Validation of Electronic Food Frequency Questionnaires as a Dietary Intake Assessment Method: A Review

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ABSTRACT

Food frequency questionnaires (FFQs) have been widely used in various studies assessing dietary intake. Application of technological advancements in FFQs is increasing with the aim of enhancing accuracy and decreasing the respondent and researcher burden. The objective of this review was to explore the validity of various electronic FFQs (eFFQs) as a dietary intake assessment method. A total of 23 studies were finalised for qualitative data analysis after screening of various electronic databases and hand searching. The results showed that most of the eFFQs were self-administered, web-based, used food photographs for food portion size estimation and assessed intake of both macro- and micronutrients. Validity of eFFQs was assessed by comparing nutrient intake with reference methods in terms of association (correlation coefficients) and agreement at group level (paired t-test or Wilcoxon signed rank test). Overall, the association of nutrient intake with the reference method was observed to be acceptable in most studies especially with food records. Only few studies showed good agreement of nutrient intake with the reference method. In case of micronutrients, correlation coefficients >0.20 for all vitamins and minerals were observed in nine studies. The findings highlighted some advantages of eFFQs such as less missing data, convenience, automated data entry and analysis, additional features (audio, photographs, prompts etc.) and less cost than paper. Hence, it can be concluded that eFFQs could be an ideal choice for studies assessing usual dietary intake especially with large sample size and limited resources.

Key words: FFQ, food frequency questionnaire, diet assessment, validation, electronic, web

INTRODUCTION

Development of practical and valid methods to accurately assess dietary intake is crucial in nutritional epidemiology research. A number of methods have been developed for assessment of food consumption of individuals, such as, weighed or estimated food records, diet history, 24-hour dietary recall and food frequency questionnaire (FFQ). Also, there is an increasing use of technology in researches pertaining to diet and nutrition with the objective of enhancement of accuracy of various dietary assessment methods. Hence, more information is needed regarding the validity of such innovative methods. FFQ is the widely used method to measure long term dietary intake, representative of an individual’s usual intake and relies on the concept of generic memory. The use of FFQ is advantageous due to (a) lower respondent burden; (b) quick administration; (c) easier coding and analysis if automated; (d) ability to focus on selected food groups or nutrients; and (e) provides a better representation of usual dietary intake. The aim of this article is to review the validation of various electronic FFQs (eFFQs) developed for assessment of usual dietary intake among different population groups.

METHODS

For the purpose of this review the following definitions were used:
Food frequency questionnaire (FFQ)

A dietary assessment instrument that asks respondents to give an account of their usual frequency of consumption for a list of foods during a particular period of time. The food items listed are usually selected for specific purposes of the study and may not assess the whole diet. [8,9]

Electronic food frequency questionnaire (eFFQ)

A food frequency questionnaire which is administered by a computer or any other electronic device with or without the use of a web connection.

Literature Information Sources and search strategy

Four electronic databases (Scopus, PubMed, Science direct and Web of Science) were searched during March, 2017 using the following keywords: ‘food frequency questionnaire’, ‘FFQ’, ‘dietary assessment’, ‘online’, ‘web-based’, ‘internet’ and ‘computer administered’. Search limiters for publication year, type of participants, language, and type of search results (research articles only, book review, conference proceedings, and abstracts etc.) were applied wherever options were available. Search engines (Google and Google scholar) and reference lists of all review articles related to FFQs were also searched for identifying potentially eligible research articles.

Inclusion and exclusion criteria

Inclusion criteria: Original research studies (publication date: January, 2000 - February, 2017) assessing the validity of eFFQs among participants of all income groups, both sexes, ethnicities and countries were included. The ideal comparison methods for FFQ validation studies are diet records, multiple 24 hour recalls and biomarkers. [10] Research articles in which the eFFQ was evaluated against any of these methods and were available in English language from peer-reviewed journals were selected.

Exclusion criteria: Research articles based on only development of eFFQs, assessing validity of paper FFQs and for which full text was not available were excluded.

Study Selection and data extraction

A total of 2375 records were obtained through initial database search (2361) and hand searching (14). All articles were screened as per the pre-defined eligibility criteria. A total of 23 studies on assessment of validity of eFFQs were selected for qualitative data analysis. All the data from these articles were entered in the form of a matrix (tables 1 and 2) for evaluation and qualitative analysis as follows: author, publication year, sample characteristics, FFQ details, portion size estimation method, reference method for validation of eFFQs and salient results.

RESULTS

General characteristics of electronic food frequency questionnaires

All eFFQs used in the studies were quantitative and self-administered. Most of them were web-based except two which were only computer administrable. [11,12] The consumption period covered by eFFQs ranged from ‘previous day’s intake’ [13] to ‘past one year’s intake’ [14,15] while more than half of the studies (n=12) [11,12,16–25] used ‘past one month’ as the reference intake period. Intakes of both macronutrients and micronutrients were assessed by most eFFQs whereas some estimated intakes of only specific nutrients [11–13,22,24–26] and one was limited to intake of food groups only. [16] The most commonly used method for portion size estimation was food portion photographs either exclusively (8 eFFQs) [12,14,15,18–20,27,28] or in combination with standard portion sizes (5 eFFQs) [17,22,29–32] and household units/ measures (2 eFFQs). [23,33] Other portion size estimation methods were use of serving sizes [13] and standard measures/portions sizes [16,21] Administration time was reported for twelve eFFQs. [11,13,15,16,18,23,24,26,29,32,34] It ranged from seven minutes (MiniMealQ) [29] to 45 minutes [18] in case of eFFQs covering both macro- and micronutrients and from five minutes [13] to 45-90 minutes [11] for eFFQs assessing intake of only specific nutrients.
Table 1: Studies on validation of Electronic Food frequency questionnaires (eFFQs) for assessment of macro- and micronutrient Intakes

<table>
<thead>
<tr>
<th>Author and year</th>
<th>Sample characteristics</th>
<th>eFFQ</th>
<th>Consumption period covered</th>
<th>Nutrient and micronutrients</th>
<th>Food groups and items</th>
<th>Portion size estimation method</th>
<th>Reference method</th>
<th>Salient results</th>
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</thead>
<tbody>
<tr>
<td>(Matthys et al. 2007)</td>
<td>Adolescents 12-18 years of age, n=104, Belgium.</td>
<td>-</td>
<td>Past one month</td>
<td>Only food group intake (g/d)</td>
<td>15 food groups, 69 food items</td>
<td>List of common standard measures</td>
<td>3-d Estimated FRs</td>
<td>- Correlation coefficient = All foods: r=0.38, Range: r²=0.20 (pasta/rice) to 0.64 (breakfast cereals)</td>
</tr>
<tr>
<td>(Beasley et al. 2009)</td>
<td>Adults ≥18 years, n=218, mean age 54.9±14.4 y, 75.6% F and 87.2% white ethnicity, USA</td>
<td>Web – Pictorial Diet History Questionnaire (Web-PDHQ)</td>
<td>Past one year</td>
<td>Macro- and micronutrients</td>
<td>124 food items</td>
<td>Food portion photographs</td>
<td>4-d FRs and two 24HDRs</td>
<td>Correlation coefficient (unadjusted): Energy: r=0.53, Protein: r=0.52, Fat: r=0.52 (p&lt;0.001), CHO: r=0.55 (p&lt;0.001), All nutrients were significantly OE (p&lt;0.001) by FFQ except calcium (p=0.059)</td>
</tr>
<tr>
<td>(Vereecken et al. 2010)</td>
<td>n=48, age 13-17 years, mean age 14.6±1.1 y, 46% girls, Belgium–Flemish adolescents</td>
<td>HELENA online FFQ</td>
<td>Past one month</td>
<td>Energy, Fat, Calcium, Fibre, Iron, Vitamin C</td>
<td>137 food groups and individual food items</td>
<td>Standard PSs and pictures of increasing PSI for amorphous foods</td>
<td>4 computerized 24HDRs (YANA-C)</td>
<td>Correlation coefficient (unadjusted): Energy: r=0.66 (p&lt;0.001), Fat: r=0.62 (p&lt;0.001), CHO: r=0.55 (p&lt;0.001), All nutrients were significantly OE (p&lt;0.001) by FFQ except calcium (p=0.059)</td>
</tr>
<tr>
<td>(Labonté et al. 2012)</td>
<td>n=74, 18-65 years, healthy subjects (34 men and 40 women), Canada</td>
<td>Web-FFQ</td>
<td>Past one month</td>
<td>Macro- and micronutrients</td>
<td>8 food categories, 136 questions</td>
<td>Digital food portion photographs</td>
<td>3-d FRs (40% participants weighted foods)</td>
<td>Correlation coefficient (de-attenuated, sex and energy adjusted): Energy: r=0.58 (p&lt;0.001), Protein: r=0.52 (p&lt;0.001), Fat: r=0.52 (p&lt;0.001), CHO: r=0.55 (p&lt;0.001), All nutrients were significantly OE (p&lt;0.001) by FFQ except calcium (p=0.059)</td>
</tr>
<tr>
<td>(Christensen et al. 2013)</td>
<td>n=163, 20-63 years, healthy men and women, Sweden</td>
<td>Meal-Q and Mini Meal-Q</td>
<td>Past few months</td>
<td>Energy and micronutrient intake</td>
<td>Meal-Q: 102-174 food items Mini Meal-Q: 75-126 food items</td>
<td>Standard PSs and food portion photographs (only for some foods)</td>
<td>Meal-Q: 7-d Weighed FRs (web based) and DLW (n=30)</td>
<td>Correlation coefficient (crude): Meal-Q: Range, r: 0.06 (Fat) to 0.54 (CHO) Energy: r=0.16, Protein: r=0.22, Meal-Q: Range, r: 0.02 (Fat) to 0.54 (CHO) Energy: r=0.16, Protein: r=0.21, DLW: Energy UE by both FFQs (p&lt;0.001). Correlation coefficient: Meal-Q: r=0.42, MiniMeal-Q: r=0.38</td>
</tr>
<tr>
<td>(Christensen et al. 2014)</td>
<td>n=163, 20-63 years, healthy men and women, Sweden</td>
<td>Meal-Q and Mini Meal-Q</td>
<td>Past few months</td>
<td>Fiber and micronutrient intake</td>
<td>Meal-Q: 102-174 food items Mini Meal-Q: 75-126 food items</td>
<td>Standard PSs and food portion photographs (only for some foods)</td>
<td>Meal-Q: 7-d Weighed FRs (web based)</td>
<td>Correlation coefficient: Meal-Q: r=0.16 (riboflavin) to 0.66 (fiber) MiniMeal-Q: r=0.15 (riboflavin) to 0.65 (fiber) All CCs were significant except riboflavin with MiniMeal-Q</td>
</tr>
<tr>
<td>(Fallaize et al. 2014)</td>
<td>n=49, ≥18 years, mean age 26.9±8.4 years, male (n=15) and female (n=34), UK</td>
<td>Food4Me FFQ</td>
<td>Past one month</td>
<td>Both macro and micronutrients</td>
<td>11 food categories, 157 food items</td>
<td>Food portion photographs</td>
<td>4-d Weighed FRs</td>
<td>All nutrients were OE: Energy, protein, CHO and total fat intake not significantly different. Correlation coefficient (Unadjusted): Energy: r=0.53, Protein:r=0.59, CHO: r=0.43, Fat: r=0.56 Correlation significant (p&lt;0.01). Correlation coefficient range: r= 0.11 (soups, sauces and miscellaneous foods) to 0.73 (yogurts).</td>
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</table>
Table 1 to be Continued…

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>FFQ</th>
<th>Duration</th>
<th>Food groups</th>
<th>Food portion measures</th>
<th>Macronutrients/Micronutrients</th>
<th>OE</th>
<th>Coefficient (median)</th>
<th>Ranges</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>(Kristal et al. 2014)</td>
<td>n=74, 18 to 69 years, 40 men and 34 women, Columbus, Ohio, White ethnicity</td>
<td>GraFFS</td>
<td>One month</td>
<td>Energy, macro and micronutrients</td>
<td>Food portion photographs</td>
<td>156 food items</td>
<td>6 telephone administered 24-HDRs</td>
<td>GraFFS UE: total energy, fat, CHO, and protein intake. Correlation coefficient (unadjusted): Energy: r=0.39, Protein: r=0.41, CHO: r=0.47, Total fat: r=0.42</td>
<td>Correlation coefficient (median, all food groups) r=</td>
<td></td>
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<tr>
<td>(Øverby et al. 2014)</td>
<td>n=93, 13-14 years, 53 girls, Norway</td>
<td>-</td>
<td>Past one month</td>
<td>Macro and micronutrients</td>
<td>Standard PS (unit)</td>
<td>131 food and beverage items, 156 questions</td>
<td>Relative validity: 2x24HDRs (n=93) Absolute validity: Fatty acids and 25-hydroxy-vitamin D3 in whole blood (n=92)</td>
<td>Correlation coefficient (unadjusted): all nutrients, r=0.26</td>
<td>Correlation coefficient (median, all food groups) r=</td>
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<tr>
<td>(Du et al. 2015)</td>
<td>n=644, male: n=315, mean age: 21.2±2.0 years and female n=329, mean age: 21.1±1.8 years, College students, China</td>
<td>IDQC</td>
<td>Past 4 months</td>
<td>Macro and micronutrients (total 23 nutrients)</td>
<td>Food photographs</td>
<td>135 food items, 16 food categories</td>
<td>3-d Diet records</td>
<td>All nutrients significantly OE by IDQC (p&lt;0.05). Correlation coefficient: All significant (p&lt;0.05)</td>
<td>Correlation coefficient (unadjusted) ranged from r=0.27 (oil) to 0.47 (grams) and significant for all food groups p&lt;0.05. Significant OE (p&lt;0.05) in fruits, meat, legumes and dairy.</td>
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<tr>
<td>(Tabacchi et al. 2015)</td>
<td>n=92, 14-17 years high school children, Italy. [Food group validity n=92 and nutrients validity n=76; after adjusting for high energy intake]</td>
<td>ASSEO-FFQ</td>
<td>Past one month</td>
<td>Macro and micronutrients</td>
<td>Food/beverage portion photographs and household units</td>
<td>20 major food groups, 3 sections. Total 106 food items.</td>
<td>3-d Weighed FRs</td>
<td>Significant difference nutrient intake (p&lt;0.05 to p&lt;0.001), except for Vitamin B12. Energy, protein, CHO and total fat intake OE.</td>
<td>Correlation coefficients: Macronutrients, r: Energy: -0.04, Protein: -0.11, CHO:0.04, Fat: -0.03</td>
<td>Correlation coefficients, r, ranged from 0.00 (Pasta/rice/couscous) to 0.61 (milk). 19 food groups out of 24 were significantly different (p&lt;0.01 to p&lt;0.001).</td>
</tr>
<tr>
<td>(Bentzen et al. 2016)</td>
<td>n=64, age range: 17-80 years, diabetes patients, Denmark</td>
<td>-</td>
<td>Past 3 months</td>
<td>Macro and micronutrients</td>
<td>Household measures and food photograph series</td>
<td>270 food items and mixed dishes</td>
<td>4-d pre-coded Food diary</td>
<td>All nutrients OE except SFA, alcohol, vitamin-D. Significant difference in mean intake of CHO (p=0.001) and dietary fibre (p=0.000).</td>
<td>Correlation coefficients (all p&lt;0.01): Macronutrients, r: Energy: 0.50, Protein: 0.49, CHO: 0.51, Fat: 0.36</td>
<td>Correlation coefficients, r, ranged from 0.00 (Pasta/rice/couscous) to 0.61 (milk). 19 food groups out of 24 were significantly different (p&lt;0.01 to p&lt;0.001).</td>
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<tr>
<td>(Feng et al. 2016)</td>
<td>n=292, 18-65 years, 30.5% men, Chinese</td>
<td>IDQC</td>
<td>Past 4 months</td>
<td>Macro and micronutrients</td>
<td>Food portion photographs</td>
<td>135 food items, 16 food categories</td>
<td>3-d Diet diaries</td>
<td>Correlation coefficient unadjusted (mean r=0.52; all p&gt;0.05) ranged from r=0.40 (vitamin-C and folic acid) to 0.96 (Iodine). Energy: r=0.51, Protein: r=0.54, CHO: r=0.45, Fat : r=0.53Energy, protein, CHO (p&lt;0.01) and total fat OE (p=0.05).</td>
<td>Correlation coefficients (all p&lt;0.05) ranged from r=0.19 (sweet) to 0.61 (dairy products)</td>
<td></td>
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<tr>
<td>(Knudsen et al. 2016)</td>
<td>n=97, 20–42 years, women, Denmark</td>
<td>-</td>
<td>Previous year</td>
<td>Macro and micronutrients</td>
<td>Food portion photographic series</td>
<td>220 foods and beverages</td>
<td>4-d Food diary</td>
<td>OE of total energy and macronutrients intake by Food diary Correlation coefficients (energy adjusted), r: Energy: 0.29, Protein:0.49, CHO:0.63, Fat:0.56</td>
<td>Correlation coefficients ranged from r=0.17 (fats) to 0.61 (low fat dairy)</td>
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</table>
### Table 1 to be Continued…

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Sample Characteristics</th>
<th>eFFQ</th>
<th>Consumption Period covered</th>
<th>Specific Nutrient(s)</th>
<th>Food groups and items</th>
<th>Portion Size estimation method</th>
<th>Reference method</th>
<th>Salient Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Nybacka et al. 2016)</td>
<td>n=40, 50–64 years, (men = 25, women=20), Swedish origin</td>
<td>DDW-Q</td>
<td>Past few months</td>
<td>Energy, macronutrients and alcohol</td>
<td>75 to 126 food items</td>
<td>DLW</td>
<td>Mini Meal-Q UE(^{11}) energy intake (-2.3±3.6 MJ) (p&lt;0.001). Correlation between Mini Meal-Q and TEE(_{DLW}) r=0.28 (non-significant).</td>
<td></td>
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<tr>
<td>(Delisle et al. 2017)</td>
<td>n=38, 3–6 years pre-school children, 22 boys and 16 girls</td>
<td>KidMeal-Q</td>
<td>Past few months</td>
<td>Macro and micronutrients</td>
<td>42–86 food items, drinks and dishes</td>
<td>DLW and four 24HDRs (over phone)</td>
<td>Mean energy intake from KidMeal-Q (4670±1430 kJ/24 h) statistically different (p &lt; 0.001) from TEE(_{DLW}) (6070±690 kJ/24 h). Significant difference (p&lt;0.01) in fiber and calcium intake.</td>
<td>Correlation coefficient, r(_i): range, 0.102 (bakery products) to 0.603 (vegetables).</td>
</tr>
</tbody>
</table>

eFFQ- electronic food frequency questionnaire, r- Pearson correlation coefficient, r\(_i\)- Spearman correlation coefficient, PDHQ- pictorial diet history questionnaire, HELENA- (Healthy Lifestyle in Europe by Nutrition in Adolescence, g/d- gram per day, FR- food records, 24HDR- 24 hour dietary recall, CCs- correlation coefficients, CHO- carbohydrate, YANA-C- Young Adolescent's Nutrition Assessment on Computer, OE\(^{11}\)– overestimated, UE- underestimation, UE\(^{-1}\)- underestimated, PUFA- polyunsaturated fatty acid, EPA- eicosapentaenoic acid, DPA – Docosapentaenoic acid, LA- Linoleic acid, SFA- saturated fatty acid, DLW- doubly labelled water, PS- portion size, IDQC- internet-based diet and lifestyle questionnaire for Chinese, ASSO- Adolescents and Surveillance System for the Obesity prevention, TEE- total energy expenditure.

### Table 2: Studies on validation of Electronic Food frequency questionnaires (eFFQs) for assessment of intake of specific nutrients

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Sample Characteristics</th>
<th>eFFQ</th>
<th>Consumption Period covered</th>
<th>Specific Nutrient(s)</th>
<th>Food groups and items</th>
<th>Portion Size estimation method</th>
<th>Reference method</th>
<th>Salient Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Heath et al. 2000)</td>
<td>n=49, women 19 - 31 y, Dunedin, New Zealand</td>
<td>Iron FFQ</td>
<td>Past one month</td>
<td>Dietary iron and its absorption modifiers</td>
<td>17 Food Groups, 206 food items (80 with a high iron content)</td>
<td>Common standard measures, 13 dimensional food models and cup size portions of dried beans</td>
<td>Weighed FRs (11 days) over one month</td>
<td>OE in mean intake for iron (mg/d) by Iron FFQ (11±4.5) compared to weighed diet records (10±2.6). Correlation coefficient (unadjusted), r(_i): Iron – 0.29, non-heam Iron – 0.34, heam iron – 0.52 Absorption modifiers: ranged from 0.34 (vitamin-C) to 0.86 (coffee)</td>
</tr>
<tr>
<td>(Galante &amp; Colli 2008)</td>
<td>n=30, 21 to 45 years, male (5) and female (25)</td>
<td>SFFQ</td>
<td>One month</td>
<td>Calcium and Iron</td>
<td>79 Food items</td>
<td>Photo book containing food (3 portions) and kitchenware images</td>
<td>4-d FRs in 2 consecutive months: total 8FRs</td>
<td>SFFQ OE(^{11}) mean intake (mg/d) of Calcium and Iron compared to 8 FRs: Calcium – SFFQ: 940±471 and 8FRs: 770±311. Correlation coefficient (unadjusted): r=0.64 (p&lt;0.05) Iron – SFFQ: 13.3±5.0 mg and 8FRs: 11.6±3.6. mg; r = 0.33 (not significant)</td>
</tr>
<tr>
<td>(Wong et al. 2008)</td>
<td>n=161, 11 to 18 years, 81 males and 80 females, 29% Asian, 36% Hispanic, and 35% non-Hispanic white, Utah (US)</td>
<td>-</td>
<td>Past one month</td>
<td>Calcium</td>
<td>80 Food items</td>
<td>Food portion photographs</td>
<td>2-d 24HDRs</td>
<td>Correlation coefficient (unadjusted) of calcium intake by the 2nd computerized FFQ and the mean of two 24-hour dietary recalls was r=0.42 (p&lt;0.001).</td>
</tr>
<tr>
<td>(Hacker-Thompson et al. 2009)</td>
<td>n=140, women, mean age 49±15 years, 73% White ethnicity</td>
<td>Online calcium quiz</td>
<td>Previous day intake</td>
<td>Calcium</td>
<td>34 food items + calcium fortified foods section</td>
<td>Serving sizes</td>
<td>3-d Diet record</td>
<td>Mean daily calcium intake: Online calcium quiz: 834.4±554.1 mg/day and Food record: 901.8±355.9 mg/day (not significantly different), Correlation coefficient (eFFQ and diet records): r=0.37, P&lt;0.001.</td>
</tr>
<tr>
<td>Study (Year)</td>
<td>Sample Characteristics</td>
<td>PUFA FFQ</td>
<td>Past Time Period</td>
<td>PUFA Subcategories</td>
<td>Questions</td>
<td>Method of Validation</td>
<td>Observations</td>
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<tr>
<td>(Swierk et al. 2011)</td>
<td>n=41, mean age 42.1±17.5 years (range 19-78y), 20 males and 21 females, Australia</td>
<td>PUFA FFQ</td>
<td>Past 3 months</td>
<td>Omega-3 and Omega-6 PUFA</td>
<td>5 food categories, 38 questions</td>
<td>Not mentioned</td>
<td>3-d Weighed FRs and blood biomarkers (erythrocytes and plasma)</td>
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<tr>
<td>(Allaire et al. 2015)</td>
<td>n=60, mean age 60.3±6.9 years, men with prostate cancer, Canada</td>
<td>Web-FIQ</td>
<td>Past one month</td>
<td>Omega-3 fatty acids</td>
<td>8 food subcategories, 136 questions with 40 sub-questions</td>
<td>Photographs of foods and meals and standardized portion sizes</td>
<td>PUFA FFQ vs. Weighed FRs: mean intake (g/d)</td>
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</tr>
<tr>
<td>(Segovia-Siapco et al. 2016)</td>
<td>n=55 (complete data), 12–18 years (33 girls and 22 boys) attending middle and high schools, 46% Caucasians, 58% California and 42% Michigan</td>
<td>WebFFQ</td>
<td>Past one month</td>
<td>Soy Isoflavones, nutrients (20) and caffeine</td>
<td>151 food items (36 food containing) and 8 food categories</td>
<td>Fixed PSs based on familiar measuring devices, e.g. cup, tablespoon, 12-third ounce can, and others.</td>
<td>WebFFQ OE= median total isoflavone intake (9.31 mg) compared with FRs (3.61 mg) (p&lt;0.001),</td>
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</table>

SFFQ: Semi-quantitative food frequency questionnaire, eFFQ: electronic food frequency questionnaire, r- Pearson correlation coefficient, r- Spearman correlation coefficient, FR: food records, 24HDR: 24 hour dietary recall, CCs- correlation coefficients, CHO- carbohydrate, OE Biological activity of phytoestrogens is not considered.

 PUFA- polyunsaturated fatty acid, EPA- eicosapentaenoic acid, DPA – Docosapentaenoic acid, LA- Linoleic acid, SFA- saturated fatty acid, PS- portion size.

Table 2 to be Continued…

| (Swierk et al. 2011) | n=41, mean age 42.1±17.5 years (range 19-78y), 20 males and 21 females, Australia | PUFA FFQ | Past 3 months | Omega-3 and Omega-6 PUFA | 5 food categories, 38 questions | Not mentioned | 3-d Weighed FRs and blood biomarkers (erythrocytes and plasma) |
| (Allaire et al. 2015) | n=60, mean age 60.3±6.9 years, men with prostate cancer, Canada | Web-FIQ | Past one month | Omega-3 fatty acids | 8 food subcategories, 136 questions with 40 sub-questions | Photographs of foods and meals and standardized portion sizes | PUFA FFQ vs. Weighed FRs: mean intake (g/d) |
| (Segovia-Siapco et al. 2016) | n=55 (complete data), 12–18 years (33 girls and 22 boys) attending middle and high schools, 46% Caucasians, 58% California and 42% Michigan | WebFFQ | Past one month | Soy Isoflavones, nutrients (20) and caffeine | 151 food items (36 food containing) and 8 food categories | Fixed PSs based on familiar measuring devices, e.g. cup, tablespoon, 12-third ounce can, and others. | WebFFQ OE= median total isoflavone intake (9.31 mg) compared with FRs (3.61 mg) (p<0.001), |

SFFQ: Semi-quantitative food frequency questionnaire, eFFQ: electronic food frequency questionnaire, r- Pearson correlation coefficient, r- Spearman correlation coefficient, FR: food records, 24HDR: 24 hour dietary recall, CCs- correlation coefficients, CHO- carbohydrate, OE Biological activity of phytoestrogens is not considered.

 PUFA- polyunsaturated fatty acid, EPA- eicosapentaenoic acid, DPA – Docosapentaenoic acid, LA- Linoleic acid, SFA- saturated fatty acid, PS- portion size.
Validation of electronic food frequency questionnaires

Sample characteristics:
Most of the studies were conducted on adults (n=16) and adolescents (n=6). The sample of three studies consisted of only women participants [11,13,15] and only one study had male participants. [22] The sample size ranged from 30 [25] to 644. [34]

Reference methods:
The commonly used reference methods for the purpose of validation were diet/food records [13,18,24,25,34] (n=5), weighed food record [11,19,23] (n=3), food diary [15,28,33] (n=3), multiple 24-hour dietary recalls [12,17,20] (n=3), biomarkers [22,31] (n=2) and estimated food record [16] (n=1). In six studies, a combination of two reference methods was used. [14,21,26,29,30,32]

Validation of Nutrient intake:
Electronic FFQs assessing intake of both macro- and micronutrients: Energy intake was significantly underestimated compared to total energy expenditure by doubly labelled water technique in three studies (p<0.001). [29,31,32] Comparison of nutrient intake with other reference methods in terms of correlation coefficients (association) and agreement at group level (paired t-test or Wilcoxon signed rank test) was assessed using the interpretation criteria suggested by Lombard et al. [35] The outcomes were considered poor (<0.20), acceptable (0.20 - 0.49) or good (≥0.50) depending on the correlation coefficients values and p-value of paired t-test or Wilcoxon signed rank test (p > 0.05, good and p≤0.05, poor). Good (n=6) [17–19,28,33,34] and acceptable (n=4) [14,15,20,21] association of energy intake with reference method was observed in ten studies. [14,15,17–21,28,33,34] Similar association was observed for carbohydrate intake (good outcome, n=5 studies [15,18,28,33,34] and acceptable outcome, n=5 studies [14,19–21,28]) with correlation coefficients >0.20 obtained for the ten studies. [14,15,18–21,28,29,33,34] In case of protein, good outcome was observed in four studies [18,19,28,34] and acceptable outcome was observed in six studies. [14,15,20,21,29,33] For total fat intake, correlation coefficients >0.20 were obtained for eight studies [14,15,17,19–21,28,33] (n=4 for good and n=4 for acceptable outcome). Only few studies showed good agreement of macronutrient intake (energy, protein and total fat) with reference method (n=3) [18,19,33] and carbohydrate (n=2). [18,19] On the other hand, some studies reported significant overestimation of macronutrients (energy, protein and total fat; n=4) [17,23,28,34] and carbohydrate (n=5) [17,23,28,33,34] and one study reported underestimation. [29] In case of micronutrients, correlation coefficients >0.20 for all vitamins and minerals were observed in nine studies. [14,17–21,28,33,34]

Electronic FFQs assessing intake of specific nutrients: Some eFFQs were developed for assessment of intake of selective nutrients only. [11–13,22,24–26] In case of iron (n=2), overestimation in mean intake by eFFQs was observed with correlation coefficients, r = 0.29 [11] and r=0.33. [25] Significant correlation coefficients were observed in calcium intake (n=3) [12,13,25] ranging from r=0.37 [13] to r=0.64. [25] Comparison with biomarkers was done in case of fatty acids in two studies. [22,26] Analysis revealed high validity coefficients for eicosapentaenoic acid (EPA) (ρ=0.92; 0.87), docosahexaenoic acid (DHA) (ρ=0.69;0.64) and long chain omega-3 fatty acids (ρ=0.78; 0.73) on comparison with the levels in erythrocytes and plasma (ρ < 0.05). [26] Similarly, good correlation (≥0.50) was observed between fatty acid intake and fatty acid profiles of membranes of red blood cells in case of total omega-3 fatty acid (r_s=0.540; p<0.0001), EPA and DHA (r_s=0.593; p<0.0001) and long chain omega-3 fatty acids (r_s=0.549; p<0.0001). [22] However, one eFFQ developed for assessment of soy isoflavones intake significantly overestimated median total isoflavone intake (9.31 mg) compared with food records (3.61 mg) (p<0.001). [24]
Validation of Food group intake:
Analysis for food groups was conducted in ten studies. \[15-17,19,21-23,28,32,34\] Lower correlation coefficients (≤0.20) were observed for food groups such as pasta and rice; \[16,23\] sugar, sweets and cakes; \[21,28\] fats and soups and sauces. \[19\] Higher correlation coefficients (≥0.60) were observed in case of milk, \[17,23\] dairy, \[15,21,28\] yogurt and vegetables. \[32\] Significant correlations were observed between servings of fatty fish and total ω-3 fatty acids \(r_s=0.304; P=0.02\), total long-chain ω-3 fatty acids \(r_s=0.290; P=0.03\) and DHA \(r_s=0.328, P=0.01\) in membranes of red blood cells. \[22\]

DISCUSSION

General characteristics: This review was conducted to examine the characteristics of various eFFQs developed for assessment of individual’s dietary intake and their validity. In all, twenty three studies on validation of 22 different eFFQs were reviewed. Most of the eFFQs were a) web based; b) developed for adult population; c) quantitative; d) self-administered; and e) developed to assess intake of both macro- and micronutrients.

Agreement with reference method: Diet/food records emerged as the most commonly used reference method to assess validity of eFFQs. \[13,18,24,25,34\] Correlation coefficients >0.20 were observed for eFFQs assessing intake of both macro- and micronutrients in ten studies for energy, \[14,15,17–21,27,31,33\] ten studies for protein and carbohydrate intake \[14,15,18–21,29,31,33,34\] and in eight studies for fat intake. \[14,15,17,19–21,31,33\] For micronutrients, correlation coefficients >0.20 for all vitamins and minerals were observed in nine studies. \[14,17–21,28,33,34\] In case of food groups, high correlation coefficients (≥0.60) were observed in case of milk, \[17,23\] dairy, \[15,21,28\] yogurt and vegetables \[32\] and significant correlation were observed between intakes of some fatty acids with their respective biomarkers. \[22\] Also, the association of macronutrient intake (energy, protein, carbohydrate and fat) from eFFQs was observed to be stronger (correlation coefficient >0.50) with food records/diaries as the reference method than with multiple 24-hour diet recalls. For energy and fat intake, five \[15,18,19,33,34\] and three \[15,19,31\] studies respectively showed good association (correlation coefficient >0.50) with food records/diaries. On the other hand, only one study \[17\] showed good association with multiple 24-hour diet recalls. In case of carbohydrate and protein intake, five \[18,29,31,33,34\] and four \[15,18,19,34\] studies respectively showed good association (correlation coefficient >0.50) with food records/diaries while no study showed good association with 24-hour diet recalls. One study comparing intake from eFFQ with both food records and 24-hour diet recall showed higher correlation coefficients with food records than 24-hour diet recall for both macro- and micronutrient intake. \[14\] These findings indicate that eFFQs can be a useful tool in assessing usual dietary intake of individuals. However, further research is needed to substantiate this in different population groups.

Advantages and utility of eFFQs: Comparison of paper and online FFQs have been done by four studies. \[14,36–38\] Three studies showed that the results of eFFQs were comparable to paper FFQs. \[14,36–38\] However, some advantages of eFFQs over their paper version were observed such as less missing data, ability to add features such as audio input and food images, automated data entry that omits the need of papers and data entry operators, hence reduced cost. \[14,37,38\] Certain other advantages of eFFQs also emerged from the reviewed studies. One important characteristic feature of eFFQs was that they ensure complete entry of data by not allowing the respondent to skip any questions i.e. each question must be complete before answering the next. \[18,24,33,34\] Also the web FFQs were readily available \[13\] and the respondents could...
complete them as per their convenience and location choice.\textsuperscript{[18]} Some eFFQs also had special features such as use of dual languages\textsuperscript{[18,23]} and audio narration (for prompts and reminders).\textsuperscript{[12]} The eFFQs also provided scope for adding digital food photographs to assist in portion size estimation.\textsuperscript{[12,14,15,17–20,22,28–32,34]} In terms of ‘ease of use’ also the eFFQs were found to be acceptable by the participants.\textsuperscript{[14,19,26,29]} In two studies, participants preferred eFFQ over paper FFQ\textsuperscript{[14]} and diet records.\textsuperscript{[19]} Certain qualities of eFFQs such as reduced cost and time, convenience in terms of location and time, ability to cover large sample without geographical limitations, automatic data coding and analysis, scope of adding different languages, prompts and reminders and audio-visual aids have also been highlighted in other reviews.\textsuperscript{[5,39]} High resource burden has always been a major barrier in precise assessment of diet and there is a need for valid and practical methods especially when the resources are limited. Hence, these advantages of eFFQ along with its ability to capture usual dietary intake and applicability among different age (both adolescents and adults) and population groups makes it an optimal choice for the purpose of nutrition assessment, monitoring and surveillance. It can be inferred from the findings of the current work and other reviews on technology assisted FFQs that eFFQs can be a promising tool in assessing trends in diet of individuals.

**CONCLUSION**

The use of technology in FFQs seems encouraging for nutritional epidemiological research and for nutrition monitoring and surveillance as it allows easier, accessible and more convenient administration; automatic data entry and analysis; addition of innovative features and can be used on diverse age groups and populations. Hence, more feasibility and validity studies on eFFQs should be conducted to strengthen the available evidence.

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**Conflict of Interest:** None

**REFERENCES**

Vidisha Sharma et al. Validation of Electronic Food Frequency Questionnaires as a Dietary Intake Assessment Method: A Review


