International Journal of Health Sciences and Research
www.ijhsr.org ISSN: 2249-9571

Review Article

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

Vidisha Sharma[1], Ravinder Chadha[2]

[1]PhD Scholar M.Sc. Food and Nutrition, [2]Associate Professor PhD,
Lady Irwin College, University of Delhi

Corresponding Author: Vidisha Sharma

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. [1] 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). [2] 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. [3–5] 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. [6] 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. [2,6,7] 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>
<tr><th>Author (year)</th><th>Sample Characteristics</th><th>eFFQ</th><th>Consumption Period covered</th><th>Nutrient</th><th>Food groups and items</th><th>Portion Size estimation method</th><th>Reference method</th><th colspan="2">Salient Results</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Nutrients</td><td>Food groups</td></tr>
<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>-</td><td>Correlation coefficient - All foods: r_s=0.38
Range: r_s=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><table><tr><td></td><td colspan="2">Correlation coefficient r (unadjusted)</td></tr><tr><td>Nutrients</td><td>FRs</td><td>24HDRs</td></tr><tr><td>Energy</td><td>0.39</td><td>0.18</td></tr><tr><td>Protein</td><td>0.40</td><td>0.33</td></tr><tr><td>CHO</td><td>0.44</td><td>0.24</td></tr><tr><td>Fat</td><td>0.37</td><td>0.15</td></tr><tr><td>Mean (energy and nutrients)</td><td>0.41</td><td>0.31</td></tr></table></td><td>-</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, Belgian–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 PS for amorphous foods</td><td>4 computerized 24HDRs (YANA-C)</td><td>Correlation coefficient (unadjusted): Energy: r=0.66 (p<0.001), Fat: r=0.62 (p<0.001).
All nutrients were significantly OE^{ed}(p≤0.001) by FFQ except calcium (p=0.059)</td><td>Correlation coefficient: ranged from r_s = -0.08 (other snacks) to 0.80 (Milk).</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 weighed foods)</td><td>Correlation coefficient (de-attenuated, sex and energy adjusted): Energy: r=0.58 (P≤0.0001), Protein: r=0.52 (P≤0.0001), CHO: r= 0.55(P≤0.0001), Fat: r=0.15.
No significant differences in macro nutrients (p>0.05).</td><td>-</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 macronutrient 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=39)</td><td>Correlation coefficient (crude):
Meal-Q: Range, r: 0.06 (Fat) to 0.54 (CHO)
Energy: r=0.16, Protein: r=0.22.
MiniMeal-Q: Range, r: 0.02 (Fat) to 0.54 (CHO). Energy: r=0.16, Protein: r=0.21.<hr>DLW: Energy UE^{ed} by both FFQs (p<0.001). Correlation coefficient: Meal-Q:r=0.42; MiniMeal-Q:r=0.38</td><td>-</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_s = 0.16 (riboflavin) to 0.66 (fiber)
MiniMeal-Q: r_s = 0.15 (riboflavin) to 0.65 (fiber)
All CCs were significant except riboflavin with MiniMeal-Q</td><td>-</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^{ed}. 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<.01).</td><td>Correlation coefficient range: r_s= 0.11 (soups, sauces and miscellaneous foods) to 0.73 (yogurts).</td></tr>
</table>

Table 1 to be Continued…

(Kristal et al. 2014)	n=74, 18 to 69 years, 40 men and 34 women, Columbus, 63.5% White ethnicity	GraFFS	One month	Energy, macronutrients and 17 micronutrients/ food components	156 food items	Food portion photographs	6 telephone administered 24-HDRs	GraFFS UE[ed] 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 Micronutrients: OE[ed]. r= 0.43 (Zinc) to 0.66 (β-carotene)	-
(Øverby et al. 2014)	n=93, 13-14 years, 53 girls, Norway	-	Past one month	Macro and micronutrients	131 food and beverage items, 156 questions	Standard PS (unit)	Relative validity: 2x24HDRs (n=93) Absolute validity: Fatty acids and 25-hydroxy-vitamin D3 in whole blood (n=92)	Correlation coefficient (unadjusted): all nutrients, r_s= 0.26 **Macronutrients:** Energy: r_s =0.33, p=0.001, Protein: r_s =0.42, p=0.000, CHO: $r_{s=}$ 0.41, p=0.000, Total fat: r_s =0.21, p=0.041 OE: Protein, UE: Energy and Fat **Micronutrients:** r_s =0.22 (vitamin-D) and 0.55 (calcium) **Absolute validity (biomarkers):** Significant correlation- n-3 fatty acids, EPA, DPA, and DHA	Correlation coefficient (median, all food groups) r_s =0.19 Range, r_s: 0.010 (sugar, sweets, and cakes) to 0.627 (dairy products)
(Du et al. 2015)	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	IDQC	Past 4 months	Macro and micronutrients (total 23 nutrients)	135 food items, 16 food categories	Food photographs	3-d Diet records	All nutrients significantly OE[ed] by IDQC (p<0.05). **Correlation coefficient**: All significant (p<0.05) Macronutrients: Energy: r=0.69, Protein: r=0.66, CHO: r=0.57 Micronutrients, r: ranged from 0.28 (vitamin-C) to 0.98 (Iodine).	Correlation coefficient (unadjusted) ranged from r=0.27 (oil) to 0.47 (grains) and significant for all food groups p<0.05. Significant OE (p<0.05) in fruits, meat, legumes and dairy.
(Tabacchi et al. 2015)	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]	ASSO-FFQ	Past one month	Macro and micronutrients	20 major food groups, 3 sections. Total 106 food items.	Food/beverage portion photographs and household units	7-d Weighed FRs	Significant difference nutrient intake (p<0.05 to p<0.001), except for Vitamin B12. Energy, protein, CHO and total fat intake OE[ed]. **Correlation coefficients:** Macronutrients, r_s: Energy: -0.04, Protein: -0.11, CHO:0.04, Fat:- 0.03 Micronutrients, r_s: ranged from – 0.01 (vitamin B6) to 0.27 (Vitamin- C).	Correlation coefficients, r_s ranged from 0.00 (Pasta/rice/couscous) to 0.61 (milk). 19 food groups out of 24 were significantly different (p<0.01 to p<0.001).
(Bentzen et al. 2016)	n=64, age range: 17-80 years, diabetes patients, Denmark	-	Past 3 months	Macro and micronutrients	270 food items and mixed dishes	Household measures and food photograph series	4-d pre-coded Food diary	All nutrients OE[ed] except SFA, alcohol, vitamin-D. Significant difference in mean intake of CHO (p=0.001) and dietary fibre (p=0.000). Correlation coefficients (all p<0.01)**:** Macronutrients, r_s: Energy: 0.50, Protein: 0.49, CHO: 0.51, Fat : 0.36 Micronutrients, r_s: Vitamin-D: 0.37 and calcium: 0.45	-
(Feng et al. 2016)	n=292, 18-65 years, 30.5% men, Chinese	IDQC	past 4 months	Macro and micronutrients	135 food items, 16 food categories	Food portion photographs	3-d Diet diaries	Correlation coefficient unadjusted (mean r=0.52, all p<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=0.53 Energy, protein, CHO (p<0.01) and total fat OE[ed] (p<0.05).	Correlation coefficients (all p<0.05) ranged from r=0.19 (sweets) to 0.61 (dairy products)
(Knudsen et al. 2016)	n=97, 20–42 years, women, Denmark	-	Previous year	Macro and micronutrients	220 foods and beverages	Food portion photographic series	4-d Food diary	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 Micronutrients, r: 0.08 (sodium) to 0.61 (magnesium)	Correlation coefficients ranged from r=0.17 (fats) to 0.61 (low fat dairy)

Table 1 to be Continued…

(Nybacka et al. 2016)	n=40, 50–64 years, (men = women=20), Swedish origin	Mini Meal-Q	Past few months	Energy, macronutrients and alcohol	75 to 126 food items	Food portion photographs and standard portion sizes	DLW	Mini Meal-Q UE[ed] energy intake (-2·3±3·6 MJ) ($p<0.001$). Correlation between Mini Meal-Q and TEE_{DLW} r=0·28 (non-significant).	-
(Delisle Nyström et al. 2017)	n=38, 3-6 years pre-school children, 22 boys and 16 girls	KidMeal-Q	Past few months	Macro and micronutrients	42-86 food items, drinks and dishes	Food portion photographs and standard portions	DLW and four 24HDRs (over phone)	Mean energy intake from KidMeal-Q (4670± 1430 kJ/24 h) statistically different ($p < 0.001$) from TEE_{DLW} (6070 ± 690 kJ/24 h). Significant difference ($p<0.01$) in fiber and calcium intake.	Correlation coefficient, r_s range: 0.102 (bakery products) to 0.603 (vegetables).

eFFQ- electronic food frequency questionnaire, r- Pearson correlation coefficient, r_s- 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[ed] – overestimated, OE- overestimation, UE- underestimation, UE[ed]- 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

Author (year)	Sample Characteristics	eFFQ	Consumption Period covered	Specific Nutrient(s)	Food groups and items	Portion Size estimation method	Reference method	Salient Results
(Heath et al. 2000)	n=49, women 19 - 31 y, Dunedin, New Zealand	Iron FFQ	Past one month	Dietary iron and its absorption modifiers	17 Food Groups, 206 food items (80 with a high iron content)	Common standard measures, 3-dimensional food models and cup size portions of dried beans	Weighed FRs (11 days) over one month	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_s: Iron – 0.29, non-heam Iron – 0.34, heam iron – 0.52 Absorption modifiers: ranged from 0.34 (vitamin-C) to 0.86 (coffee)
(Galante & Colli 2008)	n=30, 21 to 45 years, male (5) and female (25)	SFFQ	One month	Calcium and Iron	79 Food items	Photo book containing food (3 portions) and kitchenware images	4-d FRs in 2 consecutive months: total 8FRs	SFFQ OE[ed] 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 ($p<0.05$) **Iron –** SFFQ: 13.3±5.0 mg and 8FRs: 11.6±3.6. mg; r= 0.33 (not significant)
(Wong et al. 2008)	n=161, 11 to 18 years, 81 males and 80 females, 29% Asian, 36% Hispanic, and 35% non-Hispanic white, Utah (US)	-	Past one month	Calcium	80 Food items	Food portion photographs	2-d 24HDRs	Correlation coefficient (unadjusted) of calcium intake by the 2[nd] computerized FFQ and the mean of two 24-hour dietary recalls was r=0.42 ($p<0.001$).
(Hacker-Thompson et al. 2009)	n=140 women, mean age 49 ±15 years, 73% White ethnicity	Online calcium quiz	Previous day intake	Calcium	34 food items + calcium fortified foods section	Serving sizes	3-d Diet record	**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, $P<0.001$.

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)	**PUFA FFQ vs. Weighed FRs**: mean intake (g/d) Total n_3 PUFA – FFQ: 2.005±1.032 and FR: 1.700±0.956 (p=0.019) Total n_6 PUFA – FFQ: 10.13±2.99 and FR: 10.21±3.83 (p=0.884) **Method of triads analysis: validity coefficients (ρ)** **Erythrocytes Plasma** Total n_3 PUFA: 0.78 0.48 Total n_6 PUFA: 0.41 0.86
(Allaire et al. 2015)	n=60, mean age 60.3±6.9 years, men with prostate cancer, Canada	Web -FFQ	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	FA profiles of the RBC membranes	Correlation coefficient (age, BMI and energy adjusted), r_s :- Fatty acid intake and their respective proportions in the RBC membranes: Total ω-3: 0.540 (p<0.0001), EPA and DHA: 0.593 (p<0.0001), LC ω-3: 0.549 (p<0.0001). Fish and seafood servings and Fatty acid proportions in the RBC membranes: Total ω-3 with fresh fish (0.494) and sea food (0.472) (p<0.001).
(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 soy containing) and 8 food categories	Fixed PSs based on familiar measuring devices, e.g. cup, tablespoon, 12-fluid ounce can, and others.	Six 1-d photograph assisted FRs using mobile phones	WebFFQ OE^{ed} 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_s- Spearman correlation coefficient, FR- food records, 24HDR- 24 hour dietary recall, CCs- correlation coefficients, CHO- carbohydrate, OE^{ed} – overestimated, OE- overestimation, UE- underestimation, UE^{ed}- underestimated, 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 were 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 $p \leq 0.05$, 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 [15,18,28,29,34] 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_s = 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 total long chain omega-3 fatty acids (ρ=0.78; 0.73) on comparison with the levels in erythrocytes and plasma ($p < 0.05$). [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 ω-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 [15] and soups and sauces. [19] Higher correlation coefficients (≥0.60) were observed in case of milk, [17,23] dairy, [15,21,28] yogurt [19] 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 [19] 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. [18] Some eFFQs also had special features such as use of dual languages [18,23] and audio narration (for prompts and reminders). [12] The eFFQs also provided scope for adding digital food photographs to assist in portion size estimation. [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. [14,19,26,29] In two studies, participants preferred eFFQ over paper FFQ [14] and diet records. [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. [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.

ACKNOWLEDGEMENT

The corresponding author is in receipt of a Junior Research Fellowship from University Grants Commission, India.

Conflict of Interest: None

REFERENCES

1. Willett W. Overview of Nutritional Epidemiology. In: Willett W, editor. Nutritional Epidemiology. 3rd ed. New York: Oxford University Press; 2012. p. 1–16.
2. Gibson RS. Measuring Food Consumption of Individuals. In: Gibson RS, editor. Principles of Nutritional Assessment. Second. New York: Oxford University Press; 2005. p. 41–64.
3. Thompson FE, Subar AF, Loria CM, Reedy JL, Baranowski T. Need for Technological Innovation in Dietary Assessment. J Am Diet Assoc. 2010 Jan;110(1):48–51.
4. Long JD, Littlefield LA, Estep G, Martin H, Rogers TJ, Boswell C, et al. Evidence Review of Technology and Dietary Assessment. Worldviews Evidence-Based Nurs. 2010 Dec;7(4):191–204.
5. Illner A-K, Freisling H, Boeing H, Huybrechts I, Crispim S, Slimani N. Review and evaluation of innovative technologies for measuring diet in nutritional epidemiology. Int J Epidemiol. 2012 Aug;41(4):1187–203.
6. Willett W. Food Frequency methods. In: Willett W, editor. Nutritional Epidemiology. 3rd ed. New York: Oxford University Press; 2012. p. 70–95.
7. Pérez Rodrigo C, Aranceta J, Salvador G, Varela-Moreiras G. Food frequency questionnaires. Nutr Hosp. 2015 Feb 26;31(Suppl 3):49–56.
8. Margetts BM, Nelson M. Design Concepts in Nutritional Epidemiology. Margetts BM, Nelson M, editors. Oxford University Press; 1997.
9. Thompson FE, Kirkpatrick SI, Subar AF, Reedy J, Schap TE, Wilson MM, et al. The National Cancer Institute's Dietary Assessment Primer: A Resource for Diet Research. J Acad Nutr Diet. 2015 Dec;115(12):1986–95.
10. Willett W, Lenart E. Reproducibility and validity of food frequency questionnaires. In: Willett W, editor. Nutritional

Epidemiology. 3rd ed. New York: Oxford University Press; 2012. p. 96–141.
11. Heath A-LM, Skeaff CM, Gibson RS. The relative validity of a computerized food frequency questionnaire for estimating intake of dietary iron and its absorption modifiers. Eur J Clin Nutr. 2000 Jul;54(7):592–9.
12. Wong SS, Boushey CJ, Novotny R, Gustafson DR. Evaluation of a Computerized Food Frequency Questionnaire to Estimate Calcium Intake of Asian, Hispanic, and Non-Hispanic White Youth. J Am Diet Assoc. 2008 Mar;108(3):539–43.
13. Hacker-Thompson A, Robertson TP, Sellmeyer DE. Validation of Two Food Frequency Questionnaires for Dietary Calcium Assessment. J Am Diet Assoc. 2009 Jul;109(7):1237–40.
14. Beasley JM, Davis A, Riley WT. Evaluation of a web-based, pictorial diet history questionnaire. Public Health Nutr. 2009 May 12;12(5):651–9.
15. Knudsen VK, Hatch EE, Cueto H, Tucker KL, Wise L, Christensen T, et al. Relative validity of a semi-quantitative, web-based FFQ used in the "Snart Forældre" cohort – a Danish study of diet and fertility. Public Health Nutr. 2016 Apr 3;19(6):1027–34.
16. Matthys C, Pynaert I, De Keyzer W, De Henauw S. Validity and Reproducibility of an Adolescent Web-Based Food Frequency Questionnaire. J Am Diet Assoc. 2007 Apr;107(4):605–10.
17. Vereecken CA, De Bourdeaudhuij I, Maes L. The HELENA online food frequency questionnaire: reproducibility and comparison with four 24-h recalls in Belgian–Flemish adolescents. Eur J Clin Nutr. 2010 May 10;64(5):541–8.
18. Labonté M-È, Cyr A, Baril-Gravel L, Royer M-M, Lamarche B. Validity and reproducibility of a web-based, self-administered food frequency questionnaire. Eur J Clin Nutr. 2012 Feb 21;66(2):166–73.
19. Fallaize R, Forster H, Macready AL, Walsh MC, Mathers JC, Brennan L, et al. Online dietary intake estimation: reproducibility and validity of the Food4Me food frequency questionnaire against a 4-day weighed food record. J Med Internet Res. 2014 Aug 11;16(8):e190.
20. Kristal AR, Kolar AS, Fisher JL, Plascak JJ, Stumbo PJ, Weiss R, et al. Evaluation of Web-Based, Self-Administered, Graphical Food Frequency Questionnaire. J Acad Nutr Diet. 2014 Apr;114(4):613–21.
21. Øverby NC, Johannesen E, Jensen G, Skjaevesland A-K, Haugen M. Test–retest reliability and validity of a web-based food-frequency questionnaire for adolescents aged 13–14 to be used in the Norwegian Mother and Child Cohort Study (MoBa). Food Nutr Res. 2014 Jan 19;58(1):23956.
22. Allaire J, Moreel X, Labonté M-È, Léger C, Caron A, Julien P, et al. Validation of the omega-3 fatty acid intake measured by a web-based food frequency questionnaire against omega-3 fatty acids in red blood cells in men with prostate cancer. Eur J Clin Nutr. 2015 Sep 11;69(9):1004–8.
23. Tabacchi G, Filippi AR, Breda J, Censi L, Amodio E, Napoli G, et al. Comparative validity of the ASSO-Food Frequency Questionnaire for the web-based assessment of food and nutrients intake in adolescents. Food Nutr Res. 2015;59:26216.
24. Segovia-Siapco G, Oda K, Sabaté J. Evaluation of the relative validity of a Web-based food frequency questionnaire used to assess Soy Isoflavones and nutrient intake in adolescents. BMC Nutr. 2016;2.
25. Galante AP, Colli C. Development and use of an on-line semi-quantitative food-frequency questionnaire to evaluate calcium and iron intake. Rev Bras Epidemiol. 2008;11(113):1–9.
26. Swierk M, Williams PG, Wilcox J, Russell KG, Meyer BJ. Validation of an Australian electronic food frequency questionnaire to measure polyunsaturated fatty acid intake. Nutrition. 2011 Jun;27(6):641–6.
27. Du S-S, Jiang Y-S, Chen Y, Li Z, Zhang Y-F, Sun C-H, et al. Development and Applicability of an Internet-Based Diet and Lifestyle Questionnaire for College Students in China. Medicine (Baltimore). 2015 Dec;94(49):e2130.
28. Feng R-N, Du S-S, Chen Y, Li Z, Zhang Y-F, Sun C-H, et al. An internet-based food frequency questionnaire for a large Chinese population. Asia Pac J Clin Nutr. 2016 Dec;25(4):841–8.
29. Christensen SE, Möller E, Bonn SE, Ploner A, Wright A, Sjölander A, et al. Two new meal- and web-based interactive food frequency questionnaires: validation of energy and macronutrient intake. J Med Internet Res. 2013 Jun 5;15(6):e109.

30. Christensen SE, Möller E, Bonn SE, Ploner A, Bälter O, Lissner L, et al. Relative Validity of Micronutrient and Fiber Intake Assessed With Two New Interactive Meal- and Web-Based Food Frequency Questionnaires. J Med Internet Res. 2014 Feb 21;16(2):e59.
31. Nybacka S, Bertéus Forslund H, Wirfält E, Larsson I, Ericson U, Warensjö Lemming E, et al. Comparison of a web-based food record tool and a food-frequency questionnaire and objective validation using the doubly labelled water technique in a Swedish middle-aged population. J Nutr Sci. 2016;5:e39.
32. Delisle Nyström C, Henriksson H, Alexandrou C, Bergström A, Bonn S, Bälter K, et al. Validation of an Online Food Frequency Questionnaire against Doubly Labelled Water and 24 h Dietary Recalls in Pre-School Children. Nutrients. 2017 Jan 13;9(1):66.
33. Bentzen SMR, Knudsen VK, Christiensen T, Ewers B. Relative validity of a web-based food frequency questionnaire for patients with type 1 and type 2 diabetes in Denmark. Nutr Diabetes. 2016 Sep 26;6(9):e232.
34. Du S-S, Jiang Y-S, Chen Y, Li Z, Zhang Y-F, Sun C-H, et al. Development and Applicability of an Internet-Based Diet and Lifestyle Questionnaire for College Students in China: A Cross-Sectional Study. Medicine (Baltimore). 2015 Dec;94(49):e2130.
35. Lombard MJ, Steyn NP, Charlton KE, Senekal M. Application and interpretation of multiple statistical tests to evaluate validity of dietary intake assessment methods. Nutr J. 2015 Dec 22;14(1):40.
36. Boeckner LS, Pullen CH, Walker SN, Abbott GWA, Block T. Use and reliability of the World Wide Web version of the Block Health Habits and History Questionnaire with older rural women. J Nutr Educ Behav. 34 Suppl 1:S20-4.
37. Kilanowski JF, Trapl ES, Kofron RM. Audio-Enhanced Tablet Computers to Assess Children's Food Frequency From Migrant Farmworker Mothers. Infant Child Adolesc Nutr. 2013 Jun 1;5(3):163–9.
38. Lo Siou G, Csizmadi I, Boucher B, Akawung A, Whelan H, Sharma M, et al. The Comparative Reliability and Feasibility of the Past-Year Canadian Diet History Questionnaire II: Comparison of the Paper and Web Versions. Nutrients. 2017 Feb 13;9(2):133.
39. García-Segovia P, González-Carrascosa R, Martínez-Monzó J, Ngo J, Serra-Majem L. New technologies applied to food frequency questionnaires: a current perspective. Nutr Hosp. 2011;26(4):803–6.

How to cite this article: Sharma V, Chadha R. Validation of electronic food frequency questionnaires as a dietary intake assessment method: A review. Int J Health Sci Res. 2017; 7(9):291-301.

****