. After this step, using a reference food composition database and also pooled baseline food intake data from completed trials before intervention, the tool solves the optimisation problem and returns to the user their target servings per food group to meet the trial requirements suited to each participant. This solution is possible because the macronutrient energy densities are constant (e.g. fat contains 37·66 kJ/g), such that the tool needs to minimise the difference (i.e. Euclidean distance) between the target and calculated macronutrient values, varying the possible servings per food group[57].

The approaches used by most of the existing systems for checking the outputs against the references are discrete. For instance, if the reference nutrient intake for vitamin D in the UK is 10 μg and an individual is consuming 9·9 μg, a system could indicate, based on a specific rule, that this specific target was not met using a binary evaluation. However, the decision-making process for this type of evaluation is not discrete when completed by domain experts (e.g. dietitians). Human intuition would evaluate this hypothetical scenario as something similar to 'almost meeting the recommendation' or 'very close to the recommendation', but this rationale is not captured using Boolean logic. This fact motivated a number of researchers to investigate the possibility of doing this analysis using fuzzy logic[51,58–61], in which the possible values are not only true or false, but a number between 0 and 1.

Fuzzy logic for nutritional analysis

Lee *et al.* proposed an 'Adaptive personalized diet linguistic recommendation mechanism based on type-2 fuzzy sets and genetic fuzzy markup language'[58] in 2015. Taking into account nutritional guidelines (e.g. recommended percentage of energy from fat in a diet) and knowledge from domain experts, it was possible, for instance, to model the fuzziness of percentage of energy from fat. When combining opinions from different domain experts, it was possible to model how those words (low, medium and high) were perceived differently by each expert.

Using the percentage of macronutrients (fat, carbohydrates and protein), the energy ratio and food group balance obtained from the food pyramid, it was possible to compute the diet health level (i.e. very low, low, etc.) from the domain expert and the fuzzy system, as well as the degree to which they matched. For the whole diet sample (*n* 160) the matching accuracy was 55 % before training, but after learning using genetic algorithms, it increased to about 75 %. This important study only evaluated one variable (diet health level), but this approach could be expanded to more complex systems as long as evaluation from domain experts could be collected also for other aspects of the diet, including nutrients.

One important aspect of the fuzzy logic approach is that real-life nutrition recommendations are more based on words (linguistic variables) than numbers. It seems more sensible to compute with words than numbers in order to construct a mathematical solution for the nutrition decision-making process[62]. That is the main motivation for fuzzy logic in this context. Regarding evolutionary algorithms (e.g. genetic algorithms), an article published in 2014 confirms the small influence of this field on nutrition recommendation systems and indicates how promising this application could be[63].

Technologies used in remotely delivered nutrition interventions

There are a variety of systems for diet self-monitoring and for use by nutrition professionals to create tailored feedback, however the use of technology in nutrition interventions is limited, as highlighted by a 2018 systematic review and meta-analysis of remotely delivered interventions using self-monitoring or tailored feedback to change dietary behaviour[64]. This review considered any type of remote method, including printed material, text messages, CD-ROM and phone calls. Its objective was to analyse if remotely delivered standalone (i.e. no human contact) interventions were effective at changing eating behaviours[64]. This systematic review identified twenty-six studies (involving 21 262 participants), between 1990 and 2017. Of these twenty-six interventions, eleven used some type of computer technology for delivering the feedback. Their technological platforms are shown in Table 1.

Two interventions used a French online service (Minitel) which is no longer available. Another outdated technology, a personal digital assistant, was used in 2008[64]. The study conducted by Campbell *et al.* did not have human contact during the nutritional feedback but used software installed in the offices where the study was conducted[65]. These technologies are very different to the modern web apps in terms of design and

Table 1. Technologies and general information of remotely delivered nutrition interventions

First author	Year	Country	*n*	Intervention duration (months)	System
Alexander	2010	USA	2513	12	Web app
Atienza	2008	USA	36	2	Personal digital assistant
Campbell	1998	USA	526	3	Software
Huang	2006	Australia	497	5	Online shopping
Mummah	2016	USA	17	3	Native app
Poddar	2010	USA	294	5	Internet course
Springvloet	2015	Netherlands	1349	9	Web app
Tapper	2014	UK	100	6	Web app
Turnin	1992	France	105	12	Minitel
Turnin	2001	France	557	12	Minitel
Celis-Morales	2017	7 European countries	1607	6	Web app

Source: Adapted from Teasdale *et al.*[64]. Considering only interventions using computer technology and classifying these systems.

development. Huang *et al.* investigated the influence of dietary advice during online grocery shopping.

The trial reported by Mummah *et al.* in 2016 was a pilot (*n* 17) with iPhone users to encourage vegetable consumption in overweight adults. They developed a fully automated theory driven app (called Vegethon) enabling self-monitoring of vegetable consumption, goal setting, feedback and social comparison[66]. Subsequent analysis in the literature showed that a larger study (*n* 135) was conducted after the pilot. They used two nutrition assessment methods (FFQ and 24HR) and the results show a significantly greater daily vegetable consumption in the intervention *v.* control condition (2·0 servings for FFQ; and 1·0 serving for 24HR). The methodology and outcomes were reported in detail[67], but without details of the Vegethon app. It was published in the Apple app store but not made publicly available to other software developers (i.e. open source).

In the study conducted by Alexander *et al.* in 2010, three arms were used with the following materials: an untailored control website; a tailored website; or the tailored website plus motivational interviewing counselling delivered via e-mail[68]. This RCT was conducted between 2005 and 2006 and the details of the web app were not provided, but there is a publication with the results of a focus group conducted prior to the RCT, in order to collect some features preferred for a web-based educational intervention[69]. The FFQ used in this RCT contained only two items (fruit and vegetable) and the rationale for tailoring the advice was not detailed.

The intervention conducted in the Netherlands by Springvloet *et al.*[70] used a sixty-six-item online FFQ to assess the intake of fruit, vegetables, high-energy snacks and saturated fat. Each of these had a specific module in the website, so that participants could read about these food items, check availability and prices in their supermarket, before setting a personal goal and making action plans. Besides the traditional individual cognitive elements (knowledge, awareness, attitude, self-efficacy) used in health interventions, this study tailored the goal setting using additional variables such as self-regulation processes and environmental-level factors (e.g. perception of availability and prices of healthy food products in supermarkets). The treatment effects provided another set of evidence of the better efficacy of tailored advice in comparison with generalised population advice[70]. This study may reinforce the importance of using validated behaviour change techniques in health interventions, taking into account that the rationale of the advice was elementary (recommendations) and the users were asked to set their personal targets. Tapper *et al.* measured the treatment effect of a healthy eating programme on consumption of fruit and vegetables, saturated fat, and added sugar, via a 6-month RCT. The website homepage was presented using a screenshot, but without further details from a technological perspective[71].

The Food4Me project[17] has been used as the main reference of personalised nutrition intervention throughout this project (Table 1). It aimed to improve seven key dietary outcomes (fruit, vegetables, whole grains, oily fish, red meat, salt and total fat), using an online FFQ for nutrition assessment with personalised food-based advice given on the three outcomes which were furthest from the recommended target intake. It was the broadest study in terms of targeting improvements in many food groups simultaneously.

Furthermore, as shown in Table 1, only five interventions used either web or native apps, and the number of interventions conducted in the past 10 years was small (*n* 6). The analysis of the technologies and methods used in these interventions highlights that there are novel contributions to be made in terms of improving the user acceptance and effectiveness of similar digital nutrition tools. Research studies can contribute significantly to progress in this field, especially if they openly report their methods, material and evidence data.

Challenges in providing online personalised advice at scale

The primary challenge of the eNutri project was to design an online system that could automatically provide personalised nutrition advice that would be effective at changing dietary behaviour favourably. Besides factoring in an individual's dietary intake relative to general

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recommended dietary guidelines, it was important that the intervention reflected personal information (e.g. sex and dietary intake information) in defining advice. This project proposed to increase the acceptability, effectiveness and adoption of online nutrition services. The basic requirements of the proposed app, described in the following subsections, were defined as aiming to promote a wider uptake of digital nutrition assessment and personalised advice via the internet.

Reproducibility and scalability

The motivations for using the internet for encouraging healthier diets are global. With this in mind, the system deployment should be inexpensive and suitable for many populations, including low income communities. One implication of this requirement is that the proposed solution must not depend on any significant financial investment to be deployed by other institutions or organisations and be built with commercially available technologies that could be replicated in other countries and scenarios. In order to be used in public health campaigns or in similar large-scale initiatives, the solution should be scalable. In other words, it should be able to be used in population interventions with many participants using it simultaneously. Because this digital health solution would collect personal data, information security was mandatory.

User acceptability and usability

As sections of the targeted population may not be familiar with technology (e.g. older adults), the proposed system needed to be easy to use and take into account specific requirements of these individuals, to increase its user acceptance[72]. Another challenge was to develop an app that was designed to run effectively on mobile devices (smartphones and tablets) as they represent the most common devices used to access the Internet currently[73].

Validity and effectiveness of the treatment

The aim of the project was to develop a system that was a validated offering from the nutritional science's perspective (i.e. a real improvement in the diet quality) that would encourage positive dietary behaviour change via the internet. The validity of the system could be based on existing reliable publications from the nutrition field (e.g. widely referenced by the scientific community) and should be validated by experts (i.e. nutritionists and dietitians) by comparison with their specific knowledge. The effectiveness of the treatment could then be measured with robust controlled nutrition intervention studies, for example via a RCT.

eNutri app

Scope definition

There are many opportunities for using technologies to improve nutrition assessment and advice. Due to these extensive possibilities, it was necessary to limit the scope of this project, considering its requirements and challenges. From a technological perspective, the nutrition assessment stage (i.e. dietary intake recording) only considered technologies which had been validated in the field. In other words, an acceptable level of accuracy was required in order to provide valid advice. Emerging technologies not yet validated in this field, such as image recognition, were not considered in this project, particularly if they did not meet the basic requirements mentioned in the previous section.

In order to increase the reproducibility of the system, it was limited to popular technologies and programming languages, so that it could be improved by other researchers and developers who would potentially have access to its open source code. Furthermore, bespoke devices or specific hardware were not considered as alternatives, and the use of public cloud services was a key aim of the project. eNutri is independent of software requirement or plugin installation.

Nutrition advice via the internet is still at an early stage. For that reason, it was considered important to limit the target population of the EatWellUK study, so that people with specific dietary requirements (e.g. those suffering from coeliac disease or diabetes) did not receive advice that may have conflicted with the recommendations they might be receiving from health professionals or even cause some undesired consequences (e.g. recommending inappropriate foods for individuals with serious food allergies). Since this project also evaluated the effectiveness of the nutrition advice, it did not accept participants receiving face-to-face nutritional consultations, to avoid conflicting messages and potential bias. The more these systems evolve, the wider these eligibility criteria can become.

Nutrition assessment method

This project started without a pre-defined nutrition assessment method to be used during the dietary intake recording. We were aware of the use of commercial food diaries in the app stores, but the complete reliance on this method in the most popular apps was not expected. This might be an indication that due to a small number of usability and intervention studies in this field[64], the developers have possibly drawn inspiration for their solutions from existing apps, thereby repeating the same assessment method (food diary).

The creation of a database with product barcode information requires time and effort. It is likely that most of the apps have this feature due to the fact that there are barcode databases openly available, such as the Open Food Facts[74]. At the time of writing, this database contains 609 621 items registered via a collaborative effort. However, since nutrition content contained in the product labels only presents the main or legally required nutrients, the food composition database of these apps may not contain reliable information for micronutrients.

Although it would be possible to create an online service for personalised nutrition advice using food diaries,

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this alternative could be risky due to high participant burden and associated risk of dropout. In order to provide nutrition advice, the decision engine would need to consider food diaries for multiple days (baseline), in order to detect a dietary pattern and perform the calculations, and then repeat this process after a designated period in order to measure the treatment effect. This approach could be perceived as too burdensome by the participants. The Food4Me project, which developed and validated an online FFQ for their large population-based intervention study on personalised nutrition, took the decision to use an FFQ as their nutrition assessment. In our current project, we took the same decision, and were also able to benefit from permission to use the Food4Me food list and images.

The eNutri nutrition assessment and advice relied on existing and validated methods in the nutrition field. The assessment method (Food4Me FFQ) had been previously validated in the UK (i.e. it is a representation of people's dietary intake with a certain level of accuracy)[75]. In a similar way, the tool for measuring the quality of the diet (i.e. AHEI) is accepted by the scientific community[11], making the measurement of treatment effect reliable.

Design and usability

Most of the usability challenges are more complex in smartphones, as compared with desktops and laptops, due to the smaller screen size. As this proposed app does not use any specific internal hardware (e.g. GPS, accelerometer or camera), it was not necessary to develop a native app (i.e. specific to iOS or Android and requiring the app to be installed) to meet the system requirements and collect usability data. However, the eNutri app can be easily converted into a native app because it takes advantage of responsive JavaScript frameworks and there are commercial tools providing this conversion for running web apps as native apps for the major mobile operating systems[76].

To present the food items as a list on smartphones was very challenging. Although possible, it placed constraints on the font size and required users to scroll the page repetitively. Originally, the whole of the FFQ was presented as a list that appeared on a single screen[77]. After a usability evaluation of this version, a newer version of the app was developed presenting each food item individually on the screen[3].

To increase the acceptability by older adults, some design principles were included in the app such as: reduction of the user choices on the screen, appropriate font size, reduction of hidden items, having a help button always visible, individual help links for some items and user journey serialisation[3].

Both versions[3,77] resulted in similar completion times and user acceptance but there is evidence from the literature that a serialised design is more appropriate from a usability perspective, especially if the solution is aimed at including older adults[72]. Based on these results, the serialised FFQ design would appear to be the more appropriate one of these two options.

Reproducibility and scalability

The only back-end service used by eNutri was Google Firebase, which is offered by one of the most popular public cloud providers currently and available for other customers worldwide. Because it is a single page app, the content (i.e. texts, images, etc.) is initially downloaded from the hosting provider (i.e. Google Firebase) and processing occurs mainly in the browsers, making this solution scalable[77]. It also facilitates the reproducibility, because it does not require any server-side installation or maintenance. The app can be deployed using the Google Firebase free plan[78], meeting the low-cost requirement. Regarding security, Google Firebase is compliant with the main global standards and security certifications, including the recent 2018 General Data Protection Regulation from the EU[79,80]. From a software perspective, the security rules, detailed in a previous publication[77], met the authentication and authorisation requirements needed for processing and storing personal data.

Decision engine

Within this project, a modified version of the AHEI (m-AHEI) was selected as the foundation of the decision engine for tailoring the personalised advice (unpublished results). Indexes of overall quality of diets have previously been used for diet assessment, but not for generating online advice. This novel app of a diet quality score (m-AHEI) was associated with some risk, as there was no prior literature on the suitability of this strategy for personalised advice that effectively changed dietary behaviour. This was tested in the EatWellUK RCT (unpublished).

Future work

The version of the decision engine used in the EatWellUK RCT derived the advice based on dietary intake (FFQ data) and sex information. In alignment with behaviour change theory[81], the user should take more control of their diet changes. A possible solution is to evaluate the quality of a diet change using the AHEI itself, in order to identify multiple foods that can improve the AHEI score and to let the user choose from the multiple modifications. If the app also allows the users to rate the proposed modifications, that could act as further input to improve the recommendations. This type of approach seems to lend itself well to the use of node graphs, where the nodes represent the dietary intakes and edges the possible changes[51]. Different from basic meal planning, it is important to have different weights (i.e. change acceptability) for the edges, similar to map routing with different traffic conditions.

It is particularly important that future versions of this app are able to consider participants' actual willingness to change their behaviour. For instance, one could want to improve nutrition and yet be unwilling to increase vegetable consumption, so the cost of the path for increasing the vegetable component would need to be recognised as higher than an alternative method for increasing the diet quality index, such as including more fruit for example. In other words, the system would need to take into account participants' interactions and propose different paths for increasing their diet quality.

Another key challenge for future work is how to train the decision engine. In a typical recommender system, for example a medical diagnosis system, there is available data on the inputs (e.g. symptoms) and corresponding outputs (i.e. diagnosis/treatment). One of the main differences with a nutrition recommender system is that there is no existing openly available dataset with people's case histories and the corresponding proposed diet modifications from nutrition professionals that could be used for training. Furthermore, differently from many common recommender systems (e.g. online shopping based on previous purchases), the food items that users like and consume the most are not necessarily the healthiest. In other words, the recommender system must consider factors other than users' preferences and prior consumption.

Based on a recent systematic review[64], an analysis of the systems used to remotely deliver nutrition interventions confirmed that there is no other publicly available decision engine that provides valid online personalised nutrition advice automatically. This publication also showed that all of these interventions were conducted in high-income countries, reinforcing the need for a reproducible and inexpensive solution for online personalised nutrition advice.

Although the latest version of the eNutri app could be useful and potentially contribute to healthier dietary habits, its decision engine is elementary computationally and deterministic (i.e. if two individuals have the same dietary intake information, they will receive the same advice, even if they have different preferences). In addition, its decision engine does not take into account important data sources, such as population data, historical data or individual's preferences. In other words, the current feedback is driven purely by the diet data and sex, and the question of how best to balance nutritional healthiness against users' preferences in a way that maximises the likelihood of the user adopting healthier choices remains an open research challenge. The eNutri design and source code have been made publicly available[82] under a permissive open source license, so that other researchers and organisations can benefit from this work.

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Conflict of Interest

None.

Authorship

R. Z. F. was responsible for the draft preparation of the manuscript. All authors contributed to the conceptualization, reviewed and edited the manuscript, and approved the final version for publication.

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