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Advancing digital nutrition assessment: Development and evaluation of the UK eNutriFFQv2.0

Michelle Weech PhD [a], Rosalind Fallaize PhD [a,b,*], Rodrigo Zenun Franco PhD [c], Rachel Sutton PhD [a], Maria Fotiou PhD [a], Nicole Robertson MSc [a,#], Faustina Hwang PhD [c], Julie A. Lovegrove PhD [a]

[a] *Department of Food and Nutritional Science, Hugh Sinclair Unit of Human Nutrition, Institute of Food, Nutrition and Health, Institute for Cardiovascular and Metabolic Research, University of Reading, Reading, United Kingdom*
[b] *School of Health, Medicine and Life Sciences, University of Hertfordshire, Hatfield, United Kingdom*
[c] *Biomedical Engineering, School of Biological Sciences, Institute of Food, Nutrition and Health, University of Reading, Reading, United Kingdom*

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Background: Digital dietary assessment tools are highly beneficial for nutrition research and personalized interventions.
Objective: This paper describes the development and evaluation of eNutriFFQv2.0, an updated online food frequency questionnaire designed to reflect current diets in the United Kingdom (UK). Updates included modernized food lists based on recent UK population surveys, food composition tables, and food portion photos to improve accuracy and user experience.
Methods: To assess reproducibility, UK adults completed the FFQ twice, 14 days apart; validity was evaluated against a 3-d weighed food record in a sub-sample. Multiple statistical methods were used. After excluding participants with unfeasible energy intakes, 87 participants completed the reproducibility and 53 the evaluation.
Results: The final eNutriFFQv2.0 captured 164 items and estimated intake for 56 nutrients and 6 food groups. Agreement with the WFR was *acceptable* to *good* for 25 out of the 29 nutrients analyzed (weighted kappa 0.21−0.77), with ≤10% misclassification into opposite quartiles for most nutrients. Bland−Altman plots showed good agreement for energy (176 kcal/d higher in FFQ1) and macronutrient estimates. Reproducibility was *good* for 24 out of the 29 nutrients analyzed (weighted kappa 0.58−0.85) with <5% misclassification. Mean bias for estimates of carbohydrate, fat, and protein was small (0.0−0.7). Energy estimates were 209 kcal/d (10.7%) higher in the first compared with the second completion of the FFQ.
Conclusions: These findings demonstrate that eNutriFFQv2.0 is a valid and reliable tool for assessing nutrient intake in UK adults, offering a practical, scalable solution for research and public health in the context of digital health and personalized dietary interventions.

Introduction

Dietary assessment tools are vital in nutrition research for exploring diet-disease associations, evaluating the effectiveness of dietary interventions, and informing public health policy. Dietary intake is commonly assessed using prospective (e.g., weighed food records [WFR], estimated food diary) or retrospective methods (e.g., 24-h recalls, Food Frequency Questionnaires [FFQ]) [1]. Of these tools, FFQs are most frequently used to assess habitual diet in large-scale studies (e.g., observational, cohort) due to their ease-of-use and relatively low cost compared with interviewer-led 24-h recalls [2]. It is well recognized that all self-reported dietary assessment methods are prone to errors and biases. These include underestimation of total energy intake due to portion size estimation mistakes, omitted foods, self-report biases (e.g., social desirability or weight status), and inaccuracies in nutrient composition databases [3,4].

Digital dietary assessment tools, which are growing in popularity for national dietary surveys and nutrition research in the United Kingdom (UK), may address some of these errors. For example, compared with non-digital methods, they offer automated data

Michelle Weech and Rosalind Fallaize are joint first authors.
*Corresponding author.
E-mail address: r.fallaize@reading.ac.uk (R. Fallaize).
Present address: Department of Nutrition and Dietetics, East Lancashire Hospitals NHS Trust, Blackburn, United Kingdom

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storage, reduced data entry errors (i.e., omitted foods), efficiencies in data entry, and instantaneous analysis of dietary intakes [2]. Digital tools include self-administered 24-h dietary recalls (such as Intake24 [5], MyFood24 [6], and Oxford WebQ [7]), diet diaries (such as MyMealMate [8]), and FFQs (as developed for the large, pan-European Food4Me study [9]). There are also increasing numbers of commercial mobile applications (apps) available in app stores for the public to download and track their own dietary intakes, such as MyFitnessPal, FitBit, Lose It!, and Lifesum [10]; many have unknown or suboptimal reliability, making them less suitable for nutrition research [11–14].

FFQs assess habitual diet using frequency of consumption data from a pre-defined list of foods, typically 20 to 200, over a defined time period [1]. However, dietary patterns change over time, and FFQs require periodic redevelopment to reflect this. Many existing FFQs, including the widely used EPIC-Norfolk FFQ, were developed decades ago [15] and, hence, do not include food items that have become more commonly consumed in recent years. They also do not take full advantage of recent advances in technology that could help automate data analysis. As dietary habits evolve, up-to-date, user-friendly, and validated FFQs are needed to improve accuracy, relevance, and usability. eNutri is a novel web-based tool developed by the eNutri research team at the University of Reading, which can be used for dietary assessment. It enables: 1) recording of the user's dietary intake for the previous month using a graphical, semiquantitative FFQ, 2) automated analysis using integrated food composition tables, and 3) assessment of the quality of their diet using a validated UK-based diet quality score (DQS) [16], from which it immediately delivers automated, personalized food-based nutrition advice that is unique to the user [17–19]. The original eNutri FFQ (eNutriFFQv1.0) [18] was based on the 2011/2012 validated UK and Irish online Food4Me FFQ [9], which was partially adapted from the EPIC-Norfolk FFQ developed in the 1990s [15]. However, despite previous modifications, the eNutriFFQv1.0 did not represent modern UK dietary patterns. For example, consumption of dairy alternatives and meat alternatives increased by 169% between 2001 and 2019 [20], but these food items were either absent or inappropriately recorded on the FFQ. Moreover, since the Food4Me FFQ was developed using portion sizes and food consumption data from Ireland's 2008 to 2010 National Adult Nutrition Survey [21], there was further scope to improve the suitability of eNutriFFQv1.0 for a UK population. In addition, eNutriFFQv1.0 was not developed to detect small changes in an individual's diet over time [22], thus lacking the sensitivity required to assess the effectiveness of its personalized nutrition advice.

The aim of this project was to redevelop eNutriFFQv1.0 with four primary objectives: 1) modernize to reflect current food patterns, 2) tailor to a UK population, 3) improve food group estimation, and 4) increase sensitivity, allowing detection of small dietary changes on repeated use. With redevelopment, it is necessary to reevaluate the FFQ for validity to ensure any changes have not affected its accuracy [23]. Therefore, a second aim was to evaluate the reproducibility and validity of the redeveloped FFQ, which we call eNutriFFQv2.0, against a 3-d WFR in an adult UK population (ENVAL study). Our hypothesis was that the redeveloped FFQ eNutriFFQv2.0 would demonstrate good reproducibility and agreement with WFR for estimates of energy, macro- and micronutrients intake.

Study design and methods

To achieve our objectives, methods were organized into 1) redevelopment of eNutriFFQv1.0 to create eNutriFFQv2.0 and 2) eNutriFFQv2.0 evaluation. Our research is reported in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology—Nutritional Epidemiology (STROBE-nut) checklist [24] (Supplementary Table 1).

Developing eNutriFFQv2.0

FFQ food list

The original eNutri FFQ (eNutriFFQv1.0) was redeveloped in 2018 to 19 (eNutriFFQv2.0), starting with the food list. For modernization and tailoring, food items popular in the UK at the time were included, such as dairy alternative drinks/products, meat alternative products, and pulse-based products (e.g., houmous, falafel). These were identified using food-level datasets from Years 1 to 6 of the UK's National Diet and Nutrition Survey (NDNS) Rolling Programme (2008–2014; the most recent data available at the time), which listed every food and drink item recorded in 4-d food records from 4739 adults aged 19 to 96 y [25,26]. Likewise, foods not typically eaten in the UK were removed (e.g., potato dumplings and sauerkraut). For food group estimation, certain food items were adapted. For example, to distinguish between red meat and poultry, the original meat-based dish items (e.g., "lasagne, moussaka, and ravioli" and "stew and casserole") were converted more broadly to "red meat dishes" and "poultry dishes." Additionally, two questions relating to discretionary salt (added during cooking and at the table) were included, as were frequently used dietary supplements (e.g., fish oils/omega-3 fatty acids, multivitamins/minerals, vitamin D, and whey protein). The final eNutriFFQv2.0 included 165 items (157 foods/drinks and eight supplements).

FFQ subquestions

Of the 157 food/drink items, the FFQ only collected information on frequency and portion size for 113 items. For the remaining 44 food/drink items, eNutriFFQv2.0 also included subquestions to increase the sensitivity of the FFQ. For 29 items, users specified the type consumed (e.g., "Did you eat reduced fat yoghurt?") with responses "never/rarely," "sometimes," or "mostly/always" that determined which food composition/food group contribution data to use. Other examples included plant-based spreads (regular/reduced fat), flat breads (white/whole meal), soft drinks (regular/no added sugar), and beer (regular/low or no alcohol). Other FFQ items (n = 9) allowed participants to select multiple options. For example, "What type of meat substitutes did you eat?" with checkbox responses for "tofu," "meat substitutes" (e.g., soya protein and Quorn) and "vegetarian products" (e.g., meat-free sausages). A further subquestion type was included for six food/drink items where milk is typically added (hot drinks and breakfast cereals), as described in the section "Foods/drinks with milk added." Although the eNutriFFQv2.0 FFQ list comprised 157 primary food/drink items, the inclusion of multiple subquestion (secondary) responses for 44 of these increased the total number of individual food/drink items used by eNutriFFQv2.0 to 236 (referred to as the "category level").

Frequencies of food consumption

FFQ items are typically based on groups of closely related foods (e.g., citrus fruits, cakes, and pulses) rather than individual foods. We used the food-level NDNS dataset (as described in "FFQ food list" above) to identify individual foods that were most representative of each FFQ item for the purpose of calculating nutrient compositions and portion sizes (as described below).

Each food item recorded by NDNS participants was mapped onto one of eNutri's 236 category-level food/drink items. Within each eNutri category level, the NDNS foods were reorganized into individual/similar foods (referred to as the "individual level"). For example, all the NDNS foods we categorized as “citrus fruits” were split at the individual level into “oranges,” “grapefruit,” etc. Next, the total number of eating occasions was determined for each. For example, oranges were consumed 971 times within the NDNS dataset (e.g., a participant consuming oranges twice during their food record was counted as two occasions). The total number of eating occasions at the category levels was also determined (e.g., citrus fruits were consumed 2466 times), from which percentage frequencies were calculated (e.g., when NDNS participants consumed citrus fruits, 39.4% of these occasions were oranges). Since certain food categories included a large number of individual foods, those that were consumed infrequently within the NDNS dataset (defined as frequencies $<5\%$) were excluded at this point. To ensure the sum of percentage frequencies for individual foods totaled 100% for each category, the percentage frequencies of the retained items were adjusted to the new category level totals. In total, approximately 600 individual foods from the NDNS dataset were mapped onto the eNutriFFQv2.0 food list. Of these, individual foods with the highest percentage frequencies (i.e., consumed most often) were selected as examples of the food items to present on eNutriFFQv2.0.

Nutrient compositions and food group contributions

eNutriFFQv1.0 calculated 39 nutrients, which increased to 56 nutrients for eNutriFFQv2.0 to include additional fatty acids, individual sugars, and macronutrients expressed as a percentage of total energy (%TE). For each of the 236 category-level FFQ items, weighted nutrient and food group compositions were calculated. Firstly, each of the 600+ retained individual foods (identified from the NDNS dataset) was matched to a food item on McCance and Widdowson’s Composition of Foods Integrated Dataset (CoFID) v.2015 [27], where nutrient contents per 100 g were obtained. Since eNutri presents portion size images of foods/drinks as consumed, nutrient compositions for cooked/made-up items were used. Where data were absent from CoFID, the NDNS Nutrient Databank [28] and Nutritics food composition dataset (v.5.03-5.04) [29] were used. Values were estimated (if appropriate) where data were unavailable from any UK database, e.g., free sugars were estimated using the UK’s definition of free sugars [30] and AOAC fiber by multiplying non-starch polysaccharides by 1.33 [31]; both approaches are used by the NDNS [32]. Missing nutrient compositions were most prominent for iodine (31.7% of food items), selenium (19.0%), vitamin E (16.3%), and pantothenic acid (13.6%). For each FFQ item, weighted average nutrient compositions were calculated based on the % frequencies of individual items within each category to better reflect UK eating habits versus simply calculating mean compositions. For example, milk consumption in the UK was 73% semiskimmed, 15% whole, and 12% skimmed, so weighted means reflected this distribution.

Due to the absence of nutrient compositions for supplements in food composition databases, nutrient information for the eight dietary supplements was sourced from an average of 60 products available from UK retailers. Given marked differences in the strength and dosage between products, the nutrient compositions for each supplement were standardized by determining the recommended adult daily “dose” (i.e., nutrient content per fish oil capsule x number of capsules recommended per day). Nutrient contents of daily doses were then averaged for each FFQ supplement category (weighted averages were not possible due to incomplete supplement usage data in the NDNS).

Food group variables included on eNutriFFQv2.0 included: fruits, dried fruit, fruit juices, vegetables, wholegrains, cheese, yoghurt, milk, nuts/seeds, pulses, red meat, processed meat, and alcoholic drinks. Since food composition tables do not include food group data, individual-level food/drink items were disaggregated into the above food groups, using a similar approach to the NDNS [33]. Using ingredient lists of food/drink items on UK supermarket and manufacturer websites, the percentage of each food group was identified (or estimated), e.g., percentages of cheese, vegetables, and processed meat on a pepperoni pizza. For each food/drink item, ingredient data were obtained from a range of supermarkets and brands, from which mean percentages were calculated. Exceptions were made for certain high-fat, salt, and sugar foods where inclusion was considered inappropriate, e.g., fruit in jams did not contribute to “fruit.” Weighted average food group compositions were calculated for each FFQ category as described for the nutrients.

Frequency options

Daily frequencies from the original eNutriFFQv1.0 were revised for greater differentiation in eNutriFFQv2.0, increasing the total number of frequency options from 9 to 10: not in the last month, 1 to 3 times a month, once a week, 2 to 4 times a week, 5 to 6 times a week, once a day, twice a day, 3 to 4 times a day, 5 to 6 times a day and 7+ times a day. Dietary supplements had six options, ranging from “not in the last month” to “1 dose per day.”

Portion sizes

Typical portion sizes for the FFQ items were determined using the NDNS dataset. Since these food/drink items were reported as a mixture of cooked/made-up weights and raw/unprepared weights, they were first standardized, ensuring all were expressed as weights consumed. NDNS foods recorded with wastage, including (e.g., chicken leg with bones and banana with peel), were converted to edible weights using CoFID’s edible weight conversion factors [27]. Next, foods/drinks expressed as raw/unprepared weights (e.g., dried pasta, raw meat, and fruit drink concentrate) were converted to cooked/made up weight equivalents using cooked weight conversion factors or food item descriptions (e.g., “fruit juice drink/squash diluted” contained 50 g concentrate added to 200 mL water), both from CoFID [27]. eNutriFFQv1.0 included three portion size images. To allow for more accurate portion size estimation by eNutriFFQv2.0, seven portion sizes were determined for each FFQ item, broadly reflecting extra-small, small (S), small-medium, medium (M), medium-large, large (L), and extra-large portions, which would be used to create portion size images. For FFQ items where foods/drinks are usually consumed as whole items, portion sizes were based on these, broadly aligning with NDNS data, to support portion size selection. For example, portion sizes for bread increased in $^1/_2$ slice increments with 1, 2, and 3 slices representing S, M, and L portions, respectively, whereas yoghurts were represented by increasing pot sizes. For all other FFQ items (e.g., peas, breakfast cereal, and pasta), quantities (g) consumed by NDNS participants were split into percentiles per item, with the fifth percentile reflecting the extra-small portion and 95^{th} percentile reflecting the extra-large portion. The difference between percentiles was divided by 6, with this interval used to calculate equidistant weights between the fifth and 95^{th} percentiles to generate the remaining five portion sizes. In the absence of reliable data on added salt intakes from NDNS, portion sizes were based on the Project Big Life “Salt Calculator” [34], where “a dash or shake of salt” added to food at the table or during cooking was classified as 200 mg of sodium (equivalent to 0.5 g salt). For eNutriFFQv2.0, a fixed portion size of 0.5 g salt was used for the two salt items.

Foods/drinks with milk added

For eNutriFFQv1.0, users estimated their portion sizes for milk using three images presenting different volumes of milk in a glass. User feedback indicated participants found this visualization challenging, especially for milk added to breakfast cereal or hot drinks. This was reflected in the FFQ input data, where some users reported unusually high milk intakes, indicating overestimation (unpublished data). A revised approach was used to estimate milk intake for eNutriFFQv2.0. In addition to the FFQ item “milk as a drink or cooking ingredient,” milk consumption was also estimated for six food/drink items where milk is usually added (three breakfast cereal and three hot drink items). Using muesli as an example, users selected a frequency and portion size as usual, then identified whether they added milk (yes/no). If yes, they selected the type(s) of milk from a checkbox list, then indicated the amount of milk from images showing a medium portion of muesli covered with varying amounts of milk. An algorithm calculated the amount of milk in relation to the portion size selected for muesli.

Portion size photos

Portion size images were taken by a professional photographer (Bennetto Photography, Reading, UK) and followed published guidelines [35,36]. Full details of the photography methodology are presented in the supplementary materials (Methods, Supplementary Table 2, Supplementary Fig. 1). Photography took place over five consecutive days, with around 1500 images being taken overall. Food items were presented in a specific way to reflect how they would usually appear on a plate and to aid portion size estimation (Fig. 1), e.g., vegetables were placed towards the side of the plate and slightly heaped. Other food items included split plates showing two identical portion sizes on the same plate (e.g., “dried fruits” showed the same amount of apricots and sultanas on either side, whereas “cheese” showed slices and grated cheese on either side), whereas foods typically spread on bread (e.g., jam, butter, and peanut butter) were presented both as a heap and spread on bread. Sugar and oil were shown in the number of teaspoons.

Additional eNutriFFQv2.0 features to facilitate FFQ completion

Tutorial

Prior to completing FFQ1, participants viewed a mandatory online tutorial (approximately 2−3 min to read). They scrolled through nine annotated eNutri screenshots that described the different FFQ screens they would encounter (e.g., frequency/portion size screens and explanation of split plates) and how to respond, aiming to reduce errors and confusion. Also, in the tutorial were screens showing images of an empty plate/bowl, including a banknote, and the full range of mugs and glasses, all annotated with dimensions/volumes for scaling purposes. The tutorial could be viewed again at any time via the Menu.

Personalization

When starting the FFQ, participants were asked four opening questions to determine whether they ate any foods containing meat, fish, and/or dairy or took any of the eight dietary supplements within the last month (yes or no responses). These responses tailored the FFQ to the user (e.g., meat-related questions were not presented to participants who had not eaten meat) and informed eNutri to use different nutrient and food group compositions for five FFQ items, such as meat-free pizza, egg dishes, and pâté.

Quality checks

To prevent potential over-reporting, most FFQ items included an upper frequency cut-off, above which an “are you sure?” pop-up message appeared on the screen asking the user to double-check their response. They could either confirm this frequency or amend their response if a mistake had been made. Cut-offs were specific to each item, reflecting unusually high frequencies broadly based on NDNS data (e.g., the message would appear if participants reported consuming “beef” “3−4 times a day” or more often).

Data outputs from eNutriFFQv2.0

Inputs were used to estimate mean daily intakes for each FFQ item (frequency x portion size). Using its integrated nutrient and food group composition databases, eNutri automatically calculated the mean daily intakes for 56 nutrients and 14 food groups. These were exported as a single CSV file from the eNutri researcher dashboard. Nutrient intakes were expressed in three ways: with dietary supplements included, without dietary supplements included, and dietary supplements only. Food group intakes were expressed as g/d.

Evaluation protocol: ENVAL study

Study design and procedure

The study received a favorable ethical opinion for conduct by theUniversity of Reading School of Chemistry, Food and Pharmacy Research Ethics Committee (study ID: 22/18) and was conducted in accordance with the Declaration of Helsinki. Between March and April 2019, UK adults were recruited using the Hugh Sinclair Unit of Human Nutrition, University of Reading volunteer database, University of Reading mailing lists, social media posts/adverts (including Facebook and Twitter), posters/leaflets distributed around the Reading area and posted nationally to organizations with community noticeboards (e.g., supermarkets and coffee shops), and word of mouth. Recruitment material included the URL for accessing the eNutri web app, which included a link to the participant information sheet and the research team’s contact details on the homepage. All participants provided informed online consent on eNutriFFQv2.0 prior to taking part in the study. On study completion, participants were entered into a prize draw with the opportunity to win one of four £50 online shopping vouchers, unless they opted out. The entire study was conducted remotely.

Best practice guidance by Cade et al. [23] on validating FFQs was followed in our study design. As recommended, participants completed the eNutriFFQv2.0 (FFQ1; test method) first, followed by the 3-d WFR (reference method) commencing 2 to 3 d later. Participants were prompted to complete FFQ2 14 d after FFQ1. Since the eNutriFFQv2.0 recorded dietary intakes for the previous month, a duration of 2 wk was selected for the reproducibility study to ensure food intakes across the two FFQs had a degree of overlap, whilst ensuring the interval was long enough that participants did not remember their previous responses. The sample size was also guided by Cade et al., who recommended at least 50 participants for FFQ validation and 100 for reproducibility. To allow for a 20% dropout rate (as observed in the Food4Me FFQ validation study [9]), our target sample sizes were 60 and 120 participants for the validation and reproducibility, respectively.

eNutri: Online consent and screening criteria

On the eNutri web app, interested participants first viewed the participant information sheet, then registered with an email address and password (at this point, a unique participant ID code was assigned). Next, the study consent form was presented (anybody not consenting could not progress further), followed by a short screening questionnaire. Key inclusion criteria included: aged 18 years and above, living in the UK, able to read English, no food allergies/intolerances, not following specialized dietary advice or a specialized diet (e.g., weight-loss and vegan), no health

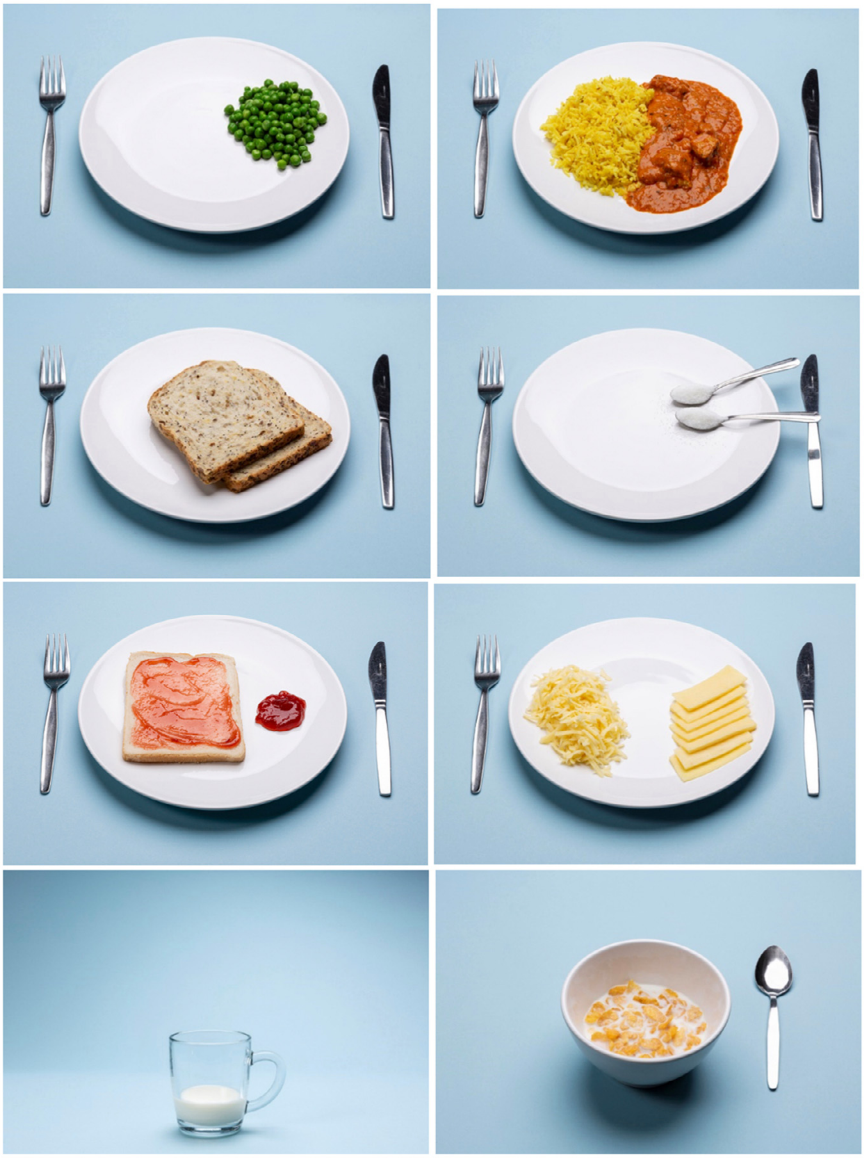

Fig. 1. Examples of food portion images for eNutri FFQ items (clockwise from top left: green peas, poultry dishes, sugar, high-fat cheese, milk [added to non-wholegrain breakfast cereals], milk [added to hot drinks], sweet spreads, and granary bread).

conditions or using medications that affect metabolism, diet, and/or appetite (e.g., weight-loss medications, steroids, and chemotherapy), and not pregnant or breastfeeding. For certain criteria, participants were requested to provide additional information in a text box for review by a researcher. Participants meeting all eligibility criteria could proceed to the FFQ.

eNutri: Anthropometrics, physical activity, and sociodemographic information

Participants input their name and address on eNutri, which were required for delivery of the WFR equipment, and answered sociodemographic questions (including sex, ethnicity, highest education level, and average household income) using drop-down lists with a "prefer not to say" option. Three questions relating to work activity, exercise/sport, and cycling from the validated General Practice Physical Activity Questionnaire [37] were used by eNutri to calculate a simple, 4-level physical activity index (inactive, moderately inactive, moderately active, and active). Self-reported weight and height measurements were also provided, from which eNutri calculated BMI. These questions were only completed at FFQ1, except for physical activity and weight, which were completed at both time points.

eNutriFFQv2.0

Before completing the FFQ, participants first viewed the tutorial screens and completed the four opening questions, which subsequently tailored the FFQ items presented to them. For each FFQ item, they selected how often they consumed it within the last month (Fig. 2A), then identified their typical portion size (unless "not in the last month" was selected) by selecting one of the three portion size images (representing S, M, and L portions) or one of the four text buttons (Fig. 2B). Due to the smaller screen size of smartphones, smartphone users selected one of the three images first, then identified if their typical portion size was "slightly more," "slightly less," or "exactly" like the image selected. For certain FFQ items, subquestion responses were also provided. The full

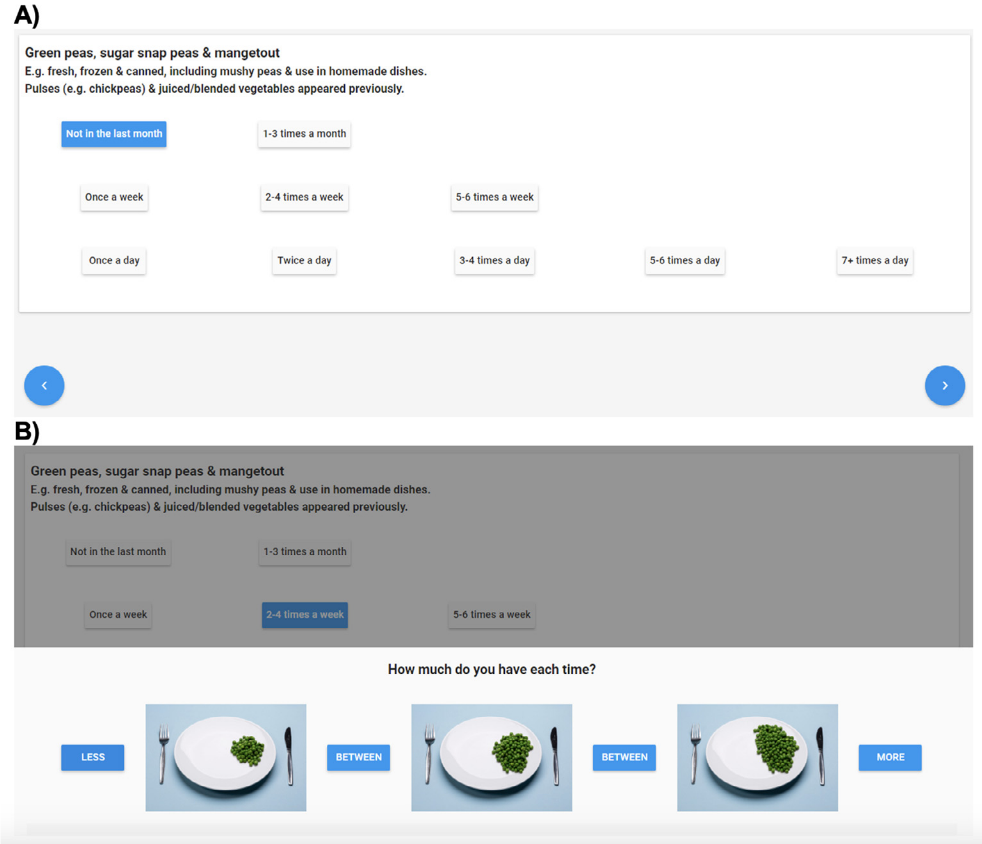

Fig. 2. Images of the eNutriFFQv2.0 frequency (A) and portion size (B) screens eNutriFFQv2.0: system usability and participant feedback.

list of eNutriFFQ2.0 food items is presented in Supplementary Table 3. Upon FFQ completion, mean daily intakes (g/d) for each item were automatically calculated by eNutriFFQ2.0.

Each food selection was automatically saved, allowing participants to return to the last food item if they paused/exited. Incomplete FFQs expired after 36 h to preserve reporting accuracy. The interval between FFQ1 and FFQ2 was managed by the software, preventing participants from completing FFQ2 early. An email reminder (with the study URL) was sent on day 14, plus up to two reminders for those yet to complete.

To assess the usability of eNutriFFQv2.0 after FFQ1, participants completed the System Usability Score (SUS) questionnaire [38], a widely-used metric to assess the usability of digital tools, including digital dietary assessments [39,40]. The questionnaire consists of 10 general statements relating to the usability of technology. The resulting SUS scores (out of 100) were automatically calculated by eNutri using the published methodology and categorized using the recognized acceptability ranges (>70: acceptable usability; 63–70: high marginal; 51–62: low marginal; ≤50: not acceptable) [41]. In the final SUS question, participants rate the user-friendliness of the technology on a 7-point adjective scale from “best imaginable” [1] to “worst imaginable” [7]. Participants could also report any technical issues encountered in a free-text box.

Following FFQ2, eNutri presented a short feedback questionnaire, where participants reported FFQ items they thought were missing or difficult to report, as well as offering suggestions for improvement (all free-text responses). They were also provided with 10 statements about their experiences of using eNutriFFQv2.0, each with 5 Likert responses from “Strongly Agree” to “Strongly Disagree.” For example, “It was clear how I should select my typical portion size image” and “The tutorial explaining the food and drink questionnaire was helpful.” These items were included to help us identify potential areas for tool improvement. On study completion, all data outputs were exported from eNutriFFQv2.0, which also included details about the participants’ devices (e.g., screen size) and web browsers used. Available screen width size (pixels) indicated the most likely device used: <600 pixels: small (e.g., smartphone), 600 to 1280 pixels: medium (e.g., tablet), or >1280 pixels: large (e.g., PC/laptop) [42].

3-Day WFR

The first 65 participants to complete FFQ1 were invited to complete the WFR. Researchers posted Salter Arc digital kitchen scales (Salter, Manchester, UK), blank paper-based food records, and detailed guidelines, including an example of a correctly completed WFR. On receiving these items, participants were instructed to start recording their food and drink intake the following day and to include 2 weekdays and 1 weekend day within the same week (days were chosen by the participants). If participants could not weigh their food/drink at any time (e.g., if eating out), portion sizes were indicated using a selection of adult-appropriate portion size images provided [43]. Completed WFRs were returned via pre-addressed return envelopes with pre-paid postage. Researchers reviewed the WFR and emailed participants for clarification or missing details, where required. Data were input into the Nutritics dietary analysis software [29] by a single researcher (RS) and checked by the lead researcher (MW). Mean daily energy and nutrient intakes were exported, and %TE for macronutrients was calculated.

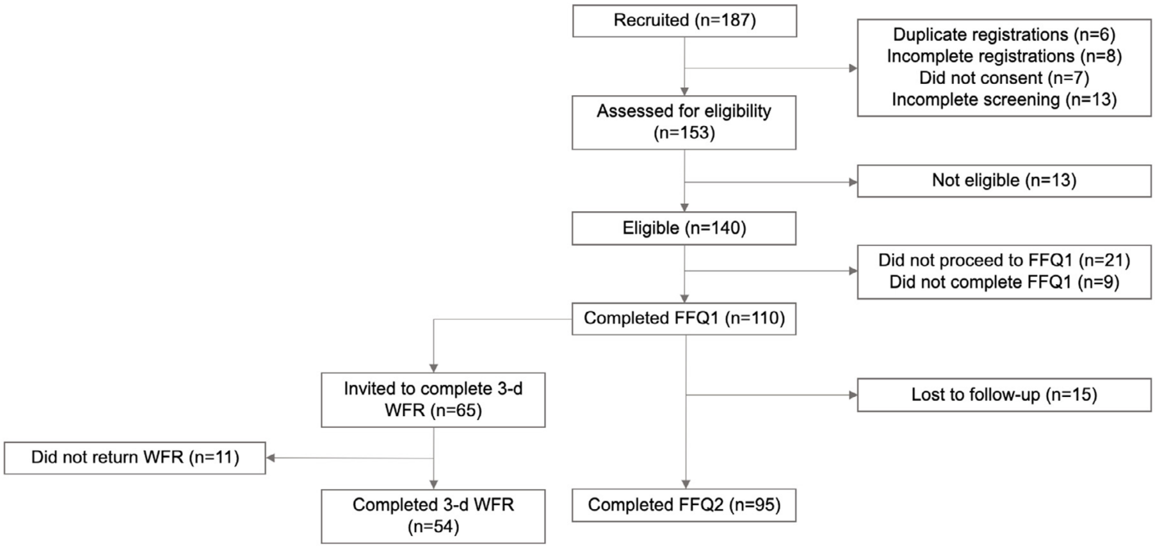

Fig. 3. Flow of recruitment for the ENVAL study.

Statistical analysis

Mean energy intakes of <600 or >4500 kcal/d, adapted from Willet [44], were considered unfeasible, and participants with energy intakes exceeding these cut-offs were excluded from all analyses. Participants with unfeasible reported weight changes between FFQ1 and FFQ2 (>5%) were also excluded from the reproducibility analysis.

Analysis included 29 nutrients (including energy), with macronutrients expressed as %TE. Percentage differences between FFQ1 (method $[M]_1$) and WFR or FFQ2 (M_2) were calculated as $([M_1 - M_2]/[M_1 + M_2]/2) \times 100$. For validation and reproducibility, nutrient intakes were split into quartiles (Q) for the corresponding methods. Ranking agreement between methods was assessed using cross-classification to estimate the percentage of participants classified into the same, adjacent (same ± 1), and misclassified (extreme-opposite, i.e., Q1 vs. Q4) quartiles for each nutrient. To compare quartiles of intake for each nutrient, Cohen's weighted kappa (κ_W) values (with quadratic weighting) were calculated. Prior to intraclass correlation (ICC) analysis (two-way with absolute agreement), data were assessed for normality and log or square root transformed to normalize data, where required. Values obtained for Cohen's weighted kappa were interpreted according to cut-off points described by Lombard et al. [45]: where <0.21 indicates *poor* agreement, 0.21 to 0.60 *acceptable* agreement, and >0.60 *good* agreement. For the reproducibility analysis, paired samples t-tests compared weight and body mass index (BMI), and a Chi-square test compared physical activity classifications at both timepoints. Chi-square was also used to analyze differences in SUS scores by age and sex. Analyses were performed using SPSS v.25 (IBM Statistics), and *P* values ≤ 0.05 were considered significant. Using the Bland–Altman method [46], the difference between methods (M_1 - M_2) was plotted against the average ($[M_1 + M_2]/2$) for energy, carbohydrate, total fat, and protein. Estimates were considered comparable if the mean differences (mean bias) were small, >95% of data plots lay within the limits of agreement (LOA; 1.96 SD of the mean difference), and the LOA were narrow.

Results

Participant characteristics

The flow of participants through the study is shown in Figure 3. Of the 187 participants recruited to the study, 140 were eligible for inclusion. Of 110 participants who completed FFQ1, 95 also completed FFQ2, and 54 participants completed a 3-d WFR. Eight participants were excluded from the reproducibility analysis (n = 6 energy misreporting; n = 2 unfeasible weight change) and one from the validation analysis for energy overestimation. Participant characteristics per analysis are shown in Table 1. Participants included in the validation analysis (n = 53) were predominantly

Table 1
Baseline characteristics of participants in the ENVAL study

	Mean (SD) or %	
	Validation	Reproducibility
N	53	87
Sex (% male/% female)	28.3/71.7	19.5/80.5
Age (years)	45 (15)	43 (15)
<40 y (%)	37.7	46.0
40–64 y (%)	52.8	46.0
≥65 y (%)	9.4	8.0
BMI (kg/m^2)*	25.0 (4.1)	24.5 (4.7)
<18.0 (%)	1.9	2.3
18.0–24.9 (%)	56.6	60.9
≥25.0 (%)	41.5	36.8
Physical activity (%)†		
Inactive	13.2	14.9
Moderately inactive	17.0	14.9
Moderately active	26.4	25.3
Active	43.4	44.8
Ethnicity (%)		
White	86.8	86.2
Black	3.8	2.3
Asian	3.8	5.7
Other, including mixed race	3.8	4.6
Not specified	1.9	1.1

*Calculated from self-reported weight and height.
†Determined from the eNutri physical activity questionnaire based on the validated NHS General Practitioner Physical Activity Questionnaire (GPPAQ) [37].

Table 2
Statistical test outcomes for daily energy and nutrient intakes derived from eNutriFFQv2.0 (FFQ1) and 3-d Weighed Food Record (n = 53).

Nutrients	FFQ1 Mean (SD)	3-d WFR Mean (SD)	Difference (FFQ-WFR) Mean (SD)	% difference	ICC	Quartile agreement, % Same	Same ± 1	Misclassified†	κ_w	Qualitative interpretation*
Energy (kcal/d)‡	2102 (731)	1926 (495)	176 (736)	8.7	0.26	34.0	81.1	5.7	0.41	Acceptable
Total fat (%TE)	33.8 (5.3)	35.2 (6.9)	−1.5 (7.2)	4.1	0.30	33.3	68.6	7.8	0.21	Acceptable
SFA (%TE)	11.9 (2.5)	12.1 (3.5)	−0.2 (3.5)	1.7	0.32	39.6	77.4	9.4	0.32	Acceptable
MUFA (%TE)	12.7 (2.7)	12.7 (3.8)	0.0 (3.6)	0.0	0.39	34.0	73.6	5.7	0.33	Acceptable
PUFA (%TE)	6.3 (1.7)	5.8 (1.9)	0.5 (1.8)	7.8	0.52	49.1	81.1	3.8	0.49	Acceptable
LC n-3 PUFA (g/d)‡	0.45 (0.48)	0.24 (0.45)	0.22 (0.54)	60.8	0.26	32.1	71.7	3.8	0.32	Acceptable
Protein (%TE)‡	16.7 (3.0)	17.0 (3.4)	−0.4 (3.5)	1.8	0.40	34.0	79.2	9.4	0.31	Acceptable
Carbohydrate (%TE)	44.7 (5.4)	41.6 (6.6)	3.1 (6.7)	7.2	0.33	32.1	79.2	5.7	0.36	Acceptable
Total sugars (%TE)	19.3 (5.2)	16.2 (4.5)	3.2 (3.9)	17.5	0.56	43.4	86.8	1.9	0.59	Acceptable
AOAC dietary fiber (g/d)‡	27.2 (11.5)	23.2 (8.3)	4.0 (11.5)	15.9	0.32	43.4	79.2	3.8	0.47	Acceptable
Alcohol (%TE)§	4.9 (5.3)	3.4 (5.5)	1.5 (3.4)	36.1	0.68	64.2	92.5	0.0	0.77	Good
Sodium (mg/d)	2340 (836)	2250 (715)	90 (821)	3.9	0.45	32.1	71.7	1.9	0.35	Acceptable
Potassium (mg/d)‡	3869 (1235)	3274 (1012)	595 (1342)	16.7	0.24	30.2	73.6	5.7	0.30	Acceptable
Calcium (mg/d)‡	1258 (486)	918 (358)	340 (436)	31.3	0.30	35.8	77.4	7.5	0.33	Acceptable
Iron (mg/d)‡	13.0 (4.3)	11.7 (3.2)	1.3 (4.6)	10.5	0.37	37.7	79.2	3.8	0.44	Acceptable
Zinc (mg/d)‡	10.4 (3.2)	9.7 (3.3)	0.7 (3.3)	7.0	0.40	30.2	84.9	3.8	0.47	Acceptable
Selenium (μg/d)	59.9 (22.1)	49.6 (18.3)	10.3 (26.4)	13.7	0.14	30.2	75.5	7.5	0.30	Acceptable
Iodine (μg/d)‡	215 (99)	131 (77)	83 (93)	48.6	0.14	41.5	75.5	11.3	0.27	Acceptable
Retinol (μg/d)‡	387 (322)	308 (476)	79 (272)	22.7	0.38	28.3	71.7	9.4	0.21	Acceptable
Total folate (μg/d)‡	371 (131)	303 (114)	68 (147)	20.2	0.24	35.8	73.6	9.4	0.25	Acceptable
Riboflavin (mg/d)‡	2.6 (1.0)	1.8 (0.7)	0.8 (1.0)	36.4	0.26	30.2	77.4	5.7	0.34	Acceptable
Thiamin (mg/d)	2.1 (0.8)	1.7 (0.6)	0.4 (0.8)	21.2	0.21	45.3	71.7	7.5	0.30	Acceptable
Niacin (mg/d)‡	32.2 (25.0)	37.4 (12.3)	−5.2 (28.1)	14.9	0.08	26.4	77.4	11.3	0.23	Acceptable
Pantothenic acid (mg/d)‡	9.6 (6.1)	6.0 (2.4)	3.6 (6.5)	46.2	0.06	34.0	71.7	11.3	0.17	Poor
Vitamin B6 (mg/d)‡	2.7 (1.7)	1.7 (0.7)	1.0 (1.8)	45.5	0.04	32.1	66.0	13.2	0.08	Poor
Vitamin B12 (μg/d)	8.4 (3.8)	4.8 (2.3)	3.6 (3.9)	54.5	0.16	26.4	71.7	11.3	0.14	Poor
Vitamin C (mg/d)‡	138 (83)	102 (71)	36 (85)	30.0	0.41	47.2	86.8	3.8	0.57	Acceptable
Vitamin D (μg/d)‡	4.7 (2.8)	2.8 (2.1)	1.9 (3.0)	50.7	0.18	26.4	73.6	5.7	0.29	Acceptable
Vitamin E (mg/d)	13.5 (6.2)	9.9 (4.7)	3.6 (8.2)	30.8	0.00	32.1	62.3	15.1	0.00	Poor

%TE, percentage of total energy; ICC, intraclass correlation; κ_w, Cohen's weighted kappa coefficient; LC, long chain; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids

*Values obtained for Cohen's weighted kappa and ICC were interpreted according to cut-off points described by Lombard et al. [45], where <0.21 indicated poor agreement, 0.21−0.60 acceptable agreement, and >0.60 good agreement.

†Opposite quartiles (i.e., Q1 vs. Q4).

‡Log transformed for ICC analysis.

§Square root transformed for ICC analysis.

female (71.7%), had a mean (SD) age of 45 [15] y (range: 20−78 y) and BMI of 25.0 (4.1) kg/m^2. Those included in the reproducibility analysis (n = 87) had similar characteristics: 80.5% female, aged 53 [15] y (range: 19−87 y), and BMI of 24.5 (4.7) kg/m^2.

Validation analysis

Overall, differences between FFQ1 and WFR estimates of energy and most nutrients were <20%, indicating generally good consistency between the two methods. Percentage differences ranged from 0.0% for monounsaturated fatty acids (MUFA) to 60.8% for long-chain n-3 polyunsaturated fatty acids (PUFA), with only long-chain n-3 PUFA and alcohol showing differences >20%. Based on weighted kappa values, 86.2% (n = 25/29) of nutrients showed *acceptable* or *good* agreement (κ = 0.21−0.77), while four nutrients showed *poor* agreement (pantothenic acid and vitamins B6, B12, and E). Quartile classification results were consistent with this: >70% of participants were classified in the same or adjacent quartiles for all nutrients except vitamin E (62.3%), vitamin B6 (66.0%), and total fat (68.6%) (Table 2). Misclassification was ≤5% for 9 nutrients and ≤10% for 23 out of 29 nutrients, with the highest misclassification observed for vitamin E (15.1%) and none for alcohol (0.0%). ICC values ranged from 0.00 for vitamin E to 0.68 for alcohol, mirroring the variability observed in the quartile agreement.

Bland−Altman plots showed relatively good agreement between the methods for energy and macronutrient estimation (Fig. 4; Supplementary Table 4), with only 3 cases falling outside of the LOA for energy (5.7%) and four cases for macronutrients (all 7.6%). The mean difference for estimates of energy intake was 176 kcal/d, with greater values estimated by FFQ1. The mean difference for estimates of carbohydrate was 3.1 %TE (higher for FFQ1), whereas estimates of fat and protein were lower for FFQ1 vs. WFR with a relatively small mean bias: −1.5 and −0.4 %TE, respectively.

Reproducibility of the eNutri FFQ

Overall, differences between FFQ1 and FFQ2 estimates were small, with 58.6% (n = 17) of nutrients showing percentage differences <10% (Table 3). Classification agreement between repeated administrations was high across most nutrients, with 86.2 to 97.7% of participants placed in the same or adjacent quartiles, and alcohol, fiber and energy showing the highest proportions within the same quartile (all >60%). Misclassification was low (<5%), ranging from 0% to 2.3% for all nutrients except for MUFA (3.4%), protein (3.4%), and vitamin C (4.6%). ICC values ranged between 0.65 (riboflavin) and 0.86 (alcohol), and weighted kappa values ranged from 0.58 (vitamin E) to 0.85 (alcohol), indicating *good* agreement for most nutrients (n = 24/29, 82.8%) and *acceptable* agreement for total fat, MUFA, selenium, and vitamins B6 and E.

Bland−Altman plots showed good reproducibility for total fat and carbohydrate estimation (Fig. 5; Supplementary Table 4), with <5% of cases outside the LOA. For energy and protein, 8.0% and

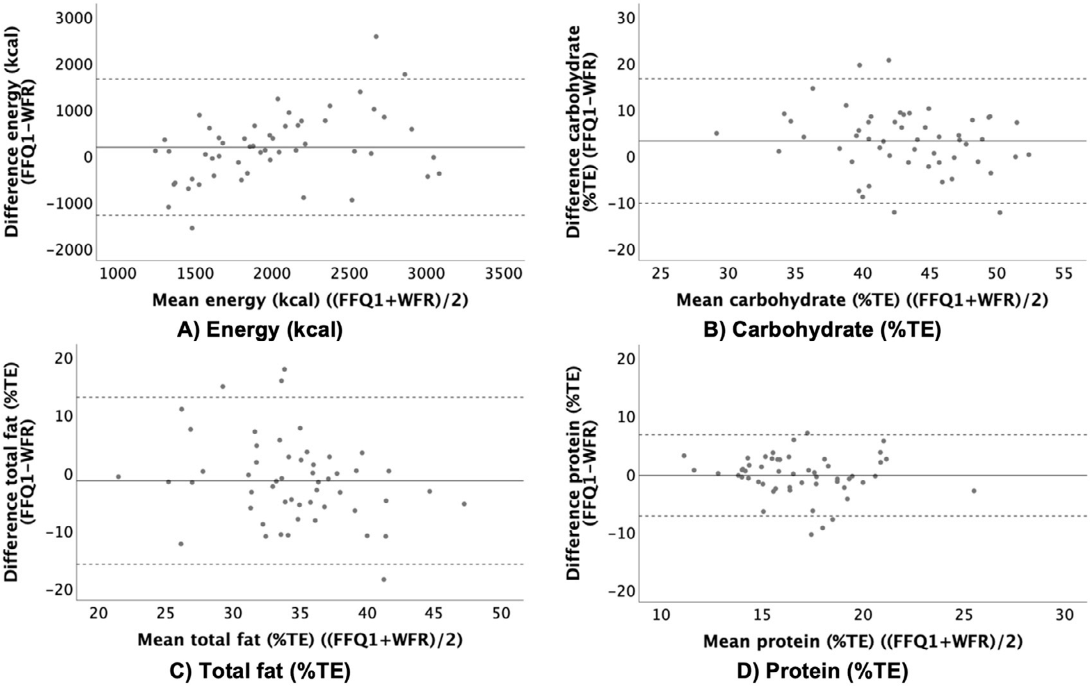

Fig. 4. Bland−Altman plots for the validation study (energy, carbohydrate, total fat, and protein): eNutriFFQv2.0 FFQ1 versus 3-d weighed food record (WFR).

6.9% of cases fell outside the LOA, respectively, although the LOA was narrowest for protein, suggesting good agreement. The mean difference for estimates of energy intake was 209 kcal/d, with greater values estimated at FFQ1. The mean differences for estimates of carbohydrate, fat, and protein were 0.7%, 0.0%, and 0.0% TE, respectively.

Self-reported anthropometry and physical activity levels for FFQ1 and FFQ2 are shown in Table 4. There were no significant differences for reported weight, BMI, or physical activity classifications, indicating good reproducibility in self-reporting.

System usability and participant feedback

The SUS questionnaire was completed by 108 (of 110 participants) after FFQ1. Mean SUS scores indicated acceptable usability (mean = 74.0, SD = 13.2; median = 75.0, IQR = 16.3). When split by age, both the <40 y and 40 to 64 y groups reported *acceptable* usability, and the ≥65 y group reported slightly lower SUS scores (categorized as *high marginal* usability, reflecting scores that did not quite meet the threshold for *acceptable*), although this difference was not significant ($P = 0.771$) (Table 5). When split by sex, both men and women reported similar *acceptable* usability ($P = 0.560$).

When asked to rate the overall user friendliness of eNutriFFQv2.0, 38.9% rated it “excellent,” and 43.5% rated it “good.” All, except one participant, rated the eNutriFFQv2.0 between “best imaginable” and “fair” (Fig. 6). Technical difficulties affected 10% of participants (n = 11/108) who reported images not appearing properly (n = 2), and difficulties/confusion when trying to return to previous FFQ items (n = 6).

In total, 88 participants completed the eNutriFFQv2.0 feedback questionnaire after FFQ2. Of these, 52% of participants agreed or strongly agreed when asked if they had completed a FFQ before starting the study. Figure 7 shows responses to selected Likert questions. Most participants agreed or strongly agreed the tutorial was helpful (70/88, 79%), they liked being able to select additional portion sizes beyond the three images (77/88, 87%), they thought eNutriFFQv2.0 asked enough questions to reflect their diet (74/88, 84%) and they remembered they were recalling intake for the previous month (84/88, 95%).

When describing any challenges encountered when completing the FFQ, participants mentioned difficulties recalling what they ate over the previous month (3/88, 3%), reporting foods not made or prepared by them (4/88, 5%), and choosing portion size images to reflect what they ate (3/88, 3%). The length of time to complete eNutriFFQv2.0 was also mentioned by two participants; however, when all participants were presented with the statement “I would prefer fewer questions even if my diet assessment was less accurate,” responses were mixed, with 38% (33/88) disagreeing and 29% agreeing (25/88). Users’ suggestions for improvement included introducing each FFQ category (e.g., fruit and vegetables, meat) so users can predict what is coming up (1/88) and showing a progress bar (1/88), suggesting that the current progress icon was not obvious to everyone.

Device types

Most participants opted to use small or large devices for FFQ1 (40.0% each), as compared with medium-sized devices. For FFQ2, participants again predominantly used small or large devices, with 37.9% using small and 42.1% using large devices (Table 6). When split by age, most participants aged <40 y and ≥65 y used large devices (57.5% and 66.7%, respectively) for eNutriFFQv2.0, whereas in the 40 to 64 y age group, the majority used small devices (48.9%).

Discussion

The eNutriFFQv2.0 was developed to reflect typical UK dietary patterns and incorporate updated food composition data. Its development process, guided by user feedback and multiple datasets, provides transparency that can support researchers considering its

Table 3
Statistical tests outcomes for daily energy and nutrient intakes derived from repeat measures of the eNutriFFQv2.0 (n = 87).

Nutrients	FFQ1	FFQ2	Difference (FFQ1-FFQ2)	% difference	ICC	Quartile agreement, %			κ_w	Qualitative interpretation*
	Mean (SD)	Mean (SD)	Mean (SD)			Same	Same ± 1	Misclassified[†]		
Energy (kcal/d)	2057 (696)	1848 (631)	209 (417)	10.7	0.77	63.2	93.1	0.0	0.77	Good
Total fat (%TE)	33.2 (5.9)	33.2 (5.7)	0.0 (4.3)	0.0	0.72	44.8	86.2	1.1	0.60	Acceptable
SFA (%TE)	11.8 (2.9)	12.0 (2.7)	−0.2 (1.9)	1.7	0.77	51.7	92.0	0.0	0.71	Good
MUFA (%TE)	12.5 (2.7)	12.3 (2.4)	0.2 (2.0)	1.6	0.70	51.7	87.4	3.4	0.59	Acceptable
PUFA (%TE)[‡]	6.1 (1.6)	6.1 (1.7)	0.0 (1.2)	0.0	0.76	51.7	89.7	2.3	0.64	Good
LC n-3 PUFA (g/d)[‡]	0.40 (0.43)	0.37 (0.41)	0.04 (0.30)	7.8	0.70	48.3	92.0	1.1	0.68	Good
Protein (%TE)	16.2 (3.5)	16.2 (3.2)	0.0 (2.5)	0.0	0.72	58.6	87.4	3.4	0.62	Good
Carbohydrate (%TE)	45.4 (7.2)	44.8 (7.0)	0.7 (4.8)	1.3	0.77	50.6	86.2	1.1	0.62	Good
Total sugars (%TE)[‡]	20.1 (7.6)	20.5 (6.9)	−0.4 (5.1)	2.0	0.78	54.0	89.7	1.1	0.67	Good
AOAC dietary fiber (g/d)	26.5 (10.6)	23.9 (9.1)	2.7 (7.0)	10.3	0.72	62.1	94.3	2.3	0.74	Good
Alcohol (%TE)	5.0 (5.8)	5.8 (6.8)	−0.7 (3.3)	14.8	0.86	70.1	97.7	0.0	0.85	Good
Sodium (mg/d)[‡]	2287 (832)	2061 (817)	226 (569)	10.4	0.66	50.6	90.8	1.1	0.67	Good
Potassium (mg/d)[‡]	3756 (1307)	3470 (1237)	287 (931)	7.9	0.70	51.7	96.6	1.1	0.75	Good
Calcium (mg/d)[‡]	1240 (586)	1127 (495)	113 (431)	9.5	0.70	48.3	90.8	0.0	0.69	Good
Iron (mg/d)	12.9 (4.3)	11.6 (3.9)	1.3 (2.9)	10.6	0.72	51.7	90.8	0.0	0.70	Good
Zinc (mg/d)	10.2 (3.6)	9.3 (3.5)	0.9 (2.8)	9.2	0.66	48.3	90.8	0.0	0.69	Good
Selenium (μg/d)	56.5 (23.0)	52.3 (21.5)	4.1 (17.3)	7.7	0.69	46.0	88.5	2.3	0.60	Acceptable
Iodine (μg/d)[‡]	204 (121)	188 (106)	16 (92)	8.2	0.72	54.0	93.1	0.0	0.74	Good
Retinol (μg/d)[‡]	364 (283)	337 (246)	27 (162)	7.7	0.72	54.0	90.8	1.1	0.69	Good
Total folate (μg/d)[‡]	366 (137)	330 (116)	35 (90)	10.3	0.67	59.8	95.4	0.0	0.79	Good
Riboflavin (mg/d)[‡]	2.5 (1.2)	2.3 (1.0)	0.2 (0.9)	8.3	0.65	54.0	86.2	1.1	0.63	Good
Thiamin (mg/d)[‡]	2.1 (0.7)	1.8 (0.6)	0.3 (0.5)	15.4	0.68	59.7	94.3	0.0	0.77	Good
Niacin (mg/d)[‡]	31.3 (22.8)	27.3 (19.6)	3.9 (13.8)	13.7	0.70	50.6	92.0	1.1	0.69	Good
Pantothenic acid (mg/d)[‡]	9.2 (5.6)	8.1 (4.9)	1.0 (3.4)	12.7	0.71	57.5	92.0	2.3	0.69	Good
Vitamin B6 (mg/d)[‡]	2.6 (1.5)	2.3 (1.3)	0.3 (0.9)	12.2	0.68	47.1	87.4	2.3	0.60	Acceptable
Vitamin B12 (μg/d)[‡]	7.9 (4.3)	7.2 (3.7)	0.7 (3.1)	9.3	0.71	51.7	86.2	0.0	0.65	Good
Vitamin C (mg/d)[‡]	137 (96)	119 (67)	18 (73)	14.1	0.68	56.3	89.7	4.6	0.61	Good
Vitamin D (μg/d)[‡]	4.3 (2.6)	3.9 (2.4)	0.4 (1.8)	9.8	0.71	52.9	92.0	2.3	0.67	Good
Vitamin E (mg/d)[‡]	13.1 (6.1)	11.4 (4.8)	1.7 (4.5)	13.4	0.67	47.1	86.2	2.3	0.58	Acceptable

%TE, percentage of total energy; ICC, intraclass correlation; κ_w, Cohen's weighted kappa coefficient; LC, long chain; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids

*Values obtained for Cohen's weighted kappa and ICC were interpreted according to cut-off points described by Lombard et al. [45] where <0.21 indicated poor agreement, 0.21−0.60 acceptable agreement, and >0.60 good agreement.

[†]Opposite quartiles (i.e., Q1 vs. Q4).

[‡]Log transformed for ICC analysis.

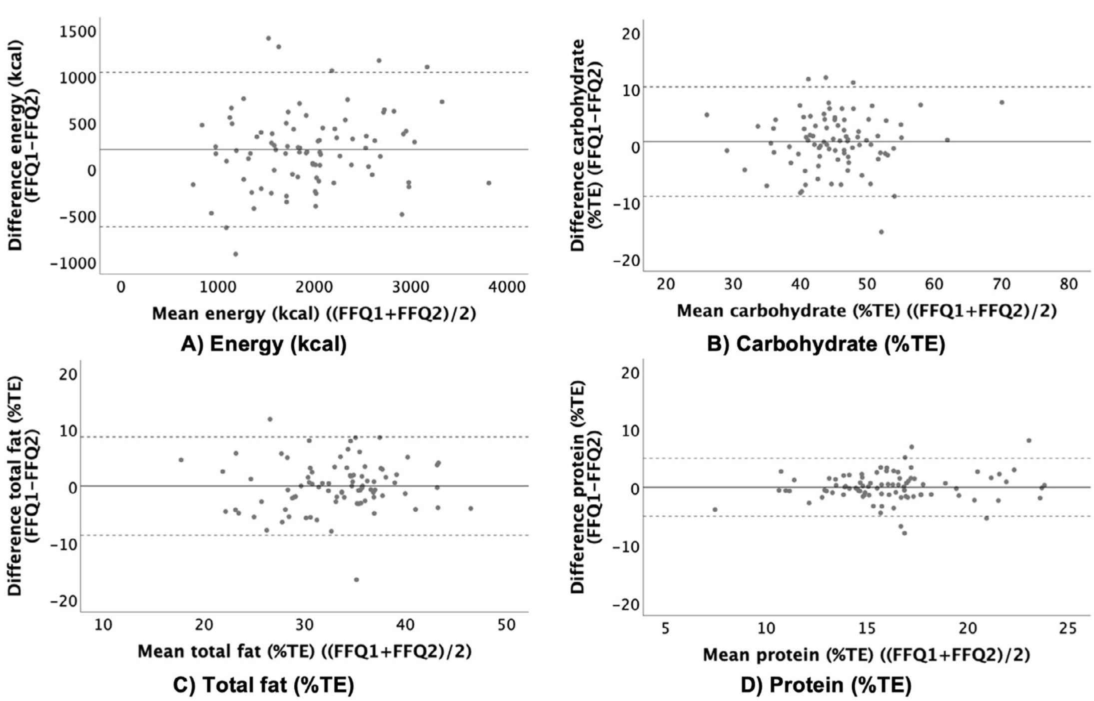

Fig. 5. Bland−Altman plots for the reproducibility study (energy, carbohydrate, total fat, and protein): eNutriFFQv2.0 FFQ1 versus FFQ2.

Table 4
Reproducibility of anthropometrics and physical activity status between repeat measures of eNutriFFQv2.0 (n = 87)

	Mean (SD) or %		Difference	P
	FFQ1	FFQ2	FFQ1-FFQ2	
Weight (kg)	68.0 (14.3)	68.0 (14.3)	0.0 (1.1)	0.993*
BMI (kg/m^2)	24.5 (4.7)	24.5 (4.8)	0.0 (0.4)	0.993*
Physical activity (%)				
Inactive	14.9	14.9	0.0	0.820†
Moderately inactive	14.9	10.3	4.6	
Moderately active	25.3	25.3	0.0	
Active	44.8	49.4	-4.6	

*Paired samples t-test, data log transformed prior to analysis.
†Chi-square test.

Table 5
System Usability Scale (SUS) scores for eNutriFFQv2.0 (FFQ1) by age and sex

Group	N	SUS score* Mean (SD)	Acceptability classification†	P‡
All	108	74.0 (13.2)	Acceptable	
Age (years)				
<40	49	73.5 (13.7)	Acceptable	0.771
40–64	51	75.2 (12.5)	Acceptable	
≥65	8	68.8 (14.6)	High marginal	
Sex				
Male	18	73.3 (11.3)	Acceptable	0.560
Female	90	74.0 (13.6)	Acceptable	

*Out of 100, where higher scores reflect greater usability.
†SUS scores were interpreted according to ranges described by Bangor et al. [41] where >70: acceptable usability; 63–70: high marginal; 51–62: low marginal; ≤50: not acceptable.
‡Chi-square test.

use or adapting FFQs. As dietary behaviors and composition databases evolve, ongoing refinement of FFQs remain essential for maintaining accuracy [23], and validation within the target population is critical to ensure reliability.

Overall, the eNutriFFQv2.0 demonstrated good reproducibility and acceptable validity compared to a 3-d WFR, supporting its use in dietary assessment research for UK adults.

Validity of the eNutriFFQv2.0 compared with 3-d WFR

Patterns of agreement observed for the eNutriFFQv2.0 reflect findings commonly reported in FFQ validation research, where nutrients with stable and habitual intake, such as alcohol, typically show the strongest concordance across methods. This was also seen in evaluations of the Scottish Collaborative Group (SCG) FFQs [47–49], and is further supported by a meta-analysis comparing nutrient intakes from FFQs with multiple reference methods that also found the greatest agreement for alcohol. These similarities reinforce the notion that foods and nutrients consumed regularly are more easily recalled and more reliably captured by FFQs.

Masson et al. reported higher agreement in women than men, with 93% of nutrients meeting Lombard's thresholds in females compared to 59% in males [47]. The high proportion of female participants in our study (71.7%) may have contributed to the level of acceptable agreement observed; further research is required to explore this.

Cross-classification results also fell within the range typically reported for FFQs, with most participants correctly or adjacently classified. Comparable classification has been observed in a range of paper-based [48,50] and web-based FFQ [51], supporting the ability of the eNutriFFQv2.0 to rank individuals according to nutrient intake.

Energy intake was modestly overestimated by the FFQ (176 kcal/d) relative to the 3-d WFR, consistent with findings from several other validation studies. For example, the 184-item Toronto-modified Harvard FFQ over-estimated energy by 220 kcal/d compared with a 3-d estimated food record [50]; the SCG FFQ v.7.0 produced estimated 380 kcal/d higher in females, although 75 kcal/d lower in males, relative to a 4-d WFR [48]; a 92-item web-based FFQ overestimated energy intake by 157 kcal/d compared with a 4-d estimated food record [51]; and Masson et al. reported overestimation of 510 kcal/d in males and 310 kcal/d in females for the SCG FFQ versus a 3-d WFR [47]. Validation of the SCG FFQ v6.6 showed an even greater difference of 718 kcal/d compared with a 7-d non-weighed food diary [49]. While overestimation is common, some FFQs underestimate energy intake; for example, the Australian CSIRO paper-based FFQ reported intakes 142 kcal/d lower than two 4-d WFRs [52]. A systematic review emphasized that factors such as the reference method, administration mode (self-reported or interview-based), FFQ duration and item count, sample size, and participants' sex all influence observed correlations [53]. These discrepancies highlight the complexity of dietary assessment methods. The relatively narrow LOA observed for energy intake in the present study (−1268, 1619 kcal/d) compared with the wider ranges summarized for UK FFQs (−2036, 2129 kcal/d) [54], suggests a higher degree of agreement for eNutriFFQv2.0 with the WFR than typically reported.

Agreement for pantothenic acid, vitamin B6, vitamin B12, and vitamin E was lower, highlighting that nutrients prone to day-to-day variation or incomplete reporting in food composition tables are more difficult to estimate accurately via FFQs. While limited comparable data exist for all four nutrients in the NDNS, the National Health and Nutrition Examination Survey (NHANES) data provides useful context. In the 2017 to 2020 NHANES sample, mean intake from food for adults aged >20 y was 2.62 mg and 1.70 mg for vitamin B6, and 5.84 μg and 3.69 μg for vitamin B12 in males and females, respectively, values that align more closely with the 3-d WFR estimates, given that 71.7% of our participants were female. Vitamin E intake is especially challenging to estimate because absolute amounts and the types of fats used in cooking are often omitted in dietary reports [55], particularly FFQs. Consistent with our findings, a systematic review also reported low

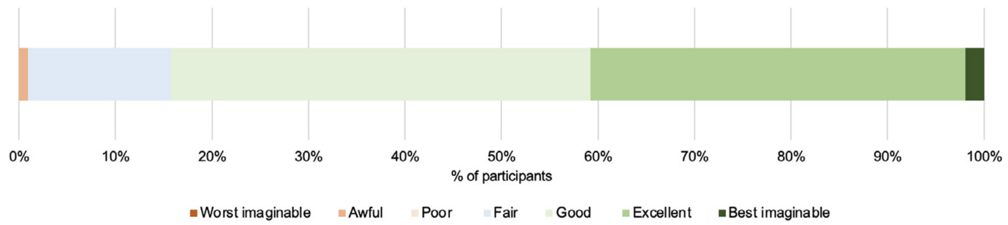

Fig. 6. Adjective usability ratings of eNutriFFQv2.0 (n = 108).

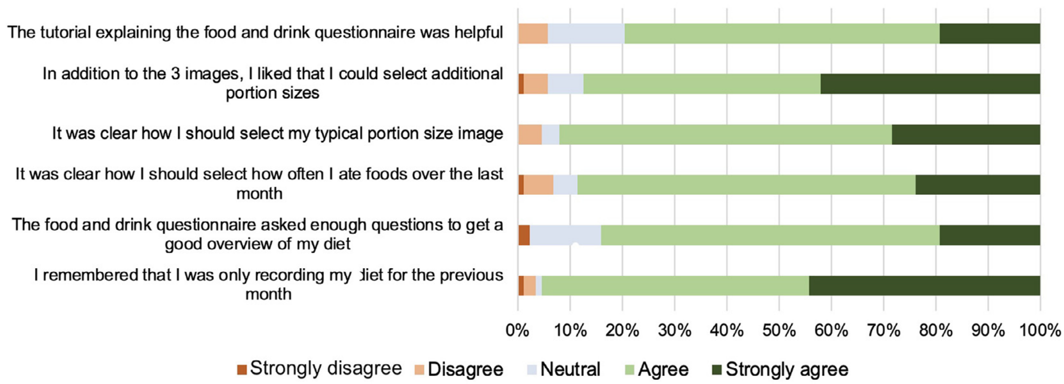

Fig. 7. User evaluation of eNutriFFQv2.0 using a Likert scale (n = 88).

Table 6
Most likely device types used to complete eNutriFFQv2.0

	All participants (%)		FFQ1 by age group (%)		
Screen size (most likely device type)	FFQ1 n = 95	FFQ2 n = 95	<40 y n = 40	40–64 y n = 47	≥65 y n = 18
Small (smartphone)	40.0	37.9	35.0	48.9	5.6
Medium (tablet)	20.0	20.0	7.5	23.4	27.8
Large (PC or laptop)	40.0	42.1	57.5	27.7	66.7

agreement between FFQs and reference methods for several fat-related nutrients, including α- and β-tocopherol and vitamin E [53]. Supporting the plausibility of our WFR estimates, Iyengar et al. estimated daily pantothenic acid at 5.88 mg using mixed total diet composites [56], more closely resembling the WFR values than those from the FFQ. A further contributor to the low agreement in these nutrients is the extent of missing data within the UK CoFID [27] and other composition tables: among the ca. 600 items used to construct the FFQ, data were missing for selenium (19%), iodine (31.7%), vitamin E (16.3%), and pantothenic acid (13.6%). Because Nutritics also relies on these same food composition sources, similar gaps may have affected WFR-derived estimates [29].

Despite the inherent measurement error present in all dietary assessment methods [57], the patterns observed here mirror those reported in previous validation studies. The eNutriFFQv2.0 provides reliable estimates for most nutrients, with limitations for pantothenic acid, vitamin B6, vitamin B12, and vitamin E.

Reproducibility of the eNutriFFQv2.0

The eNutriFFQv2.0 energy estimates were 209 kcal/d lower for FFQ2 compared to FFQ1, a pattern consistent with previous studies [48,58–61]. Such reductions have been attributed to participant fatigue [62] and/or a learning effect following the first administration [61], rather than true changes in dietary intake. The near identical bias reported for the Food4Me FFQ (210 kcal/d) [58], the basis for the original eNutriFFQv1.0, suggests similar bias and a pattern reflective of self-administered FFQs.

Weighted kappa values indicated good repeatability across nutrients and were generally higher than those reported for the SCG FFQ v.7.0 [48]. The proportion of participants classified into the same quartiles was similarly favorable compared with the SCG v.7.0 [48], and aligned with performance for repeat administrations of the Food4Me FFQ [58]. Refinements to the food list, portion size options, and nutrient database may have enhanced consistency across administrations.

Previous meta-analysis notes that FFQs with larger food lists (>120 items) and shorter test–retest intervals (<6 mo) tend to yield higher reproducibility [63], which aligns with the strong ICCs observed here. Notably, ICCs for 93% of nutrients estimated by repeat eNutriFFQv2.0 exceeded the equivalent crude and energy adjusted values reported in the meta-analysis [63], indicating stability in estimated intake using eNutriFFQv2.0. Pooled ICC values for riboflavin and vitamin B6 were slightly higher in the meta-analysis [63]. While an interviewer-led Middle Eastern and Mediterranean FFQ produced higher ICC values (0.822–0.996) [64] methodological and population differences limit direct comparison.

Overall, the reproducibility of the eNutriFFQv2.0 FFQ compares favorably with other FFQs, reinforcing its suitability for dietary assessment in epidemiological research in UK populations.

Strengths and limitations

A key strength of our evaluation is the evidence-based and transparently reported development of the eNutriFFQv2.0, informed by up-to-date UK dietary intake data to ensure relevance to current eating patterns. The digital, automated format supports efficient and scalable nutrient estimation, making the tool practical for large population studies.

Another strength is the comprehensive, multi-method statistical approach used to assess validity, including Bland–Altman, weighted kappa, cross-classification, and ICC analyses, in line with best practice recommendations [45]. In contrast, a review of 29 web-based FFQ validation studies identified a general lack of recommended statistical techniques, particularly Bland–Altman plots (used in 71% of studies), cross-classification (43%) and kappa coefficients (14%) [65]. Including reproducibility analysis further strengthens confidence in the reliability of the tool; a previous review found only 28% of web-based FFQ validations evaluated repeatability [65].

Assessing usability of the eNutriFFQ2.0 using the widely recognized SUS score was another strength, confirming that the eNutriFFQv2.0 is user-friendly, and providing clear suggestions for improving user experience in future iterations. For example, 20.5% of participants reported not finding the tutorial helpful, so alternate formats will be explored with users, e.g., short video. The usability rating of eNutriFFQ2.0 was similar to other popular dietary assessment tools, such as Intake24 [39] and myfood24 [40].

The study also has limitations. The FFQ relied on UK food composition databases that contain incomplete data for some micronutrients, which may have affected estimates, although these are the most appropriate sources for UK research. The NDNS dietary data were already between 4 and 10 y old at the time of eNutriFFQv2.0 development. Although these were the most up-to-date datasets available at the time, they may not have reflected the most current dietary patterns. Additionally, the sample size of 87 participants fell below the recommended threshold of 100 for repeat assessments [23], which may limit the generalizability of the reproducibility findings. Biomarker validation, often considered a gold standard, was not included due to cost and participant burden. Finally, the lack of full overlap between the first FFQ recall period and the WFR is acknowledged, although the administration order followed recommended practice [23].

Conclusion

The eNutriFFQv2.0 digital FFQ demonstrated *acceptable* validity for most nutrients when compared with a 3-d WFR, alongside *good* reproducibility. Developed using a rigorous, data-driven methodology informed by the most recent UK dietary datasets available at the time, the tool reflects prevalent consumption patterns. Usability testing further confirmed that the eNutriFFQv2.0 is user-friendly, supporting its feasibility for large-scale epidemiological studies and public health initiatives.

Overall, these findings establish the eNutriFFQv2.0 as a valid, reliable, user-friendly tool for assessing dietary intake in UK adults. The structured development process also provides a practical framework for researchers aiming to develop or refine FFQs or other dietary intake assessment tools.

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Declaration of competing interest

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CRediT authorship contribution statement

Michelle Weech: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rosalind Fallaize:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Rodrigo Zenun Franco:** Writing – review & editing, Software, Resources, Methodology, Investigation, Data curation. **Rachel Sutton:** Writing – review & editing, Validation, Resources, Project administration, Investigation, Formal analysis, Data curation. **Maria Fotiou:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Nicole Robertson:** Software, Resources, Methodology, Formal analysis. **Faustina Hwang:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Julie A. Lovegrove:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nut.2026.113212.

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