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For the degree of Doctor of Philosophy

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ADVANCING DIETARY ASSESSMENT THROUGH TECHNOLOGY AND BIOMARKERS

A Dissertation

Submitted to the Faculty

of

Purdue University

by

TusaRebecca E. Schap

In Partial Fulfillment of the

Requirements for the Degree

of

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This dissertation is dedicated to my mother. Thank you for letting me dance to the beat of a different drummer. You show me what it is to be a strong, independent, and determined woman.

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ABSTRACT

Schap, TusaRebecca, E. Ph.D., Purdue University, May 2012. Advancing Dietary Assessment Through Technology and Biomarkers. Major Professor: Richard Mattes.

The inherent complexity and error associated with self-report dietary assessment methods have interfered with establishing the presumed relationships between diet and disease. Current technology including mobile devices with integrated cameras and biomarkers of dietary intakes provide unique means for addressing errors in dietary assessment. The mobile telephone food record (mpFR) is a unique dietary assessment tool in development. The user records foods and beverages in images taken before and after eating. The images can be used for automated food identification and portion size estimation. Using advanced technologies, there is an opportunity to improve estimates of dietary intake. However, the outcomes of mpFR use may be influenced by the interaction of the participant. Thus, the purpose of the studies described in this dissertation is to evaluate the reactivity among adolescents and adults using the mpFR. The objectives of these studies were to: 1) evaluate adolescents' abilities to identify foods and estimate the portion size of foods consumed; 2) investigate the influence of mpFR use among adolescents in a laboratory setting on expected energy intake for individual meals and 24-hour dietary intake; 3) compare reported energy intake from 3 non-consecutive days of mpFR use to estimated energy requirements among adults. Participants included adolescents (n= 78, ages 11-18 y) and adults (n=12, ages 20-58 y) who were recruited from the local community. Data were collected during studies taking place in the laboratory setting for adolescents, and the community dwelling environment for adults. All foods and beverages of known composition and quantity were provided to all participants. Although portion size estimation was a challenge, adolescents were able to correctly identify foods at the time of consumption and when prompted with an image of their meal 14 hours post-prandial. Among adolescents, there was no evidence that use of the mpFR contributed to undereating in the laboratory setting. Furthermore, reported energy intakes of the adults using the mpFR for 3 non-consecutive days were not significantly different from estimated energy requirements. These studies inform the continuing development of the mpFR and suggest that reactivity among users of the mpFR is limited.

The development of objective biomarkers will also help improve assessment of dietary intake. Urinary sucrose and fructose, an indicator biomarker of total sugar intake, may help stratify low, medium, and high adolescent consumers of total sugar intakes. The objective of this study was to compare estimates of total sugar intakes to 24-hour urinary sucrose and fructose. Fifteen adolescents (ages 11-18y) were provided 3 meals and ad libitum sweet snacks over a 24-hour period. Gram weights of served foods and plate waste was recorded and nutrient composition was estimated. Urinary sucrose and fructose were

significantly correlated with total sugar intakes among these adolescents (r = 0.642; p=0.013; r = 0.579; p= 0.030, respectively). The results of this analysis support urinary sucrose and fructose as indicator biomarkers for stratification of total sugar intakes among adolescents. Together, improvements in dietary assessment methodology along with the use of biomarkers to objectively assess dietary intakes, will lead to a better understanding diet's effect on disease risk and health outcomes.

CHAPTER 1. INTRODUCTION

The inherent complexity and error associated with self-report dietary assessment methods have interfered with establishing the presumed relationships between diet and disease. Despite the challenges diet assessment provides some of the most valuable insights into the occurrence of disease and subsequent approaches for mounting intervention programs for prevention. Diet assessment methods that are more accurate are needed to further grasp eating behaviors, define diet-disease relationships, and to measure the effectiveness of intervention programs for diet-related diseases such as obesity as well as its co-morbidities.

The research described in this dissertation involved collaboration with a multidisciplinary team to use current technology including biomarkers, mobile devices, and digital imaging to improve diet assessment methods. The studies described focused on two areas: the development and evaluation of a mobile phone food record (mpFR), and the evaluation of urinary sucrose and fructose as a biomarker of total sugar intakes among adolescents.

This dissertation is written in a non-traditional format. Chapter 2 is a comprehensive literature review. Chapter 3 was written in response to an invitation to summarize the Technology Assisted Dietary Assessment project (TADA) project and mpFR development up to that point in time. At the time of dissertation deposit, this Chapter was in the review process with a peer-reviewed journal. Chapter 4 has been published, and is available in the National Library of Medicine PubMed system (1). There is intent to submit Chapters 5, 6 and 7 for publication to peer-reviewed journals after the deposit of this dissertation.

Collectively, the studies described in the Chapters of this dissertation are intended to advance the field of dietary assessment. The specific objectives of these studies described in Chapters 3 through 6 were to: 1) evaluate adolescents' abilities to identify foods and estimate the portion size of foods consumed; 2) investigate the influence of mpFR use among adolescents in a laboratory setting on expected energy intake for individual meals and 24-hour dietary intake; 3) compare reported energy intake from 3 non-consecutive days of mpFR use to estimated energy requirements. The objective for the study described in Chapter 7 was to compare estimates of total sugar intakes to 24-hour urinary sucrose and fructose. The introduction, hypotheses, methods, and conclusions specific to each manuscript are described in the respective Chapter. The final Chapter 8 discusses the findings and implications of the culmination of these studies.

CHAPTER 2. REVIEW OF LITERATURE

The inherent complexity and error associated with self-report dietary assessment methods have interfered with establishing the presumed relationships between diet and disease. Measuring dietary intake presents more challenges than other environmental exposures. Despite challenges, diet assessment provides some of the most valuable insights into the occurrence of disease and subsequent approaches for mounting intervention programs for prevention. Co-morbidities of obesity are now estimated to cost $147 billion per year (2). The prevalence of poor dietary intake as well as prevalence of obesity and chronic diseases among the US population is evident (2-8). Unfortunately, errors in dietary assessment methods attenuate the association between diet and chronic disease outcomes which derails efforts to aggressively pursue policies directed to improving dietary intakes in the population.

Diet assessment methods that are more accurate are needed to grasp eating behaviors, define diet-disease relationships, and to measure the effectiveness of intervention programs for obesity as well as its co-morbidities. Dietary assessment includes methods of food intake recording as well as biomarkers of dietary intake. The aim of this Chapter is to review methods of dietary assessment, errors that occur with the use of these methods, methods for validating dietary assessment methods in development, and finally explore ways in which technology can be used to improve the accuracy of dietary assessment.

2.1 Methods of Dietary Assessment: Food Reporting and Recording

Methods in which foods are reported include methods of self-report as well as direct observation. Conventional methods of diet assessment include the 24-hour dietary recall, dietary records, and food frequency questionnaire which all rely on self report of energy intake. A food frequency questionnaire is designed to measure usual intakes of selected foods, whereas 24-hour dietary recalls and dietary records are designed to measure daily intakes of actual foods and beverages consumed. Direct observation in a congregate meal environment (e.g. school lunch) or in a laboratory setting allow research staff to observe dietary intakes, and record foods and beverages consumed. Food portions may be estimated by research staff, or served and remaining portions may be weighted (i.e. plate waste studies). Research studies are carefully designed to use the appropriate method of dietary assessment as each has unique characteristics to consider.

2.1.1 24-hour Dietary Recall

During a 24-hour dietary recall, a person recalls the previous day's intake. This usually occurs during an interview with a trained nutritionist administered in person or over the telephone. The interviewer uses verbal cues to help the respondent remember what he/she consumed the previous 24-hours. In conventional methods of dietary assessment such as the 24-hour dietary recall, a participant must not only remember what was consumed, but also how much was eaten. The interviewer may provide portion size estimation aids (PSEAs) to help the respondent estimate portions of foods and beverages consumed.

PSEAs are designed to capitalize on and improve a participant's ability to visualize the amount consumed and compare to a container, size, or other physical aid (9). Three-dimensional (3D) and two-dimensional (2D) PSEAs are used to help people conceptualize portions. 3D PSEAs include household measures (e.g. measuring cups, drinking glasses, bowls), realistic and general food models. 2D models may include drawings of foods, abstract shapes or household measures, food photographs, digital images of foods on a screen, or food package labels. Participants using 2D models have a similar level of reporting accuracy as those using 3D models making them a more cost effective PSEA for most large scale population studies (10). Recently, digital images of food portions shown on a computer screen have been developed for use with computerized methods of dietary assessment (11). There is no indication that one particular PSEA is better than another for improving portion estimates, thus 2D PSEAs are often used for their practicality. The ramification of error related to poor estimation of portion sizes will be discussed in section 2.4.3.

The 24-hour dietary recall used by the United States Department of Agriculture (USDA) provides a well documented example of how one method evolved over time. The nutrition monitoring program has focused on developing the most effective way to collect 24-hour dietary recalls since the first nationwide collection of individual dietary intakes in 1965 (12). A multiple-pass method was found to provide maximal opportunities for the respondent to recall foods consumed. A new multiple-pass method was tested in 1999. This improved method includes five passes: a quick list, forgotten foods list, time and occasion of eating occasions, a detail cycle, and a final review probe for any missed foods (13;14). The additional cues (e.g. time, place, activity, and people) increased the remembrance of foods consumed. The multiple-pass method further evolved to a computer-assisted version called the Automated Multiple-Pass Method (AMPM) (14). Standardized questions and possible response options were designed to reduce interviewer bias. The AMPM is used for collection of dietary data for the United States National Health and Nutrition Examination Survey (14).

Recently, the AMPM has been modified. The Automated Self-administered 24-hour Recall (ASA24™) is designed such that a researcher can send a participant a link to an online 24-hour dietary recall (11;15;16). The participant completes the recall with the aid of an on-screen avatar who fills many of the same roles as a human recall administrator. The ASA24 holds potential take advantage of the benefits of a 24-hour dietary recall (e.g., request to complete has element of surprise, standardized probes to collect deatail) while minimized the weaknesses of the method (e.g. cost of distribution, time and monetary burden to researcher).

2.1.2 Dietary Records

Written dietary records are another common method of dietary assessment. A person records foods and the portions at the time of consumption throughout the recording period. Instructions for completing a dietary record may include weighing of food portions prior to plating. For all dietary records, weighed or not, participants are asked to include as much detail about the foods consumed as possible. Detail including brand name and personal recipes helps a trained nutritionist code each food entry into a program that indexes with a nutrient database. As with 24-hour dietary recalls; PSEAs may also be provided to participants completing dietary records. Ideally, participants record eating events without delay. Some participants are inclined to delay recording, thus introducing the act of recall into the method. In addition, the written writing can be difficult for research staff to decipher (17). Further discussion on the effect of recording related to accuracy will be in section 2.4.2.

The advent of personal digital assistants (PDAs) brought a new medium for collecting data for dietary studies in which time stamps could document when the recording was completed, illegible handwriting would not be an issue, and the burden of coding entries could be reduced. Many researchers began investigating the use of digital entry dietary records in hopes of alleviating participant and researcher burden and improving accuracy of dietary intakes.

Digital entry dietary records, like pen and paper dietary records often utilize PSEAs. Fukuo *et al* provided 50 participants with a PDA-based diet diary with food images loaded on the PDA to aid in portion size estimation (18). Another PDA application, Balance Log, was used in a 7-day recording period (19). Participants using the Balance Log, used the same portion size estimation aids as their written dietary record counterparts (19). Researchers have hoped that digital entry dietary food records would improve cooperation as well as reduce researcher burden (e.g. data entry) when compared to pen and paper records. However, thus far digital entry dietary records have shown no improvement in accuracy when compared to conventional pen and paper methods (20).

2.1.3 Food Frequency Questionnaire

A food frequency questionnaire (FFQ) is designed to measure usual consumption of specific nutrients or foods over a defined period of time (21). FFQs are known for having low respondent and researcher burden when compared to 24-hour dietary recalls and dietary records. FFQs are most useful when tailored to the population among whom they are being used. Thus, many different and specific FFQs exist. FFQs have been designed to identify consumers of foods such as fruits and vegetables and nutrients such as calcium. FFQs may be qualitative, semi-quantitative or quantitative. The Block Food

Frequency Questionnaire is a quantitative FFQ in which participants mark the usual frequency of consumption along with a usual portion size (22). The portion size estimation aid available to use with the Block FFQ is a 2D picture with bowls and plates containing small cubes representing portions ranging from ¼ cup to 2 cups (Block Dietary Data Systems, Berkeley, CA USA; http://www.nutritionquest.com). The Diet History Questionnaire is another quantitative FFQ, and was developed at the National Cancer Institute (22). To improve accuracy of reporting using a FFQ, the DHQ was designed to improve frequency estimates and includes a list of foods based on nationally representative dietary data (22).

Semi-quantitative FFQs do not burden participants with the task of estimating a usual portion consumed. Measuring frequency has been found to be more informative than portion size estimation when using a FFQ, therefore a semi-quantitative FFQ may be best suited for many populations (e.g. children and adolescents) (23). One example of a FFQ tailored to the population of interest is a semi-quantitative FFQ for identifying consumption of calcium containing foods has been developed for use among Asian, Hispanic, and white adolescents (24).

FFQs have been used in large prospective studies for the relative ease of use and distribution. The cost is low when compared to 24-hour dietary recalls and dietary records when scannable forms are used. Thus, making them advantageous for large studies. A commonly used FFQ, the Harvard FFQ, is another example of a semi-quantitative FFQ (25;26). This FFQ is used in familiar studies such as the Nurses' Health Study and the Health professions Follow-up Study which are longitudinal studies providing insight into associations between diet and disease (27;28).

2.1.4 Direct Observation of Dietary Intakes

Direct observation of dietary intakes is an arduous task, but can be useful for studies in which the researcher desires to know not only the energy consumed, but also the individual foods and portions. Studies comparing direct observation of intakes to intakes reported by participants completing a 24-hour dietary recall or dietary records have been used to assess accuracy of dietary intake reporting among children and adolescents and adults (14;29-32). School meals and other congregate meal programs provide the most unobtrusive opportunity to observe people in a natural eating environment. A trained nutritionist observes individuals during a meal while noting the foods and portions consumed. In many studies, there are 2 observers assigned to monitor a participant's intake (33). Direct observation has been particularly useful for defining that which contributes to differences between known energy intake and reported energy intake.

2.2 Biomarkers of Dietary Intake

A concerted effort is being made to develop and identify objective dietary biomarkers to aid in defining dietary exposures. Dietary biomarkers in specimens such as blood, urine or hair are objective biochemical indicators of dietary intake or nutritional status that accommodate for the error in self-report methods and thus, shed light on the diet-disease relationship (34). Biomarkers may also be defined as a biochemical indicator of dietary intake/nutritional status, an index of nutrient metabolism, or a marker of the biological consequences of dietary intake (35). Inherent errors (e.g. underreporting and undereating) in self-report of dietary intake may be difficult to eliminate. However, the use of dietary biomarkers may help define the errors in self-report methods and thus, may shed light on the diet-disease relationship.

In order to obtain independent observations, epidemiologists have utilized different biomarkers assessed in biological samples as predictors of disease risk. High density lipoprotein cholesterol and low density lipoprotein cholesterol are examples of well known biomarkers that are strongly associated with risk for cardiovascular disease. Biomarkers that are related specifically to individual components of dietary intake hold promise for improving associations between diet and disease outcomes. There are three classes of nutritional biomarkers: recovery, concentration/replacement, or predictive biomarkers.

2.2.1 Recovery Biomarkers

One of the key reasons for the use of dietary biomarkers is to use them as a reference measurement to assess the validity and accuracy of dietary assessment methods. Recovery biomarkers are based on the concept of metabolic balance between intake and excretion over a fixed period of time.

Therefore, there is a high recovery of the biomarker and it is strongly correlated with intake. The two most common recovery biomarkers are doubly labeled water (DLW) and urinary nitrogen. These biomarkers are unbiased markers of energy and protein intake, respectively. DLW, as described previously, is a marker of total energy expenditure. During weight maintenance, TEE is equal to energy intake (EI). Thus, DLW is used to define errors in energy reporting.

First reported for use in human studies in 1982, DLW is an objective measure of energy expenditure. Participants consume a dose of labeled water ($^2H_2O^{18}$). The isotopes mix with total body water, and the ratio of ^2H to ^1H is measured to calculate total body water. The rate of loss of the isotopes is measured by change in urine over 7-14 days. The difference between the rate of loss of ^{18}O and ^2H is used to calculate CO_2 production for calculating energy expenditure. In weight stable people, DLW can be used as a measure of energy intake (36). Under controlled conditions, the difference between TEE and known energy intakes and weight change was only 2% (37). Thus, DLW is used to estimate errors in reported energy intakes (38).

Nitrogen intake is primarily from sources of dietary protein. Urinary nitrogen as a recovery biomarker is based on the principals of nitrogen balance (34). Thus, for use as a biomarker of nitrogen intakes, participants must not be in a state of growth nor weight less, nor in a state of muscle or tissue repair. Other sources of nitrogen loss include skin and feces. A constant factor is used to account for fecal and skin losses, thus urine nitrogen represents approximately eighty percent of dietary intakes. Urinary nitrogen is measured in 24-hour urine collections. Because on any given day, a participant may not be in nitrogen balance, multiple 24-hour urine collections provide a more accurate estimate of nitrogen excretion (39). A single 24-urine collection has a correlation between diet and nitrogen excretion of approximately 0.5 with high coefficient of variation (39). However, when 8, 24-hour urine collections are available, the correlation is 0.95 and coefficient of variation is dramatically reduced. Incomplete 24-hour urine samples will result in skewed measurements of biomarkers such as urinary nitrogen (40). Thus, a marker is needed to verify complete urine collection.

PABA-check is a procedure used to monitor the completeness of urine collection during a 24-hour period (40). Para-amino benzoic acid or *p*-amino benzoic acid (PABA) is a naturally occurring substance that is a component of the structure of folate. PABA is absorbed by the gastrointestinal tract and excreted in the urine as the urine as the unchanged compound (41). This concept of unchanged excretion makes PABA a good candidate for use as a biomarker for urine collection compliance. The routine procedure is to instruct individuals to take three 80mg tablets of PABA (supplied by the Laboratories for Applied Biology, London, United Kingdom) at intervals during a 24-hour collection period, then measure the PABA in the urine using colorimetric or high-performance liquid chromatography methods (42).

2.2.2 Predictive Biomarkers

The concept of predictive biomarkers is relatively new. These biomarkers are sensitive, time dependent and show a dose-response relationship with intake levels. While the correlation to intake is high, the actual recovery of the marker is quite low. Predictive biomarkers not only help to identify reporting errors for specific nutrients, but might also be used independently of self-report to categorize individuals by their level of intake of a nutrient.

Foods high in refined sugars are among the most frequently underreported foods (43) contributing to the difficulty in relating sugar intake to disease risk. Urinary fructose and sucrose concentrations represent a predictive biomarker which has been shown to significantly correlate with sugar intake and provides a useful, independent qualitative index of sugar consumption (44).

2.2.3 Concentration Biomarkers

Concentration biomarkers have a lower correlation coefficient than recovery or predictive biomarkers, yet are useful for comparison with estimates of dietary intake. Concentration biomarkers cannot be translated into absolute levels of intake but the biomarker concentrations do correlate with intakes of corresponding foods or nutrients. Concentration biomarkers are not a direct translation of intake, but are still quite useful for understanding intake and disease relationships. For instance, total cholesterol is a concentration biomarker for which observed changes are often evident when dietary changes are made.

An example of a more novel concentration biomarker are plasma alkylresorcinols (ARs) which are correlated with intake of whole grains and are under investigation as a concentration biomarker (45-47). Alkylresorcinols are phenolic compounds found in the bran layer of whole grains. ARs are found in small amounts in many plant foods, but are primarily found in wheat and rye bran, thus indicating that ARs would be a whole wheat and rye specific biomarker (45). ARs are a potential biomarker for people who eat foods containing wholegrain wheat and rye, rather than cereal products based on white flour (45). Plasma AR concentrations show a dose response at low, medium and high levels of intake of bran cereal (46). Similarly, plasma AR concentrations show a marked increased with intake of rye, but not wheat bread (47). Both Landberg, *et al* and Linko, *et al* have shown that the plasma concentrations return to baseline during a washout period when whole-grains were avoided or when diet returned to self-selection, respectively (46;47). The dose response along with short time sensitivity is of particular interest in the development of this biomarker which could help explain associations between diet and risk for cardiovascular disease and certain cancers (45).

Each class of biomarker plays a role in proposed hypothesis testing regarding the relationship between diet and risk for disease. Recovery biomarkers help quantify error in self-report of intake. It is possible to use recovery biomarkers to better understand true intake through calibration of reported intake. The continued attention to the discovery of biomarkers for individual foods and nutrients will advance nutritional epidemiology and the establishment of diet-disease relationships.

2.3 Validation of Dietary Assessment Methods

The accuracy of dietary data is important for elucidating presumed relationships between diet and disease. Validity indicates the degree to which a tool measures what it is intended to measure. Validation studies ensure that a dietary assessment tool useful for measuring what it is intended to measure (e.g. macro- and micro-nutrient intakes). Accuracy of self-report can be compared to known dietary intake from either observed dietary intakes are recorded by trained research staff, or during plate waste studies in which foods and beverages are known and the amounts served and amounts left over are recorded. While biomarkers of dietary intake are considered to be objective measures, they too must be validated. Biomarkers of dietary intake are validated in comparison to known intakes of specific nutrients. Studies of convergent validity compare two methods in order to see how well they compare to one another. Lastly, self-report may be compared to unbiased biomarkers. These three types of validation will be further discussed along with examples of their use in the research community.

2.3.1 Comparison to Direct Observation or Plate Waste

Direct observation and plate waste studies are the best comparison for self-report dietary assessment methods. Comparison of self-report to observed intakes is the closest to absolute validity that we have in dietary assessment. Through the use of direct observation studies, researchers can compare reported intakes from dietary records or 24-hour recalls to known food intake. Baxter, *et al* have used observed intakes during congregate lunch time times help define specific errors in reporting among children (33). These studies have allowed errors in reported energy intake to be defined. Notably these studies have informed a better understanding of the contributors to error among children. These errors could not otherwise be understood without the direct observation method.

The DietMatePro, a digital entry dietary record installed on a PDA device was tested for accuracy among a group of 39 computer savvy adults (48). The use of an observed plate waste study in the laboratory setting allowed for a direct comparison of foods recorded and portion size estimations to known foods and their amounts. In addition, the observation provided an opportunity for research staff to record the amount of time it took each participant to complete the digital dietary record for one meal (48).

Plate waste studies conducted in a laboratory setting are particularly useful for validation of biomarkers. Validation of biomarkers for dietary intake includes dose-response studies as well as studies in which the biomarker of interest is compared to ad libitum, known intakes (44) For the development of urinary sucrose and fructose as indicator biomarkers of sugar intakes, the first studies involved biomarker recoveries to known intakes of total sugars consumed in a laboratory setting (44). After establishing the existence of a dose-response, participants consumed ad libitum diets in which all foods consumed were provided, and gram weights measured for both provided and returned portions. In this study, Tasevska *et al* were able to validate the biomarker against known intakes among adults (49).

Observation and plate waste studies are not without limitation. The main limitations relate to feasibility. These studies are tedious and would be impractical for validation of a tool in a large sample. The observed environment is somewhat contrived. Particularly in a laboratory setting, participants may not behave as they would in a free living environment. School lunch times or other usual congregate meal settings may be the least obtrusive as students would be used to being observed by teachers or other staff in the lunch room, thus research observation would be less noticeable. Although some might argue that observers would be susceptible to recording bias, inter-observer reliability is usually quite high. Thus, most observation studies operate on the assumption that observation bias is minimal.

2.3.2 Convergent Validation

Validation studies in which one method is compared to an existing method are referred to as convergent validation studies. Convergent validity is described as "the extent to which several different measures of a concept agree with each other and with a test measure type of relative validity" (50). Examples of convergent validation studies include comparison of FFQs to dietary records and digital entry dietary records to pen and paper dietary records.

Two examples of convergent validation are related to a tool described previously in sections 2.1.2 and 2.3.1. The DietMatePro was validated using a direct observation plate waste study (48). The validation also included a convergent validation comparison of reported energy intakes on the third day of using the digital dietary record program to a 24-hour dietary recall (48). Another digital dietary record, Balance Log was evaluated using convergent validity (19). Reporting accuracy for participants using a digital dietary record was compared to reporting accuracy of participants using pen and paper dietary records. Accuracy was found to be similar between the two methods of recording (19).

2.3.3 Comparison of Self-report to Biomarkers of Dietary Intake

Biomarkers of dietary intake are unbiased; therefore they are not susceptible to the same types of error as self report. Recovery biomarkers including doubly labeled water and urinary nitrogen are well established for use in validation studies. Doubly labeled water, as described in section 2.1.1, estimates energy expenditure. During weight maintenance, energy expenditure and energy intake are in balance, thus DLW can be used as an objective marker of energy intakes. Similarly, urinary nitrogen is used as a marker of protein intake. These recovery biomarkers and others are often used to measure the accuracy of self-reported dietary intakes. In a summary of early studies in which doubly labeled water was evaluated as a validation tool, Black *et al* suggest a now well accepted concept; that biomarkers will not only help validate dietary assessment tools, but also help define errors in self-repot (51). Indeed, as biomarkers of dietary intakes are utilized for validation, the studies often shed insight on the degree of error and where the error may stem from.

DLW is used as an objective measure of energy expenditure, and is considered the gold standard for use as a measure of energy intake. Errors between TEE as measured by DLW are small, thus the difference between TEE and reported energy intake (rEI) are generally presumed to be underreporting (51;52). DLW was one of the first biomarkers used to quantify errors in reported energy intakes (38;52-54). Unlike observation and plate waste studies, DLW is relatively unobtrusive and the measurement period ranges from 5 to 14 days (54). This allows participants to be in their free living environments for an extended study period without constant monitoring by research staff. The major limitation of DLW is the expense, laboratory equipment, and staff expertise needed to use the method (54).

Accuracy of self-report dietary assessment methods vary. Ratios of rEI to TEE range from +25 to 76% among individuals (29;32;55). Adult participants completing a 24-hour dietary recall underreported between 12 and 20% of EI measured as TEE by DLW (29). Similar results are found when adults complete dietary records (31;56). A food frequency questionnaire is not designed to capture 100% of daily energy; therefore it is not surprising when adults completing a FFQ report only about 50-60% of daily energy intake (29).

Accuracy of self-report dietary assessment methods among children and adolescents is similar to adults. For 4th to 5th grade students keeping dietary records, daily reported energy intakes were under-estimated by 17-33% when compared to TEE as measured by doubly labeled water (32). A study by Bandini *et al* examined longitudinal changes in reporting accuracy among girls completing dietary records (57). Mean reporting accuracy decreased as girls aged from 88% at age 10 y to 77% at age 12 y, and finally 68% at age 15 y (57).

With advances in technology, there are few studies that compare rEI from a digital recording method to TEE as measured by DLW. In one study, a digital entry dietary record, Balance Log, was validated through comparison of rEI to TEE (19). Study participants were randomized to use the PDA or written dietary records. Reported energy intakes were compared to DLW. The authors concluded that the bias in using a PDA is similar to that observed when using a written record for estimation of EI in weight-stable volunteers (19). .

Urinary nitrogen is another recovery biomarker commonly used in validation studies. Urinary nitrogen accounts for approximately 80% of dietary intake, the biomarker can be used to identify underreporters of protein intake (58;59). In an elaborate study comparing biomarkers to dietary intakes as recorded in dietary records, Bingham and Day were able to use the ratio of urinary nitrogen excretion to dietary nitrogen in order measure the accuracy of dietary reporting as well as to identify those who underreported food intake (60).

Urinary potassium may also be a viable biomarker for use as a validation tool due potassium being found in a variety of foods (34). Correlation between urinary potassium and dietary intake was found to be at least 0.7 in healthy participants providing complete 24-hour urine samples (60).

2.4 Error in Dietary Assessment Methods

Accuracy of self-report dietary assessment has been a concern for many years. Sempos *et al* note that underreporting may have contributed to the observation of low nutrient intakes among women published in 1984 (61). Highly motivated women of upper socio-economic status reported approximately 100% of their energy intake during 24-hour dietary recalls (14). In other studies, errors in reported energy intakes among adult participants completing a 24-hour dietary recalls ranged from 20-40% to 60-80% of true energy intake as measured by DLW (29). Similar results were found when adults completed dietary records (31;56). A food frequency questionnaire is not designed to capture 100% of dietary intake; therefore it is not surprising when adults completing a FFQ report only about 50-60% of daily energy intake (29;56;62). For 4th to 5th grade students keeping dietary records, daily reported energy intakes were under-estimated by 17-33% (32). Another study examining longitudinal changes in reporting accuracy among girls completing dietary records indicated that mean reporting accuracy decreased as girls aged (57).

Self report dietary assessment methods involve complex cognitive tasks that may be further complicated by social desirability, and respondent bias. Evaluating errors occurring during completion of dietary assessment methods is complicated by these various sources of error. Errors, or misreporting, can be classified as errors in portion size estimation, intrusions i.e., foods reported, but not consumed, or exclusions i.e., foods consumed but not reported (63). Error may be random or systematic. Random error may include writing mistakes or variations in processing (64). Systematic error is often related to participant characteristics. In other words, underreporting of true intake occurs more frequently among certain groups of people. These sources of error have been explored in effort to better define and accommodate for error in dietary assessment methods. Some error, such as errors in portion size estimation, may result from the complexity of mental tasks required to complete methods of self-report. Contributors to reporting error that may occur among all ages include memory errors, portion size estimation error, errors related to social desirability, and age-related errors. These types of error are described in detail below.

2.4.1 Cognition Related Errors in Dietary Assessment

Reporting dietary intake involves a complex set of mental processes including attention to the food consumed, perception, long-term memory organization, memory retention, and retrieval from long term memory to short term memory in order to form a response (65). Among older adults, the Modified Mini Mental State Exam of cognitive function was inversely related to reporting errors on an FFQ, further emphasizing the high cognitive function needed to report dietary intake (66). Younger children have limited capability to complete self-reported dietary intakes. Cognitive issues that may negatively affect self-report among children include low literacy, short attention span, limited concepts of chronology, and limited knowledge of food preparation (67). Adolescents have stronger cognitive skills, but may still be limited in knowledge of food preparation, have unstructured eating habits, and begin to be influenced by social desirability and peer influence (67).

Errors in dietary recalls may be related to the task of memory, that is the retrieving and reporting specific information about an eating event that occurred in the past. These memory related errors can be categorized as intrusions (reporting of items that were not eaten) and omissions (eaten items that were not reported) (63). Observation of dietary intake makes it possible to identify the source of these errors.

Baxter *et al*, have closely examined the origins of reporting errors among fourth grade children (68). School meals provide an opportunity for children to be unobtrusively observed. This observation opportunity combined with the production records from the school; provide a unique opportunity to identify the origins of intrusions. The most common intrusions at school breakfast were beverages, while at lunch were vegetables and combination entrees. Intrusions from lunch were related to foods served on days previous to the reporting day (68). Among adults, performance on a memory task was a weak predictor of energy misreporting (69). For children, and likely adults, confusion of episodic memory contributes to intrusions errors in reporting of dietary intakes.

2.4.2 Reactivity Related to Errors in Dietary Assessment

Among adolescents as well as adults, errors in reporting of dietary intake are usually in the direction of underreporting. Studies using DLW indicate underreporting as well as undereating occurs during the period in which a person is recording his/her dietary intake (38). When rEI is less than TEE, and the participant maintains body weight, the error is categorized as underreporting. However, when rEI is less than TEE and the participant loses weight during the recording period, the error is categorized as undereating. Both may be a result of social desirability, and is related to personality characteristics (69). Reactivity in dietary assessment is associated with participant characteristics. Underreporting occurs more frequently among females than males (69;70). The prevalence of underreporting has also been found to increase with higher body fatness and in some studies with increasing body mass index classification among both adolescents and adults (69-71). Perception of body image and previous experience with dieting are also associated with underreporting energy intake (69). Even among children and adolescents, the accuracy of reporting varies by gender and weight status (67). These associations between underreporting and participant characteristics may be related to social desirability, social approval, respondent bias, or the self monitoring effect.

Social desirability is described to be a defensive tendency to avoid criticism and to depict oneself as conforming to social norms. Influence of social desirability may be seen as early as childhood and adolescence (67). Social desirability is measured using one of several scales. The Marlowe-Crowne Social Desirability scale which includes 33 true/false questions designed for adults. Cradall *et al* modified this scale for use in children. The Children's Social Desirability scale includes 1 test for older children (ages 6-12 years) and for younger children (ages 3-5 years). A scale for social desirability for Foods was developed by Worsley *et al* and adapted for children by Baxter *et al* (72). Social approval is subtly different from social desirability. Social approval is the desire to seek a positive response particularly in testing situations. The Martin-Larsen Approval Motivation scale consists of 20 questions rated on a likert scale.

Self-report of dietary intakes may be biased by both social desirability and social approval (69). Participants who score high on these scales may be more inclined to overreport "good" foods and underreport "bad" foods. In one study among adult men and women completing a 24-hour dietary recall, social desirability was a stronger predictor of underreporting for woman and social approval was a stronger predictor of underreporting for men (69). During focus groups, adult women report concerns that researchers would judge their reported dietary intakes (71). Among 4^{th} grade children, underreporting of energy intakes was also positively associated with social desirability score (72).

Another form of reactivity would be the change of intake in effort to ease the burden of reporting. A participant may eat differently than usual during the recording period for dietary records or prior to a scheduled 24-hour dietary recall in effort to make reporting easier (71;73). Women participating in focus groups admit to simplifying their diet to reduce the burden of completing dietary records (71;74). Simplifying the diet was reported to include consuming simpler foods, choosing foods with defined portions, consuming packaged foods, eating fewer snacks, and avoiding restaurants (71). For adults completing a food checklist, there was a small decrease in reporting frequency across time (73). Interestingly, among these participants, there was no association between reactivity and BMI (73).

Self-monitoring of dietary intake has long been considered a cornerstone for weight management. The systematic observation and recording of dietary intake increases self-awareness and thus, self-regulation of intake. For weight loss interventions, capitalizing on the self-monitoring effect is desirable. However, for population based studies, changes in usual intake due to the self-monitoring effect and social desirability during a reporting period interfere with the examination between diet and disease. There are documented differences between participants who have previously participated in weight loss regimens when compared to those who have not. For those who have had previous attempts at weight loss, undereating as well as underreporting may occur. In another study, previous attempted weight loss was a strong predictor of underreporting in both men and women (69). In another study, women who had previously been on a weight loss program were more likely to use standard measurements for portion size estimation as opposed to more tactile methods (e.g. showing an estimate using hand motions) used by those who had not been engaged in formal weight loss plans (71). These studies give examples of how previous exposure to self-monitoring of dietary intake may affect dietary reporting.

2.4.3 Errors in Portion Size Estimation

Errors in portion size estimation can contribute greatly to the errors observed in reported energy intakes (10). Portion size estimation is a complex task that often involves conceptualizing an amount never seen, that is the portion consumed is estimated by subtracting the amount left over from the amount served. Cognition, the process of perceiving, is an important concept to consider when helping a participant remember how much food or beverage was consumed. Portion size information must be first be retrieved from the memory and then processed and communicated verbally or in written form (65). Strategies used by participants to retrieve portion size information include but are not limited to known purchase amounts, e.g. 12 oz soda, counting, e.g. 2 pieces, and visualization comparisons, e.g. compare to a container size. A study by Chambers *et al* examined the use of these cognitive strategies during a 24-hour dietary recall (9). Interestingly, estimations based on amounts known, measured or purchased were most common for liquids consumed. Visualization comparisons were the more common strategies used for estimating solid and amorphous foods.

Studies designed to specifically evaluate participants' abilities to estimate portion sizes further indicate the complications of the task of memory (10). Studies in which a food is present at the time of portion size estimation indicate a wide variation in portion size estimates (75). Even these studies in which memory and conceptualization are not factors in the cognitive process of estimating portions, errors in portion size estimation should be expected. The accuracy of estimates is related to the amount served, closeness in size to the PSEA, and the state of the food (i.e. solid, liquid, amorphous.) If accurate estimates cannot be expected in the absence of cognitive challenges like memory, then it should be no surprise that even brief periods of time between seeing the food and then estimating a portion negatively affect a participant's ability to accurately estimate portion size.

Many studies have investigated the use of PSEAs in effort to improve portion size estimation among children and adults. There is no evidence that one type of portion size estimation aid is better than another, thus suggesting that other factors may contribute more to portion estimation errors more than the PSEA itself. Even when a participant reports a common measurement such as 1 cup, or 16 oz, measurement aids can clarify the amount perceived by the participant. For example, when "1 cup" is reported, the participant may be conceptualizing a 10 oz coffee mug rather than an 8 oz measuring cup (9). Studies designed to compare the usefulness of specific portion size estimation aids describe how researchers have sought to improve reporting of perceived portion sizes.

2.4.4 Commonly Underreported Foods

Evidence would suggest that some foods are reported less often and in smaller portions than others. In a study by Krebs-Smith, *et al*, commonly underreported foods included savory snacks, soft drinks, condiments, sweets, and beverages (43). Given that most adults and adolescents report consuming daily snacks such as coffee, soft drinks, and dessert items; one might presume that snacks are underreported in general. Notably, these underreported foods and beverages are often carbohydrate based items. Studies using urinary nitrogen as a biomarker of protein intake along with observation studies have established that protein-based foods are reported with better accuracy than total energy (29;76). For example, in the OPEN study, women underreported total energy by 16-20% (29). However, protein underreporting was only 11-12%, suggesting that the greatest errors in underreporting are associated with carbohydrate and fat (29).

2.5 Using Technology to Improve Dietary Assessment Methods

The integration of computer technology has improved data management, and reduced researcher cost for the AMPM as well as other 24-hour dietary recalls, FFQ and diet records. Nonetheless, these methods continue to be fraught with error. Errors in self-report have been evident for over 30 years, and continue to exist despite efforts to improve dietary assessment methods. The errors occurring in self-reported dietary assessment have been documented in early studies and although they may be better defined, these errors have not been eliminated. Technological advances have prompted researchers to investigate the use of technology to improve accuracy of diet assessment methods. Efforts to utilize available technology include applications for mobile devices with integrated cameras, as well as the development of objective biomarkers for dietary intakes (77). Mobile technology holds promise for engaging participants and reducing participant burden related to recording and portion size estimation, thus improving cooperation and accuracy (77;78). Objective biomarkers hold promise for improving associations between dietary intakes and disease outcomes in tandem with or independent of dietary assessment methods (e.g. 24-hour dietary recall, dietary record).

2.5.1 Mobile Technology with Use of Images for Dietary Assessment

While some error is related to psychological factors, (e.g. social desirability, self-monitoring), errors attributed to participant burden related to completing any method of dietary assessment might be reduced with technology based dietary assessment. Mobile technology in particular has been implicated for improving dietary assessment methods. As technology has evolved, so have the programs which now utilize mobile devices with data processing capabilities, cameras, and internet connectivity. With the wide-spread use of mobile devices, the development of health applications has exploded. For the Apple iPhone, there were over 9,000 health apps in July 2011, and 1,263 of them were diet related (e.g. healthy eating, weight loss, food tracking) (79). These applications are inexpensive. The average price of a diet related app is only $2.39, and many are free (79). Consumer apps are certainly gaining popularity, but most are not developed with the nuances of research in mind. There is rarely any report of evidence based development or testing for validity.

The use of technology based dietary assessment holds potential to improve data quality, reduce participant burden and alleviate many researcher burdens (e.g., data entry, interview staff) (77;80;81). Currently, there is little evidence to suggest that digital dietary records result in significantly more accurate records of dietary intakes when compared to conventional methods (18-20). This is likely because these word-based digital dietary records are still susceptible to the errors associated with self-report. The methods described thus far do not remove the challenge of portion size estimation, nor do they remove errors associated with social desirability, social approval, and reactivity related to self monitoring. These applications require users to report and track their food consumed by following a series of questions displayed on the mobile device's screen. As a result of this user input, these applications estimate and summarize total energy and selected nutrients. However, these apps may introduce new barriers (e.g. poorly lit screen (20)) while failing to address the shortcomings of the traditional methods. However, reductions in participant burden and researcher burden alone may make these methods preferable over pen and paper methods among some groups of study participants (82).

As technology has rapidly evolved and become more widely adopted by the general public, applications for mobile devices with integrated digital cameras have become a more desirable tool for the research community. With the wide spread availability of digital cameras and mobile devices with integrated cameras; applications in which a participant or "user" takes images of foods and beverages consumed have become of increasing interest. With the use of image-based dietary assessment methods, there may be an opportunity to significantly improve measures of dietary intakes.

Digital images have specific characteristics that set them apart from pictures or photographs. A picture is likely the most general of the terms, and could be a drawing, a printed image, etc. A photograph refers specifically to a picture developed from film. A digital image is different from a picture or a photograph in that it has meta-data (e.g. time stamp, pixel information); has GPS coordinates, if available and active;; can be manipulated (zoom in, zoom out), and can be easily transferred from a camera, computer or mobile device to a central server for data management. Proposed image-based dietary assessment methods can be categorized by the manner in which the images are processed. Images may be reviewed by the participant/ user, images may be reviewed by a trained analyst, or the images may be reviewed by automated systems.

2.5.1.1 Images Reviewed by the User/ Participant

One proposed use of digital images is to supplement a 24-hour dietary recall, in other words, an image-assisted dietary recall. Arab *et al* have proposed a method in which a user wears a mobile device hanging around his/her neck for a 24-hour period. During this time, intermittent images are automatically taken. The day following, images are called to display only those images where food is present. These food-specific images are presented to the user to help him/her remember all foods and beverages encountered the previous day while simultaneously completing a 24-hour dietary recall. Image assisted dietary recall could be of particular interest for use in the clinical setting where a brief review of images combined with client-provided detail could reduce the time spent during clinical out-patient counseling visits. This would allow more time spent on goal setting rather than time spent reviewing a client's previous day's intake. Although the digital images of foods reviewed by user reduce memory related burden, issues related to portion size estimation still exist. In addition, one the primary advantages of the 24-hour dietary recall is to conduct interviews unannounced which reduces reactivity. Thus, this advantage is lost when image capture is occurring the day prior to administration of the 24-hour dietary recall.

2.5.1.2 Images Reviewed by Human Analysts

The use of digital images in dietary assessment has the most potential to improve data accuracy when as much burden as possible is removed from the participant. Methods in which images are reviewed by a trained human analyst remove participant burden and improve accuracy. These methods overcome the user burden of portion size estimation, and ameliorate its associated errors in reporting energy intake.

One of the most well documented programs in which images taken by users are evaluated by human analysts is the remote food photography method (RFPM) first developed by Williamson *et al* with continued development and evaluation by Martin *et al* (83-85). A historical perspective on the RFPM includes a series of evaluation studies that lead to the culmination of a method that has been used for intervention studies. RFPM analysts are trained to estimate portions as a proportion, in units of 10%, of a reference portion amount for the served portion as well as the plate waste portion (83). In early studies, a high correlation was found between the estimates made by analysts who made visual estimates of foods present and those made by analysts who estimated amounts of foods in images (83). For the RFPM, estimate errors were in the direction of over-reporting, with small mean differences between the estimates and the actual gram weights of food intake (83). Only for one of these studies (83) was the mean difference statistically significant. When compared to self-report dietary records in which rEI error can be up to 40%, the errors made by RFPM analysts are quite small.

For some studies, the images for RPFM were taken by research staff using a camera mounted on a tripod which may be useful in cafeteria settings where foods are known (83;84). The RFPM has since evolved such that participants use mobile phones with integrated cameras to record intake in the free-living environment (85). For images taken in the free-living environment, it may be difficult for analysts to identify foods and beverages. Participants using the RFPM are trained to use the mobile telephones to take pictures, as well as identify their foods before sending to the data management system made available to the analysts (85). Ecological momentary assessment prompts can be sent to users as reminders to take images of their meals. The RFPM analyst error in these more recent studies ranges from -4.7-6.6% (85). These errors would still be considered small when compared to rates of underreporting in pen and paper methods of dietary assessment. Not only does the RFPM show improvements in accuracy of reported dietary intakes, nearly all participants indicated that the RFPM would be preferred over a pen and paper dietary record (85). Participants' satisfaction ratings ranked high for comfort using the mobile telephones and the RFPM.

Matthiessen, *et al*, explored the use of an analyst using digital image based dietary records (DIFR) among children ages 9-12 y (86). The children and their parents were provided instruction for taking images of all eating events from 5pm to bedtime for 7 consecutive days. Reported food groupings as opposed to energy or nutrient intakes were estimated. The estimates made by separate analysts were highly correlated ($p<0.001$). Convergent validity was used to measure accuracy. The DIFR was compared to three 24-hour dietary recalls. There was a significant correlation between average food group estimates from the DIFR method and from the 24-hour dietary recall for all food groups except for grains (86). For many studies in which food group based intakes are of interest, this method holds promise. In particular, this study indicates how image-based methods can be simplified for immediate use in clinical and small scale research studies.

The Genes, Environment, and Health Initiative (GEI) from the National Institutes of Health encouraged the use of technology for improving dietary assessment (http://www.riskfactor.cancer.gov/diet/gei/; Retrieved March 6, 2012). These projects have brought the fields of nutrition and engineering together to develop innovative tools to further improve dietary assessment methods. Three subprojects of the GEI include image-based dietary assessment in which images are primarily reviewed by a trained analyst (87-89). The Food Intake Visual and Voice Recognizer (FIVR) application issues queries regarding the foods consumed (87). Unique to FIVR is a voice recognition component so that participants can describe the foods consumed and clarify details (87). The goal is that the foods reported using FIVR can automatically be matched with foods in the USDA Foods and Nutrient Database for Dietary Studies (FNDDS). However, when the voice recognition software does not work properly, a human analyst will match reported foods with the appropriate food in FNDDS (87). Another publication on FIVR would indicate that the user will take 3 images in different positions above the plate using the mobile telephone, and that the user's audio identification of foods will assist with semi-automated identification and volume estimations (90).

A second subproject of the GEI, is a wearable electronic system developed by Sun *et al* (88). This system is essentially a badge worn by the participant. The badge includes a video camera for continual video recording that would capture food intake. Other components include an accelerometer for monitoring physical activity and a global positioning system (GPS) for location identification. Portion size estimation will be estimated by a research analyst using an interactive program on a desktop computer (91). Engineering researchers in the group developing this wearable sensor have explored ideas for automating portion size estimation, and have further explored using a plate as a circular reference of size (91) or context from the surface on which the food is eaten (92). Once food identifications and volume estimates are obtained, nutrient composition would be estimated using the FNDDS (88).

Although the technicalities of FIVR and the wearable sensor are described, no studies of user interaction or validation for these methods have been published. Therefore, it is unknown whether key features of FIVR (i.e. verbal descriptions of foods into the telephone and taking multiple images) would be adopted by users, if the images captured by users would be useful for the automated analysis, or if the automated volume estimations are valid. Similarly, the wearable sensor has not been tested for utility among users nor have adoption of key features such as use of a round plate and participants willingness to measure plates used been tested.

A third program in development is the Dietary Data Recorder System (DDRS) (89). In this system, the user uses a mobile telephone to record images of eating events. The mobile telephone is modified to include a laser module. Participants move the mobile telephone with the laser module around the food in a circular motion, projecting the laser around the entire surface of the food (89). Rather than a single image, a video sequence of the food is captured. Prior to and at the end of a study period, the user will complete an on-device survey regarding eating habits. Throughout the recording day, the user will answer questions in regards to the time and place of the meal. Audio recording and barcode scanning is also available for the participant to use to add descriptions to video sequences. The user also has the opportunity to review and edit the intake data. While the volume will be automatically computed, a trained nutritionist will analyze the images and review the audio recordings and participant entered information for identifying the food type (89).

All of these programs aim to collect diet intake information. The use of images along with self-entered word descriptions of foods provides an incredible amount of information not otherwise captured in words alone. One aspect that may be overshadowed in the excitement of improved measures of dietary intake is the researcher burden related to analyzing images. Currently countless hours are spent in research labs, interpreting and entering hand-written dietary records into programs like NDS-R and conducting 24-hour dietary recalls. For image-based methods described thus far, there is still considerable burden on the researcher to quickly analyze images and estimate portions. For small studies, the use of researcher analysts may be feasible; however for population based studies it is likely not feasible to have research staff analyzing all food images. The time commitment would make this a cost-prohibitive analysis method. Ideally, image-based dietary assessment methods would reduce error-related burden not only on the user, but also on the researcher.

2.6 The Technology Assisted Dietary Assessment Program

The Technology Assisted Dietary Assessment (TADA) program, also a subproject of the GEI aims to leverage technology to improve dietary assessment methods. One of the systems under development is a dietary record application for real-time recording of dietary intakes in which images of eating occasions will be captured using a mobile hand-held computing device with an integrated camera (e.g. iPhone, iPod Touch). The dietary record application deployed on a mobile telephone is referred to as the mobile telephone dietary record (mpFR). The mpFR utilizes sophisticated image analysis software, and relies primarily on automated analysis of images. Both food identifications and portion size estimations are done by a computing system rather than a trained analyst. An overview of this method is in Chapter 3.

An evaluation model for mobile health applications has been developed by Dohan, *et al* (93). Factors to consider when developing an electronic dietary assessment method or other electronic health assessment program include the utility, usability, and features that contribute to adoption by users (93). Technological advances provide an opportunity for applications with unique functions, but the resulting outcomes of device use are influenced by the level of adoption among users. In many studies, the focus of publications is to describe validity of an application relative to a conventional method (e.g. 24-hour dietary recall). Thus far, electronic dietary records have not improved accuracy of dietary assessment (20). Digital versions of modified traditional dietary assessment methods are offered as consumer mobile telephone applications. The applications described in section 2.1.3. require users to report the food they consumed by following a series of questions displayed on the mobile telephone's screen. As a result of this user input, these applications estimate and summarize total energy and selected nutrients. However, these apps may introduce new barriers (e.g. poorly lit screen (20)) while failing to address the shortcomings of the traditional methods. The technology specific barriers are often not addressed. Using a model such as the Dohan model during the development of a mobile health application can help identify and address barriers that are related to an application's utility, usability and features.

During the development of the mpFR, there has been a keen awareness of the need for evidence based development. Initial studies focused on the interaction between the user and the application in order to inform the development of the user interface (94). These studies are part of what make the development of the mpFR unique from other GEI projects (87;88) in which the focus has been on the engineering components without iterative input from potential users of the dietary assessment tools. Questions that needed to be addressed related to the utility, usability, and features as outlined in the Dohan model (93). Initial studies investigated the usability of the mpFR (82;94;95). For many recording methods, accuracy may be attenuated by reactivity to self-report. This concept relates to feature evaluation in the Dohan model in that social aspects of mpFR should be addressed. Chapter 5 describes the study designed to assess for reactivity among adolescents using the mpFR in a laboratory setting. The mpFR includes a review process for explicit contextual information from the user, and will eventually include a digital recording mode to be used when an image is not captured. For both of these functions, we must know if adolescents' can identify the foods they eat, and furthermore, if they can identify foods in an image several hours post-prandially. For the digital recording mode, I tested adolescents' abilities to estimate portions of foods consumed using two PSEAs that would be appropriate for the small mobile telephone screen. Utility and adoption were examined among adults using the mpFR for 3 non-consecutive days. Chapter 6 describes the study designed to address whether adults using the mpFR in a free-living environment wouldadopt the mpFR to record eating events for 3 days. In addition, reporting of commonly underreported foods and time of eating event were evaluated. Reported energy intakes using the mpFR were compared to expected energy requirements among the adults in this feasibility study. In the Chapter 7, the use of urinary sucrose and fructose as a biomarker of dietary sugars intake is described. As adolescents frequently consume foods high in total sugars, urinary sucrose and fructose holds promise for use as an indicator/predictive biomarker for identifying high consumers of total sugars. Chapter 7 describes the evaluation of this biomarker among adolescents.

Automated image-driven methods such as the mpFR hold the most potential to reduce the burden of many aspects of recording dietary intake for the users and reduces burden of analysis for the researchers. Innovative biomarkers of dietary intakes show promise for elucidating diet disease relationships and compensate for self-report errors in conventional methods of dietary assessment (e.g. 24-hour dietary recall, dietary records). Together, this collection of research contributes to efforts for improving dietary assessment methods so that associations between diet and disease risk might be better understood

CHAPTER 3. MERGING DIETARY ASSESSMENT WITH THE ADOLESCENT LIFE STYLE

This Chapter has been submitted to and is under review with the Journal of Human Nutrition and Dietetics

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3.1 Abstract

The use of image-based dietary assessment methods shows promise for improving dietary self-report among children. The Technology Assisted Dietary Assessment (TADA) food record application is a self-administered food record specifically designed to address the burden and human error associated with conventional methods of dietary assessment. Users would take images of foods and beverages at all eating occasions using a mobile telephone or mobile device with an integrated camera, (e.g., Apple iPhone, Google Nexus One, Apple iPod Touch, Nokia N810 internet tablet). Image analysis, i.e., segmentation, feature extraction, and classification, allows for automated food identification. Portion size estimation is also automated via segmentation and geometric shape template modeling. When an image is not suitable for image analysis, the user

can self-label the foods and beverages in the image. When an image is not taken there would be an alternate method for self-reporting foods and beverages consumed. Both automated and self-entered data can be indexed with the Food and Nutrient Database for Dietary Studies (FNDDS) to provide a detailed diet analysis for use in epidemiologic or intervention studies. Data collected during controlled feeding studies in a camp-like setting have allowed for formative evaluation and validation of the TADA food record application. This review summarizes the system design and the evidence-based development of image-based methods for dietary assessment among children.

3.2 Introduction

Assessment of diet among adolescents is problematic. Energy intake estimates are under-reported among adolescents with reported energy intakes representing 67-88% of energy expenditure as measured by doubly labeled water (32;57). The more accurate reporting was found among younger rather than older adolescents. Early adolescents, ages 11 to 14 years, in particular, are in that period of time when the novelty and curiosity of assisting in or self-reporting of food intakes starts to wane and the assistance from parents is seen as an intrusion (96;97). Dietary assessment methods need to continue to evolve to meet challenges and there is recognition that further improvements will enhance the consistency and strength of the association of diet with disease risk, especially in light of the current obesity epidemic among youth.

Children and adolescents are eager in terms of adopting new technology. Among early adolescents completing a questionnaire in 2005, 59% (17/29) owned a cell phone and 66% (19/29) reported owning a digital camera (82). When testing a prototype PDA food record tool among 31 adolescents, almost every child indicated previous experience using a PDA and readily adapted to using the tool (82). Recent consumer reports indicate that 75% of adolescents aged 12-17 years have their own mobile telephone (98). This is a substantial increase since 2004 when only 45% of adolescents had a mobile telephone. Mobile phones have become “indispensable tools in teen communication patterns (98).” Young people desire a phone that allows for taking and sending images, playing games, social networking, and texting (98). Mobile devices have evolved to meet market demand for general purpose mobile computing devices and their high-speed multimedia processors and data network capability also make mobile devices ideal as a field data collection tool for dietary assessment.

3.3 Development of a Mobile Telephone Food Record

The Technology Assisted Dietary Assessment (TADA) program aims to leverage technology to improve dietary assessment methods. One of the systems under development is a food record application for real time recording of dietary intakes in which images of eating occasions will be captured using a mobile hand-held computing device with an integrated camera (e.g. iPhone, iPod Touch). The food record application deployed on a mobile telephone is referred to as the mobile telephone food record (mpFR). Image processing for identification and quantification of foods and beverages consumed will be employed and indexed with the USDA Food and Nutrient Database for Dietary Studies (FNDDS) for computation of macro- and micro-nutrient intakes. Automated image-driven methods hold the most potential to reduce the burden of many aspects of recording dietary intake for the users and reduces burden of analysis for the researchers.

Given the rapid evolution of mobile technology, design decisions for the mpFR must consider cross-platform usability as much as possible. Initial development of the mpFR was conducted on HTC mobile telephones running Windows for Mobile (94;99). For the purpose of developing a product for testing, current platforms' consumer popularity is a major consideration. Platforms currently being deployed include iPhone and smartphones running Google Android (e.g., Motorola and HTC). Schools often prohibit mobile telephone use in schools. Therefore, small handheld mobile devices such as the iPod Touch offer a viable non-telephone alternative that could be suitable for use in schools. All of these mobile handheld devices have high-speed multimedia processors, integrated cameras and data network capability that are necessary components for use with the TADA food record application together with the functions desired by young people.

The TADA food record applications will provide a detailed diet analysis for use in epidemiologic or intervention studies. The primary focus of development is an image-based system in which images captured by the user during eating occasions are sent to the server for automated food identification and volume estimation (100;101). The analyzed image is then returned to the user for confirmation before being indexed with FNDDS for nutrient analysis. The integrated system design is outlined in Figure 1. Other methods of data entry complement the automated image-based method. If an image cannot be used for automated analysis, a user can aid in identification by scanning the bar code of the product when available and aid in volume estimation by manually entering the portion of the product consumed (1). The user may also manually identify the food item in the image using a type and search mechanism that will search the FNDDS and then the user will estimate the portion consumed. When an image is not available, the user may record foods and beverages or scan the bar code of the product wrapper and estimate the portion consumed.

All of the dietary intake data are sent to a server for indexing with the FNDDS for daily estimates of energy and nutrient intake (102). All versions of the TADA food record application are designed so that any data entered can be sent to a central server using available networks such as 3G or WiFi. The advantages of storing data on a central server include: 1) allowing the researchers to periodically ensure participants in the study are properly recording food intake, 2) keeping the image analysis within a reasonable timeframe, and 3) reducing the likelihood of lost data that can occur when a mobile device malfunctions.

3.4 Image Analysis

3.4.1 Segmentation and Identification

The first step in the image analysis process is to locate each food in the image. This is called image segmentation. Various approaches to segment food items in an image that have been successfully used in many computer vision and image analysis applications have been investigated (100;103;104). Results from the segmentation step are used for food labeling and volume estimation. Thus, the accuracy of this step plays a crucial role in the overall performance of the system.

After segmentation, the next step is to extract visual features from each segment that can be used for food identification. A digital image is different from a photograph in that useful information, called metadata, is captured that is not visible, such as the time stamp and digital information. Image analysis methods use visual characteristic features such as color and texture from an image to automatically identify a food. Methods for automatic identification of food using image analysis have been previously published (99;103;105;106). Initially, synthetic plastic food models were used and the methods developed resulted in 94% of 32 food objects being correctly identified (99). The success of this system with synthetic foods provided the foundation for progress to real food images captured by adolescents. Currently, texture descriptors, local and global features, and a “voting” based classifier to identify food items have lead to enhanced final decisions for food identification (107;108). Figure 2 shows a Confusion Matrix for 19 food items in images taken by adolescents. Figure 2 (a) shows categorization results using global features, while Figure 2 (b) illustrates categorization results by decision fusion of the global and local features. The latter decision fusion approach improves the categorization rate of the classifier considerably by reducing the number of misclassified foods, i.e., fewer non-diagonal elements in Figure 2(b) compared to 2(a).

3.4.2 Volume Estimation

A context dependent, automated volume estimation technique is used for approximating food volumes using 3D primitive shapes reconstructed from a single image. Recent work has demonstrated the efficacy of this approach in generating repeatable, low variance volume estimates (109). Improved accuracy was achieved by minimizing the false-segmented regions and smoothing the segmentation boundaries of foods.

The input to the volume estimation method consists of the original meal image, the segmented regions, and food identification information (food label and FNDDS food code number) obtained from the image segmentation and classification methods described above (104). In the camera calibration step, the camera parameters are estimated using the fiducial marker in the original image and this information is used to reconstruct the 3D shape of a food. Given the food name and food code from the food classification process, each food is associated with an appropriate template shape. For example, a glass of milk would correspond to a generalized cylindrical shape and an orange to spherical shape. Once the best-matched template shape is assigned, errors in the segmented region are minimized to improve the next step, 3D volume feature extraction. The shape template is then used to determine geometric information for a food, such as the height, radius and area. The 3D shape is reconstructed to estimate the food volume using the geometric information. Currently, spherical, cylindrical, and arbitrary extruded solids as shape templates are used.

3.5 The User Interface

Initial testing of the TADA food record has been done among adolescents (1;94). As previously reported two samples of adolescents used the TADA food record during meals and then provided feedback about their experience during interactive sessions (94). Sample 1 included 63 adolescent boys and girls who participated in one lunch and 55 (87%, 55/63) returned for breakfast the next morning. Adolescents in Sample 2 (n=15) received all meals (08:30, 12:30, and 18:00 hrs) and snacks for a 24-hour period. All foods served were familiar to adolescents and each food was matched to a food code in the FNDDS 3.0.

Observation of adolescents interacting with the TADA food record and weighing of all foods served and plate waste provides an ideal study design for the development of components for the TADA food record. Automated food identification (i.e. automated assignment of an FNDDS food code) can easily be compared to the known food code. The error associated with automated volume estimates can be determined by comparing automated estimate to the true value using a Pearson's correlation coefficient statistic, paired *t*-tests, or Bland Altman plots. Errors detected can be addressed through improvements in the user instruction, the user interface, programming, database linkages, nutrient analysis, device memory, or hardware. Using known foods and carefully recording gram weight of served portions and plate waste allows for development of the most accurate tool possible.

The expertise of a multi-disciplinary team allows for the development of novel tools for improving accuracy of dietary assessment. However, it is critical to use evidence-based development in order to design the TADA food record from the perspective of the user (94;110). Interaction design is one form of evidence based development that focuses on designing interactive products that support the way people communicate and interacts in their everyday lives (111). Interaction design is an iterative cycle of usability testing in which user feedback is applied to future versions of device development, in this case the TADA food record application. Input from use among adolescents improves accuracy to acceptable levels, enhances usability, minimizes burden, and improves analytical output. The remainder of this review describes the interaction design of individual components of the research including the user interface, automated food identification, and automated volume estimation.

3.5.1 Capturing an Image

The primary method of collecting dietary intake data using the mpFR is image-based. Of major concern is an adolescent's ability and willingness to capture images of all eating occasions. Organized meal sessions were ideal for observing adolescents' skills necessary for following directions and capturing images useful for analysis. During meals, adolescents in Samples 1 and 2 used the mpFR running on HTC p4351 mobile telephones (HTC Corp, Taoyuan, Taiwan) running Windows Mobile 6.0 (Microsoft Corp, Redmond, WA). The adolescents were instructed to include all foods and beverages and the fiducial marker, an object of known dimensions and markings, in the image. All foods and beverages appeared in 61 (78%) of the before and after meal images taken for the first meal. In the second meal, 59 (84%) of the before and after meal images included all food and beverages (94). Similarly, the fiducial marker was completely visible in 54 (69%) of the images taken during the first meal and 53 (76%) in the second meal (94).

Following the first meal, participants took part in an interactive session where they received additional training on capturing images in various snacking situations (94). The instruction improved the adolescents' perceptions with regard to the ease of capturing images with the mpFR. Prior to the session, only 11% (n=78) of participants agreed taking images before snacking would be easy. After the session, the percent increased significantly to 32% ($p<.00001$). For taking images after snacking, there was also improvement (21% before and 43%

after, p<.00001) (94). Adolescents readily adopt new technologies and images useful for analysis can be captured by adolescents. However, creative training sessions will likely enhance cooperation among adolescents.

During interactive feedback sessions, forced choice and open-ended questions were used to collect preferences and perceptions of adolescents in regards to their experience with the mpFR. Input from adolescents clarified their reactions to using the mpFR and was informative for revisions to the TADA food record application. After using the mpFR one time, 79% of adolescents agreed that the software was easy to use (94). A majority of the adolescents (78%) agreed that they would be willing to use a credit card sized fiducial marker. Therefore, the current version of the fiducial marker is similar in dimension to a credit card.

The TADA food record does not include voice recognition because adolescents have repeatedly responded that they would not feel comfortable using voice recognition to record the names of foods into a mobile device (82;94). The individuals that consumed all foods and beverages recommended the addition of a touch-option, “ate all food and beverages”; rather than capturing an image of completely empty plates and glasses (94). The bottom line, adolescents want a tool to have as few steps as possible. Updated versions of the TADA food record have fewer screens to interact with and a more streamlined approach to capturing images. Repeated use, focused training, and timely reminder messages will alleviate errors associated with remembering to take images of all eating occasions that include all foods and beverages. To maintain cooperation of users, our system relies on a single image. Thus, it is important to assist the user in taking a quality image by providing immediate feedback about image quality. Work is underway to incorporate quick image feedback to users.

3.5.2 User Confirmation and Adjustment

After foods have been automatically identified, the server returns the image with corresponding food identification labels to the user for review. The user can confirm the labels or correct them when mistakes have been made in the automated process. Although the mpFR relies primarily on automated systems, there may be times when the image is not useful for analysis. For example, when an image is blurry the user may be able to identify foods that the system cannot (1). In this instance the user can complete the image-assisted record method during which the user can manually type the names of the foods and beverages present in the image.

There may also be times when technical error (e.g. dead battery, software malfunction) or situation (e.g. driving a car) could prevent an image from being taken, or there may be times when the user simply forgets to take an image. An alternative method for self-reporting foods and beverages as well as portions consumed is being developed.

The image assisted record method and the alternate method rely on the users' abilities to correctly identify foods and beverages consumed. To distinguish knowledge from memory, a task was designed to test the abilities of adolescents in Sample 1 to identify foods at the time of consumption (1). For Sample 2, the adolescents were provided with a printed image of their meals and were asked to identify the foods in the image approximately 10-14 hours after the meals were consumed. All adolescents wrote down the food and beverage identifications on a blank worksheet.

Adolescents in Sample 1 correctly identified thirty of the thirty-eight foods correctly 100% of the time. For Sample 2, eleven of the thirteen foods were identified correctly. All misidentified foods were identified within the same major food group. For example, Coca-Cola® was misidentified as root beer which is still a cola drink. These results provide evidence that adolescents can correctly identify familiar foods at the time of the meal and that they can look at an image of their meal up to 14 hours post-prandial and correctly identify foods in the image. Thus, providing evidence that delaying the user confirmation step to a time convenient to the user is feasible among adolescents.

To complete the alternate method, the user will need to provide not only the name but also the amount of food consumed. Portions size estimation among adolescents is problematic, and the small screen of a mobile device is a limiting factor for on screen estimation aids. Fourteen hours after the breakfast meal, Sample 2 participants were asked to estimate the amount of each food consumed at breakfast and at day time snacks using one of two estimation aids (i.e. 2 dimensional estimation aid or multiple descriptors) (1). The results were congruent with other studies indicating the challenge of estimating portions. Two foods were estimated within ±10% of the true amount consumed at least once when the 2 dimensional estimation aid was used, while six foods were estimated within ±10% of the true amount consumed at least once when the multiple descriptors estimation aid was used (1). A single estimation aid does not work well with all foods, however the use of technology may allow for using portion size estimation aids tailored to an individual food. Careful consideration must be used when choosing portion size estimation aids to be displayed during the alternate method on the mpFR.

3.6 Summary and Conclusions

The TADA mpFR system takes advantage of the technology present in recent mobile devices in order to integrate digital images, image processing and analysis, and a nutrient database to allow an adolescent user to discretely "record" foods eaten. Further advancements in mobile device technology as well as advances in image analysis techniques can be leveraged to further the success of the TADA research. While technology development often emphasizes the requirements of the system as determined by the engineer or software programmer, the goal of the TADA research aims to focus on the interaction of the user with the system (110;111). Involving adolescents has been key to developing a mpFR that will fit into the lives of the users. The adolescents' ideas have been assessed qualitatively and quantitatively to aid in the refinement of the mpFR (94). Studies to test the feasibility of implementation and full integration of the mpFR in clinical and population studies of adolescents will further drive the refinement of the application. Dietary assessment methods need to evolve to meet challenges and burdens faced by adolescents. The use of properly designed mobile device applications that work through the paradigm of how young people live and interact in the 'digital' age may address many of the issues outlined as barriers to recording food intake among adolescents. There is recognition that further improvements in dietary assessment methods will enhance the consistency and strength of the association of diet with disease risk, especially in light of the current obesity epidemic among youth.

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CHAPTER 4. ADOLESCENTS IN THE UNITED STATES CAN IDENTIFY FAMILIAR FOODS AT THE TIME OF CONSUMPTION AND WHEN PROMPTED WITH AN IMAGE 14 H POSTPRANDIAL, BUT POORLY ESTIMATE PORTIONS

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4.1 Abstract

Objective: To evaluate adolescents' abilities to identify foods and estimate the portion size of foods consumed in order to inform development of the mobile telephone food record (mpFR).

Design: Data were collected from two samples of adolescents (11–18 years). Adolescents in sample 1 participated in one lunch (n 63) and fifty-five of the sixty-three adolescents (87 %) returned for breakfast the next morning. Sample 2 volunteers received all meals and snacks for a 24 h period. At mealtime, sample 1 participants were asked to write down the names of the foods. Sample 2 participants identified foods in an image of their meal 10–14 h postprandial. Adolescents in sample 2 also estimated portion sizes of their breakfast foods and snacks.

Results: Sample 1 identified thirty of the thirty-eight food items correctly, and of the misidentified foods all were identified within the correct major food group. For sample 2, eleven of the thirteen food items were identified correctly 100% of the time. Half of the breakfast and snack foods had at least one portion size estimate within 10% of the true amount using a variety of measurement descriptors.

Conclusions: The results provide evidence that adolescents can correctly identify familiar foods and they can look at an image of their meal and identify the foods in the image up to 14.5 h postprandial. The results of the present study not only inform the development of the mpFR but also provide strong evidence of the use of digital images of eating occasions in research and clinical settings.

4.2 Introduction

Measuring an individual's dietary intake presents more challenges than other environmental exposures. Diet assessment is a challenge with adolescents (97). Portion size estimation and description of foods have been identified by adolescents as burdensome components of diet assessment (82). The development of a mobile telephone application for dietary assessment that fits into the lifestyle of young people may address these barriers (103;112). In previous studies, adolescents indicated that they would prefer dietary assessment methods using technology, e.g. a personal digital assistant with or without a camera or with a disposable camera (82). The mobile telephone food record (mpFR) is an innovative dietary assessment tool in the developmental stages (94;99;103). Ideally, a mobile telephone with a built-in camera that integrates image analysis, visualization methods and a nutrient database will be used to discretely ‘record’ foods eaten. Improvements in diet assessment methods will provide more accurate information about eating behaviours of adolescents.

The mpFR relies on a symphony of processes, both automatic and manual, that together will provide an accurate account of daily energy and nutrient intakes. The iterative cycle of capturing images, confirming or entering food descriptions and confirming or estimating portions is illustrated in Fig. 1. The primary method of acquiring a record of intake using the mpFR is akin to a traditional food record with fully automated processes (e.g. image analysis to identify foods and estimate volume). The user captures an image of his/her food and beverage before and after completing the eating occasion. The image is sent to the server where the image analysis software automatically identifies the foods and beverages on the basis of colour, texture and other visual characteristics (103). Once a food is identified, geometric equations corresponding to the shape of the food are used for automated computation of volume. After this process, the server returns an image of the labelled foods and beverages. The user can confirm the labels on each food/beverage or correct the labels when mistakes have been made in the automatic process. After confirmation, the information (i.e. food descriptions) is again sent to the server where the foods/beverages in the image are indexed with the US Department of Agriculture Food and Nutrient Database for Dietary Studies (94).

There may be times, however, when an individual takes a poor image in low lighting or when movement blurs the image. Such images cannot be used for automated image analysis. When an image is taken, but not useful for analysis, the user can type the names of the foods and beverages present in the image and estimate portions consumed. This process is referred to as an image-assisted record.

Technical error (e.g. dead battery, software malfunction) could prevent an image from being taken or an individual may be unable to take an image (e.g. driving a car). Adolescent-reported perceptions of mpFR use indicate that there will be times when a user may forget to take an image of an eating occasion (94). Given a scenario when an image is not available, there must be an alternative method for self-reporting estimated portions of foods and beverages consumed. Pre-arranged reminders will aid in prompt entry when food images are not captured. Similar to the automated data, the self-entered data can be indexed with a nutrient database.

In this iterative cycle, participants will confirm and identify foods in an image, as well as recall and identify foods eaten when an image is not available. Portion size estimation is needed when an image is not useful for analysis and when no image is available; however, portion size estimation aids are limited by the small screen on mobile devices. Therefore, we have two hypotheses related to food identification and one regarding portion size estimation. First, adolescents can correctly identify foods at the time of consumption. Second, adolescents can correctly identify foods in an image of their meal up to 14 h postprandial. Our third hypothesis is that adolescents can estimate portions of foods eaten within ±10% of the actual amount consumed when provided with a variety of portion size estimation aids suitable for a small screen.

4.3 Experimental Methods

4.3.1 Recruitment and Study Design

Data were collected from two samples of adolescents. Sample 1 included adolescents recruited from summer camps on the campus of Purdue University. Sample 2 was a convenience sample drawn from the local community (n 15). Recruitment was limited to those individuals between 11 and 18 years of age as described previously (94). Boys and girls from sample 1 participated in one lunch (n 63) and fifty-five of the sixty-three (87 %) returned for breakfast the next morning. Sample 2 volunteers received all meals (08.30, 12.30 and 18.00 hours) and snacks for a 24 h period. Between meals and snacks, activities such as scavenger hunts, bowling and miniature golf were scheduled to provide a camp-like experience.

At the time of the meal, sample 1 participants were asked to write down on a worksheet the names of the foods served to establish that adolescents can confirm food names, if needed (see Fig. 1, image analysis method). For sample 2, lunch and dinner food identifications were delayed up to 14 h to establish confirmation as in sample 1, but at a later and more convenient time. At 22.30 hours, the adolescents in sample 2 were asked to identify lunch foods and beverages (10 h postprandial) and estimate portion sizes of breakfast foods and daytime snacks. The estimation of portion sizes was to inform the development of the alternative method (see Fig. 1, alternative method). The food identification activity was repeated again at 08.30 hours the following morning at which time dinner foods consumed the previous evening were identified (14-5 h postprandial). The adolescents were not told to expect these activities. The study methods were approved by the Purdue University Institutional Review Board, and informed consent and assent were obtained from the volunteers and their parents, respectively.

4.3.2 Food Identification

Sample 1 participants were asked to identify the foods in the lunch and breakfast meals at the time of consumption. A worksheet representing the meal was provided and food names were written on the worksheet by each adolescent (see Fig. 4(a)). Thirty-seven different food items as listed in Table 1 were served to the participants in sample 1. The participants in sample 2 were asked to identify the foods from their lunch and dinner meals. A total of thirteen different food items as listed in Table 2 were served at lunch and dinner. In all, 10–14 h after their meals, participants in sample 2 were provided with an image of their meal along with the worksheet for food identification (Fig. 4(b)). This activity was designed to simulate typing labels for foods on the mpFR. For both samples 1 and 2, the adolescents were instructed to spell the words to the best of their ability and to use words they would usually use to describe the foods.

4.3.3 Portion Size Estimation

After 14 h of the breakfast meal, sample 2 participants were prompted with the names of the foods they were served at breakfast and as daytime snacks. They were asked to estimate the amount of each food consumed.

Two methods of portion size estimation were used. A worksheet modified from the ‘What’s In The Foods You Eat’ Search Tool, 3.0 (http://www.ars.usda.gov/Services/docs.htm?docid517032) included multiple measurement descriptors pertinent to each specific food and is referred to as the multiple descriptors (MDes) estimation aid. Examples for portion size descriptors of scrambled eggs were one egg (size not specified), one cup and one egg extra large. The second was a two-dimensional (2D) food portion visual (2D estimation aid) with 2D images of standard-sized plates and bowls with cubes depicting one-quarter, half, one and two cups (Block Dietary Data Systems, Berkeley, CA USA; http://www.nutritionquest.com). Participants were randomly divided into two groups. The first group (n 8) used the 2D estimation aid for breakfast foods and the MDes estimation aid for daytime snacks. The second group (n 7) used the MDes estimation aid for breakfast foods and the 2D estimation aid for snacks.

4.4 Data Analysis

For an identified food to be considered an exact food match, the words used by the adolescent must have matched or meant the same thing as the food served (e.g. fruit cocktail was served and fruit salad was written on the worksheet). Second, the identified food was examined for being within the same major food group (70). The words written by adolescents were evaluated as follows: Are their food identifications misspelt? Was the misspelling phonetic? Was a colloquial (or common) term used to identify the food?

For portion evaluation, the estimated intake of each food was converted into grams and compared with the actual weighed food intake in grams (estimated-actual). Paired t tests were used to examine the mean difference between the estimated intake and the weighed intakes.

Descriptive analysis included frequencies and percentages. All analyses were conducted using the Statistical Package for the Social Sciences statistical software package version 17.0 (SPSS Inc., Chicago, IL, USA).

4.5 Results

4.5.1 Food Identification Results

For sample 1, the results of the adolescents' abilities to identify and spell foods at the time of consumption are summarized in Table 1. Thirty of the thirty-eight food items were identified correctly by all the participants to whom they were served. Of the eight foods that were misidentified at least once, the names given by adolescents were within the same major food group. For example, one participant identified peaches as pears and Coke® was identified as root beer twice.

Twenty-two food items served to adolescents in sample 1 were misspelt at least once for a total of eighty-six misspelt food items. Fifty-nine of the eighty-six (69 %) misspellings were categorized as phonetic errors. Colloquial terms (e.g. soda, pop, PB&J, burger) were used at least once to describe thirteen of the foods served to sample 1 participants.

Sample 2 participants identified foods in an image of their meal 10–14.5 h postprandial. These results are summarized in Table 2. Eleven of the thirteen food items were identified correctly 100% of the time. Foods that were misidentified at least once included: chocolate cake, which was identified as brownie by four adolescents; pears, which were identified as peaches three times and as applesauce one time; and French dressing, which was identified as Italian dressing once. Common terms were used to identify three of the foods served. Every food item was misspelt at least once and only one of the misspelt words was not a phonetic misspelling.

4.5.2 Portion Size Estimation Results

Table 3 describes the results of the adolescents' abilities to estimate portion sizes of breakfast foods and daytime snacks. Using the 2D estimation aid, the mean estimates for toast, scrambled eggs, sausage links and gummy bears were not significantly different from the actual gram weight consumed. The other snacks consumed by those assigned to use the 2D estimation aid could not be converted to gram weights on the basis of the volume estimates and thus are not included in the analysis. Comparing the mean difference between estimates made using the MDes estimation aid and the actual weighed intakes of breakfast foods, no significant differences were found except for toast. The mean differences between the estimates and actual intake for gummy bears, ice cream sandwich and sugar cookie when the MDes estimation aid was used were not significantly different. Granola bar and Swiss roll were consumed by only one participant each; therefore, paired t tests could not be performed.

Considering all foods estimated by those using the 2D estimation aid, toast and gummy bears were each estimated within ±10% of the true amount consumed once. For the MDes group, four participants estimated within ±10% of the true amount consumed for scrambled eggs, two for margarine, six for jam, two for toast, one for brownie and one for gummy bears.

4.6 Discussion

The results of the present study indicate that adolescents can correctly identify foods at the time of consumption when foods are present and up to 14.5 h postprandial when prompted with an image of their meal. These results are in contrast to the results of studies that ask children and adolescents to recall foods consumed without a visual prompt (68;113-115). Baxter *et al*.(33;68) validated children's self-report of dietary intake through the use of observed meals. One of the outcomes of these observational studies is the novel approach to compare the foods recalled with the actual foods consumed and identify omissions, intrusions and misidentified foods. In a study among fourth-grade students, longer intervals between consumption and recalled intake resulted in more intrusions (68), and in another study a shortened retention interval increased accuracy (115). An image-assisted record could alleviate errors related to time sequencing, thus limiting omissions and intrusions. This suggests that individuals could be encouraged to take pictures of their foods and beverages throughout the day to assist with a 24 h dietary recall.

The results from the present study are congruent with other research indicating that portion size estimation is a challenge for adolescents. Using the MDes estimation aid, six foods (i.e. scrambled eggs, toast, jam, margarine, brownie and gummy bears) were estimated within ±10% of the truth at least once. Only toast and gummy bears were estimated within ±10% of the truth by the adolescents who used the 2D estimation aid. The range of estimates for the foods consumed further highlights the variability between participants that is sometimes overlooked. Even with the use of creative portion size estimation aids, such as modeling clay, photographs and tableware, children's estimates were considered a source of error in quantifying food and energy intake (41;116;117). Many innovative estimation aids can be used on full-size computer screens. However, the use of an integrated estimation aid on the mpFR is limited by the small screen size.

These results support that a single type of portion size estimation aid will not work well with all foods. Careful consideration should be given when choosing estimation aids to be displayed. An estimation aid used out of context of its original design could erroneously be perceived as a poor tool. For example, the smallest portion displayed on the 2D estimation is one-quarter of a cup; therefore this tool would not work well with foods usually eaten in amounts less than one-quarter of a cup, such as jam. The 2D estimation aid was likely most useful for gummy bears because the amorphous pile of gummy bears could be related to the amorphous piles of small cubes depicted in the 2D estimation aid. However, for other foods such as a brownie it may be easier for a participant to relate the shape to a portion descriptor (i.e. ‘1 brownie (2” square)’) as used in the MDes estimation aid. Our results indicate that a variety of portion size estimation aids that are tailored for the use of specific foods would result in better estimates of intake among adolescents. Technology, such as the mobile telephone, may allow for tailored estimation aids to be presented to the user.

The overall high proportion of foods correctly identified by the participants in the present study may be an artifact of serving foods familiar to adolescents (94). Although the foods served were selected because they were familiar to 162 adolescents (aged 10–18 years) who participated in two 24 h recalls (24;118), information was not collected as to these foods being familiar to individual participants in the present study. There could be variation in identification of foods served at home, school or restaurants. Alternatively, identification may be influenced by how a food is served. For example, French dressing was served to sample 1 participants for use as a dipping sauce for celery or carrots and was identified correctly by 81% of those to whom it was served (thirty-five out of forty-three). For sample 2, French dressing was served as salad dressing and only one participant out of fifteen misidentified French dressing. The possibility exists that participants in sample 2 were more likely to correctly identify French dressing because it was served in a familiar manner (i.e. salad dressing), whereas French dressing as a vegetable dip may not have been a familiar serving. Future studies should consider collecting information regarding how familiarity of foods served affects adolescents' abilities to identify food items.

Probing programmed into the mpFR is needed to obtain a more detailed account of foods eaten. A hamburger is a good example of a combination food that can contain a variety of condiments that contribute to changes in nutrient and energy intakes. The adolescents were served a hamburger on a bun with cheese, ketchup, lettuce and tomato; however, five of the twenty-four participants identified this food simply as 'hamburger' or 'burger'. For these participants, probing would potentially verify the other ingredients that may or may not accompany a hamburger, such as cheese, ketchup, tomato and lettuce, thus gathering important energy and nutrient intake data. Probing will also help to define foods when common terms such as soda, pop or cola are used. With more detail, a better match in the nutrient database can be made by the mpFR software leading to a more accurate estimate of energy and nutrient intakes. Probing would not correct misidentified food items. In the present study, chocolate cake was identified as brownie four times. Although probing would not necessarily lead an adolescent to correct the misidentified food to chocolate cake with frosting, the energy and nutrient content of the brownie with frosting is similar to the cake.

Researchers and programmers should be aware when designing food search tools for consumers, especially for adolescents, that the tool needs to accommodate misspellings, phonetics, abbreviations and common terms or synonyms. Words used by adolescents to describe foods inform the development of a search mechanism for the mpFR.

Many automated processes that will reduce error-related burdens make the mpFR unique when compared with other diet assessment methods integrating technology. The results of the present study not only inform the development of the mpFR but also provide strong evidence for the use of digital images of eating occasions in the clinical setting. A 24 h account of foods and beverages in the form of images has the potential to improve the accuracy of adolescents' 24 h dietary recalls. For the first time, there is documented evidence that adolescents can look at an image of their meal and identify the foods in the image up to 14.5 h postprandial. Most notable would likely be the decline in under-reporting due to food exclusion. The immediate benefits of image-assisted dietary assessment in research and clinical practice should not be overlooked.

CHAPTER 5. WHEN USING THE MOBILE TELEPHONE FOOD RECORD, ADOLESCENTS' ENERGY INTAKES ARE SIMILAR TO EXPECTED INTAKES

5.1 Abstract

To ensure accuracy, diet assessment methods must not influence behavior. This study sought to investigate the influence of the mobile telephone food record (mpFR) use on expected energy intake. The following proportions of estimated energy expenditure (EER) were used to determine expected energy intake from meals and snacks: breakfast 16%, lunch 27%, dinner 33% and snacks 24%. In a laboratory setting, adolescents (26 males, 51 females) aged 11-18 y used the mpFR to record meals that were eaten to satiation. Adolescents participated in breakfast (n=70), lunch (n=78), and 15 were also provided dinner and snacks. There was no significant difference between the EER and the energy consumed over the total day (n=15, p=0.35), although boys consumed significantly less energy from snacks than expected (n=12, mean difference 324 kcal, p=0.01). Girls consumed significantly more energy at dinner than expected (n=3, mean difference 196 kcal, p=0.044). Adolescents with a BMI-for-age in the 85-95th percentile consumed significantly less energy at lunch than expected (n=16, mean difference 88 kcal, p=0.047). These results suggest that mpFR use will not likely lead to reductions in energy intakes in adolescents.

5.2 Introduction

Dietary assessment can provide valuable data on factors related to disease outcome and subsequent approaches for mounting intervention programs for prevention of diseases such as overweight, obesity, type 2 diabetes and cancer. A limiting factor related to the accuracy of dietary assessment methods such as the 24-hour dietary recall and food records is the issue of underreporting of intake which occurs among both adolescents and adults. It is important to improve the accuracy of food records as they provide detail on food and beverage consumption and meal patterns not easily captured with other methods. In previous work, energy intakes assessed by paper-based food records were underestimated (57;119;120). This can occur due to a number of factors such as the burden of the task, social desirability and the effect of self-monitoring (5435; 2524; 2648; 4242). Peer pressure and social desirability are types of respondent bias in which participants respond in a manner that will be viewed favorably by others. Influences of social desirability may result in a person changing their intake during the recording period, or may result in misreporting foods and/or portions consumed. The later may contribute to underreporting of energy intake.

Paper-based food records are known to change behavior and as a result are useful for raising awareness among individuals of their dietary intakes. However, this presents problems for researchers who wish to accurately measure outcomes of interventions. Even among adolescents, underestimation of energy intake during the food record recording period occurs. Younger adolescents completing food records reported 90% and older adolescents reported approximately 70% of energy expenditure as measured by doubly labeled water . In adolescents, characteristics of under-reporters include perception of being overweight and report of weight concerns (e.g. wish to weigh less, attempting weight loss), and being female (120). In regards to peer pressure, girls may influence each other's eating behaviors more than boys (121).

With advances in technology, image-based food records offer a new approach to improving food records. Adolescents indicate a preference for image-based food records over pen and paper methods (122;123). Using a preferred method may increase cooperation for recording diet; however, few studies have been done to evaluate eating behavior changes among adolescents using an image-based dietary assessment method. In one study, children and adolescents were assisted by their parents to record diet intake in written diet diaries as well as recording intake using disposable cameras (123). The results of this study focused on the ability of the human analysts to identify foods in the images and estimate portions rather than validate the adolescents' compliance through direct observation of intake in a congregate meal setting. Studies are needed to evaluate adolescent behaviors while using image-based food record applications among their peers in order to assess for and limit behavior change during the dietary intake recording period.

The mobile telephone Food Record (mpFR) is a novel mobile device application being developed for use by researchers in dietary studies (104). The mpFR differs from paper-based food records as participants are not required to keep a written record of their food intake and estimate or weigh foods consumed. With the mpFR, participants only need to take a before and after image of their food and beverage intake. However, in order to improve the accuracy of food records, ideally the use of the mpFR should minimize the influences on dietary behaviors. One might expect that contributors to underreporting when using a pen and paper food record would also be contributors to underreporting when using the mpFR. If actual energy intakes are not significantly different from expected, and if known contributors of underreporting, e.g. BMI, gender, do not alter this relationship, then we can deduce that the mpFR is not a contributor to under-eating among adolescents. The purpose of this study was to investigate the influence of mpFR use among adolescents in a laboratory setting on expected energy intake for individual meals and 24-hour dietary intake. We hypothesized that adolescents using the mpFR in a laboratory setting would have energy intakes that were not significantly different from expected energy intakes at individual meals or over a 24-hour period.

5.3 Recruitment and Study Design

Data were collected from two convenience samples of volunteers all between the ages of 11-18 yr. The study methods were approved by the Purdue University Institutional Review Board, and informed assent and consent were obtained from the adolescents and parents, respectively. Sample 1 was drawn from summer camps for adolescents taking place on the campus of Purdue University. Sample 1 included sixty-three volunteers who attended one lunch session and 55 of those returned for breakfast the next morning. Sample 2 was drawn from the local community where recruitment posters were posted in campus buildings, churches, and community centers. These volunteers received all meals and snacks during a 24-hour observation period. Use of the mpFR involves taking an image of the meal prior to eating, interacting with any screen prompts on the mobile phone, and taking an image of the meal after eating as described previously (94). Participants in both samples used the mpFR for observed eating occasions. The participants were instructed to eat as much or as little as they wanted and to ask for seconds if desired. The foods served were prepared based on descriptions of foods listed in the USDA Food and Nutrient Database for Dietary Studies (FNDDS), thus each food closely represented the nutrient profile of the food listed in the FNDDS. Pre- and post-food weights were obtained for each participant for each food item in order to calculate actual food intake in grams (pre-weight – post-weight = amount consumed). Energy (kcal) intake was calculated using values obtained from the Food and Nutrient Database for Dietary Studies (FNDDS). For participants in Samples 1 and 2, energy was summed for each eating occasion. For Sample 2, energy was also summed for the entire 24-hour period.

Estimated energy requirements (EER) were calculated using an activity factor of low active (1.13 for boys and 1.16 for girls) (124). For this study, the reference distribution of energy intake from individual meals and snacks (breakfast 16%, lunch 27%, dinner 33%, snacks 24%) were derived from results reported by Dwyer (125) among 8th graders and consistent with results among the majority of adolescents from a nationally representative sample (126). These values were used to determine expected energy intake as a percent of the daily estimated energy requirement at each eating occasion. For sample 1, body mass index (BMI) was calculated using reported heights and weights. For sample 2, heights and weights were systematically measured by trained research staff. Using BMI-for-age growth charts provided by the Centers for Disease Control and Prevention, participants were classified as underweight (< 5th percentile), normal weight (≥ 5th and < 85th percentiles), overweight (≥ 85th and < 95th percentiles), or obese (> 95th percentile).

Paired *t*-tests were used for comparison between the expected energy intake and actual energy intake for each eating occasion for Sample 1 and Sample 2. Actual energy intakes over a 24-hour period and EER were compared for Sample 2. Comparisons included analysis by gender, age group, and BMI-for-age classification in order to assess known contributors to under-reporting. Among adolescents, the most prevalent observation is energy intakes below expectation as documented by Bandini *et al* n=26 (57) and, Champagne *et al* n=118 (32). Thus, a priori the proportion of adolescents with energy intakes below expectations should exceed those with expected energy intakes. Bland-Altman plots (127), the recommended method to assess the agreement between the 24-hour actual and expected energy intakes, were used in Sample 2. A Bland-Altman plot is not an inferential statistical method; therefore a sample size calculation would be inappropriate.

5.4 Results

The findings of this study indicated that adolescents using the mpFR in a laboratory setting have energy intakes that were not significantly different from expected energy intakes over a 24-hour period (See Table 4) or at individual meals (See Table 4 and 5). The mean EER for the 15 adolescents in Sample 2 was 2731kcal, and the mean energy consumed was 2522 kcal. There was no significant difference between the mean EER and the actual mean energy consumed over the total day (p = 0.35). Boys consumed significantly less energy from snacks than expected (mean difference 324 kcal, SE 111, p = 0.01). However, there was no significant difference between total day energy intake and EER among boys. Girls in Sample 2 consumed significantly more energy at dinner than expected (mean difference 196 kcal, SE 43, p = 0.044). Adolescents from Sample 1 and Sample 2 with a BMI for age in the 85-95th percentile consumed significantly less energy at lunch than expected (p = 0.047), but this only amounted to a mean difference of 88 kcal. No other differences were detected by evaluating factors usually associated with under-reporting (i.e., BMI, gender) (See Tables 4 and 5). For Sample 2, the Bland-Altman plot indicated one outlier and otherwise no visual bias. All values were within the limits of agreement. See Figure 5.

5.5 Discussion

Self-monitoring through the use of food records has been considered a cornerstone for weight loss interventions (128). Taking digital images as a complement to traditional paper-based food records has been suggested to influence behavior in the direction of reduced intake (129). However, in the current study, energy intakes were not significantly different from EER for one day when participants were recording images of eating events using the mpFR. Energy intakes at individual eating occasions were similar to expected energy intakes. As there was no significant difference between total day energy intake and EER, the boys who consumed less energy than expected from snacks likely compensated during meals.

Notably, under-eating as opposed to under-reporting was examined in the present study. In the present study, participants used the mpFR to record their meals. However, the difference between the weighed portions of foods served and the weighed portions of foods remaining were used to evaluate the energy intakes of each participant. One might suspect that psychosocial factors that are associated with under-reporting could also apply to under-eating in a laboratory setting, and that the use of the mpFR for recording diet could result in a self-monitoring effect. In particular, social desirability and social acceptance might have an effect on energy intakes in the presence of unfamiliar peers as well as the research staff present.

Although this study included a small number of participants, particularly small for those in Sample 2, the resulting similarity between expected intakes and actual intakes are congruent with a study among ??(ref). Among adults, energy intakes in the laboratory setting were similar to reported energy intake in the free-living environment (130). These results found by Obarzanek, *et al.* did not compare rEI to expected energy intakes (130), thus could not differentiate between under-reporting and under-eating. In our study, intakes at individual meals and across a full day were compared to expected energy intakes allowing assessment of under-eating. Participants in this study did not exhibit patterns of under-eating that could be attributed to social desirability or social acceptance, the laboratory setting, or by use of the mpFR.

Development of the mpFR takes advantage of technology present in mobile devices to integrate digital images, image processing and analysis, and a nutrient database to allow an adolescent user to discretely “record” foods eaten. The device’s digital camera is used to capture an image of a user’s meal or snack both before and after eating. Based on the results reported here, forgetting to take an image is likely to contribute more toward under-reporting than social desirability among adolescents.

5.6 Implications and Conclusions

Improved accuracy of diet assessment will aid in efforts to understand relationships between diet and health. A mpFR that translates to an accurate account of daily food and nutrient intake among adolescents and adults holds promise for improved study outcomes. However, in order to get an accurate account of energy and nutrient intake, dietary patterns must not be influenced by mpFR use. Adolescents and parents of adolescents have reported that taking images of food is much simpler than keeping written food records (123). This may be why use of the mpFR was not a contributing influence on energy intake among these samples of adolescents.

These findings contribute to the evidence-based development of a mpFR that holds promise of being a data collection tool that will match the lifestyle of respondents while providing better information about daily food and nutrient intakes of adolescents. Over all, the results of this study suggest that use of the mpFR does not alter eating behaviors in adolescents either at single eating meals or an entire day.

CHAPTER 6. REPORTED ENERGY INTAKES AMONG ADULTS USING THE MOBILE TELEPHONE FOOD RECORD DOES NOT DIFFER SIGNIFICANTLY FROM ESTIMATED ENERGY REQUIREMENTS

6.1 Abstract

The mobile telephone food record (mpFR) is a unique dietary assessment tool in development. The user records eating events in images taken before and after eating. The objective of this feasibility study was to compare reported energy intake (rEI) from 3 non-consecutive days of mpFR use to estimated energy requirements (EER). Evaluation of potential reporting error in image-based methods was also explored. Twelve adults (aged 20-58 y. 5 women, 7 men) were recruited from the campus community in fall, 2010. All meals and snacks of known portions were provided to participants in excess of their EER. Participants received training on using the mpFR. Participants were asked to capture images of all meals and snacks each day. Participants' images were reviewed by research staff who estimated portions of foods and beverages. Foods were categorized according to the 16 AMPM major food groups. Each image was assigned to a time of day quadrant using the stamp on the image. The mean difference between rEI and EER was -348 kcal (SE 227). There was no significant difference between mean rEI across recording days and EER (p = 0.155). Foods categorized as beverages, sweets, desserts, snacks and

condiments accounted for 51% of reported foods and mean 44% of rEI. Foods consumed during between 10pm and 6am represented 13% (min: 0; max; 23%) of total rEI across 3 recording days. These results reinforce the use of image-based dietary assessment in the clinical and research settings leading to more accurate accounts of dietary intake.

6.2 Introduction

Dietary assessment provides valuable insight for understanding the relationship between diet and disease such as cancer and diabetes. Traditional methods of dietary assessment, such as the 24-hour dietary recall and written food record, are fraught with error associated with self-report. Underreporting may include not writing down foods eaten, or reporting a lesser amount than actually consumed. Studies using doubly labeled water as a biomarker of energy expenditure, which in weight maintenance is synonymous with energy intakes, reveal the level of error associated with self-report of dietary intakes. Energy intakes are often underestimated by as much as 20% with 24-hour dietary recalls and 40% with food records (14;29;30).

Contributions to these differences between reported energy intakes (rEI) and energy expenditures as measured by doubly labeled water may include errors in portion size estimation as well as intrusions i.e. foods reported, but not consumed or exclusions i.e. foods consumed but not reported (63). The burden associated with completing conventional methods of self-reported dietary intakes have been associated with participant cooperation. Among adults keeping a food record, the rEI decreases as number of recording days increases (64;76). While some attribute this phenomenon to change in behavior due to a self-monitoring effect, others would suggest that the mere burden of recording drives this change (131).

Technology has been pursued as a way to improve diet assessment. Subar *et al* suggest that technology will be paramount for decreasing burden and increasing cooperation among participants in dietary intake studies (77). The wide-spread use of digital cameras and mobile devices with integrated cameras provides a unique opportunity for developing electronic, image based food record. Image-based dietary assessment methods in which a user takes images of his/her meals and snacks hold promise to improve dietary assessment through reduced participant burden as well as improved estimates of portions consumed. Use of images for aid in estimating portions of foods present the images include three categories; 1) images reviewed by the user/participant, 2) images reviewed by a trained analyst, and 3) images reviewed by an automated system with confirmation from the user/participant. Image Diet Day is a promising approach to image-assisted dietary recall (132). In this system, the images captured by users are reviewed by the user to aid in the recall of foods and portions consumed (132). In other methods, the images are reviewed by trained analysts who estimate portions of foods and beverages in the image (86;133). These methods reduce burden on the user, but not necessarily the researcher. The mobile telephone food record (mpFR) is a unique dietary assessment tool that relies primarily on automated portion size estimation (99-101;103-105;107-109) in an effort to reduce the burden on both the user/participant as well as reducing the researcher burden related to trained analysts and data entry (134). The user records foods and beverages in images taken before and after eating. The resulting images can be used for automated food identification and portion size estimation followed by a simple review process in which the user/participant aids in confirming and/or correcting the automated food identifications (1;100;101;109).

The mpFR is being designed to fit in the life-style of its user in hopes to capture the best estimates of dietary intake (1;94). However; remembering to take images of snacks may be difficult (94), thus underreporting may still manifest when eating events are not reported. For conventional methods of dietary assessment, low-energy reporters when compared to plausible energy reporters provide insight into foods that are more likely to be underreported in frequency and in portion size. Foods that are often underreported include savory snacks, soft drinks, condiments, sweets, and beverages (43). Over half the adult participants in the 1994-96 Continuing Survey of Food Intakes by Individuals reported consuming multiple snacks per day (135). Most frequently reported snacks included similar foods to frequently underreported foods such as coffee, soft drinks, beer, and ice cream (43;135). The simplistic design of an image-based dietary assessment method such as the mpFR may ameliorate both frequency and portion size estimation errors related to commonly underreported foods.

This feasibility study, in preparation for a larger validation of the mpFR, was designed to evaluate the cooperation of participants using the mpFR in a free living environment. In previous studies, participants used the mpFR to record eating events in the laboratory environment (1;94). This is the first study to investigate use of the mpFR among free-living adults consuming meals mainly outside the laboratory environment. When using the mpFR, reported energy intake (rEI) is the energy represented by the foods in the images taken by the participants. Images taken in real-time provide a unique opportunity to assess intake during hours of the day in which foods may be less likely to be reported. Providing foods commonly consumed by adults, provided opportunities for evaluating cooperation of mpFR use compared to known foods and portions of those foods. Thus, the objectives of this study were three-fold: First, to compare reported energy intake (rEI) from 3 non-consecutive days of mpFR use (i.e., images of meals and snacks) to Estimated Energy Requirements (EER); second, to assess whether commonly underreported foods would be recorded in images (e.g., snacks, beverages); third, to assess rEI across time of day quadrants.

The primary hypothesis of this study was that across 3 non-consecutive days, rEI will not significantly differ from expected energy intakes. The secondary hypothesis was that users will remember to capture images of commonly underreported foods and snacks throughout a 24-hour period and will be reflected in the rEI.

6.3 Methods

Adult participants were recruited from the campus community. The study methods were approved by the Blinded University Institutional Review Board, and informed consent was obtained from the participants. A pre-study visit was arranged in which participants' heights and weights were measured by trained research staff using standard procedures (136). Estimated energy requirements (EER) for each participant were calculated using an activity factor of low active; 1.12 for males, 1.11 females (137).

All meals and snacks of known portions were provided to participants. Menus at three energy levels (i.e. 2000, 2500, and 3000 kcal) were designed such that participants would receive a daily menu in excess of their EER allowing for participants to eat to satiation. For participants with EER >3000, extra portions of entrees and snacks were provided. On two days, participants' eating events occurred in their free-living environments. On these two days, meals and snacks were packed in the laboratory setting and given to participants to take home. For one day, all meals were consumed in the research facility and the provided snacks were eaten in their free-living environments. Participants were randomly assigned to consume meals in the research facility on recording day 1, 2, or 3. Portions of foods and beverages provided were recorded prior to distribution to participants. Participants were asked to return all uneaten food, and portions returned were recorded.

The participants received training on using the mpFR installed on iPhone 3Gs. Participants were asked to capture images of all meals and snacks on each of three non-consecutive days. Participants were encouraged to take images of any foods or beverages they consumed that were not provided to them. Before and after images taken by the participants were reviewed by research staff and portions of foods and beverages in each image were estimated using a standard protocol. The mpFR relies primarily on automated food identification and portion size computations; however for the purpose of this study trained analysts identified foods and estimated portions of foods consumed. Analysts had knowledge of the foods and portions provided.

The Food and Nutrient Database for Dietary Studies was used for obtaining energy content for each food and beverage. Reported energy intakes (rEI) of all foods present in images were calculated. In order to account for estimation error that could occur in the identification and estimation of foods present in images, but not provided to participants, reported energy intakes of only foods that were provided (rEI-provided) were also calculated. For example beverages such as sodas and alcoholic beverages were not provided, but were present in images. Presumed energy intakes were estimated as the difference between the energy content food portions provided and food portions returned. The presumed energy intakes served as an imbedded assessment of the analyst estimations of portions in the images. Under- and over-reporters were defined as those with rEI fell outside the 95% confidence interval of the mean.

Food items recorded in images were assigned to one of the AMPM major food groups (14) for analysis by food group. The meta-data time stamp on the image was used to assign each image to a time of day quadrant defined as A) 06:00 – 10:59, B) 11:00-16:59, C) 17:00-21:59, and D) 22:00-05:59.

6.4 Statistical Methods

IBM SPSS statistics release 19 (SPSS, Inc, Chicago, Illinois) was used for all analysis. Descriptive statistics included frequencies, percents and means. Differences within participants were examined using paired *t* tests.

6.5 Results

Twelve adults (aged 20-58 y. 5 women, 7 men) participated in this feasability study. Participant characteristics are described in Table 6. Mean EER (n = 12) was 2566 kcal. The mean rEI for all foods in images on all reporting days was 2190 kcal (CI: 1791, 2590). Mean presumed energy intake for all recording days was 2313 kcal. The mean rEI based only on foods provided was 2165 kcal. One participant did not use the mpFR on one recording day, thus only contributed 2 recording days in the analysis. The mean difference between rEI-provided and mean presumed energy intake was -148 kcal (SD 416 kcal); however the difference was not significant (p = 0.243). The mean difference between the average rEI across three recording days and EER was also not significant (p = 0.155). Among the males, 2 participants were identified as underreporters and 1 overreporter. Among the women, there was one identified underreporter and one overreporter. Those participants who may have under- or over-reported energy intakes based on did not affect the mean rEI, thus were included in all analysis. There were no significant differences found between mean rEI and mean EER on recording day 1, 2 or 3. Nor was there a significant difference between the mean rEI and mean EER across 1, 2, or 3 combined recording days. See Table 7.

Among the 12 participants, 754 food items were reported. Foods categorized as beverages, candy, syrups, sweeteners, desserts, snacks and condiments (i.e. commonly underreported foods (43), were provided to participants and these foods were recorded in images. The number of foods and proportion of energy from each AMPM major food group is outlined in Table 8. Of the 754 foods reported 109 (14%) were beverages not provided to the participants (e.g., coffee, sodas, beer, water). Beverages contributed a mean 13% of participants' total rEI and together, candy, syrups, sweeteners, desserts, snacks, and condiments accounted for a mean 29% of rEI (214 foods; 28% of foods reported). A majority of participants recorded images in all four time quadrants at least once. One participant did not report any images in quadrant D. The highest mean rEI was reported in time quadrant C (41% of rEI). The mean proportions of rEI during quadrants A, B, and D were 19%, 26%, and 14%, respectively.

6.6 Conclusions

A mobile telephone Food Record that translates to an accurate account of daily food and nutrient intake among adolescents and adults holds promise for improved study outcomes. This is the first study to assess reported energy intake across three days of mpFR use in a free living environment. The mean rEI among adults in this study was not significantly different than was expected. In this study, un-reported energy cannot be quantified. The study did allow for interesting observations of individual foods reported as well as reported energy intakes across 3 non-consecutive days and during time quadrants within those days.

Results from conventional methods have been fairly consistent that compliance, as demonstrated by total energy intake reported, falls off after several days or after repeated measures (28; 29; 30), (ref). This has been observed with multiple days of dietary records (76). Additionally, the second 24-hour dietary recall is usually lower than the first recall, and the estimated intakes from a second food frequency questionnaire have usually been lower than the first (29). In contrast to these observations with the traditional methods, the small levels of underreporteing observed with the mpFR use were consistent across the three days, (i.e. mean differences -297, -231, -307 respectively) except in the one case where one individual only completed two days. The lack of evidence for a tapering off of compliance across the 3 days is consistent with the concept of an individual establishing a tolerable level of compliance and maintaining this level.

The allocation of PAL is a limitation in our study. Tooze *et al* suggest using a PAL constant of 1.55 when estimating expected energy requirements (138). We chose to use a PAL of 1.12 for males, 1.11 females as outlined by the Dietary Reference Intakes for estimating expected energy intakes in our study sample (137). Unless an entire report of PA over a 24-hour period is available, then the use of PAL is unclear (138). Thus, selection of PAL is a recognized limitation. The concept of identifying under- and over-reporters as those participants with rEI outside the 95% confidence limits was explored in the current analyses. Both under- and over-reporters were identified among the 12 participants in the current study. Considering the small sample size of this feasibility study, we would expect to identify under-, but not over-reporting as over-reporting is rare. Based on data from the OPEN study, 5 of the 484 participants were considered over-reporters (29). These participants were excluded from analysis of sensitivity and specificity of the Goldberg method applied to the OPEN study reporting (138). The application of the designated PAL used in the current study, although a recognized limitation is of particular interest in that it allowed for identification of reporters on both extremes.

Furthermore, foods that are commonly underreported in other studies, e.g. soda, sweets, condiments, included 116 reported foods (15%) represented food and beverage items that we did not provide. One might suspect that foods commonly underreported in conventional methods of dietary assessment would be underreported when using the mpFR. However, the possibility exists that the image capture process is so effortless that the time and opportunity to dwell on social desirability is abated. However, we cannot rule out that our distribution of foods such as candy bars and cookies may have attenuated the motivation for social desirability.

Despite no formal reminders being integrated in the mpFR system used in this study, there is evidence that commonly underreported foods are captured in images at all hours of the day among participants who were not shift workers. Two types of reminders have been proposed as a result of this study. Primary reminders set at three times suggested by an individual for main eating events. Secondary reminders set for 4 hours after the last eating event may provide an opportunity for an individual to quickly record any eating events that may not have been captured in an image as participants in previous studies (139) have suggested that there may be times when images are forgotten. Reminders to take images, or record foods not recorded in images will only improve image-based dietary assessment methods.

This study was a feasibility study in preparation for validation of the mpFR in which energy estimates generated from one week of mpFR use will be compared to energy expenditure measured by doubly labeled water. Thus, allowing for biomarker validation of underreporting. In the present study, there is evidence that the analyst estimates of portions in before and after images were not significantly different from presumed intakes based on the difference between portions provided and returned. For many studies in which food is provided to participants, analyst estimates may be a good alternative until the mpFR or other automated systems are available for wide-spread use in the research community.

Despite the challenges in the collection of food intake, diet assessment provides valuable insight into the occurrence of disease and subsequent approaches for mounting intervention programs for prevention. Improved diet assessment methods will translate to a better understanding of eating behaviors, as well as a way to test the effectiveness of diet intervention programs. These results reinforce the use of image based dietary assessment in population-based, epidemiology studies leading to more accurate accounts of dietary intake.

CHAPTER 7. APPLICATION OF URINARY SUCROSE AND FRUCTOSE AS AN INDICATOR BIOMARKER FOR IDENTIFYING LOW, MEDIUM, AND HIGH ADOLESCENT CONSUMERS OF DIETARY SUGARS

7.1 Abstract

Urinary sucrose and fructose have been introduced as indicator biomarkers for dietary sugar intake. Although urinary sucrose and fructose are not widely adopted biomarkers, they hold promise for evaluating intake among adolescents given their high intakes of sugars. The objective of this study was to compare estimates of total sugar intakes to 24-hour urinary sucrose and fructose. Adolescents were recruited from the local community. Fifteen adolescents (ages 11-18y) were provided 3 meals and ad libitum sweet snacks over a 24-hour period. Gram weights of served foods and plate waste were recorded and total sugar was estimated using the Food and Nutrient Database for Dietary Studies. Three total sugar intake levels emerged (p<0.0001) which were defined as low (n=5, mean 123 g/d, SD 22), medium (n=7, mean 173 g/d, SD 13), and high (n=3, mean 235 g/d, SD 25). Fourteen out of 15 adolescents provided complete 24-hour urine collections confirmed by the PABA-check method. Sucrose and fructose concentrations in urine were measured using an enzymatic assay specific for sucrose and fructose. By the total sugar intake levels, mean urinary sucrose and fructose were significantly different (ANOVA p = 0.001 and

p <0.0001, respectively). The mean fructose recovery for each intake level was: low 18.8 ± 12.3 mg/d, medium 22.4 ± 12.9 mg/d and high 91.7 ± 13.0 mg/d. These results support urinary sucrose and fructose as indicator biomarkers for stratification of total sugar intakes among adolescents. Notably, urinary sucrose and fructose could be used to identify high consumers of often under-reported foods (e.g. sweet snacks, sugar sweetened beverages, and desserts).

7.2 Introduction

Adolescents' snacking frequency has been positively associated with intakes of energy, carbohydrate and total sugars, and negatively associated with protein and fat intakes (139). For adolescents, grain desserts and soda are two of the top 5 sources of total energy intake as well as top sources of added sugars (6). Besides soda and grain desserts, the other top sources of added sugars in the adolescent diet include fruit drinks, dairy desserts, and candy (6). Excess consumption of sugar sweetened beverages is of particular concern, as adolescents consume between 145 -299 kcal per day from sugar sweetened beverages alone (6).

Despite the data indicating high intakes of dietary sugars and high prevalence of obesity, associating dietary sugars with risk for disease such as cancer and even obesity is controversial. In a large prospective study, there was no significant association between intakes of sugars and risk for any major cancer type among adults (140). Such studies may be plagued by the limitations of food frequency questionnaires and reliance on self-report. Dietary assessment among adolescents is a challenge. Adolescents are susceptible to social desirability, reactivity, and have trouble estimating portion sizes (97). Studies in which reported energy intakes are compared to energy expenditure as measured by doubly labeled water indicate under-reporting of energy intakes among adolescents (31;56). Given the sporadic schedules of many adolescents (141), it may also be difficult for them to remember everything they have consumed when responding to a 24-hour dietary recall, or they may forget to record all foods and beverages when completing a food record. Self-report dietary assessment methods are informative; however there may be times when a more objective measure is necessary to define diet-disease relationships.

Objective dietary biomarkers are being developed to address inherent errors in self-report methods and thus, shed light on the diet–disease relationship (33). Urinary sucrose and fructose were introduced as indicator biomarkers for dietary sugar intake by Tasevska *et al* (43). Urinary sucrose results from small fractions of sucrose that bypass hydrolysis and are excreted in urine (141). Fructose may bypass hepatic metabolism and thus, be excreted in urine (141). While the recovery of the marker is quite small, the correlation between dietary intakes and dietary sugars intakes shows a dose response for low, medium, and high intake levels. Urinary sucrose and fructose were found to be indicators of added sugar and total sugar intakes among adults (141). Johner *et al* explored the use of this biomarker in prepubertal children, and found that urinary fructose alone was associated with both total sugar intakes and added sugar intakes (142).

Urinary sucrose and fructose as a biomarker has not been investigated among adolescents. The purpose of this study was to examine the feasibility of urinary sucrose and fructose as a biomarker for total dietary sugar intakes among adolescents in observed settings. The primary hypothesis was that estimates for total sugars from one day of known dietary intakes will significantly correlate with 24-hour urinary sucrose and fructose among adolescent boys and girls.

7.3 Study Design and Methods

Adolescents (ages 11-18y) were recruited from the local community. Participants and their parents provided informed consent and assent, respectively. All procedures were approved by the Purdue University Institutional Review Board. Participants arrived to the research facility after having voided the rising urine at home. All subsequent urinations were collected until the following morning when the 24-hour urine collection ended with the rising urination. Urine collections were transported throughout the day in insulated coolers. Each child’s collected urine was pooled for total volume measure, and 2g/L boric acid was added as a preservative. Urine aliquots were frozen until analysis. Completeness of urine collections were confirmed by the PABA-check method (39). Urine collections are considered complete if PABA recovery is at least 85%. Sucrose and fructose concentrations in urine were measured using an enzymatic assay kit specific for sucrose and fructose (r-biopharm) using a spectrophotometer. This is the same analysis method used by Tasevska *et al* (43;143). All runs were performed in duplicate.

Participants were provided 3 meals (consumed to satiation), and ad libitum sweet snacks over a 24-hour period. Sweet snacks made available were chocolate chip cookies, sugar cookies, brownies, ice cream sandwiches, gummy bears, granola bars, Hostess® Ding Dongs® and Little Debbie® Swiss Rolls. The menus included foods commonly consumed by adolescents in the United States and are described elsewhere (144) (94). Gram weights of served foods and plate waste were recorded to the nearest tenth of a gram.

Total sugar intake was estimated using nutrient composition for each food as listed in the USDA Food and Nutrient Database for Dietary Studies (FNDDS) (145). Included in the estimates of total sugars using the FNDDS are individual monosaccarides (i.e. galactose, glucose, fructose) and disaccharides (i.e. sucrose, lactose, maltose) (146).

7.4 Statistical Analysis

One way ANOVA was used to examine whether means of quantitative variables were significantly different. Bonferroni was used for any post-hoc analysis. Pearson's correlation coefficient was used for defining correlations between urinary sucrose and fructose excretion with total dietary sugar intakes. All analyses were conducted using the Statistical Package for the Social Sciences statistical software package version 17.0 (SPSS Inc., Chicago, IL, USA).

7.5 Results

Fifteen adolescents (12 boys, 3 girls) participated in this study. Using the criterion of PABA recovery, 14 of the 15 adolescents provided complete 24-hour urine collections. Participant characteristics are listed in Table 9. As shown in Table 10, three total sugar intake levels emerged (ANOVA $p<0.0001$). Intakes were defined as low (n=5, mean 123 ± 22 g/d), medium (n=7, mean 174 ± 12 g/d), and high (n=2, mean 220 ± 1 g/d). Among the 14 participants with complete urine samples, mean total energy intake during the 24-hour period was 2462 ± 400 kcal and mean total sugar intake was 162 ± 37 g/d.

Urinary sucrose and fructose were significantly correlated with dietary intakes of total sugars (n = 14; r = 0.642, $p = 0.013$ and r = 0.579, $p = 0.030$, respectively) as shown in Figure 6. The means for urinary sucrose and fructose at each total sugar intake level were significantly different (ANOVA $p = 0.001$ and $p < 0.001$, respectively). For sucrose, the mean recovery at each intake level was low 13.21±3.6 mg/d, medium 15.3±4.5 mg/d, and high 33.6±7.9 mg/d. The mean fructose recovery for each intake level was low 18.9±12.3 mg/d, medium 22.4±12.9 mg/d, and high 91.7±13.0 mg/d. When all participants were included (n = 15), the statistically significant correlation was maintained (sucrose $r = 0.547$, *p* = 0.035 and fructose *r* = 0.518, *p* = 0.048). However, the correlation was stronger when only participants with complete urine collections were included.

7.6 Discussion

To the best of our knowledge, this is the first study to report a significant correlation between intakes of total sugars and urinary sucrose and fructose among adolescents. Three distinct levels of dietary intakes of total sugars emerged among 14 adolescents consuming meals to satiation and ad libitum sweet snacks. Furthermore, the mean urinary sucrose and fructose excretion were significantly different between levels of total sugar intakes. These results are congruent with the results of Tasevska (43;142). Thus, urinary sucrose and fructose hold promise as an indicator biomarker for total sugar intakes across the lifespan; children (142), adolescents in the present study, and adults (43).

In the present study, total dietary intake was known. Foods served have been described elsewhere (94;144). In brief, foods served were foods known to be commonly consumed by adolescents. The participants' choices of sweet snacks varied as is represented by the range of total sugar intakes. Among the adolescents in this study, sweet snacks were provided for the participants to consume ad libitum throughout the day. This may have encouraged intake and resulted in intakes that are not representative of a usual day for some of these participants.

Despite the laboratory eating environment, mean urinary sucrose and fructose excretion were similar to previous studies (141, 142, 42). Whereas studies by Tasevska *et al* included multiple 24-hour urine collections, the study by Johner *et al* (143) along with the present study only included 1, 24-hour urine collection. Even in the present study which took place in the laboratory setting, one participant did not provide a complete 24-hour urine collection. In one of the largest studies to collect 24-hour urinary samples, the OPEN study (147), 76% of the adult participants provided complete urine samples for the 1st collection and 73% on the 2nd collection. The merit and feasibility of needing only 1, 24-hour urine collection to potentially assess a more accurate level of dietary sugar intake in larger population samples should be explored.

Recovery biomarkers, e.g. urinary nitrogen, are defined by high recoveries and high correlations between intake and urinary output. Linear regression equations have been used for adjusting urinary nitrogen, sodium and potassium in urinary collections in cases where the PABA recovery is below the 85% cut-off (41). However, urinary sugars are defined as a predictive, or indicator biomarker in which excretion of the marker of interest is quite small (43). Therefore, in the case of urinary sugars, there are no known adjustments. Incomplete urine collections will likely skew the relationship between urinary sugar excretion and presumed intake. In the present study, the significant correlation between intake and urinary sugar excretion was maintained even when the participant with an incomplete urine collection was included in analysis. A similar significant correlation was reported among prepubertal children with urine collections that were not confirmed using PABA (142). Notably, in our study, the correlation was stronger when the participant was excluded. The need for complete urine collections as confirmed by PABA has been indicated by Tasevska *et al*, and studies in which urine samples are not confirmed for completeness should be approached with caution.

These results support urinary sucrose and fructose as indicator biomarkers for stratification of total sugar intakes among adolescents. Although fruits, vegetables, and dairy products have naturally occurring sugars that contribute to total dietary sugar intakes, adolescent intakes of fruits, vegetables and dairy foods do not meet the recommendations defined by the Dietary Guidelines for Americans (148). In addition, consumption of added sugars exceeds recommendations for discretionary energy (149). These observations would suggest that discrimation between adolescents by urinary sucrose and fructose would likely represent added sugars versus naturally occurring sugars. Notably, urinary sucrose and fructose could be used to identify high consumers of often under-reported foods such as sweet snack foods, sugar sweetened beverages, and desserts.

CHAPTER 8. DISCUSSION

The culmination of the studies presented in this dissertation contributes evidence for improving dietary assessment among adolescents and adults. Diet assessment methods that are more accurate are needed to grasp eating behaviors, define diet-disease relationships, and to measure the effectiveness of intervention programs for obesity as well as its co-morbidities. Dietary assessment includes methods of food intake recording as well as biomarkers of dietary intake. Rapid advancement of technology in the last 15 years has led to new methods of measurement. Mobile devices with integrated cameras provide a new measurement avenue for recording dietary intakes. Laboratory equipment capabilities have also been a part of the rapid evolution of technology. Before these advancements, the focus was on understanding the error in dietary assessment and accommodating for error in analysis (150). However, these advancements give us opportunities to improve dietary assessment measures. In particular, image-based methods for self-reported dietary intakes and unbiased biomarkers such as urinary sucrose and fructose.

8.1 Implication

8.1.1 Evaluation of the mpFR among adolescents and adults

Positive aspects of the mpFR development study include the evidence-based developments that not only inform us about the accuracy of the tool, but also of the usability, utility and adoption among its users. Previous work in the development of digital dietary recording whether digital entry or image-based has been on accuracy. For digital entry food records, there has been no evidence that implementing a digital version of a food record translates to improved measure or more accurate measures. While burdens such as small screen size and scrolling through long lists have been suggested as barriers specific to the technology, we must remember that these tools do not remove existing barriers such as portion size estimation (20). Even in the development of image-based methods, there has been little published regarding the user-interaction. There is much interest in the engineering principles for the FIVR (151), Unified Sensor System (88;91;92;152;153) and the DDRS (89) that might remove burden of portion size estimation. However, the developers of these innovative tools have not reported any studies relating to usability, utility and adoption as suggested by Dohan, *et al* (93). The mpFR is unique for having a strong interdisciplinary team of nutritionists and engineers who work together and disseminate findings related to the user interaction experience, the engineering principles in development, and the validation of the tool (1;82;94;95;99;102-104;107-109;134;154-157).

Studies described in this dissertation have highlighted the advantages of using the mpFR for dietary assessment. For example, taking an image at off times of the day may be easier than traditional recording. The novelty of the tool may improve cooperation. Social desirability or burden of recording commonly forgotten foods may be minimized. These studies have also confirmed that the proposed user interaction design is viable. For example, participants will confirm the automated food identification and correct any foods which may be misidentified (1). Prior to the study described in Chaper 4 (1), it was unknown whether this review step could be delayed to a time that would be convenient to the user. This study confirmed that accurate food identification can be obtained up to 14 hours after an eating event (1). This removes the potentially undesirable act of prolonged interaction with the mpFR at the time of the eating event while maintaining accuracy of recorded dietary intakes.

Limitations of the mpFR have also been identified, and user feedback has contributed to making improvements in the application's user interface as well as the training program designed for mpFR users. Adolescents and adults can take images useful for analysis (94;95). However, there may be times when a user forgets to take an image (94;95). When an image is not captured, the user will need to complete a digital entry of the foods consumed and the portions of those foods (1). Adolescents estimating portions of breakfast foods using PSEAs that could be modified for use on the mpFR struggled with accurate estimates of portions which is congruent with other portion size estimation studies (41;158).

Reminders will be important for maximizing the opportunity to capture eating events in images, and thus avoiding the need for users to estimate portion sizes. We propose 2 types of reminders. Primary reminders at pre-set for eating times designated by the user may help prevent forgotten images at eating events. Secondary reminders could be implemented 4 hours after the last received event. This would give users an opportunity to make note of any foods or beverages consumed, but not captured in an image.

The results described in Ch 6 among adults using the mpFR for 3 non-consecutive days emphasize a unique aspect of image based methods. The use of images allows us to explore and evaluate the environments in which people are eating. Prompts used in a 24-hour dietary recall or a food record may gain information on eating event location (e.g. home, work, restaurant). Images captured by adults using the mpFR indicated a variety of eating environments. Foods were provided, thus restaurant eating was not expected. However environment variations including a dining table with table cloth, work space with electronic parts, notebook paper, or computer were visible in the images.

8.1.2 Evaluation of Urinary Sucrose and Fructose as a Biomarker for Total Sugar Intakes Among Adolescents

Among adolescents, there was a significant correlation between intakes of total sugars and urinary sucrose and fructose among adolescents. Even among a small sample of adolescents, three distinct levels of dietary intakes of total sugars emerged among adolescents consuming meals to satiation and ad libitum sweet snacks. Furthermore, the mean urinary sucrose and fructose were significantly different between levels of total sugar intakes. Thus, urinary sucrose and fructose hold promise as an indicator biomarker for total sugar intakes among adults as well as adolescents.

Taseveska's work and analysis suggests that urinary fructose and sucrose could be used to assess gradients of sugar intake, thus helping improve diet assessment methods by assessing error in methods of self-report (e.g. 24-hour dietary recall) (44;144;159). Alternatively, a predictive biomarker might be used independently of self-report to categorize a participant close to his/her true intake of dietary sugars.

A statistical model is being developed by Tasevska *et al* for evaluating error in self-report of participants in the OPEN study (144). If we could accommodate for underreporting of foods high in refined sugars (43), we might be able to better define presumed disease risks. Collecting 24-hour urine samples is not always feasible. However, the work Tasevska has begun evaluating self-report among adults in the OPEN study (144) using urinary sucrose and fructose as unbiased markers of total sugar intakes may lead to interesting opportunities. Further exploration using urinary sucrose and fructose as a predictor variable may elicit a dietary pattern from the self-report obtained through FFQs. The resulting dietary pattern could then be applied for use in longitudinal studies examining the relationship between sugar intakes and cancer incidence which is currently an unresolved relationship.

8.2 Future Directions

The development of the mpFR has depended on a dedicated team of nutritionists and engineers. The studies described in this dissertation as well as others suggest that the mpFR will be a tool that will be adopted by adolescents and adults. The results of these studies have informed the interaction design. In particular, those who have participated in these studies have helped our research team prioritize automated design features as well as training guidelines that aid in the image capture process. These studies highlight the importance of the multidisciplinary teamwork needed to continue the development and maintenance of the mpFR.

The development of biomarkers for dietary intake shows promise for improving our understanding of diet-disease relationships. Particularly in light of commonly underreported foods (e.g. sweet snacks, sugar sweetened beverages) that are presumed to contribute to the obesity epidemic. Using urinary biomarkers that require a 24-hour urine collection may not be feasible in large, prospective cohorts. However, there may be future possibilities merging the concepts of biomarker measures and dietary pattern analysis. Tasevska *et al* have measured urinary sucrose and fructose among a large cohort of adults who have completed food frequency questionnaires (160). It is possible that a dietary pattern may emerge if urinary sugars were used as a depended variable in regression analysis. The dietary pattern could then be applied to a prospective cohort monitoring cancer incidence which used the same FFQ. This would give researchers a new opportunity to examine the relationship between total sugar intake and incidence of disease.

The results of studies conducted thus far suggest that the mpFR is a promising tool for improving the accuracy of dietary assessment. If the mpFR were to become widely adopted for nutritional research studies, there may be similar opportunities for merging biomarkers of dietary intake with dietary intake data resulting from mpFR use to examine dietary patterns that might be applied to the data collected in other studies in which the mpFR is used.

8.3 Conclusion

The evaluation of the two novel methods for measuring dietary intakes in this dissertation (i.e. the mpFR and urinary sucrose and fructose as biomarker of total sugar intakes) contributes to the understanding and knowledge of advancing dietary assessment for improved measures of diet as well as stronger associations between diet and disease outcomes. Despite the challenges in the collection of food intake, diet assessment provides some of the most valuable insights into the occurrence of disease and subsequent approaches for mounting intervention programs for prevention. Improved diet assessment methods will translate to a better understanding of eating behaviors, as well as a way to test the effectiveness of diet intervention programs. My contribution to improved methods of diet assessment will translate to accurate accounts of food intake with the potential to inform future interventions.

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Table 1Adolescents’ ability to identify and spell foods at time of consumption

Meal	Number of participants	Food Item	Correct Identification n (%)	Misspelling n (%)	Phonetic Misspelling n (% phonetic/total misspelled)
Breakfast A	n=5	Milk, 2%	5 (100)	0 (0)	--
		Peanut Butter	5 (100)	0 (0)	--
		Bagel	5 (100))	0 (0)	--
		Apple Juice	5 (100)	0 (0)	--
		Cream Cheese	2 (40)	0 (0)	--
		Strawberry Jam	5 (100)	0 (0)	--
Breakfast B	n=27	Milk, 2%	27 (100)	0 (0)	--
		Gogurt	26 (96)	9 (33)	6 (67)
		Mini Muffins	26 (96)	6 (22)	3 (50)
		Granola Bar	26 (96)	9 (33)	5 (56)
		Orange Juice	27 (100)	3 (11)	--
Breakfast C	n=12	Milk, 2%[1]	24 (100)	0 (0)	--
		Honey Nut Cheerios®	12 (100)	3 (25)	3 (100)
		Banana	12 (100)	2 (17)	2 (100)
		Apple Juice	12 (100)	1 (8)	1 (100)
Breakfast D	n=11	Milk, 2%	11 (100)	0 (0)	--
		Sausage Links	11 (100)	0 (0)	--
		Scrambled Eggs	11 (100)	0 (0)	--
		White Toast	11 (100)	0 (0)	--
		Orange Juice	11 (100)	1 (9)	1 (100)
		Margarine	11 (100)	1 (9)	1 (100)
		Jam	11 (100)	0 (0)	--
Lunch A	n=28	Milk, 2%	28(100)	0(0)	0(0)
		Grilled Cheese Sandwich	28(100)	6(21)	4(14)
		Chocolate Chip Cookie	26(93)	4(14)	3(11)
		Cheese Puffs	27(96)[2]	7(25)	6(21)
		Apples	28(100)	0(0)	0(0)
		Celery	28(100)	10(36)	8(29)
		French Dressing	22(79)	7(25)	6(21)
		Coke®	26(93)	3(11)	2(7)
Lunch B	n=15	Milk, 2%	15(100)	0(0)	0(0)
		Peanut Butter and Jelly Sandwich	15(100)	1(7)	0(0)
		Fruit Cocktail	15(100)	0(0)	0(0)
		Potato Chips	15(100)	2(13)	1(7)
		Carrot Sticks	15(100)	0(0)	0(0)
		French Dressing	13(87)	0(0)	0(0)
		Gummy Bears	15(100)	3(20)	2(13)
		Coke®	15(100)	1(7)	1(7)
Lunch C	n=11	Milk, 2%	11(100)	0(0)	0(0)
		Pudding	11(100)	1(9)	1(9)
		Hot Dog on a Bun	11(100)	2(18)	0(0)
		Orange, sliced	11(100)	1(0)	1(9)
		French Fries	11(100)	0(0)	0(0)
		Catsup	11(100)	0(0)	0(0)
		Pickle Relish	11(100)	0(0)	0(0)
		Mustard	11(100)	0(0)	0(0)
		Coke®	11(100)	0(0)	0(0)
Lunch D	n=9	Milk, 2%	9(100)	0(0)	0(0)
		Sugar Cookie	9(100)	0(0)	0(0)
		Peaches	9(100)	0(0)	0(0)
		Cheeseburger on a bun	9(100)	1(11)	0(0)
		French Fries	9(100)	0(0)	0(0)
		Catsup	9(100)	2(22)	2(22)
		Coke®	9(100)	0(0)	0(0)

[1] milk served as beverage and as addition to cereal
[2]one participant did not label food item

Table 2 Adolescents' ability to identify and spell foods up to 14 hours post-prandial (n=15)

Meal	Food Item	Correct Identification n (%)	Misspelling n (%)	Phonetic Misspelling n (% phonetic/total misspelled)
Lunch	Milk, 2%	15 (100)	1 (7)	1 (100)
	Sugar cookie	15 (100)	2 (13)	2 (100)
	Peaches	15 (100)	2 (13)	2 (100)
	Cheeseburger on a bun	15 (100)	5 (33)	5 (100)
	French fries	15 (100)	1 (7)	1 (100)
	Catsup	15 (100)	5 (33)	5 (100)
	Coke®	15 (100)	1 (7)	1 (100)
Dinner	Milk, 2%	15 (100)	0 (0)	--
	Garlic toast	15 (100)	0 (0)	--
	Spaghetti	15 (100)	9 (60)	9 (100)
	Chocolate cake	10 (67) [1]	4 (27)	3 (75)
	Pears, canned	10 (67)	1 (7)	1 (100)
	Salad greens	15 (100)	1 (7)	1 (100)
	French dressing	14 (93)	2 (13)	1 (50)
	Coke®	15 (100)	0 (0)	--

[1] One participant did not identify food item

Table 3 Adolescents' abilities to estimate portion size of breakfast foods and day time snacks

Portion Size Estimation Aid	Breakfast food	n	Estimated (g)		Consumed (g)		Mean difference Estimated - Consumed		Number of Estimates within ±10% of true intake
			Mean	SD	Mean	SD	(g)	(kJ)	
2D	Scrambled Eggs	8	93.63	55.4	64.66	26.1	+29.0	188	0
	Sausage Links	8	43.13	16.0	52.78	17.5	-9.5	-130	0
	Margarine	7	33.91	20.3	5.64	4.5	+28.3*	636*	0
	Jam	8	46.80	23.4	9.79	5.5	+37.0*	402*	0
	Toast	7	43.50	21.4	46.03	25.4	-2.5	-29	1
	Gummy Bears	3	54.13	10.8	67.3	23.9	-13.2	-218	1
MDes	Scrambled Eggs	7	52.36	34.7	48.03	21.9	+4.3	29	4
	Sausage Links	7	66.29	92.5	46.24	0.6	+20.0	268	0
	Margarine	7	12.04	12.4	8.79	7.7	+3.3	71	2
	Jam	7	10.00	17.5	2.86	7.6	+7.1	79	6
	Toast	7	69.50	35.8	41.31	17.0	+28.2*	347*	2
	Brownie	3	34.0	0.00	42.9	8.3	-8.9	-142	1
	Chocolate Chip Cookie	2	29.0	21.2	42.3	20.1	-13.3*	-272*	0
	Gummy Bears	3	108.6	64.2	40.2	0.5	+68.4	1134	1
	Granola Bar	1	18.0	--	30.3	--	-12.3†	-238†	0
	Swiss Roll	1	80.0	--	59.1	--	+20.9†	+83†	0
	Ice Cream Sandwich	2	44.2	20.9	68.3	1.3	-24.0	-58	0
	Sugar Cookie	2	20.5	6.4	28.2	0.2	-7.6	-36	0

*Significant difference between estimated and actual intake, $p<0.05$

† Paired t-test cannot be computed because n=1

Table 4 Mean energy difference between expected and actual energy intakes among adolescent boys and girls in Sample 2[a]

Sample 2	n	Eating Occasion	EER (kcal) (mean ± SE)	EI (kcal) (mean ± SE)	Energy Difference (kcal) (mean ± SE)	*p*-value
Boys and girls	15	24-hour intake	2731(163)	2522(117)	-209 ± 217	0.352
Ages 11-14 years	6	Snacks	524(15)	560(46)	36 ± 48	0.482
	6	Dinner	720(21)	1066(34)	346 ± 43	0.000
Ages 15-18 years	9	Snacks	743(44)	237(77)	-506 ± 94	0.011
	9	Dinner	1022(61)	853(73)	-168 ± 63	0.028
BMI percentile[b]						
≥ 5th and < 85th	11	Snacks	605(36)	419(78)	-186 ± 97	0.085
	11	Dinner	832(50)	919(70)	87 ± 99	0.401
≥ 85th and < 95th	3	Snacks	765(101)	251(106)	-513 ± 204	0.129
	3	Dinner	1051(139)	974(54)	-77 ± 134	0.622
Boys	12	Snacks	689(43)	366(77)	-324 ± 111	0.014
	12	Dinner	948(59)	945(65)	-2.51 ± 95	0.979
Girls	3	Snacks	520(31)	371(122)	-149 ± 99	0.271
	3	Dinner	714(42)	912(72)	197 ± 43	0.044

[a] Sample 2 participants received 3 meals and snacks throughout the day, thus 24-hour intake, dinner, and snacks reported only for Sample 2.

[b] Using BMI-for-age growth charts provided by the Centers for Disease Control and Prevention participants were classified as underweight (< 5th percentile), normal weight (≥ 5th and < 85th percentiles), overweight (≥ 85th and < 95th percentiles), or obese (> 95th percentile).

Table 5 Mean energy difference between expected and actual energy intakes among adolescent boys and girls in Samples 1 and 2.

Samples 1 and 2	n	Eating Occasion	EER (kcal) (mean ± SE)	EI (kcal) (mean ± SE)	Energy Difference (kcal) (mean ± SE)	*p*-value
Ages 11-14 years	40	Breakfast	356(8)	378(31)	22 ± 29	0.445
	44	Lunch	599(12)	578(33)	-21 ± 29	0.472
Age 15-18 years	29	Breakfast	422(21)	454(31)	32 ± 31	0.316
	32	Lunch	706(33)	692(46)	-13 ± 55	0.811
BMI percentile[a]						
<5th	3	Breakfast	339(41)	359(132)	21 ± 123	0.881
	3	Lunch	572(70)	798(306)	225 ± 238	0.443
≥ 5th and < 85th	44	Breakfast	362(9)	395(29)	33 ± 27	0.230
	49	Lunch	609(14)	617(37)	9 ± 36	0.810
≥ 85th and < 95th	14	Breakfast	407(25)	448(49)	41 ± 46	0.395
	16	Lunch	679(38)	590(44)	-88 ± 41	0.047
> 95th	8	Breakfast	483(51)	450(49)	32(61)	0.615
	8	Lunch	815(86)	684(51)	130(96)	0.214
Boys	24	Breakfast	458(23)	508 (41)	50 ± 44	0.267
	25	Lunch	765 (37)	740(49)	-25 ± 60	0.680
Girls	45	Breakfast	345(5)	358(23)	14 ± 22	0.546
	51	Lunch	585(8)	570(31)	-14 ± 31	0.647

[a] Using BMI-for-age growth charts provided by the Centers for Disease Control and Prevention participants were classified as underweight (< 5th percentile), normal weight (≥ 5th and < 85th percentiles), overweight (≥ 85th and < 95th percentiles), or obese (> 95th percentile).

Table 6 Participant characteristics of adults using the mpFR for 3 non-consecutive days.

Gender	Males	Females	Total
Male	7	5	12
Median Age (yr)	25	22	23
Anthropometric Measures		Mean (SD)	
Height (m)	1.8 (.05)	1.6 (0.7)	1.7 (0.09)
Weight (kg)	80.1 (12.0)	57.8 (11.7)	70.8 (16.1)
Body mass index	25.3 (3.4)	21.0 (3.1)	23.5 (3.8)
Dietary Intake Parameters		Mean (95% CI)	
Estimated energy requirement based on DRI[1]	2866 (2594, 3137)	2145 (1941, 2350)	2566 (2286, 2846)
Reported energy intake based on images of all foods	2313 (1713,2913)	2156 (1357,2955)	2190 (1791, 2590)
Presumed energy intake based on foods returned	2505 (2064, 2946)	2043 (1211, 2875)	2313 (1940, 2685))
Reported energy intake of only study provided foods	2245 (1743, 2747)	2052 (1215, 2889)	2165(1796, 2533))

[1] Dietary Reference Intakes for Americans, Physical Activity Level of low active: 1.12 for males, 1.11 for females IOM, 2006

Table 7 Reported energy intakes compared to estimated energy requirements for individual recording days and for number of recording days among adults using the mpFR.

		rEI	EER[1]	Difference	p-value
Individual Recording day	n	Mean kcal for each day (SD)			
Day 1	12	2266	2566	-297 (651)	0.142
Day 2	12	2301	2566	-231 (811)	0.344
Day 3	11*	2223	2530	-307 (905)	0.286
Number of Recording Days		Mean kcal for 1, 2 and 3 days (SD)			
1 Day	12	2266	2566	-297 (651)	0.142
2 Days	12	2334	2566	-264 (697)	0.216
3 Days	11	2283	2530	-247 (757)	0.306

[1] Dietary Reference Intakes for Americans, Physical Activity Level of low active: 1.12 for males, 1.11 for females IOM, 2006

* One participant did not record any eating events on 1 recording day, thus contributing only 2 days to the analysis.

Table 8 Number of foods reported and mean proportion of rEI within each AMPM major food group (n = 12)

AMPM major food group[1]	Number of Foods Reported[2]	Mean % of rEI[3]
Beverages, Milk, Cream	176	13
Breads, Sweet Breads	80	18
Candy, Syrup, Sweeteners	26	5
Cereals, Pasta, Rice	13	3
Cheese, Eggs, Yogurt	63	8
Dessert, Ice Cream	50	8
Fruits and Vegetables	96	6
Meat, Poultry	15	2
Frozen Meals	21	11
Mixed Dish	42	11
Sandwiches	20	2
Sauce, Gravy, Salsa	14	0
Snacks	45	10
Spreads, Dressings, Oils	93	7
Total number of reported foods	754	104

[1] Major food group names adapted from AMPM food group names.
[2] Total number of foods reported by all participants across 3 days.
[3] Total sum of percents is 101% due to rounding.

Table 9 Characteristics of adolescents by urine recovery status

Characteristic	Total sample	Complete urine sample[1]
	n	
Male	12	11
Female	3	3
	Mean ± SD[2]	
Age (y)	14.7 ± 2	14.8 ± 2
Weight (kg)	63.6 ± 18.2	64.9 ± 18.2
Height (m)	1.7 ± 0.14	1.69 ± 0.14
Body mass index (kg/m^2)	22 ± 4	22 ± 4
Estimated energy requirement (kcal)	2731 ± 630	2767 ± 639

[1] Complete urine sample defined by PABA recovery of ≥85%.

[2] Standard deviation

Table 10 Total energy intake (TEI), total sugar intake, and urinary sugar excretion among adolescents by total sugar intake level[1]

	n	Total energy intake (kcal)[2]	Total sugar intake (g)[3]	Total sugar intake/TEI (%)[4]	Sucrose recovery (mg)[5]	Fructose recovery (mg)[6]
				mean (SD)		
Total Sample	14	2462 (400)	162 (37)	26 (3.3)	17.5 (8.0)	31.0 (2.8)
Total Sugar Intake Levels						
Low (97 – 144 g)	5	2143 (414)[a]	123 (22)[a]	23 (2.4)[a]	14.2 (3.6)[a]	18.9 (1.2)[a]
Medium (161-192 g)	7	2536 (212)[a,b]	174 (12)[b]	28 (2.7)[b]	15.3 (4.5)[a]	22.4 (1.3)[a]
High (219 – 221g)	2	2997 (64)[b]	220 (1)[c]	29 (0.4)[b]	33.6 (7.9)[b]	91.7 (1.3)[b]

[1]Columns with different alphas are statistically significantly different.
[2] Total energy intake overall ANOVA $p = 0.014$; intake level low vs high is $p = 0.016$.
[3] Total sugar intake overall ANOVA $p < 0.0001$; intake level low vs medium is $p = 0.001$, low vs high is $p<0.0001$, medium vs high is $p = 0.012$.
[4] Total sugar intake/TEI overall ANOVA $p = 0.013$; intake level low vs medium is $p = 0.032$, low vs high is $p = 0.034$.
[5]Sucrose overall ANOVA $p = 0.001$; intake level low vs medium is $p = 0.001$ and medium vs high $p = 0.001$.
[6]Fructose overall ANOVA $p<0.0001$; intake level low vs medium is $p < 0.001$ and low vs high $p < 0.001$.

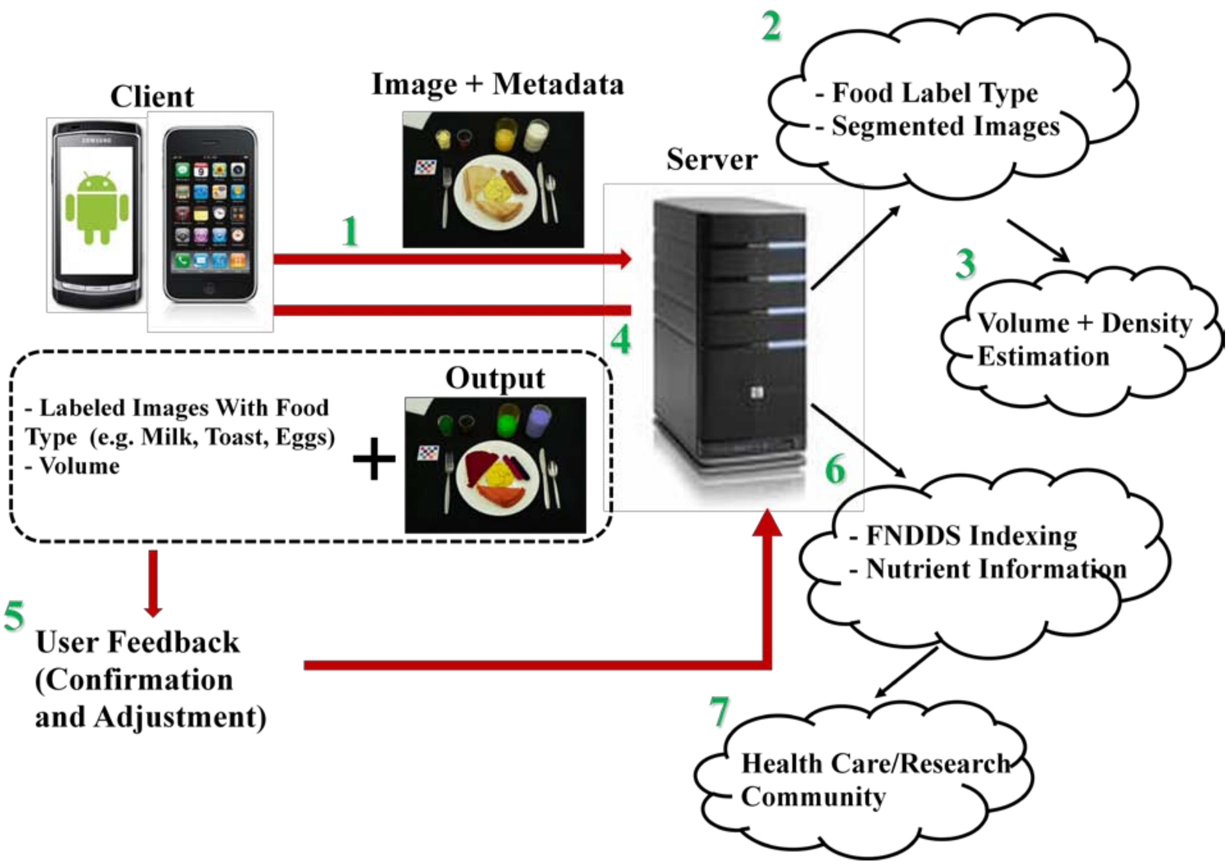
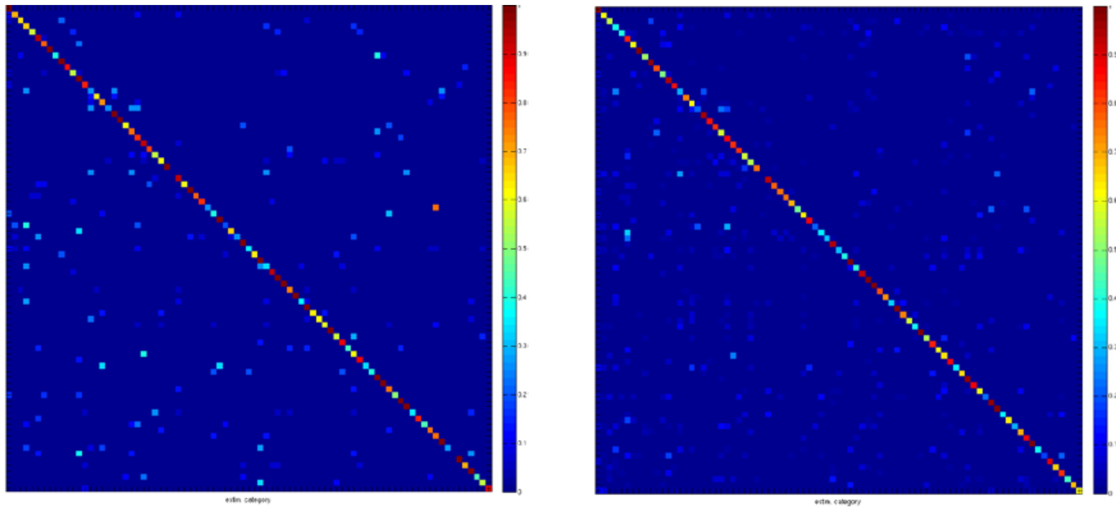


Figure 1 System overview of the mobile telephone food record. Numbers refer to distinct steps in the system



(a) (b)

Figure 2 Confusion Matrix (a) Using only global color and texture features and (b) using local and global features. The nearly straight-line performance indicates accurate classification.

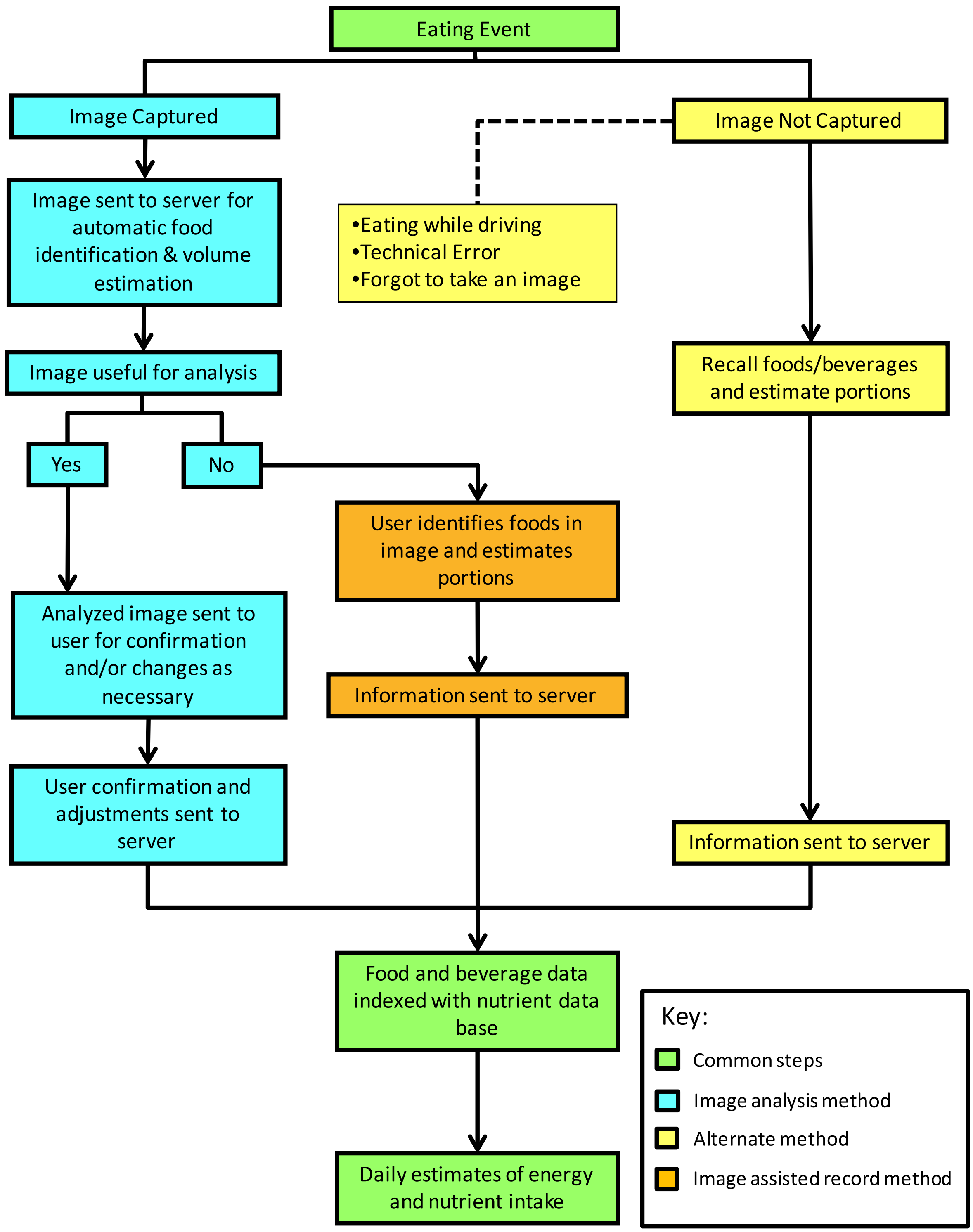


Figure 3 Iterative process for automated and self-entered dietary data collection on the mobile telephone Food Record

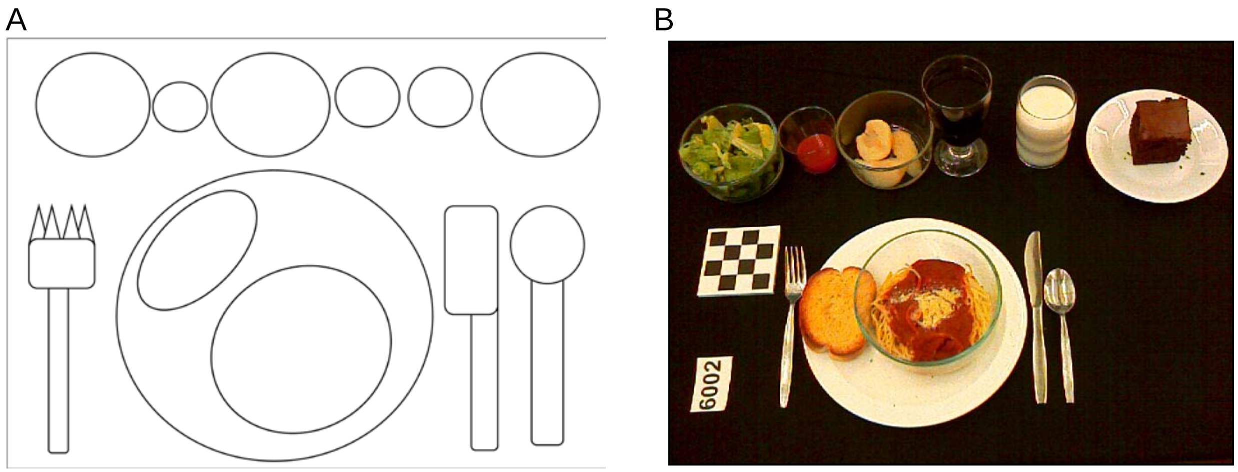


Figure 4 Meal identification form and image of dinner meal

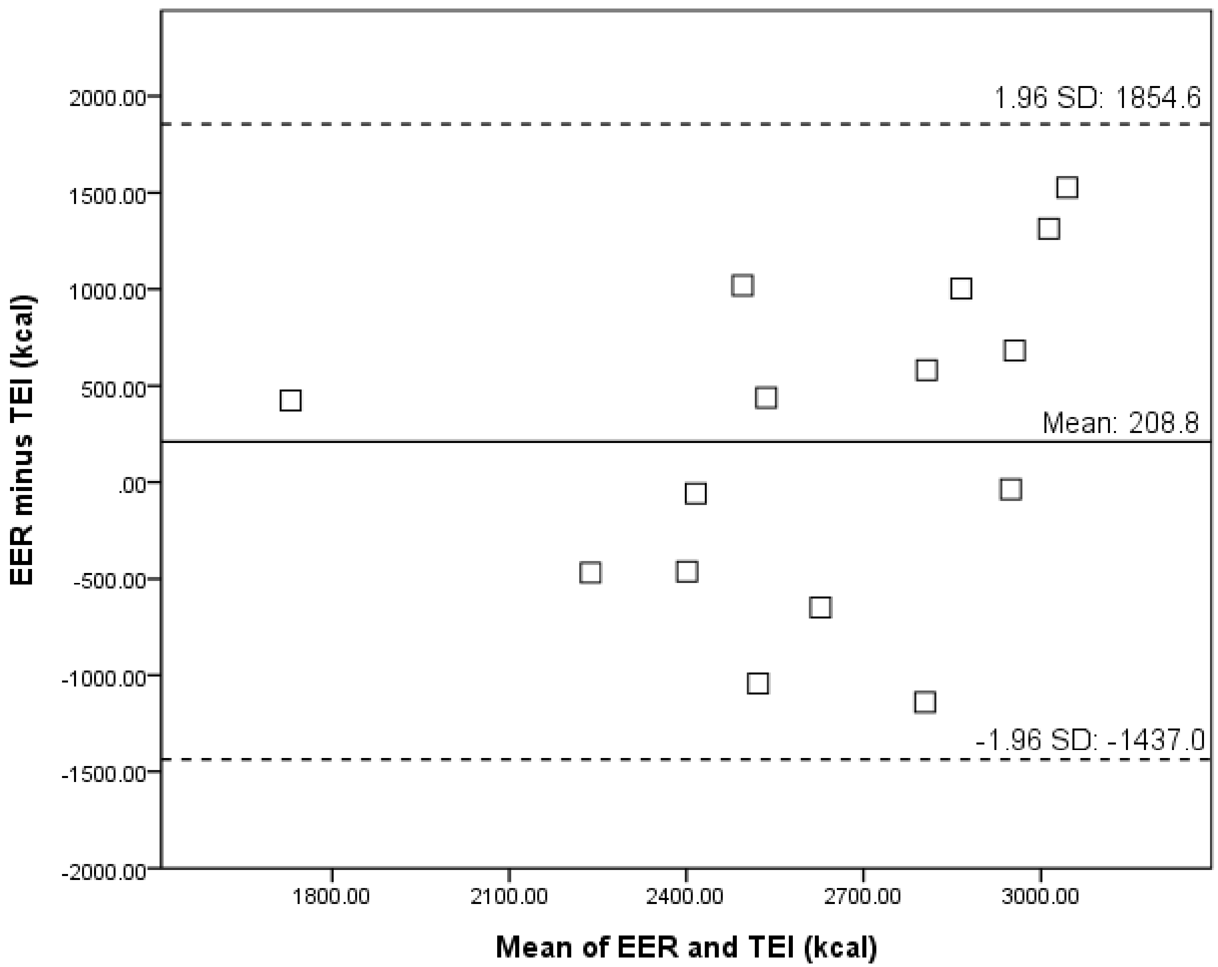
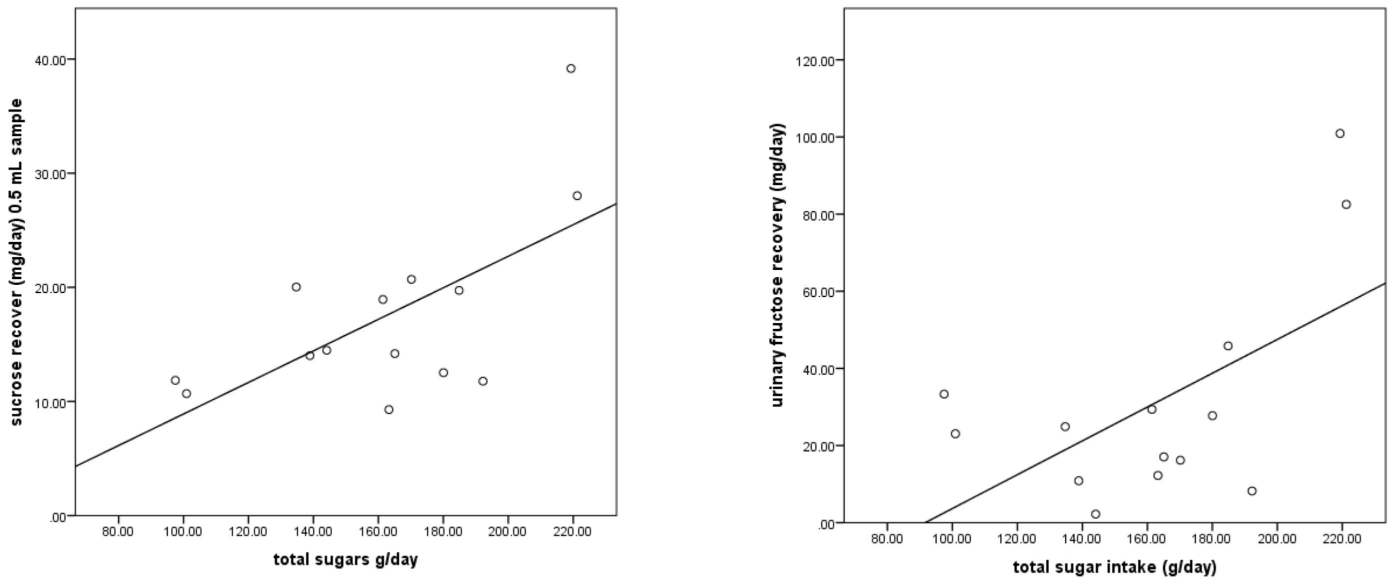


Figure 5 Bland-Altman plot of the difference between Estimated Energy Requirements (EER) and total energy intakes (TEI) vs. the mean of EER and TEI



a) r = 0.642, *p* = 0.013

b) r = 0.579, *p* = 0.030

Figure 6 Urinary sucrose (a) and fructose (b) correlate significantly with dietary intakes of total sugars

VITA

VITA

TusaRebecca Eleanor Schap

Education

Purdue University, West Lafayette, IN, USA Fall 2008 to present
Department of Nutrition Science
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Purdue University, West Lafayette, IN, USA Date of Graduation: August 2005
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Bachelor of Science, double major: Dietetics and Nutrition, Fitness, & Health
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Work Experience

Clinical Dietitian, Logansport Memorial Hospital, Logansport, IN, (574) 753-7541
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Planned and implemented nutrition and physical education activities for Summercise Day Camp available to children in 3 rural villages in Alaska.

Grant Coordinator, SmokeFree Purdue, Purdue University Student Wellness Office, West Lafayette, IN (765) 494-9355
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Board Certifications
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Committee Memberships
American Society of Nutrition Translation from Bench to Consumer Research Interest Section, Student Representative, 2011-present

Western Indiana District Dietetic Association President, 2010-2011

Western Indiana District Dietetic Association President Elect, 2009-2010

HOSTS Graduate Student Mentor, 2009-2010

Global Connect Cultural Exchange Conversation Partner, 2009-2010

Purdue Alumni Association International Contact for Ireland, 2006-2008

Purdue Alumni Association, lifetime member
Honors and Awards
36th National Nutrient Databank Conference, Student Travel Award; March 25-28 Houston TX, ($1000).

Indiana Clinical and Translational Sciences Institute Pre-doctoral Trainee, July 2010-July 1012

American Society for Nutrition, Nutritional Epidemiology Research Interest Section, Experimental Biology Meeting, Student Poster Competition Poster of Excellence, April 2011

Patsyjane O'Malley Memorial Scholarship, American Dietetic Association Foundation, 2010

Interdepartmental Nutrition Program Poster Contest, Honorable Mention, Feb 2009

Mary Hebenstreit Memorial Award, Indiana Dietetic Association, 2009-2010

American Dietetic Association Foundation Scholarship, 2009-2010

Purdue Oncological Sciences Center, Cancer Prevention and Control Poster Session, 2nd Place ($500), Dec 2008

Purdue Consumer and Technology Symposium Poster Session, 1st Place ($250), Nov 2008

Erasmus Mundus Scholarship Award, Dublin Institute of Technology 2006-2008

Outstanding Student, Coordinated Program in Dietetics, Purdue University, 2005

Outstanding Student, Coordinated Program in Dietetics, Indiana Dietetic Association, 2005

Professional Society Memberships
American Dietetic Association: Member since 2002

Indiana Dietetic Association: Member since 2002

Western Indiana Dietetic Association: Member since 2002

American Society for Nutrition: Graduate Student Member since 2008

Scientific Presentations
Schap TE, McCrory, M, Boushey CJ. Contributions of commonly under-reported foods and intakes at unexpected eating times to reported energy intakes among adults using an image-based dietary assessment tool. *International Conference on Diet and Activity Measures*. Rome, Italy, May 13-18, 2012 (accepted for poster presentation)

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Khanna, N., Boushey, C. J., Kerr, D., Okos, M., Ebert, D. S., and Delp, E. J. An overview of the technology assisted dietary assessment project at Purdue University. *IEEE International Symposium on Multimedia*, Taichung, Taiwan; December, 2010. (oral presentation by TusaRebecca Schap)

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Schap TE, Six BL, Kerr DA, Delp EJ, Ebert DS, Boushey CJ. Improving dietary assessment methods using cell phones and digital imaging. *Consumer and Technology Symposium Poster Session*, West Lafayette, IN; November, 2008.

Teaching

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Dietary assessment, method validation, biomarkers of dietary intake, dietary patterns

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