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Accuracy of a PDA-based dietary assessment program

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Abstract

Objective: Study objectives were to assess the accuracy of a food record delivered on a personal digital assistant (PDA) and to examine sources of error from the PDA-based food record.

Methods: Thirty-nine adults recruited with a newspaper advertisement were trained to record food intake using DietMatePro, a dietary assessment program delivered on a PDA. After 3 d of use, subjects returned for a follow-up visit in which a 24-h recall was conducted. Subjects also were timed while recording an observed, weighed lunch. Recalled and actual food intakes were compared with estimates recorded by the subjects when using the PDA. Paired sample t tests and Pearson's correlations assessed means and measurements of association between DietMatePro data compared with the 24-h recall data and observed meal data. Bland-Altman plots were used to assess bias in food recording. Sources of error were quantified by using calories as the unit for comparison.

Results: There were no significant differences in daily totals for calories and macronutrients between DietMatePro data and comparison measurements. Pearson's correlations of associations between DietMatePro data and the comparison measurement ranged from 0.505 to 0.797 ($P < 0.005$, $n = 28$) for the 24-h recall and from 0.419 to 0.786 ($P < 0.005$, $n = 33$) for the observed lunch, depending on the nutrient measured. The largest source of absolute error in caloric estimation was attributable to portion size estimation error (49%).

Conclusions: DietMatePro, a PDA-based dietary assessment program, provides a method of assessing energy and macronutrient intakes comparable to the 24-h recall in samples lacking dietary restrictions.

Keywords: Nutritional assessment; Diet record; Personal digital assistant computer

Introduction

Several methods for dietary assessment are currently used in clinical and research practice, including food records, 24-h recalls, food frequency questionnaires, and biochemical markers [1,2]. Each of these approaches has inherent strengths and weaknesses, and multiple assessment tools that have independent sources of error are often used within a study to validate findings.

Food records remain one of the more common assessment measurements because they are based on actual rather than on relative food intake, do not rely on recall, are open-ended, and have a high level of specificity [3]. Nonetheless, use of food records requires literacy, a high level of subject motivation, coding of intake by researchers, and the understanding that self-monitoring can influence intake. Accuracy of reports is another concern because sources of error include failing to report all foods eaten, mistakes in food portion estimation, or incorrectly describing a food eaten [4].

Technology has the potential to improve accuracy and efficiency of dietary assessment methods and interventions. Research studies that integrate technology potentially provide enhanced ability to update and maintain scientific knowledge, improve consistency in procedures across users, tailor information to specific users, and increase access to information [5]. Computerized systems such as NDS-R (Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN, USA), the U.S. Department of Agriculture (USDA) five-step multiple-pass method [6], automating 24-h recalls, and the Nutrition Evaluation Scale System, a computerized food-scale system that provides a means to

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track weighed food intakes [7], have the potential to improve the consistency and accuracy of dietary recalls.

The primary purpose of the present study was to evaluate the validity of DietMatePro, a research tool designed to automate the food record. The DietMatePro program is an integrated Web and personal digital assistant (PDA) application that provides dietary professionals with the ability to set up the program to monitor dietary intake or to provide nutrient feedback compared with predefined dietary targets. The resulting dietary information recorded is uploaded to a database and is immediately available for analysis.

The most recent version of the USDA Standard Release nutrient database serves as the foundation for the program, with the option to expand the food list to include brand foods and fast foods. To accommodate the rapidly changing food supply, DietMatePro users can add foods to their personal food database by using the food label for nutritional information.

Methods and materials

General experimental design

After providing written informed consent, subjects completed a questionnaire that collected information related to demographics, history of food recording, and computer use. A research assistant measured the subject's weight using a triple-beam balance scale and oriented the subject to the DietMatePro program, instructing the subject to record all foods consumed until the follow-up visit. Subjects were scheduled to return to the office 3 d later to give subjects adequate time to practice using the PDA. A $50 security deposit was obtained from all subjects for return of the PDA.

Subjects returned to the office 72 h later to complete a usability questionnaire, 24-h recall, participate in an observed lunch, and return the PDA for upload of the food record data. A trained research assistant conducted the 24-h recall by asking subjects to report all foods and beverages consumed from midnight to midnight the previous day by using food models as food portion estimation aids. After the dietary interview, subjects participated in an observed lunch. Subjects were asked to select foods in the quantity and type they normally would, and a research assistant weighed each item after it was added to the plate. After selecting foods, subjects were asked to record the meal with the DietMatePro program. A research assistant used a timer to document the amount of time it took the subject to record the meal.

Foods were selected to represent a typical lunch (white and wheat breads, American and Swiss cheeses, ham, bologna, turkey, peanut butter, jelly, potato chips, vanilla wafers, chocolate chip cookies, canned peaches, grapes, applesauce, lettuce, tomato, mayonnaise, mustard, soft drinks, grape juice, and tomato juice). Subjects were instructed to serve themselves and to choose foods in the quantity and type that they normally would. After each food was added to the plate, the subject passed the plate back to a research assistant for weighing on a portion control scale that measured portions to one-tenth of 1 oz. The weights of serving containers and other foods were subtracted by the research assistant to obtain individual weights for food portions. Subjects were aware that their food portions were being weighed but they were not allowed to see the results of each food weighed. After all weights were obtained and before eating, subjects were instructed to record the meal in the DietMatePro program. The research assistant remained in the room and noted the length of time it took the subject to record a meal.

Each of the foods served was assigned a code from the ESHA database by the registered dietitian, and actual portion sizes consumed were entered in ounces by the research assistant. Nutrient composition of the actual food portion was determined using the ESHA Food Processor SQL (ESHA, Salem, OR, USA). The DietMatePro database served as the source of nutrient composition data for the food portions recorded by the study participant. A research assistant synced the food record and observed lunch data recorded using the DietMatePro to a central server, which calculated nutritional information. A registered dietitian used the date field and meal period to match the actual observed lunch data to the appropriate meal from the subject's food record, and the recall day to the appropriate records in the DietMatePro data.

Subjects and recruitment

Thirty-nine men and women were recruited through an advertisement in the *Washington Post*. Subjects were excluded if they could not provide a $50 deposit to secure the PDA, had difficulty reading small print, had dietary restrictions that prevented them from eating a deli lunch, lacked familiarity with personal computers, or were pregnant or nursing. Subjects were paid $50 for completing the study.

Dietary recall

To develop recall methodology adapted from the USDA's five-step multiple-pass recall method, a registered dietitian attended a workshop sponsored by the USDA's Food Surveys Research Group (27th National Nutrient Databank Conference) and trained research assistants to use the script published by the Centers for Disease Control and Prevention's National Health and Nutrition Examination Survey (NHANES) 24-h recall [8,9]. Research assistants were trained to conduct a dietary recall by running through a quick list, followed by probing for forgotten foods, eliciting time and occasion, running through a detail cycle using the NASCO exchange list food model kit (Fort Atkinson, WI, USA) and the cups and measuring spoons described by the NHANES [10,11]. After the training session, each research assistant conducted a mock 24-h recall interview with the

Table 1
Mean 24-h recall and DietMatePro intakes and the difference between recalled and recorded intakes of energy, protein, carbohydrate, and fat ($n = 28$)

	24-h recall intake		DietMatePro intake		Difference between recalled and reported intakes	
	Mean ± SEM	Range	Mean ± SEM	Range	Mean Δ* ± SEM	Δ† Range
Energy (kcal/d)	2159 ± 194	838–5026	2091 ± 204	433–4970	−68 ± 151	−1657–1979
Protein (g/d)	71 ± 6.0	22–142	72 ± 6.9	9–158	1.5 ± 5.7	−60–74
Carbohydrate (g/d)	327 ± 39.4	115–1106	292 ± 34.3	85–946	−34.8 ± 23.9	−413–307
Fat (g/d)	63.7 ± 7.1	9–157	74.9 ± 10.5	8–261	11.3 ± 9.3	−87–158

SEM, standard error of the mean.
* Δ = (DietMatePro intake − 24-h recall intake) calculated per subject.
† A negative value indicates an underestimation in the food record; a positive value indicates an overestimation.

registered dietitian to ensure consistency across interviewers. A registered dietitian or research assistant recorded the foods consumed by each subject in ESHA Food Processor SQL 9.1.2.

Data analysis

Nutrient composition data provided by ESHA Food Processor SQL and the DietMatePro was ported to SPSS 12 (SPSS, Inc., Chicago, IL, USA) for statistical analysis. Pearson's correlation analyses, paired *t* tests, and calculations to determine discrepancies due to database nutrient composition differences, food selection error, and portion size estimation error were conducted as necessary to address research objectives.

A Bland-Altman plot, which is a statistical method to compare two methods that assess the same parameter [12], was prepared to detect possible bias between actual and reported energy intakes. As described by Bland and Altman, the limits of agreement were set as two standard deviations (SD) of the difference above and below the mean difference.

To determine sources of error of DietMatePro compared with the observed, weighed lunch, individual foods recorded in DietMatePro were matched to ESHA foods by USDA nutrient database (NDB) number. A registered dietitian matched 80 of the remaining DietMatePro food entries (37%) to the actual foods documented in ESHA. For calories, error attributable to portion size estimation, differences between nutrient databases, and differences due to selecting a similar but not exact food were calculated by:

$$\text{portion size estimation error} = \text{actual calories} - [(\text{reported calories}/\text{reported gram weight}) \times (\text{actual gram weight})]$$

$$\text{nutrient database differences} = \text{reported calories} - [(\text{reported calories}/\text{reported gram weight}) \times (\text{actual gram weight})]$$

The impact on nutritional information of selecting similar but different foods (i.e., brand name versus generic, whole wheat bread versus white bread) was computed by applying the nutrient database differences calculation to similar foods having different USDA NDB numbers. The remaining discrepancy between actual and reported calories or nutrients was due to failing to report a food served or reporting a completely different food. Absolute error was computed by summing errors across all foods, and attributable percentage of error was tabulated.

Results

Subject characteristics

Twenty-one women (54%) and 18 men (46%) participated in the study. Thirty-six participants were white (93%), three participants were black (7%), and one subject was Hispanic (3%). Mean age was 53 y (SD 1.7) and ranged from 19 to 69 y. The average body mass index of the participants was 28 kg/m^2 (SD 1.4), with a range of 17 to 52 kg/m^2, and mean years of education completed was 16 and ranged from 12 to 21 y (SD 0.4).

Six subjects were excluded from the analysis of observed lunch data, four due to non-compliance to PDA recording, one due to a hardware malfunction, and one due to a data entry error (e.g., recording 1111 pieces of Swiss cheese). Eleven subjects were excluded from the 24-h recall analysis: five due to non-compliance to PDA recording, four due to a software problem related to the date/time stamp, and two due to a hardware problem.

DietMatePro accuracy compared with recall

Estimated intakes from 24-h recalls and DietMatePro food records for energy, protein, carbohydrate, and fat for the study population are presented in Table 1. A paired *t* test showed no significant differences between calories or macronutrient values obtained by these two methods. Mean percentages of energy intake from macronutrients were comparable between 24-h recall reports and DietMatePro data, respectively, for carbohydrate (60% versus 56%), protein (13% versus 14%), and fat (27% versus 32%). There

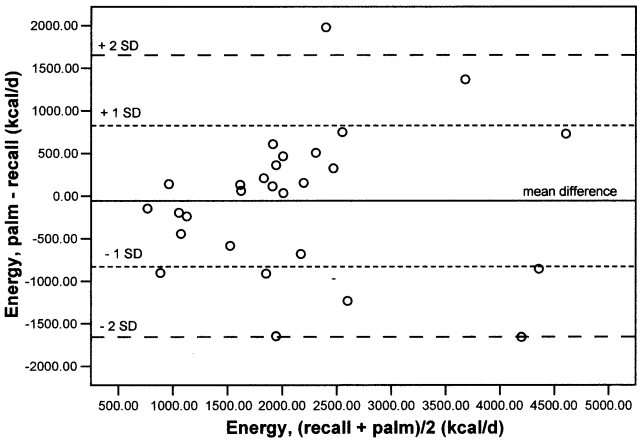

Fig. 1. Bland-Altman plot of the mean difference between 24-h recall and DietMatePro reported energy intakes versus the mean of the recalled and reported energy intakes, indicating ±1 SD and ±2 SD from the mean difference. The limits of agreement, which equal 2 SD of the difference above and below the mean difference, are plotted (n = 28). SD, standard deviation.

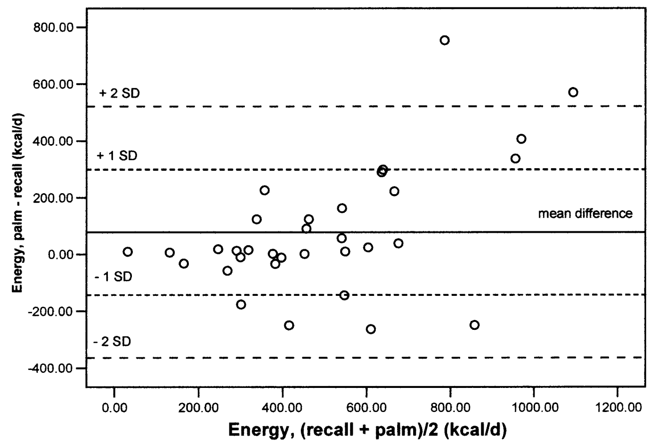

Fig. 2. Bland-Altman plot of the mean difference between weighed lunch and DietMatePro reported energy intakes for lunch versus the mean of the recalled and reported energy intakes, indicating ±1 SD and ±2 SD from the mean difference. The limits of agreement, which equal 2 SD of the difference above and below the mean difference, are plotted (n = 33). SD, standard deviation.

was a six-fold range in the reported intake of energy, and protein, carbohydrate, and fat intakes similarly varied greatly among participants, consistent with the wide range in body mass index (16.7 to 52.1 kg/m^2).

Pearson's correlations of association between DietMatePro data and the 24-h recall showed significant and moderate relations of 0.713 ($P < 0.001$) for calories, 0.505 ($P < 0.005$) for total fat, 0.520 ($P < 0.004$) for saturated fat, 0.622 ($P < 0.001$) for protein, 0.797 ($P < 0.001$) for carbohydrates, and 0.601 ($P < 0.001$) for cholesterol. Because high correlations can be found when one measurement produces consistently higher values than the other, a Bland-Altman plot of the differences between DietMatePro and 24-h recall intakes compared with average energy intake of these two measurements was produced (Figure 1). Figure 1 suggests a tendency toward overestimation of food intake using DietMatePro compared with 24-h recall, although this tendency is not reflected by mean differences in energy intake between the two methods (Table 1). One subject overestimated energy intake by greater than 2 SD above the mean difference, whereas two subjects bordered on underestimating their energy intake by greater than 2 SD below the mean difference. Therefore, the two methods of intake were ±2 SD of the mean difference for 97% of subjects (Bland-Altman criteria for agreement) and ±1 SD of the mean difference for 75% of subjects.

DietMatePro accuracy compared with the observed lunch

Pearson's correlations of association between DietMatePro data and the observed, weighed lunch showed significant relations of 0.720 ($P < 0.001$) for calories, 0.511 ($P < 0.002$) for total fat, 0.786 ($P < 0.001$) for saturated fat, 0.640 ($P < 0.001$) for protein, 0.707 ($P < 0.001$) for carbohydrates, and 0.419 ($P < 0.02$) for cholesterol. A Bland-Altman plot of the differences between actual (observed and weighed lunch) and recorded (DietMatePro) energy intakes against the average energy intake is displayed in Figure 2. Twenty-one subjects underestimated food portions, whereas 12 subjects overestimated the amount of food they served themselves for lunch. With the exception of two subjects (6%) who overestimated lunch calories by greater than 2 SD above the mean difference, the difference between reported and actual energy contents of the lunch fell within 2 SD. Therefore, these two methods of intake were ±2 SD of the mean difference for 94% of subjects (Bland-Altman criteria for agreement) and ±1 SD of the mean difference for 71% of subjects.

Sources of error between DietMatePro and the observed lunch

Portion size estimation error explained approximately 50% of the error between actual and recorded food intakes (Table 2). Seventy percent (3570 cal) of the food portion error was due to overestimation of portion sizes, whereas

Table 2
Attribution of total absolute error in food estimation during the observed, weighed lunch (n = 33)

Error source	Calories	
	kcal	%
Portion size estimation error	5094	49
Reporting incorrect food	2539	25
Omitting food	1601	15
Reporting similar food	945	9
Nutrient database differences	189	2

30% (1525 cal) was due to underestimation of food amounts.

Omitting a food from the food record accounted for 15% of the error. Thirty-nine foods selected by subjects during the observed lunch were not entered in the DietMatePro food record. The most commonly forgotten food was mustard ($n = 6$), and beverages were omitted on seven occasions. Ten foods were recorded by subjects that were not offered at the observed lunch, and this accounted for 25% of the overall error.

Recording a food that was similar, but not identical, to the food provided occurred 85 times (35% of all foods) and accounted for 9% of the error. Twenty-nine of these food selections resulted in an overestimation of calories, ranging from 0.01 cal for applesauce to 55 cal for ham. Thirty-eight of these food selections resulted in an underestimation of calories, ranging from 0.06 cal for lettuce to 83 cal for differences in bologna selections. In 18 instances, choosing a similar but not exact food had no effect on calories.

Although the ESHA and DietMatePro databases use the USDA Standard Release Database as the core and common source, ESHA cites version 12 as the source (ESHA Research Web site), whereas the source for the DietMatePro database is version 15. Percentage of error attributable to database differences was less than 2%.

Reported and actual times to record a meal

Subjects completing the observed lunch ($n = 33$) took an average of 10.3 min (SD 5.59) to record the meal. After initial orientation to the DietMatePro program, subjects were timed while recording their most recent meal, and this took an average of 8.3 min (SD 5.7). At the follow-up visit, subjects reported that it took an average of 8.5 min (SD 9.2) to record a typical meal.

Discussion

Energy and macronutrient intake from the DietMatePro program were comparable to a 24-h recall interview for the same 24-h reference period. Recall/record ratios from other comparison studies of mean energy intakes range from 0.88 to 1.00 [3] and was 1.03 in this study. Correlations between the PDA-based recording and 24-h recall were moderate to high. With the exception of one subject, Bland-Altman plots comparing energy values between these two methods were within the limits of agreement.

Prior research has provided data at the group rather than at the individual level, so it is difficult to compare these results with previous findings. In a study comparing data collected using the 24-h recall and the 1-d food record among older adults, Fanelli and Stevenhagen [13] reported mean energy intakes of 1929 ± 735 cal by recall and 1924 ± 739 cal by food record for men and 1430 ± 542 cal by recall and 1439 ± 555 cal by food record for women. These findings are consistent with the means reported comparing the 24-h recall to DietMatePro values.

Compared with an actual observed and weighed meal, DietMatePro records of the same meal also showed agreement and concurrent validity. Correlations of calories and macronutrients between actual and recorded intakes were moderate to high, and Bland-Altman plots indicated agreement rates of 94%. These correlations and agreement rates, however, were obtained under optimal food recording conditions in which subjects were familiar with the DietMatePro, having used it for 3 d, and knew that their recording for the meal would be compared with the meal being observed and weighed. Under less optimal conditions, the relation between actual and recorded values is not likely to be as high as obtained in this trial.

Analysis of the sources of error between the PDA-based food record and the actual meal revealed that food portion estimation was the greatest source of error, accounting for 50% of the error between actual and recorded meals. In comparison, food database differences between the DietMatePro and the ESHA Food Processor were negligible, whereas differences in food selection (i.e., selecting similar but not exact foods, failing to select foods eaten, or selecting foods not served) accounted for the remainder of the total error. One-fourth of the total error was due to reporting an incorrect food, and further investigation is needed to identify whether the error was due to the food recording method or to subjects' lack of knowledge with respect to food composition.

Reviewing the data for error sources elucidated the need for future studies to examine whether portion size and food selection errors were due to mistakes in data entry or true estimation error. This level of portion estimation error occurred despite training in portion estimation and 3 d of practice in estimating portion sizes before the observed meal. Further study is clearly needed to improve the process of portion estimation given the degree to which such estimation is relied on, not only by automated food records such as DietMatePro, but also by most dietary assessment methods.

Analysis of sources of error in DietMatePro illustrates the potential limitations of a PDA-based computerized food record. Even though PDA or computer-based food record systems offer a number of potential aids to improve recording compliance (e.g., recording reminders, reusable meals), subjects must select the appropriate foods, record all foods eaten, and estimate portion sizes accurately. These user-controlled actions remain the primary sources of error in most dietary assessment methods, whether delivered by low or high tech mechanisms. Although the Bland-Altman plots did not suggest a strong bias toward over- or underestimation when using the DietMatePro to record food intake, the magnitude of the difference between the DietMatePro record and recall was quite large in some cases, approaching 800 cal for a single 24-h period. This underscores the importance of training subjects in using the DietMatePro in estimating portion sizes and identifying foods correctly.

An additional limitation of computerized food records is the increased burden on the user to record relative to paper-based food diaries. Although the burden on the professional is greatly decreased by removing the need for data entry to analyze nutritional information from the food record, the user cannot simply "jot down" what is eaten. Users must search or scroll to find each food eaten and specify the amount. As a result, subjects reported that it took approximately 8 min to record a typical meal and could take significantly longer for meals with complex or mixed foods.

Despite these limitations, a PDA-based system such as DietMatePro offers a number of advantages to food recording. Food entries are date/time stamped, providing a record of when the meal was recorded, not just when it was eaten. With use periods longer than the 3 d of this study, saved meals can be reused to facilitate entry of meals similar to ones previously recorded. Alerts can be used to remind users to record meals. Nutritional feedback can be provided in real time to the user and can be compared with daily targets for these values to help shape dietary behavior. Data can be provided to the health professional as often as the user syncs the data, thus providing the ability to track progress and obtain nutritional information without data entry burden. Finally, as shown in this study, a PDA-based food record provides data comparable to 24-h recall and to an observed, weighed meal.

Conclusions about the validity of DietMatePro must be considered within the limitations of this study. The sample was small, computer literate, predominately white, and consisted of people without any dietary restrictions. Therefore, generalizations of these validity findings to minority groups, computer-illiterate populations, or samples having dietary restrictions are premature. The data on DietMatePro compared with an observed, weighed meal were obtained under optimal recording conditions. Concurrent validity of DietMatePro in real-life settings is likely to be lower. This validation study provides a record for a single meal or a single day only, and future research should focus on examining the validity of 3-d or 7-d PDA-based food records. Computerized programs for recording food intake differ greatly on characteristics such as food database source, extensiveness of food selections, the user interface for recording foods, and the portability of the application. Therefore, the validity for this particular method of computerized food record, DietMatePro, may not be generalizable to other computerized food records.

The results of this study suggest that DietMatePro is comparable to 24-h recall data as a method of monitoring dietary intake, particularly for non-minority users who have no medical conditions that require dietary restrictions. The ranges of weight and body mass index in this study suggest that DietMatePro is valid for monitoring food intake in weight management and obesity studies. Further study is required to extend these findings to a more diverse population and to assess the ability of the DietMatePro to improve compliance to dietary regimens.

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