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Effectiveness of food portion size estimation aids for diet assessment: A systematic review

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Abstract

Background: Accuracy in food portion size (PS) estimates is fundamental in diet assessment methods. Information concerning the validity and efficacy of food PS estimation aids (PSEAs) is essential to enhance accuracy of dietary intake data.

Objectives: This review explored the validity and effectiveness of various PSEAs assessed among adult participants.

Methods: Potentially eligible original research articles (adult participants, full text in English language and comparing PSEAs against a valid reference method) were identified through a systematic search of seven databases (Cochrane Library, PubMed, Science Direct, Scopus, Web of Science, WHO Virtual Health Library and Wiley Online Library) from January, 2005 - September, 2016.

Results: A total of 1355 records were obtained through initial search, of which 27 were included in qualitative synthesis. Three categories of PSEAs were identified: 2-dimensional, 3-dimensional, and technological aids. Two dimensional aids (n=9) were the most often evaluated PSEA followed by technological aids (n=8). Aspects like type of food item, its shape and food PS (small vs. large) were recognized as influencers of PS estimates. Training improved the PS estimation accuracy.

Conclusions: Various PSEAs and factors influencing their efficacy were emphasized in this review. Use of food photographs, technological aids, and training of individuals appears to be promising in enhancing accuracy of dietary intake data.

Keywords: food portion size, food portion size estimation, portion size estimation aids, diet assessment, adult, dietary intake

Introduction

Accurate dietary intake assessment is crucial for planning and monitoring diet counselling, nutrition strategies and their evaluation. Various methods such as single or multiple 24-hour dietary recalls, weighed or estimated diet records, diet history, and food frequency questionnaires have been used to assess dietary intakes [1]. However, each of these methods presents certain challenges in determining food intake especially accurate portion size (PS) estimation as reliance is on participant's memory [2, 3]. Biomarkers and weighed food records are traditional 'Gold Standard' dietary assessment methods. However, these methods are time consuming, invasive, cumbersome for respondents and expensive to implement. Reduction of participant burden and attrition rates while preserving data precision remains a prominent challenge. Use of portion size estimation aids (PSEAs) to assist participants in reporting food intake seems encouraging [4, 6]. Use of PSEAs is the necessity of every dietary assessment method. The need to provide information to nutrition researchers regarding the validity of PSEAs and their effectiveness must be addressed. Therefore, the role of PSEAs in dietary assessment requires more attention.

The aim of this article is to review the various PSEAs developed, their validation and effectiveness. This review addressed the following questions:

1. Which types of PSEAs and tools have been reported in research studies?
2. What is the reported effectiveness of these PSEAs?

Methods

Operational definitions

Food portion size- The quantity of a food served or consumed per eating occasion including the successive helpings and minus the leftovers. It is not a consistent amount and varies among individuals [7, 9].

Portion size estimation aids- Aids/tools that facilitate or improve individual's ability to correctly estimate the quantity of food servings. These are the instruments that assist in food amount evaluation among individuals.

Validation studies, related to PSEAs, usually intend to measure inaccuracy related to PS estimation and food and nutrient intake in individuals.[9] Biomarkers and weighed food records have been identified as the most accepted reference methods.[10] For this review, studies assessing the validity of PSEAs against any one of these two methods have been included.

Literature Information Sources and Search Strategy

Seven electronic databases were searched during October, 2016 (figure-1) using the following keywords: 'food portion size', 'dietary assessment', 'validation', 'portion size estimation aids', 'photographs' and 'food models'. Search limiters for publication year, type of participants, language, and type of search results (research article, book review, conference proceedings, and abstracts etc.) were applied wherever options were available. All search results were saved and imported into reference manager for study selection.

Inclusion and Exclusion Criteria

Inclusion criteria: (a) *Population/participants*: adult participants of all income groups, sex, ethnicity, and country; (b) *Intervention*: all studies assessing aids/tools for PS estimation among adults; (c) *Comparison*: comparison of PSEAs against a valid reference method (biomarkers and/or weighed food records/amounts); (d) *Outcomes*: Primary outcome: effectiveness of PSEAs/tools in facilitating PS recall and/or estimation among adults. Secondary outcome: factors affecting applicability and usage of PSEAs in terms of participant and researcher effort, level of literacy required, texture of food items etc.; (e) Original research articles providing results in sufficient detail; (f) Full text articles in English language from peer-reviewed journals; and (g) Publication date: January, 2005 till September, 2016.

Exclusion criteria: Articles comparing PSEAs/tools against methods other than biomarkers and/or weighed food records/amounts, not reporting results on necessary aspects (e.g. conference proceedings, only qualitative data, insufficient estimation error results) and for which full text was not available were excluded.

Study Selection

All database search results were screened for duplicate records, titles, and abstracts to identify potentially eligible articles. Irrelevant articles were removed and the reasons for their exclusion were noted. The full text articles were then selected and evaluated as per the pre-defined eligibility criteria. The article search and inclusion process are presented in the form of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart (figure-1) [11].

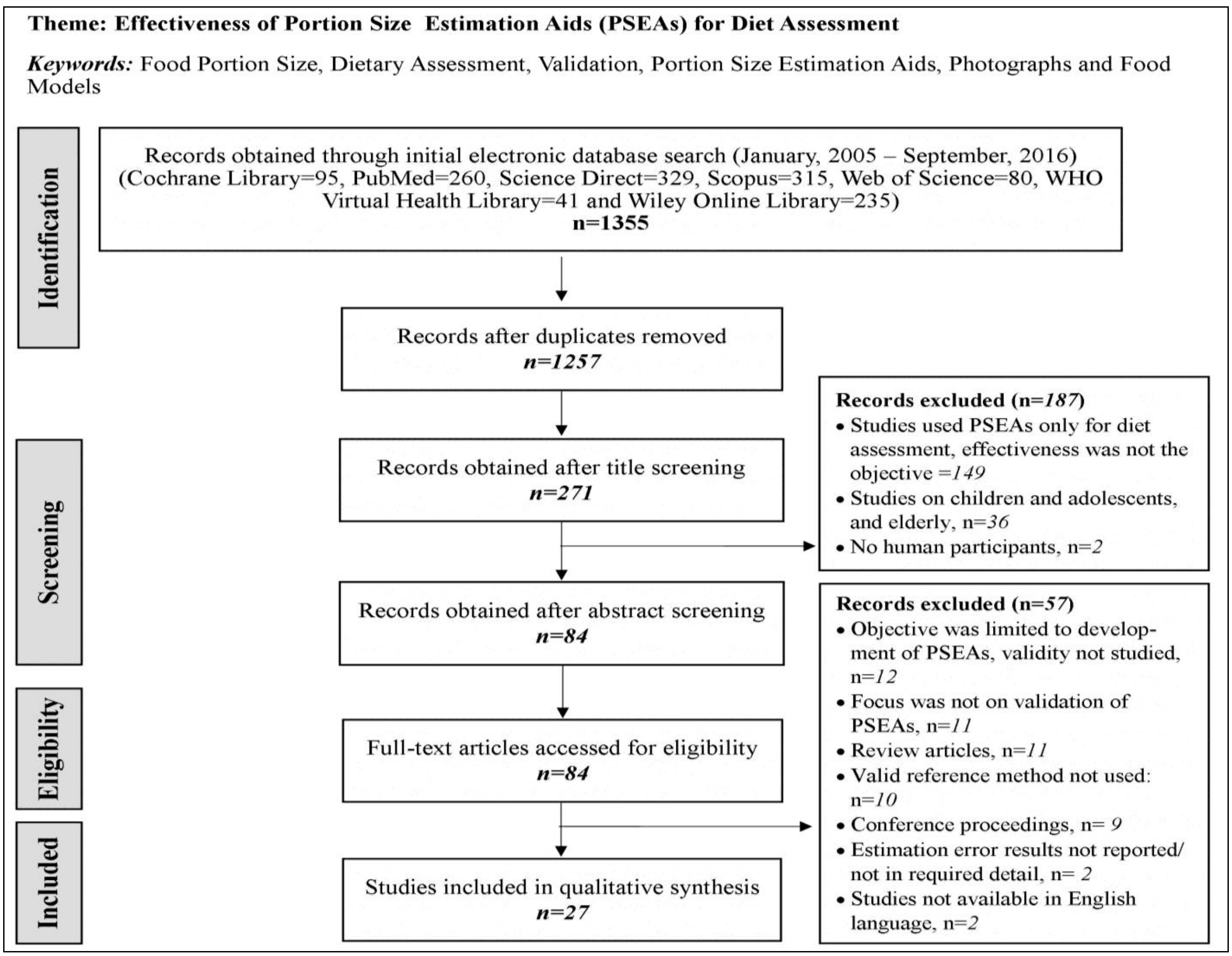

Fig 1: Flow chart of database search and inclusion process of research articles for the systematic reviews

Data Extraction

All data were entered in the form of a matrix (table-1 and 2) for evaluation and qualitative analysis as follows: author, publication year, sample characteristics, PSEAs used, reference method for validation, and salient results.

Table 1: Studies assessing 2-D, 3-D, and more than one type of aid

Author	Sample	Type of PSEA	Test Method	Reference method	Salient Results
2D-PSEAs					
Turconi *et al.* 2005 [12]	n=448, 247 males and 201 females, 6–60 years (Pavia, Italy)	FPs	PS estimates (on spot, 5-10 min after meal)	Weighed food preparations	▪ Estimated vs. actual portions significantly associated (P<0.05). ▪ Estimated vs. actual portions significantly associated for food categories: main courses (r=0.81), vegetables (r=0.76), bread (r=0.82) and beverages (r=0.82).
Huybregts *et al.* 2008 [13]	n=257, women, 15–45 years (rural, West Africa)	FPs	PS estimates (recall)	Pre-weighed foods	▪ % difference (estimated vs. actual) ranged from -8.4% to +6.3%. Significant impact of PS served (small vs. largest sizes) on estimation ability (p<0.001).
Ovaskainen *et al.* 2008 [14]	n=161 (complete data: n=146) 25-65 years, male (n=45) and female (n=101); Turku, Finland	FPs	PS estimates (on spot)	Pre-weighed foods	▪ Estimation error (g): -32 to +16 (men) and -18 to +22 (women).Correct estimation associated with smallest PS than larger (P<0.001).
De Keyzer *et al.* 2011 [15]	n= 111, male (49) and female (62), 45–65 years (Belgium)	2-D models (drawings and photographs)	PS estimates recall: short term (2 days) and long term (4 days)	Pre-weighed meal	▪ Estimation errors (short- and long-term recalls) not significantly different. CCs (estimated vs. actual): 0.42 to 0.75 and significant (p<0.01) for all foods.
Tueni *et al.* 2012 [16]	Study-1: n=40 (male =female=20) and study-2: n=50 (male=female=25), 21-62 years (Lebanese)	FPs	PS estimates Study-1: On spot Study-2: Recall	Pre-weighed foods 1. Presented PSs 2. Previous day's meal PS	▪ Mean differences (estimated vs. actual PSs): On-spot: -13.1% to +24.5% Recall: -10.4% to +3.8%.
Zainal Badari *et al.* 2015 [17]	n=15, male (93.3 %) and female, mean age 43.7±8.2 years (Malaysia)	FPs	24HR (one day)	Weighed Food Record (one day)	▪ % difference (estimated vs. actual): -10.7% to +5.3%. CCs: -0.623 to 1.00. ▪ Nutrients: No significant difference (p≥0.05)
Amougou et al. 2016[18]	n=361, women (193) and men (168), 14 to 84 years (Cameroon, Central Africa)	FPs	24HR	Weighed food amounts	▪ Correct estimates: 77% by adults, significantly higher for solid foods than amorphous (P≤0·05). ▪ Amorphous foods: Equally OE[ed] and UE[ed]. Solid foods: more OE[ed] than UE[ed] (P≤0·05). ▪ Smaller PSs OE[ed] (P≤0.05).
Harris-Fry *et al.* 2016 [19]	n=95, mean age= 36 years, 76% females (Rural area, Southern Nepal)	FPs	PS estimates (recall)	Weighed meal (single)	▪ % difference range (estimated vs. actual): -34.5 to +40. ▪ Overall, PSs (mean error= -4.5%) and nutrients (energy, protein and iron) were UE[ed]. ▪ CC between energy intakes (estimated and actual) was 0·446 (P<0·001).
Subasinghe *et al.* 2016[20]	n=45 adults (53% men), 19-85 years (South India)	FPs	24HR (single meal)	Weighed meal (single)	▪ UE in carbohydrate intake (~4%). ▪ CCs: 0.19-0.67 (P<0.001).
3D-PSEAs					
Gibson *et al.* 2016[21]	n=67, male=20 and female=47, aged 19-77 years (Sydney)	finger width method, fists and thumb or finger tips	PS estimates (on spot)	Pre-weighed foods, Household measures and size estimates (small, medium and large)	▪ Estimates within ±10 %: 13% for finger width method and 8% for household method. ▪ Geometrically shaped foods more accurately estimated using finger width method.
More than one type of aid					
Godwin *et al.* 2006[22]	n=320, male and female 18-65 years (US)	Ruler, adjustable wedge	PS estimates (on spot)	Food items with measured dimensions	▪ Adjustable wedge more accurate than ruler (P<0.05) in 1/3rd of comparisons. ▪ Food profile (height, thickness and orientation) influenced estimation ability.
Hernández *et al.* 2006[23]	n=101, male and female (ethnicity: Caucasian, African–American and other), mean age 33 and 41 years (2 study sites)	Computer and poster based photographs of food portions	PS estimates (on spot and short-term recall)	Pre-weighed foods	▪ Real time testing: mean relative % error was 4.8±1.8% (solids: 8.3±2.3%, amorphous: -10±2.7% and liquids: 19±5%). ▪ Mean error (real-time test): 5.2% for computer FPs and 67.1% for posters 67.1%.

Lazarte *et al.* 2012 [24]	n= 45, Women, 20–52 years (rural area, Bolivia)	Digital FPs (meals) and food photographic atlas	24HR (one day) with digital FPs	Weighed food record (one day)	▪ Mean % difference (estimated vs. actual): -0.90% (vitamin-C) to -5.98% (total fat). All nutrients were UE[ed]. ▪ CCs ranged from 0.96-0.99 (nutrients) and 0.75-0.98 (food groups).
Faulkner *et al.* 2016 [25]	n=120, 61 males and 59 females, 18-64 years (Ireland)	Quantities and measures, reference objects, FPs and food packet indicators	SS estimates (on spot)	Pre-weighed foods	▪ Most accurate PSEA: Quantities and measures > household measures > FPs. ▪ Household measures most useful for amorphous grain foods.

PSEA: portion size estimation aid, PS: portion size, SS: serving size, UE: under-estimation, OE: over-estimation, UE[ed]: Underestimated, OE[ed]: Overestimated, 2-D: 2-dimentional, 3-D: 3-dimensional, FP: Food photograph, IPSAS: Interactive portion size assessment system, SD: standard deviation, CC: Correlation coefficient, 24HR: 24-hour recall, DLW: Doubly labelled water

Table 2: Studies assessing technological portion size estimation aids

Author	Sample	Type of PSEA	Test Method	Reference method	Salient Results
Fukuo *et al.* 2009 [26]	n=60; Japanese patients n=44 without diabetes, mean age 23 years and n=16, type 2 diabetes, mean age 53 years	PDA (with reference database of 423 FPs)	PDA-based food diary (7 days)	24 HR (7th day PDA data vs. recall of 8th day)	▪ No significant difference between two methods in macronutrient intake. ▪ CCs: Non-diabetic group; r=0.715 (carbohydrate) to 0.854 (energy) and diabetic group; r= 0.733 (protein) to 0.846 (carbohydrate).
Martin *et al.* 2009 [27]	n=50, male (23) and female (27), 18–54 years (70% Caucasians, African-American 30%)	RFPM	RFPM (3 days)	Weighed food records (3 days)	▪ High correlation between estimated and actual energy intakes (r =0·93; P<0·0001). ▪ Energy intake UE[ed.]
Subar *et al.* 2010 [28]	Study-1:n=29, Study-2: n=20 male and female, 18-69 years (50% Non-White)	Digital FPs	PS estimates (recall)	Weighed food servings (2 meals)	▪ No significant difference but better accuracy observed with simultaneous presentation vs. sequential and 8 vs. 4 FPs especially for amorphous/soft foods and small pieces.
Jia *et al.* 2014 [29]	n=7, males (5) and females (2), 27–37 years (US)	Digital FPs from ebutton	Computer based volume estimation (lunch only)	Actual food volume (seed displacement method) and Visual estimation	▪ Mean relative error from ebutton pictures was -2.8% (SD 20.4%).
Nørnberg *et al.* 2014 [30]	n=58, University students, 20–29 years (Copenhagen)	Intelligent buffet	PS estimates (on spot)	Weighed amount through Intelligent buffet	▪ Significant difference (estimated vs. actual) was observed for vegetables and whole grains (P < 0.001). ▪ No significant correlation between self-estimated and actual weights (P > 0.05).
Gemming *et al.* 2015 [31]	n=40, male=female (20), 18–64 years (New Zealand)	Digital FPs from SenseCam (SC)	Wearable camera-assisted 24 HR+ SC	24HR (3 days) and DLW	▪ Total energy expenditure was UE[ed]. ▪ Lower UEs by Wearable camera SC than 24HR alone (p<0.001).
Ptomey *et al.* 2015 [32]	n=91, overweight and obese, 18-30 years; Non-Hispanic and white (86%)	Digital FPs	Digital photography + recall method	DLW	▪ No significant difference in energy intakes (p=0.42). ▪ OE in energy intake by digital FPs (63±750 kcal/day).
Naska *et al.* 2016 [33]	n=59, 18- 64 years (Greece)	Digital FPs	PS estimates (on spot)	Pre-weighed food items	▪ Mean differences (selected vs. actual picture number, out of a total of 6 pictures for each food):-0.20±0.89 among young adults (18-24 years) and -0.18±0.91among older adults (35-64 years). ▪ OE of small and UE of large portions were observed.

PSEA: Portion size estimation aid, UE: Under-estimation, OE: Over-estimation, PS: Portion size, SD: Standard deviation, 24HR: 24-hour recall, FP: Food photograph, PDA: Personal digital assistant, DLW: Doubly labelled water, RFPM: Remote food photography method, CC: Correlation coefficient

Results

Search results

A total of 1355 records were obtained through initial database search (n=7) which were subjected to duplicates removal (n=1257), title (n=271), and abstract screening (n=84). After screening records as per the pre-decided inclusion and exclusion criteria, full text articles were assessed for eligibility (n=84) and a total of 27 original research articles were included in qualitative synthesis.

Study characteristics

The final studies were categorized according to sample characteristics, type of PSEA, test method, reference method, and salient findings. Five categories were obtained: 2-dimensional (2-D) aids (n=9), 3-dimensional (3-D) aids (n=1), studies comparing more than one type of aid (n=4), technological aids (n=8), and training programs on food PS estimation (n=5). A brief description of various PSEAs and training methods assessed in the studies is given in figure-2.

PSEA	**Description**
Quantities and measures	Household measures, weights and measures (gram/ml/Oz) or size descriptors of portions (small, medium and large)
FPs	Printed photographs (black and white or coloured) showing different food PSs, either stand alone or in the form of an atlas.
Digital FPs	Set of digital FPs showing different food portion sizes or photographs, taken digitally, of actual quantity of food consumed and leftovers.
2-D drawings	Diagrams or charts of measuring utensils (e.g. bowls, cups, glasses, spoons), reference objects (e.g. tennis and golf balls), size grid etc.
Measuring or household utensils	Cups, spoons, bowls, glasses etc.
Finger width method (3-D)	Use of hands and fingers for PS estimation. Width or stacks of different number of fingers is used to measure the dimensions of geometrically shaped foods and liquids in geometric packaging.
Adjustable wedge	Consists of concentric circles with movable arm attached to its center that can extend to the outermost circle to assess PS of wedged shaped foods.
Intelligent buffet	Buffet which is able to record the exact amount of food self-served by an individual.
Remote food photography method	Estimation of PSs from digital photographs of meal consumed taken with a camera-enabled cell phone.
Personal digital assistant	A hand-held electronic device for recoding dietary intake with a colour display, touch panel with pen input and a reference database of 423 coloured FPs for recording food intake
Training Approach	
Stimulus equivalence paradigm	Demonstration of associations between various PSEAs and corresponding PSs followed by a period during which similar associations may happen without training or reinforcement.
HMR calorie system	Consists of 7 pages with each page representing a food group, a scale containing anchor points or reference foods and energy content per serving (cups, tablespoons or ounces). The lower energy foods on the left of the scale and higher energy foods on the right of the scale.
PACE	Consists of pictures of foods with anchor points, portion size and energy content.

PSEA: Portion size estimation aid, PS: Portion size, FP: Food photograph, 2-D: 2-dimensional, 3-D: 3-dimensional, HMR: Health management and resources, PACE: Photographic assessment of calorie estimation

Fig 2: Portions Size Estimation Aids and Training methods assessed in the reviewed studies

2-D Portion size estimation aids

Food Photographs were the most commonly assessed 2-D PSEA (n=8) followed by 2-D models (n=1). Both underestimations (UEs) and overestimations (OEs) in PS estimation were observed but overall UEs were more frequently reported. The percentage error (estimated vs. actual PS) on average ranged from -35% to +175%. In terms of food items, UE was observed in cereals, pulses, and mixed dishes while OE was observed in butter and margarine, spreads, leafy vegetables, and flesh foods (chicken, fish, and meat). Generally, correlation coefficients between estimated and actual amounts ranged from moderate to good (r $\geq$0.40). Nutrient analysis was performed by three studies and generally satisfactory agreement between estimated and actual intakes was observed [17, 19, 20]. Overall, underestimated (UE^{ed}) nutrients were energy, protein, carbohydrate, vitamin-C, and iron whereas overestimated (OE^{ed}) nutrients were fat and fatty acids.

3-D Portion size estimation aids

Only one study tested solely 3-D aids on adults which found the finger width method as a good way to estimate PS of geometrically shaped foods and liquids. Most accurate estimates (i.e. within ±25% of actual PS) were obtained through finger width method for 80% of the PSs compared to 29% with the household measures [21].

Studies involving more than one type of PSEA

In this category (n=4), two studies compared 2-D and technological aids, one study compared 2-D and 3-D aid and one study compared 2-D, 3-D, and descriptors. Estimation errors were observed for ruler [22] and FPs [23, 25]. Use of 2-D aids was also linked with perception problems [23, 25]. Food item's shape, thickness and amorphous nature affected the efficacy of PSEAs [23, 25].

Technological PSEAs

Seven studies used digital FPs in PS estimation (table-2).

Overall, no significant differences were observed between the test method and reference method. However, in some studies differences were observed such as UE [27, 31] and OE in energy intake [32] and also differences in estimated and actual intake of vegetables and whole grains [30] and soups, sauces and potato [33]. One study observed that use of simultaneous presentation and eight vs. four digital FPs led to accurate PS estimation.[28] However, no significant differences in estimations were reported with photograph size. Technological aids were found to be helpful in reducing respondent burden [27, 29].

Effect of training

Improvement in PS estimation accuracy after training was observed in four studies [34, 37] out of five. In one study a shift from UE to OE was observed post-training [38]. Also, one study indicated difficulty in PS estimation of amorphous foods and observed that training can reduce errors [34]. Computer based PS estimation training was used in three studies [34, 35, 38]. Stimulus based paradigm approach assessed in two studies was found to be effective in improving PS estimates [36, 37]. Group training was observed to be better than individual training [34].

Discussion

This systematic review was conducted to examine the various PSEAs developed for diet assessment and their effectiveness. FPs (printed and digital) emerged as the most commonly investigated 2-D PSEA (~50% studies). This may be because it is easier to adapt them culturally, specific to food items and PSs consumed. Also, these are convenient and can also be used for low literacy population [20]. Hence, despite estimation errors observed, FPs were recommended provided the number and range of food items depicted represent the actual diet of that population [12, 14, 16, 19, 20]. Results also indicated that the use of technological aids especially digital FPs can help in reducing the respondent burden while providing relatively accurate data [26, 27]. Also, these were observed to be effective as they were less invasive, do not interrupt usual eating surroundings and excluded memory bias where actual food intakes (consumed and/or leftovers) were captured and estimated directly from FPs [27, 29]. Also, when combined with 24-hour recall, digital photographs of foods consumed facilitated PS estimation process [24, 31].

Two studies compared on-spot estimates with recalled estimates of PSs and found no significant difference [15, 23]. Effect of gender on PS estimation ability was reported by two studies and both UE [14] and OE [15] of PS by males was reported. According to food type, OE was observed in food items consumed in small quantities (spreads, sauces, and butter/margarine) and UE in main course items (cereals, starchy items, pulse, and mixed dishes). Also, difficulty in PS estimation of amorphous foods (e.g. sauces, leguminous foods, chips, cheese cubes, mayonnaise etc.) was observed compared to non-amorphous foods[18, 23, 34]. A combination of PSEAs may be more useful for improvement of accuracy. However, some studies demonstrated that these errors can be reduced by training of individuals on PS estimation using PSEAs [34, 37].

Conclusions

This review highlights various PSEAs validated and their reported effectiveness. 2D-PSEAs were most commonly assessed especially FPs. Use of technological aids appeared to be an up-coming and advantageous approach specifically in reducing respondent burden while preserving satisfactory accuracy in food PS estimates. Food type, shape and its amount consumed emerged as major factors affecting the PS estimation. A combination of PSEAs may be more useful for improvement of accuracy. Hence, it can be concluded that use of appropriate PSEAs with training results in improved PS estimates.

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