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Formative evaluation of a mobile liquid portion size estimation interface for people with varying literacy skills

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Abstract

Chronically ill people, especially those with low literacy skills, often have difficulty estimating portion sizes of liquids to help them stay within their recommended fluid limits. There is a plethora of mobile applications that can help people monitor their nutritional intake but unfortunately these applications require the user to have high literacy and numeracy skills for portion size recording. In this paper, we present two studies in which the low- and the high-fidelity versions of a portion size estimation interface, designed using the cognitive strategies adults employ for portion size estimation during diet recall studies, was evaluated by a chronically ill population with varying literacy skills. The low fidelity interface was evaluated by ten patients who were all able to accurately estimate portion sizes of various liquids with the interface. Eighteen participants did an in situ evaluation of the high-fidelity version incorporated in a diet and fluid monitoring mobile application for 6 weeks. Although the accuracy of the estimation cannot be confirmed in the second study but the participants who actively interacted with the interface showed better health outcomes by the end of the study. Based on these findings, we provide recommendations for designing the next iteration of an accurate and low literacy-accessible liquid portion size estimation mobile interface.

Keywords

Portion size; Mobile interface design; Low literacy; Behavior change

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1 Introduction

Many chronically ill patients, such as those in the later stages of chronic kidney disease (CKD V) and congestive heart failure (CHF), must restrict their daily fluid intake to avoid any further health complications. In the United States alone, there is a rising incidence and prevalence of these diseases. According to United States renal data system's (Collins et al. 2011) report, the number of CKD V patients increased by 60,000 or 17 % in the past decade. Whereas 400,000 more people develop CHF each year adding to the 5 million who already have this condition (Roger et al. 2011).

Since 80 % of the fluid intake comes from liquids not solids (Armstrong et al. 2005), CKD V and CHF patients must track portion sizes of liquid foods to stay within the recommended limits. This can be challenging for low literacy people because they often have difficulty interpreting food labels and performing calculations (Huizinga et al. 2009; Rothman et al. 2006). This is a matter of great concern because 75 % of chronically ill people in United States report having limited literacy skills (Kirsch et al. 1993).

There have been some promising technical advances such as sensor-rich containers (Lester et al. 2010), and systems based on alternative input mechanisms, voice and photographs (Arsand et al. 2008; Siek et al. 2009), that can simplify portion size estimation tasks for low literacy people. However, these technologies are not yet advanced enough to provide just-in-time feedback to the user, and they also do not effectively address the cognitive needs of the low literacy people (Siek et al. 2009; Sherwani et al. 2009).

The high literacy skills involved in portion size estimation and limitations of the existing technology may explain why chronically ill low literacy people are often unsuccessful in self-managing their diet (Huizinga et al. 2008; Rothman et al. 2004). Our goal is to design an interface that is not based on text, numbers, or calculations so low literacy people can be empowered to self-manage their diet.

To this end, we iteratively designed a diet and fluid tracking application (the dietary intake monitoring application or DIMA) for a touch screen mobile device (Connelly et al. 2012). In this paper, we discuss how we designed and performed formative evaluations of the liquid portion size estimation interface (PSEI) for DIMA with the ultimate goal of developing design implications for its next iteration. We conducted two studies with participants recruited from a chronically ill, low literacy and numeracy population. In the first study, the low-fidelity version of the liquid PSEI was evaluated by ten participants. In the second study, the high fidelity version of the liquid PSEI was incorporated into DIMA to be used and evaluated by eighteen participants while they used DIMA for 6 weeks to manage their dietary and fluid intake. Based on these study results, we developed guidelines that can be used by the human computer interaction community to design low literacy liquid portion size estimation interfaces.

2 Related work

For the past three decades, research in diet and nutrition has explored various types of portion size estimation aids (PSEAs) for liquids. Portion size estimation aids are dietitian-selected objects that can help people remember or estimate food portion sizes. For liquids, photographs (Venter et al. 2000; Nelson and Haraldsdottir 1998a), utensils and volume measures (Moshfegh et al. 1999), drawings of abstract and generic shapes, and house-hold measures (Byrd-Bredbenner and Schwartz 2004) have all been used as PSEAs. The recent trend is to make creative use of technology for portion size estimation (Comber et al. 2012; Woo et al. 2010; Zhu et al. 2010). In this section, we provide an overview of these related works.

2.1 Diet and nutrition research

While studying the cognitive skills people use to estimate food portion sizes during diet recalls, Chambers et al. (2000) discovered that people from varying literacy backgrounds can recall the amount of liquid printed on the container (they had used). Those who cannot do so, choose a PSEA that resembled the size or shape of the container while using their hands to indicate the equivalent portions of that PSEA. However, people often do not look at the PSEA's volume hence misestimate the consumed amount, for example, selecting a 32-oz PSEA to show consumption from a similarly shaped 16-oz container. Generally, it is easier for people to relate to house-hold PSEAs such as cups, mugs and glasses, both in their actual and 2D paper cut out forms without necessarily having knowledge of their volumes.

Hernandez et al. (2006) compared the life-size and computer displayed images of house-hold PSEAs for their portion size estimation accuracy. Neither media was found to be more accurate than the other. Estimation accuracy was better when the size and shape of the PSEA and the liquid container were similar. In fact, the researchers found that the availability of the right kinds of PSEAs can greatly improve portion size estimation accuracy and mitigate the effects of cognitive confounders such as memory.

The use of a photographic series is another method to assist people with the estimation of portion sizes. A photographic series is a set of photographs depicting different amounts of a particular food or drink. Several studies have established that it is possible to accurately estimate portion sizes of liquids using photographs (Ovaskainen et al. 2008; Robson and Livingstone 2000). Nelson and Haraldsdottir (1998b) identified a number of factors (such as size of a photograph, number of portion sizes, range of portion sizes, order of presentation of portion sizes) that are likely to influence an individual's interaction between the format of a photograph series and her skills in describing portion sizes.

Overall, the diet and nutrition research shows that accurate estimation of portion sizes is not yet a realistic expectation even in the absence of cognitive confounders. However, dimension and volume visualization, and the ability to relate the actual drink container to a PSEA are the predominant skills involved in liquid portion size estimation.

2.2 Mobile technology research

Some mobile technologies that are based on alternatives input mechanisms such as photographs (http://www.myfoodphone.com, http://www.mealsnap.com) and voice can be useful for low literacy populations. However, certain limitations of these systems make them unsuitable for our target population. Firstly, they do not always provide real-time feedback which is essential for a chronically ill population. Secondly, they often do not generate an interface with an overview of the total daily intake that can help a user reflect on her diet-related behaviors. Thirdly, these systems have the potential to be inaccurate because either the user is not able to accurately describe the beverage or the human (dietitian or mechanical Turk), at the other end, misinterprets the description. Lastly, researchers have found that low literacy users often find it difficult to navigate voice-based interfaces without a human facilitator because they do not know what to say and when (Siek et al. 2009; Sherwani et al. 2009).

Mappmal by Comber et al. (2012) is a tablet based application that enables professionals (not patients) to record portion sizes consumed by patients by rubbing away parts of the food or liquid on a computer-displayed photograph via a touch-enabled screen. However, this tool only works with pictures of standardized meals that are pre-entered. The professionals must also enter the nutritional value and content of the food in the system prior to use.

Some researchers explore techniques, such as image segmentation or use of mobile phone's camera parameters, to automate portion estimation and hence nutrient extraction of the photographed food items (Woo et al. 2010; Zhu et al. 2010). However, these methods are in their initial stages because it is an open problem to correctly identify a beverage (or any other food) in a picture. Moreover, different algorithmic solutions are needed to identify various types and shapes of food.

There have also been efforts to automate the process of logging different liquids through the use of advanced hardware, for example, sensor-rich cups. In an initial evaluation, a sensor-rich cup identified 68 different beverages with 79 % accuracy. The researchers suggest that with instrumentation, it would also be possible to determine the amount of liquid consumed from the cup. This idea needs further refinement before it is usable in everyday situations (Lester et al. 2010).

While diet and nutrition research has leveraged people's cognitive skills to find a solution to the portion size estimation problem, technical solutions have been trying to automate the process while bypassing these skills. Our research is an attempt to design technology to help people improve their portion size estimation skills for effective monitoring of dietary intake.

3 Context of the studies

In our prior work (Chaudry et al. 2011), we evaluated low-fidelity portion size estimation interfaces for all possible types of foods (i.e., liquids, amorphous solids, and snacks) in a one session study of ten participants. We extend this work by studying the high fidelity version of the liquid PSEI in a six-week in situ study with 18 participants. For both studies, we recruited CKD V people having variable literacy skills and low technical background.

We focused on people with CKD V because they have a very low daily fluid allowance (33.81 oz) which is very difficult to accomplish for most patients. Failure to comply can cause fluid overload in the body thereby increasing burden on a patient's heart and vessels that can ultimately lead to heart failure and death (Fouque 2003). Excess fluid can only be removed by prolonged or extra dialysis that adds to physical discomfort and health-care costs.

4 Study 1: portion size estimation accuracy

The aim of our first study was to determine whether our interface design can help a low literacy population accurately estimate portion sizes of various liquids. Specifically, we investigated:

- Can our target users estimate portion sizes of various liquids using non-life size representations of a few commonly used containers?
- What strategies did people use to interpret and estimate portion sizes with our picture cards?

4.1 Methods

The study was conducted, after obtaining Institutional Review Board approval, in an urban dialysis unit during the first 2 h of dialysis to accommodate participants' comfort and schedules. We were not allowed to use video or audio recording as per the dialysis unit's rules. The participants voluntarily participated and were compensated with a $ 10 gift card. They were free to discontinue the study at any time. The first part of the study consisted of task-based interactions with the interfaces followed by a structured interview with participants.

4.2 Prototypes: picture cards

Five picture cards were designed to facilitate portion size estimation of liquids. The top portion of each picture card, shown in Fig. 1a, had images of the following containers: (a) a coffee cup, (b) a can, (c) a 16-oz bottle and (d) a 20-oz bottle. The bottom section of each picture card was different—one was blank (Fig. 1a), and each of the remaining showed four portion sizes of one particular container at the top. We refer to each card by the container whose portion sizes the card shows. A user could choose twelve different portion sizes ranging between 2 and 20 oz through all the picture cards.

Estimating a portion size with these picture cards was a two-step process, each step showing only the desired features at a time—(a) selection of a container from the top of the screen followed by the (b) selection of a portion size from the bottom section of the screen. Figure 1b shows the *coffee cup* card, which the user saw if she picked the coffee cup/8-oz cup from the top. We chose this menu dock design philosophy because it provided the user with the ability to choose from a large number of options without facing all of them at once. It also provided a way to improve situational awareness while navigating through a number of screens. People with low literacy people often tend to feel lost while navigating through multiple interfaces (Chaudry et al. 2012).

4.3 Participants

Ten patients with CKD V were recruited from an urban dialysis facility. We recruited this population because: (a) these individuals are at risk of a broad array of complications if they do not adhere to a stringent dietary and fluid regimen, and (b) our target population included people from a low literacy background (Dowell and Welch 2006).

We administered the rapid estimate of adult literacy in medicine (REALM) test (Murphy et al. 1993) in the beginning of the study to measure the reading levels of our participants. Three participants read at or below the third grade, another three at seventh–eighth grade and the remaining four at or above the ninth grade. The years of education of these participants varied from 6 to 14, showing that more years of education does not always mean high literacy. This finding is supported by National Right to Read Foundation which found that 20 % of high school graduates can be classified as functionally illiterate at the time they graduate (Sweet 1996).

All participants identified themselves as Black/African Americans. Four were women and six men. The average age was 58 years old (SD = 16.3 years). Four participants used computers at most once a month to play games. The remaining six had never used one or did not feel comfortable using one.

Our participants reported that they watch their portions while eating. Three participants used measuring cups, a container of known volume, or some other visual aids to estimate their portion sizes. The rest reported that they stay conscious of their intake by either not cooking too much or by eyeballing the amounts they put on their plates. One participant also reported that he tried to stay away from unhealthy foods such as potatoes because of their high potassium content. None of the participants reported that they tracked or calculated their daily intake despite a fluid intake prescription of 33.81 oz per day.

4.4 Study procedures and tasks

The purpose and procedure of the study were explained and informed consent was obtained. A demonstration of how the interface worked was given prior to the study. During the experiment, two liquid samples were shown one at a time: 4 oz coffee in a coffee cup and 4 oz water in a 16-oz bottle. The order in which these liquids were shown did not change from one participant to the next. The task was to select an image that best represented the volume of the liquid sample. Participants were instructed to pick the closest estimate if none of the images exactly matched the presented amount. They were allowed to take as much time as they needed to finish the tasks. Help was provided if they were confused or stuck. Correct answers were not given at any time during the study. At the end, we asked participants to comment on the interfaces and give suggestions for improving them. They were also asked to specify which interfaces they preferred and why.

Since the prototype was low fidelity, a researcher played the role of a computer by simulating the screen flow. For example, when a participant was estimating the amount of coffee, the researcher first showed her the picture card with images of different containers at the top and nothing at the bottom (Fig. 1a). The participant had to pick one container on this card to go to the next card. If the participant put her finger on the coffee cup icon, the researcher showed her the *coffee cup* card in Fig. 1b. The participant could then select an image on this card which she felt matched the amount of the sample liquid. If she found the current card unsatisfactory, she could select a different container from the top to go a different card and so on.

4.5 Results

Participants had no problems interpreting and navigating the structure of the cards. Most made correct estimates of the study samples. There was a tendency to interpret the study task as selecting an image which depicted the amount that had been removed from the sample containers. The volume labels on the cards were interpreted correctly most of the time. The most prevalent strategy was to choose images that resembled the shape of the sample containers.

While everyone correctly estimated the portion size of coffee correctly, only seven correctly estimated the portion size of water. Participants who had incorrectly identified the portion size of water picked the reciprocal of the original quantity i.e., ¾ of the 16-oz bottle rather than ¼ of it. Some participants did not know whether they should report the amount of liquid missing from the container or the amount in it. Despite our clarification, some participants interpreted the task in its opposite.

Some participants were confused about choosing between the 16-oz bottle and the 20-oz bottle. When this happened, the researcher asked those participants to look at the numbers under the images—not revealing their meaning and purpose. Most participants correctly deciphered these numbers as container volumes and chose the correct portion size image.

We observed two strategies participants used to select a portion size correctly. They either chose the container that resembled the shape of the one in which the sample was presented (i.e., water in a 16-oz bottle), or they chose the container holding the liquid sample in the study (i.e., coffee cup for coffee). Only one participant did not use the second strategy, he made the correct choice of half coffee cup for 4 ounces of water.

5 Study 2: liquid portion size estimation interface evaluation

In a follow-up study, we integrated a high fidelity version of the picture cards (refer as liquid PSEI) into a fully functioning diet and fluid monitoring mobile application (Welch et al. 2010). The purpose was to evaluate the liquid PSEI while investigating several different questions related to the design of the mobile application and its feasibility in self-monitoring. In this paper, however, we only report on data related to the usage of the liquid PSEI. Results related to other research questions are reported in other publications (Connelly et al. 2012).

The purpose of the evaluation was to confirm the successful results of our previous study when the interface is high fidelity. It was also an opportunity to assess the PSEI for its utility and usability by varying literacy CKD V patients. Finally, the research team wanted to study the effects of the mobile application on the fluid intake behaviors of the target users. In particular, we explored the following questions:

- Did the participants use the interface?
- Did they choose the same or different portion sizes over the course of the study?
  - Which portion sizes did they choose?
  - What can we learn from their choices?
- Were there any changes in the way the application was used, and fluid was consumed over the course of the study?

5.1 Methods

Following approval from the Institutional Review Board, we recruited participants from two dialysis units during the first 2 h of dialysis. Participants had to be at least 18 years old. They were also required to have been on dialysis for at least 3 months and had reported difficulties with self-management of at least one aspect of their prescribed diet (i.e., fluid, sodium, potassium, phosphorus, protein, or caloric intake). We were not allowed to use video or audio recording as per the dialysis unit’s rules. They were paid $ 25 upon completion of the baseline interview and $ 25 for the completion of the interview following 6 weeks of self-monitoring. Compensation was not tied to the usage of the system to ensure that participants were not entering “noisy” data (to prove participation).

5.2 Prototype

The prototype was a high-fidelity mobile application designed through an iterative user-centered design process (Connelly et al. 2012). It allowed the user to record his or her diet and liquid intake through three different input mechanisms: interface icon selection, barcode scanning, and voice recording. The application also enabled the user to track the portion size of his or her liquid intake through the liquid PSEI. This interface popped up after the user had selected a liquid icon or scanned the barcode on a liquid’s container. The application automatically aggregated user’s daily liquid intake, and enabled him or her to monitor whether they were within daily limits through a just-in time feedback interface. The feedback icon for liquid, a bar graph, used a fill-up metaphor—starting empty and gradually filling up to the top as liquids were consumed, turning red near its limit. Figure 2 shows the screen flow that was generated while entering 3 oz of soda. The fluid content of voice-recorded items was not accumulated in the daily nutritional feedback. Every user interaction with the application was automatically logged for later analysis.

5.3 Participants

Initially we recruited 22 patients from the same CKD V population we recruited from for the first user study. Four participants dropped out after the baseline interview: one participant did not want the research team to access his/her medical records, two participants had difficulty seeing or using the application, and one participant contracted a contagious disease which prevented the research team from meeting with him/her.

The remaining 18 participants were all Black/African Americans and 13 were women. The average age was 53 years (SD = 15.1). This time we did not administer the REALM test to determine the literacy levels because experience taught us that many patients are embarrassed to do it in front of their peers. Therefore, we use educational levels as a proxy for describing the literacy levels of our participants. Four participants had 11 years of education, seven had 12 years, five had 13 years, and the remaining two had 14 years. With 61 % of participants having less than or equal to a high school diploma, we are confident that we recruited people with varying literacy with a majority having low literacy skills (Sweet 1996).

5.4 Study procedures and tasks

The participants completed a baseline interview once they were recruited for the study. After which, they were trained to use the mobile application. On average, training continued for three dialysis sessions, finishing when participants passed the competency assessment test for the application usage. They could then take the mobile device home and use it to track their diet and liquid intake for the next 6 weeks. This allowed us to collect in situ data related to the application usage.

During the six-week study period, four research assistants met with the participants during subsequent dialysis sessions three times a week. They ensured that: the mobile device was charged; the application functioned properly; and no participant was experiencing problems. During those sessions, they also collected participants' inter-dialytic weight gain (IWG) and administered a 3-item usability questionnaire. At the study conclusion, two lengthier usability questionnaires were administered to assess participants' perceptions of the mobile application. In this paper, we do not report the results of the usability questionnaires. Participants also returned their mobile devices to the researcher so that the research team could extract the interaction logs.

5.5 Results

We had both active and less active users of the application. Most participants made successful interactions with the liquid PSEI and selected from a variety of portion sizes each day. There was no change in the average number of portion sizes that were recorded each day during the study. The most popular portion size among all participants was 12 oz. The active participants began recording more fluids each day as the study progressed. Most of the non-compliant (four out of five) participants actively self-monitored and ended up coming close to their ideal inter-dialytic weight gain by the end of the study period.

5.5.1 Participant selection—The usage of the liquid PSEI varied greatly among the participants. Therefore, in some analyses, we distinguish actively monitoring from the less actively monitoring participants. Any participant who failed to record fluid for at least 21 days of the study was classified as less active. In other words, participants had to interact with the liquid PSEI for at least 50 % of the study days to be considered active (italicized and bolded in Table 1).

5.5.2 Expected and actual usage of the portion size estimation interface—The liquid PSEI appeared after a liquid icon was selected or a barcode on a liquid was scanned. Therefore, each recording of a liquid was ideally followed by at least one interaction with the interface to record a portion size, unless the user decided to circumvent it by clicking on the HOME icon in the bottom right corner of the screen (Fig. 2). Therefore, comparing the average number of liquids recorded per day with the average number of portion sizes recorded daily can indicate whether or not the participants interacted with the interface (Fig. 3). For all participants with the exception of participant 12, we observe sufficient usage. A two-tail student t test assuming equal variances shows no significant difference between the average number of recordings for liquids and portion sizes ($p = 0.47$). (Participant 12 was excluded from the t test because he only used the liquid PSEI 6 times throughout the entire duration of the study).

5.5.3 Comparing the unique and total number of portion sizes—The total number of portion sizes selected each day consists of portion sizes that were selected only once and also those that were selected more than once. On average, a total of 2.05 portion sizes were selected each day and 1.72 of these were unique. This means that whenever a liquid was recorded, its portion size was more likely to be different from the portion size of another liquid recorded on the same day. A comparison of these two averages for each participant (Fig. 4) shows that this trend was true for almost every participant.

5.5.4 Usage of various portion sizes—As an example, we show all the unique portion sizes that were recorded at least once in a day by participant 3 in Fig. 5. This particular participant recorded on average 3.06 liquids with 2.08 unique portion sizes each day. Although this participant chose different portion sizes on the same day, across the days the portion sizes tended to be similar. Therefore, by the end of the study, she had used most (nine) but not all available (12) portion sizes. Her most popular choice was the 10-oz portion size.

The portion size frequency of use was measured as: (a) average number of times it was selected by each participant and (b) average number of days it was used by each participant. The frequencies of use for all portion sizes are shown in Fig. 6. According to both measures, the top three choices were 12-, 8- and 6-oz. The largest (20-oz) and the smallest (2-oz) portion sizes were both used the same number of times, but the largest portion size was used more often than the smallest one. The least popular choices were 5- and 15-oz, respectively.

5.5.5 Active participants' change in recording behavior—We wanted to see how active participants' recording behavior changed during the study. On average, there were no significant changes in the number of liquids recorded by both active and less active participants over the course of the study. The average recorded fluid amount, on the other hand, fluctuated during the study in both groups. Active participants increased the recordings at a higher rate of 0.062 oz per day starting with recording an average of 14.79 oz (43.7 % of the recommended intake) at the baseline, and ending with recording an average of 17.41 oz (51.5 % of the allowed intake) towards the conclusion of the study. For less active participants, the average recorded amount at the baseline was only 11.02 oz, and this continued to decrease during the study at the rate of 0.0086 oz per day (Fig. 7).

Next, we observe how total recorded amounts of fluid changed among the participants who were not within their recommended fluid intake at the baseline or who were recruited into the study as non-compliant patients.

5.5.6 Non-compliant participants' change in behavior—Since we cannot confirm via the in situ deployment whether participants recorded every liquid they consumed, we analyzed their inter-dialytic weight gain (IWG). This is an indirect measure of fluid intake that equals the weight a patient gains per day between two consecutive dialysis sessions. Participants could have an IWG of 1 kg per day with a daily fluid limit of 33.81 oz and still be considered compliant with their dietary restrictions.

In total, five participants were non-compliant at the baseline. Four of these were active users and the remaining one used the application only 40 % of the time (Table 1). While the average IWG of all non-compliant participants was 1.52 kg per day at the baseline, they recorded only 22.02 oz of fluid (65.1 % of the recommended intake). As the study progressed, they recorded 0.0675 oz of additional fluid each day and had a 0.0093 kg daily decrease in IWG. This means that by the end of the study, they were recording 24.86 oz (73.5 % of the recommended intake), and their average IWG had decreased to 1.13 kg per day, which is closer to the allowed limit of 1 kg per day (Fig. 8).

This result shows two things: (a) participants were not recording all of the consumed liquids at the beginning of the study, but they recorded more as the study progressed; and (b) as the participants recorded what they consumed, they came closer to their recommended IWGs.

The selection of portion sizes can tell us how much liquid people tend to consume at one time. There were no significant changes in the number of times any individual portion size was selected by the non-compliant patients during the study. However, some increase in usage was observed for the 20- and 16-oz portion sizes: the 20-oz portion size recording increased from 0.042 to 0.15, while that of the 16-oz increased from 0.081 to 0.30 times per day. A decrease in usage was observed for 6-oz, which changed from 0.27 to 0.10.

6 Discussion

The motivation of these studies was to design an interface that would empower patients with varying literacy skills to record their fluid intake without performing high-level numeracy tasks such as mathematical operations of addition and subtraction. The first step was evaluating the accuracy of the low fidelity version of an interface designed to estimate the portion sizes of liquids. The second step was an in situ usability and usage evaluation of the high fidelity version of the interface with a focus on its effect on behavior change. Here we discuss our findings and their implications on the design of the next iteration of the portion size estimation interface for liquids, as well as mobile applications that promote self-monitoring.

6.1 Design implications of the findings

The overall result of these two studies is that people with varying literacy skills were able to comprehend and navigate the design of the interface to search and select specific portion sizes. Although the accuracy of estimation was high in the first study, we cannot verify this in the second study, because participants used the application during their everyday lives without invasive pervasive technologies monitoring their consumption or any research team observation. The participants selected diverse portion sizes each day and selected similar portion sizes on different days, which can suggest a conscious attempt to record actual portion sizes. This implies that an interface based on the user's cognitive strategies of portion size estimation is usable in situ.

6.1.1 Interface for estimating portion sizes of liquids—One finding from our first study was that people tended to match liquids with the household containers in which they are usually served, for example, estimating the portion size of coffee with a cup. They also tried to estimate portion size by selecting a container whose shape resembled that of the actual container. These findings suggest that people process available information with a 1-to-1 correspondence to the physical world. It also seemed that scaling down a container's size to fit the small screen of a mobile device did not negatively impact the participants' portion size estimation capability. Moreover, in the second study, we found that the most commonly recorded portion sizes were 12-, 8- and 6-oz, and that these correspond with the volumes of several common containers, which are a mug, a paper cup, and a foam cup, respectively. These findings suggest that an interface designed using containers of commonly consumed liquids (such as milk, coffee, water, soda) that are frequently available in the grocery store and/or used in the kitchen will be identified immediately and interpreted accurately by users.

Another important finding of the first study was that participants were unsure whether the images represented consumed amounts or leftover amounts (starting with a full container), despite our verbal explanations. To overcome this problem, a training manual showing the amounts in context might help people understand the concept of left over amounts.

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We noticed that the volume amounts under the containers helped participants distinguish between the 16- and 20-oz bottles. Therefore, the liquid portion size estimation interface should pair portion size volumes with the containers they represent. Our PSEI included 12 different portion sizes, ranging from 2- to 20-oz. Although some portion sizes were used more often than the others, an important result of the second study was that every single portion size was selected at least once. This shows us that the portion sizes available on our PSEI represented normally consumed amounts.

Since almost every participant occasionally circumvented the PSEI, there is a possibility that we either missed some commonly used portion sizes or that the participants were sometimes overwhelmed by the depth of application's navigation structure. The causes of circumvention need to be further investigated to overcome any limitations of the interface. Perhaps adding a balanced mix of household and grocery containers will address this problem.

6.1.2 Self-monitoring mobile application—The take-away finding of the second study was that the patients who actively used the mobile application showed signs of becoming compliant by the end of the study. These participants also recorded more fluid as the study progressed, which means that they recorded more of what they were drinking or they were becoming better at self-monitoring.

Another change in the intake behavior of these participants was that they began recording bigger portion sizes, such as 20- and 16-oz. During the recruitment interviews, participants had told us that they try to limit their liquid intake by restricting themselves to drinking from containers of known volumes. These findings show that participants usually use 20- and 16-oz containers for this purpose. Moreover, they either recorded after finishing the entire container or they consumed big portion sizes at one time. If the latter is true then participants need to be educated about the benefits of consuming smaller amounts at a time.

Since only 61 % of the recruited participants recorded for at least 50 % of the study time, we still need to understand how these applications can be designed to increase the number of active participants. Perhaps the application did not effectively address the self-monitoring needs of all the participants. This calls for an investigation of self-monitoring techniques used by various individuals.

Although we do not report it in the results, there is evidence that on various days, at least one participant was recording fluids and then deleting them soon after. It appears he was trying to test what portion sizes of different fluids would help him stay within his limits. For individuals, who like to experiment, an interactive feedback mechanism (showing implications of different decisions) might prove to be effective in self-monitoring.

6.2 Limitations

It is possible that two liquid samples were not sufficient to test the accuracy of the interface; however, we were able to target two different strategies that we know people normally use to report portion sizes that are: relating the portion to the shape of a container and relating the portion to the type of the liquid.

A sample of eighteen participants may seem small for the second study; however, smaller participant samples can help us better understand how people are using a system (Klasnja et al. 2011). We also acknowledge that we can only report on what was recorded, not what was actually consumed. Yet based on the data we collected—usage and IWG—we have a rich understanding of the application usage and its impact on fluid consumption by the target population. Finally, we could have used literacy tests other than REALM, such as NVS (Baker et al. 1999) to reduce discomfort when speaking aloud.

6.3 Future work

We are planning another self-monitoring study that will employ an improved version of the diet and fluid monitoring mobile application—with portion size estimation interfaces of other foods and more sensitive feedback mechanism to better understand the consequences of this application on a patient's self-monitoring behaviors. We hope to gain a deeper understanding of interface designs that are not only for accurate portion size estimation but are also for teaching better self-monitoring techniques.

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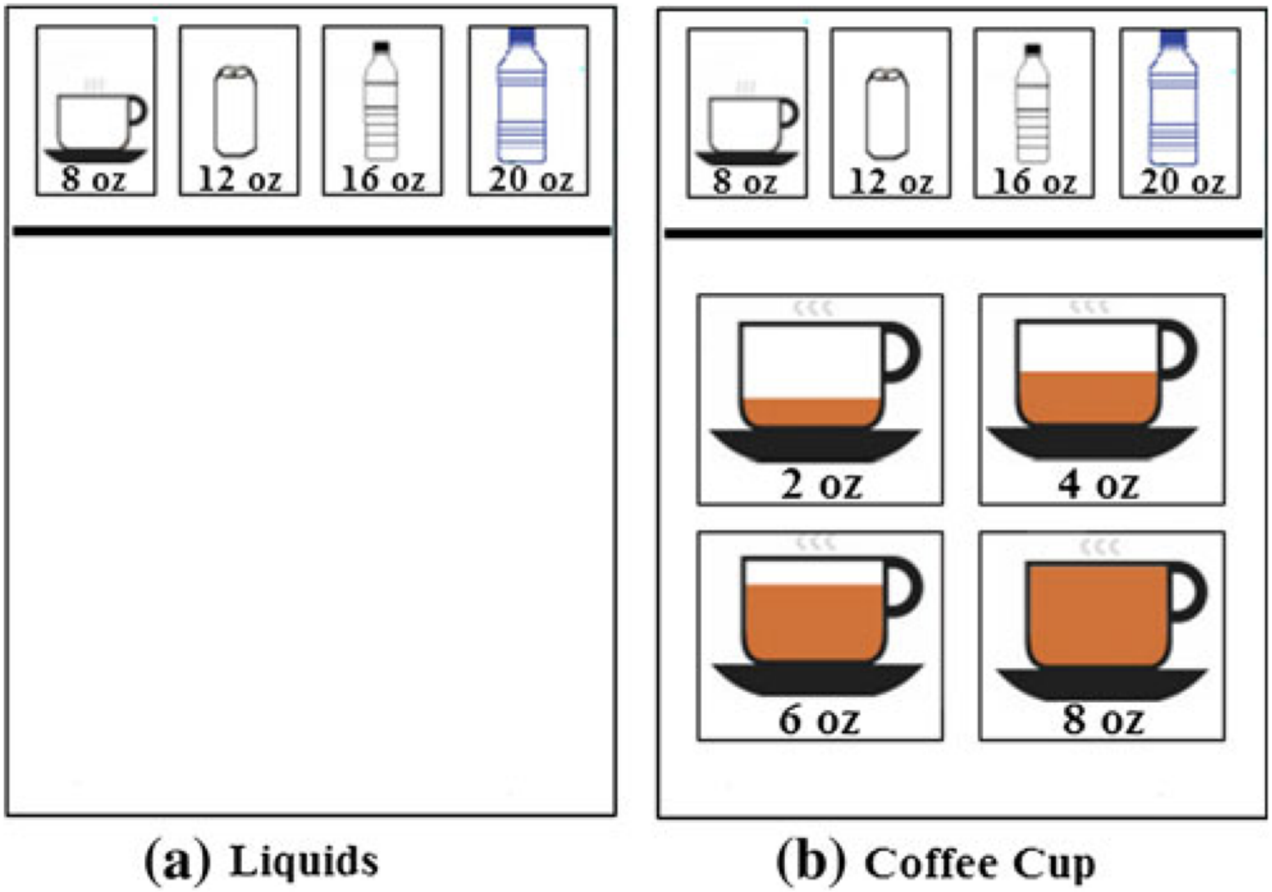

Fig. 1.
Picture card examples

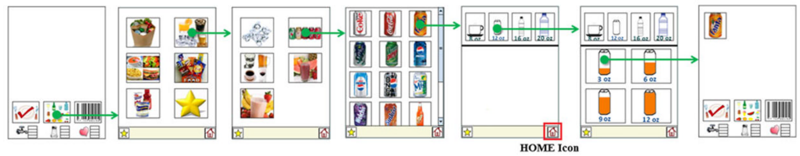

Fig. 2.

Screenshots of the hi-fi prototype demonstrating the screen flow for recording ¼ can of soda: **a** the page in which an input method is selected: select icons; **b** the type of food to enter, select drinks; **c** types of drinks, select soda; **d** types of soda, select fanta orange; **e** liquid PSEI, select can **f** can PSEI, select 3 oz; and **g** soda entered and feedback apparent along *bottom*

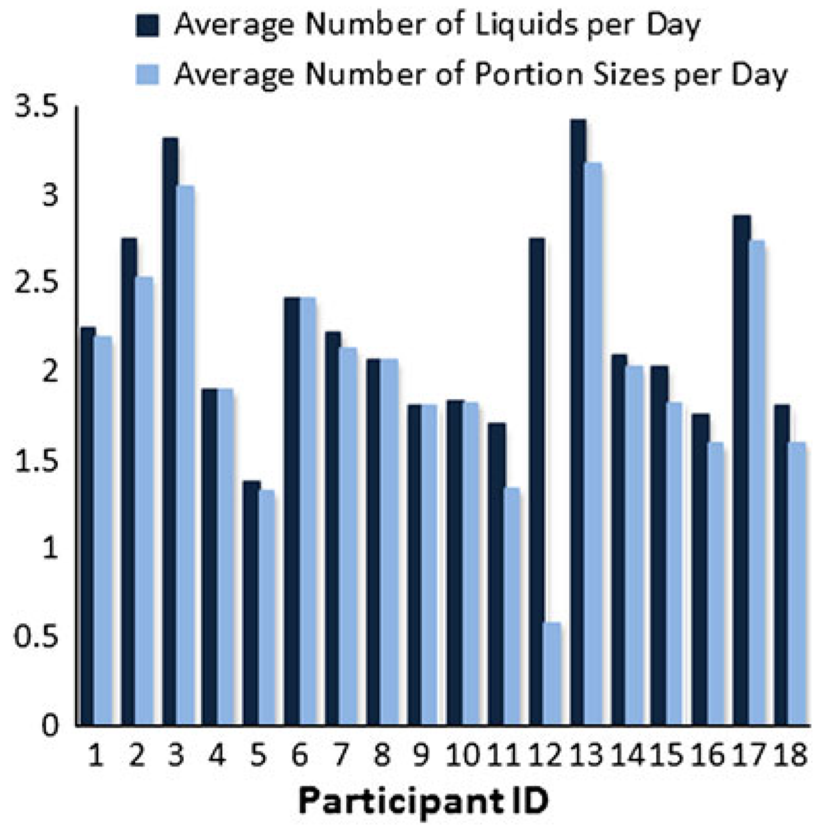

Fig. 3.
Comparing expected and actual average usages of the PSEI

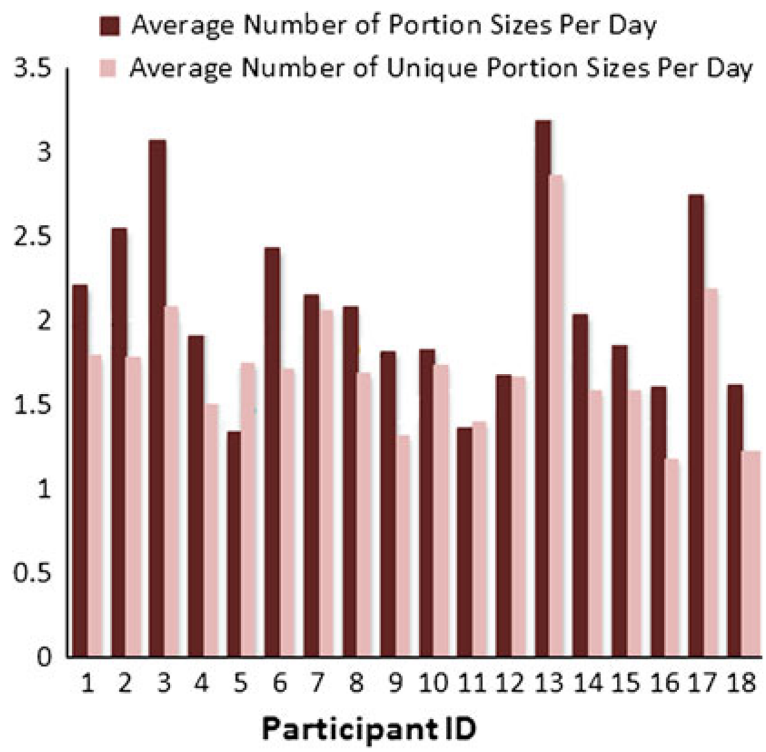

Fig. 4.
Comparing average number of portion sizes with the average number of unique portion sizes selected per day

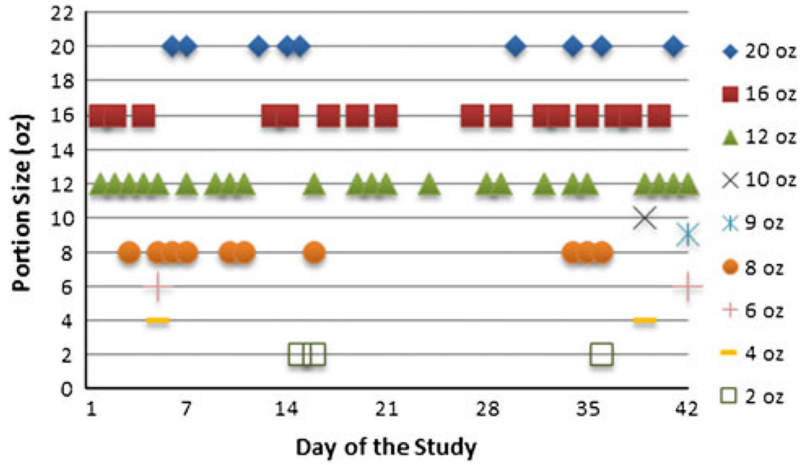

Fig. 5.
Portion sizes selected by participant three on each day

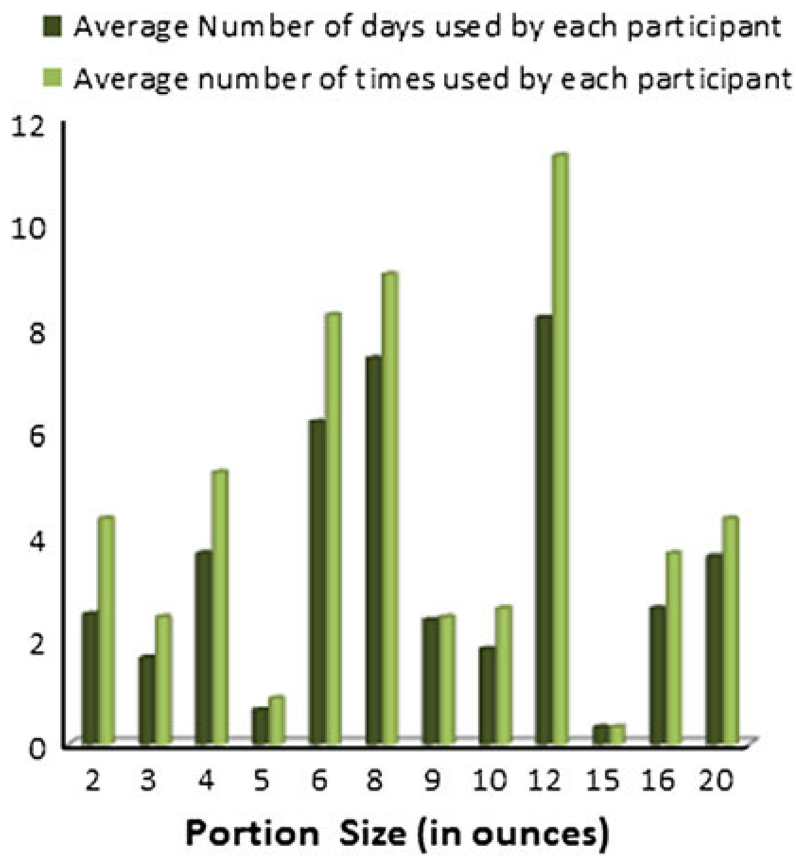

Fig. 6.
Measures of frequency of usage for all portion sizes

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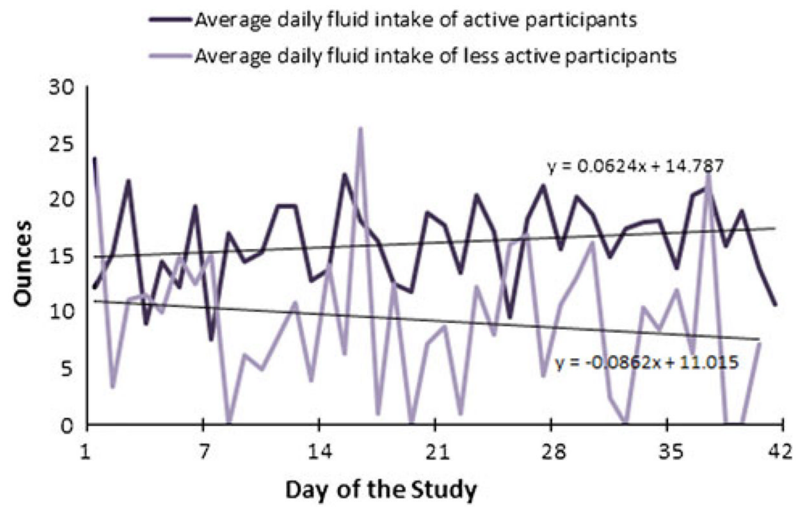

Fig. 7.
Average fluid intake with respect to each study day

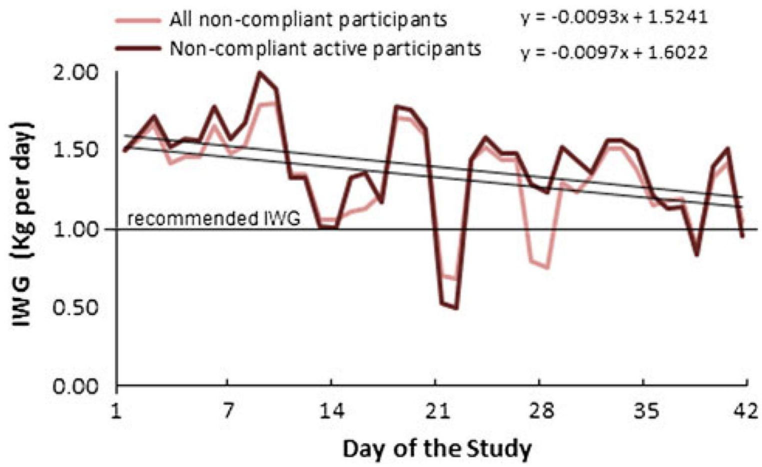

Fig. 8.
Changes in IWG of non-compliant patients

Table 1

Number of days, for each participant, on which interaction with liquid PSEI happened and did not happened

Participant ID	Days of liquid PSEI	
	No interaction	Interaction
1	28	14
2	***6***	***36***
3 (NC)	***8***	***34***
4	22	20
5	27	15
6 (NC)	***21***	***21***
7	***8***	***34***
8	***9***	***33***
9	26	16
10 (NC)	25	17
11 (NC)	***10***	***32***
12	36	6
13	28	14
14	***11***	***31***
15	***14***	***28***
16	***20***	***22***
17 (NC)	***10***	***32***
18	***11***	***31***

NC non-compliant with fluid intake