# Evaluation of a Food Portion Size Estimation Interface for a Varying Literacy Population

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## ABSTRACT

Portion size estimation is important for managing dietary intake in many chronic conditions. We conducted a 6-week field study with nine varying literacy dialysis patients to explore the usability and feasibility of a dietary intake mobile application that emphasizes portion size estimation. Seven participants demonstrated sustained use of the application and improved their self-efficacy, knowledge, and ability to estimate portion sizes in pre- and post-study assessments. Participants reported moments when portion size information in the application differed from their prior understanding, challenging them to reconcile dissonant information. Although participants acquired new knowledge about portion sizes, they struggled to accurately estimate portion sizes in situ for most foods. Despite using the application consistently, rating it highly, and exhibiting learning, we found that self-efficacy and knowledge are not sufficient to support improved behaviors in everyday life.

### Author Keywords

Portion estimate; User Interface Design; Mobile Devices; Low Literacy; Self-Efficacy; Health; Behavior Change

### ACM Classification Keywords

H.5.2 Information interfaces and presentation (User interfaces): Graphical User Interfaces (GUI), Screen Design, User-centered Design.

## INTRODUCTION

People with chronic illness, such as obesity, chronic kidney disease, and cardiovascular disease, must continuously manage their nutrition for maintenance and intervention to avoid the risk of severe health consequences. Since food portion sizes influence nutrient consumption, estimating and tracking portion sizes is a necessary enabler for nutritional assessment. Therefore, people with chronic illnesses critically need a system with accurate portion size estimation to collect this data.

Typically, people can estimate food portion sizes by using nutritional labels or by making volume comparisons with various objects known as estimation aids or reference objects. Despite the popularity of these methods, they can be problematic because people misunderstand labels [23], cannot always have estimation aids with them, and can forget comparison amounts. In addition, these techniques require people to track and calculate total daily intake – tasks that demand reading, writing, and numeracy skills often lacking in low literacy people. As a result, low literacy populations often find it difficult to manage their portion sizes, and are at risk of poor health outcomes.

Technology can help people manage particular aspects of their illnesses and enable them to practice preventative behaviors [24, 28]. Until recently, most technical solutions did not address specific needs of low socioeconomic (low SES) groups – constituting almost 1.4 billion people in the world [35]. Researchers have started to design sociotechnical solutions that can empower low SES groups who often have low literacy skills to handle various life challenges [2, 16] but more research is still needed– especially in health critical applications.

We explored the feasibility of a mobile dietary intake monitoring tracking application, DIMA, for a low SES and low literacy population [13], however DIMA included portion size estimation for fluids only. For this study, we extended DIMA with a picture-based portion size estimation module for all types of foods, DIMA-P. We deployed DIMA-P in a six-week study with nine participants who had chronic kidney disease stage V (CKD V). Our aim was to explore how participants used DIMA-P in situ. In describing our study, we make following contributions:

1. An interactive portion size estimation aid design that met the needs and the abilities of low literacy users;

2. Qualitative analysis of participants' comments about the application that sheds light on how the tool was used;

3. A quantitative analysis showing improved self-efficacy of portion size estimation.


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These contributions will help the design community increase their knowledge and understanding about designing effective health behavior change technologies for low literacy populations.

## MOTIVATION

We work with CKD V patients who often find it very difficult to comply with their strict dietary regimen [6]. Typically, CKD patients must limit their daily diet to no more than 1 liter of fluid, 2 grams of sodium, 2 grams of potassium, and 1 gram of phosphorus [18]. Transgressions in nutrient consumption can result in serious health consequences and sometimes death [26]. The only treatment is extra dialysis, which causes physical discomfort to patients and increases healthcare costs. We focused on low literacy adults because they often lack skills needed to determine their food portion sizes [23]. Indeed, their limited literacy is a potential contributor to poor CKD outcomes [5]. Moreover, current methods of nutritional assessment for CKD patients are invasive – health providers assess how CKD patients adhere to their diet via blood work, and weighing patients between dialysis sessions to assess fluid consumption.

## RELATED WORK

Mobile and ubiquitous computing fields are exploring novel methods for managing and tracking dietary intake. Recent examples include sensors for emotional eating support [8], food photography based healthy food rating systems [19], and electronic food diaries to create food entries [1]. But relatively limited work has been done to design health applications for people with low literacy skills. Moreover, food portion size estimation in diet tracking applications has not been sufficiently explored for people who want to increase their ability to estimate.

### Diet Management Applications

Recent research in designing food recording technologies for low literacy users tackle design issues with respect to the effort involved in tracking. Photograph-based food diaries can minimize the effort involved in tracking; however, such journals often do not provide any nutritional information. Cordeiro and colleagues developed a photograph-based mobile food journal that people could use to document their socio-emotional and other contextual information based on their dietary goals [15]. Other designs enable users to understand nutrition with respect to their health goals [19, 29]. Other researchers explored simplified food diaries that focus on recording food groups as opposed to specific nutrients or food items [1, 3], but found that users prefer more detailed food diaries [1].

Technologies that specifically target dietary intake in low SES populations include interactive nutritional educational programs that are either game-based [21] or use multimedia to promote learning [20, 33]. Other researchers have developed mobile application-based interventions for low socioeconomic individuals to provide support for healthy eating. SnackBuddy explores how family members use a sociotechnical system to support each other's healthy behavior [39]; whereas, DIMA engages an individual in reflection of their own health data [13]. Another notable technology solution for low SES individuals is Grimes and colleagues' voice forum that allows low SES users to exchange their food memories using voice recordings [20].

### Portion Estimation Technologies

Three main classes of technologies in this domain are: food photograph based applications; human computing based commercial nutritional assessment services; and experimental, automatic portion estimation prototypes. We discuss representative projects in each class.

### Portion Size Photographs based Applications

Dietitians typically use native and web-based desktop applications during nutritional assessment recall interviews [44, 46]. These applications consist of photographs of one meal in multiple portion sizes making them resource intensive and unsuitable for mobile devices. Applications such as MAPMAAL are less resource intensive as they allow dietitians to manipulate meal photographs by rubbing away its parts via a touch screen [12]. These interface designs support reporting (not necessarily in situ) and recalling rather than learning and understanding portion sizes. They may also require regular updates with new meal photographs and nutritional values prior to use. We evaluated interface designs based on portion size estimation strategies people regularly use [10], thus DIMA-P's interface has fewer and static images that assisted in designing a low resource intensive mobile applications with minimal updates.

### Human Computing Based Portion Estimation

Some web and mobile nutritional assessment applications (e.g., MycaNutrition, http://www.mycanutrition.com) accept dietary intake through alternative input mechanisms such as camera and voice [31]. A human facilitator then performs portion size estimation and sends nutritional feedback to the user. These systems have the capability to simplify portion size estimation tasks, but may be unsuitable for low literacy, chronically ill populations because they: (a) do not always provide real-time feedback; (b) could be inaccurate either because the user is unable to accurately describe their food selection to the system or the human (e.g., mechanical Turk) is not appropriately trained to provide accurate feedback; (c) are mainly for tracking purposes and not designed to help people learn portion estimation skills. We wanted people to improve not only their ability to track their diets, but also create opportunities for them to practice and develop skills that can lead to long-term behavior changes.

### Automated Portion Size Estimation

Automated portion size estimation systems offload the task of portion size estimation from the user. This class includes systems augmented with external hardware such as cameras [48, 49] and ambient-embedded sensor devices, such as a dining table that determines consumed food amounts via container's weight change [9]. Another example is a sensor-

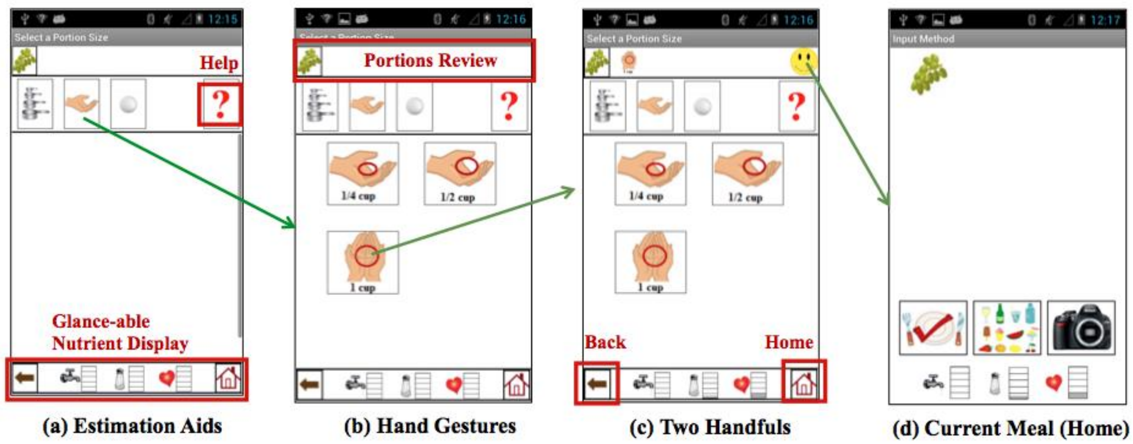


**Figure 1 © Beenish Chaudhry. Recording two handfuls of grapes on DIMA-P: (a) Portion Estimation Interface for Fruits with no Estimation Aid selected; (b) Hand Gestures Estimation Strategy selected, three possible portion estimates; (c) Two Handfuls selected and Smiley face is evident because user has not exceeded nutrient limits; (d) Home Page after entering grapes**

rich cup that identifies the type and amount of liquid consumed [27]. On-body sensor devices can estimate food portion size based on timing and count variables of the chewing cycle structure [32]. Experimental studies suggest these automated systems can be highly accurate and robust in estimating food portion sizes. This is promising in terms of providing accurate feedback to users, however such systems are still experimental and do not allow users to interact with the data such that they can understand or improve their portion estimation skills.

In summary, current systems are not focusing on empowering or improving the portion size estimation abilities of individuals. Most do not specifically target low literacy people who have special needs and limitations with respect to using and interacting with informational technologies. Our research tries to fill in these gaps while increasing our understanding around designing behavior change technologies.

## APPLICATION OVERVIEW

For this study, we extended the original DIMA application with a portion size estimation module informed by prior work [10]. DIMA is a diet tracking mobile application that we designed and developed through an iterative user-centered design process. DIMA provides users with the ability to record their meals via a picture-based interface. To locate a food item, the user must traverse a set of food category screens via a simple linear navigation. The food categories were a combination of USDA-recommended categories and target-user defined categories based on a prior study [42]. By grouping food items under categories, we limited the number of pictures to show on the small screen of a smartphone and not overwhelm the user. In the extended version of DIMA, referred to as DIMA-P, after selecting a food item, the user views the portion size estimation module. The module consisted of twenty-four distinct interfaces - a subset of the interfaces is shown in Figure 2. Each interface consisted of 2-4 reference objects or household containers specific to the chosen food's shape, size, and physical state (i.e., solid – definite geometric shape, amorphous – no defined shape, or liquids – container's shape). From that interface, the user can select an appropriate portion size and immediately see a visualization of its effect on their cumulative nutrient intake. Users view the real-time feedback and can adjust their current or future meals.

In designing this picture-based module, we aimed to enhance low literacy, chronically ill people's: (a) ability to estimate food portion sizes; and (b) self-efficacy in using estimation aids and household containers. We incorporated constructs specified in the Integrated Theory of Health Behavior Change (ITHBC) in the portion estimation module's design. ITHBC suggests that health behavior change can be enhanced by fostering knowledge and beliefs, increasing self-regulation skills and abilities, and enhancing social facilitation [34]. (Since we wanted to focus on understanding participants' own ability to use and learn from the estimation module, we did not incorporate social facilitation in this version), In addition, we incorporated goal-setting, where the application sets the (nutrient consumption) goals for the user based on health professional's recommendations.

The topmost section of any interface from the estimation module is called Portions Review section (Figure 1.b). This is where the currently selected portion sizes can be seen. The bottommost section is the glance-able nutrient display (Figure 1.a) where current intake amounts of three critical nutrients – fluid, sodium, and potassium are displayed. Clicking the glance-able display opens the feedback page where additional nutrient values are visible. The HOME and BACK icons (Figure 1.c) are on either end of the nutrient display allowing the user to exit if they decide not want to save the current recording.

Let's assume Sally wants to decide how many grapes to eat. She first selects grapes by navigating through the food category screens, as described in our prior publication [13] on the DIMA application. After Sally selects grapes, the screen in Figure 1.a opens where she can select an estimation aid from: measuring cups, hand gestures, and spherical objects. If she wants to use hand gestures to estimate the amount of grapes to eat, she clicks the hand gestures. The screen then changes to Figure 1.b where she can select the appropriate portion estimates obtainable from various hand gestures.

Each of these portion estimates is linked to a nutritional entry in the underlying database. When a portion estimate is selected, the associated nutritional values are displayed in the glance-able nutrient display (Figure 1.a) in real time. Changes to the nutrient display provide Sally with the opportunity to learn about the effect of a portion size on her daily cumulative intake and the nutritional content of the targeted food item. This awareness can help shape her beliefs and knowledge about her intake. Sally can also open the help page by clicking the Help icon (Figure 1.a) to learn more about estimation aids.

If Sally's selection puts any of the nutrients above 80% of her restricted limits or nutrient intake goals, the associated nutrient chart in the glance-able display becomes red. By monitoring changes to the glance-able display, Sally can learn to self-regulate either by decreasing her portion size or changing what she is eating. Otherwise, she can continue to record up to six portions at one time – for instance if she desires to eat more grapes, she can select another handful. The selected portion images are stored in the Portions Review bar (Figure 1.b). Sally can edit Portions Review bar by clicking it. The nutrient values in the glance-able display change in real-time as Sally adds or deletes portions from Portions Review. Through these intentional interactions and enacted feedback, Sally can plan her meals easily. The ability to modify portion sizes provides Sally with the flexibility needed to keep within her strict dietary limits – the closer to these limits she gets, the more creative she needs to be to figure out what she can eat.

If Sally's selection of portions keeps her below her recommended amounts, a smiley face appears in the right corner of Portions Review bar to let her know that she is staying within her nutritional limits. If her choices redden any nutrient chart in the glance-able display, a check mark appears in place of the smiley face. Ultimately, Sally has to click either the smiley face or the check icon to save portion sizes (Figure 1.c) and exit the estimation module.

## METHODS

In this paper, we analyze the portion size estimation module's usage; participants' reactions to the module; challenges and successes of the module; and changes in participants' self-efficacy and estimation abilities.

### Study Design

After receiving ethics board approval, we conducted a 6-week field study with low-SES CKD V patients. The recruitment and interviews were conducted in a dialysis unit during the first two hours of dialysis to accommodate participants' comfort and schedules. Participants were paid $25 after the baseline interview, $25 after self-monitoring for 6-weeks, and $25 after the post self-monitoring interview. Compensation was not tied to application usage.

### Baseline Assessment

At the first meeting, individuals completed a background questionnaire and Newest Vital Sign (NVS) [47]. NVS is an assessment that measures ability to read, understand, calculate, and apply health information.

During the second meeting, participants were trained to use the mobile phone and DIMA-P. To ensure that participants could use the application on their own, they had to pass a competency assessment test consisting of thirteen tasks. The tasks included things like making a food entry, interpreting the feedback page, and opening the help page of estimation module. Until participants could successfully complete all thirteen tasks on their own, they could not enter the next phase. Each participant passed the test after 3-5 training sessions, each lasting for 40-60 minutes. Number of training sessions did not correlate with literacy and no one could pass the test in the first try.

Once a participant passed his competency test, we conducted three Portion Size Estimation Tests. The first test, *Pictures,* assessed participants' ability to select an image from the estimation module that accurately represented portion size of a pre-weighed food sample. Twelve food samples were used in this test. Participants received 1 for correct answer and 0 otherwise. The second test, *Apportion*, evaluated participants' ability to portion out ten food samples in specified amounts (the researcher was trained to identify correct amount based on known facts, for example, half an apple is half a cup, and 4 ounces of rice is ¾ of the provided 6-ounce container). Correct responses received a 1, and 0 otherwise. In the third test, *Containers*, participants provided their estimates of the volumes of 12 real household utensils and containers. Similarly, participants were given 1 for a correct response, and 0 otherwise. Finally, participants took the Portion Size Estimation Self-Efficacy Scale (PSESES), a validated instrument developed by Ayala [4] to measure two aspects of self-efficacy specific to portion size estimation: judging portion sizes in various situations, and using estimation aids and household containers. The questions were read aloud to participants who answered on a 5-point Likert Scale.

### Self-Monitoring

After the completion of the Portion Estimation tests, participants entered 6-weeks of self-monitoring. They

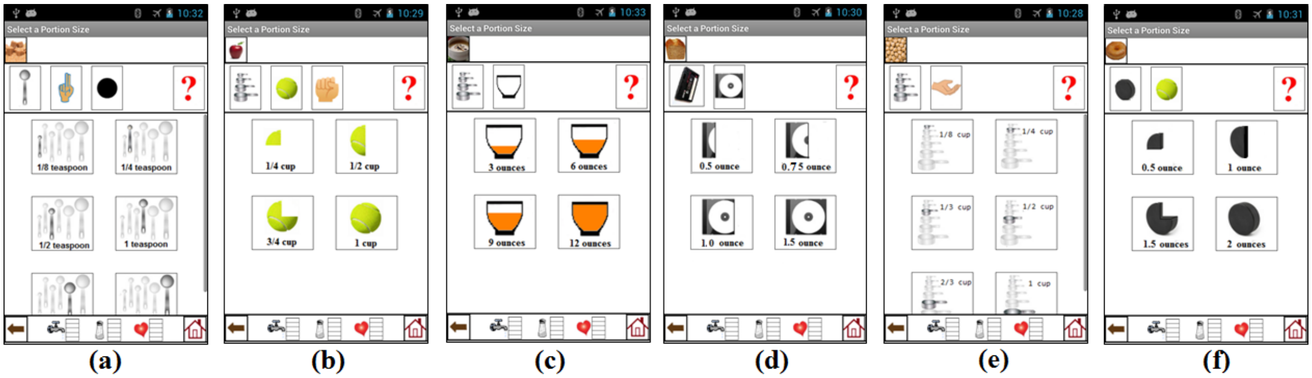


**Figure 2 © Beenish Chaudhry. Example Interfaces from Portion Size Estimation Module (a) Measuring Spoons for Condiments (b) Tennis Ball for Fruits (c) 12 ounce Bowl for Soup (d) CD Case for Breads (e) Measuring Cups for Legumes (f) Hockey Puck for Bakery Items**

received a 25-page picture-based user manual showing how to use DIMA-P, including taking pictures, entering food items, and estimating portions. During this phase, participants recorded their dietary intake and portion sizes. They also photographed their meals both before and after eating. They placed a reference object, e.g., card deck, in these photographs to help us estimate food amounts against a standard sized object. We had face-to-face encounters with the participants three times a week during the first two weeks of self-monitoring for a total of 6 times. During each meeting, we resolved issues related to application usage, and answered questions related to the study. For the remaining four weeks, we were accessible via phone.

### End of Self-Monitoring Assessment

At the end of six weeks, we met with participants to collect their phones, and conduct an end of study assessments. We conducted the same Portion Size Estimation Tests and the PSESES instrument we had used at the baseline. Participants verbally responded to the modified Rawl usability questionnaire [36], which consists of 25 closed and 3 open-ended questions, asking participants to evaluate attractiveness, comprehensibility, user-friendliness, and usefulness of the application. Participants also explained their responses to closed questions that were written and used in the qualitative analysis. In addition, they also responded to a context of use questionnaire consisting of 25 closed and 3 open-ended questions. Finally, participants responded to eight open-ended questions that assessed their self-efficacy of self-regulating their portion intake.

### Participants

We approached 15 patients in an urban dialysis facility and eleven agreed to participate. Two patients dropped out within the first week (due to difficulty seeing the screen due to cataracts, and feeling too sick to participate). In this paper, we report on the nine patients who completed the study. The study sample included two women and seven men – everyone was Black/African American with an average age of 49.4 years (SD = 8.0 years). All participants were on Medicaid and lived in a low-income neighborhood.

Participants had on average 12.6 years of education and demonstrated varying reading and functional literacy levels based on NVS scores. Two participants scored 0-1, suggesting a high likelihood of limited literacy; three scored 2-3 indicating the possibility of limited literacy, and four scored 4-5 signifying adequate literacy. We classify those who demonstrated high likelihood and possibility of limited literacy as low literacy – marked with † in Table 1.

Participants' technology familiarity ratings can be described as: (a) low – did not use computers more than once a month and never used a mobile phone before the study; (b) medium – used computers a few times a month and may have used a mobile phone before; (c) high – used a computer every day, and had also used a mobile phone including a few mobile application games before. None of the participants used computers for anything other than chatting, surfing and social networking.

Six participants reported watched their portion sizes while eating either by not cooking too much or by eyeballing the amount they put on their plates. Only two participants were familiar with the term 'estimation aid.' None of the participants reported tracking or calculating their daily nutritional intake despite a strict and prescribed nutritional regimen. Six participants regularly had problems maintaining their blood phosphorous within a normal range.

### Analysis

The data collected during the study included: (i) application usage logs; (ii) inter-dialytic weight gain and blood nutrient levels; (iii) participants' food and fluid entries and portion sizes recorded during the self-monitoring phase (meal logs); (iv) meal photographs captured by participants both before and after they ate; (v) participants' responses to the pre- and post-study portion size estimation tests; (vii) pre- and post-study responses to PSESES instrument; (viii) post-study knowledge of reference objects; (ix) post-study responses to modified 28-item Rawl usability questionnaire; (x) responses to context of use questionnaire; and (xi) participants' post-study comments and impressions about using a portion size estimation module.

| | Tech Fam. | Years of Ed. | NVS | Use Days | Average Daily Portion Sizes |
|---|---|---|---|---|---|
| P1*† | Medium | 14 | 3 | 42 | 8.76 |
| P2 | Low | 13 | 4 | 17 | 5.86 |
| P3† | Low | 14 | 2 | 27 | 3.52 |
| P4*† | Low | 12 | 3 | 41 | 8.14 |
| P5† | Medium | 12 | 0 | - | - |
| P6* | Medium | 12 | 5 | 42 | 9.19 |
| P7† | Medium | 13.5 | 1 | 34 | 3.08 |
| P8* | High | 12 | 5 | 40 | 8.97 |
| P9 | Medium | 11 | 5 | 28 | 3.39 |

**Table 1. Participants' Tech Familiarity, Literacy Levels, and Application Use (Key: Ed. = Education; Fam. = Familiarity)**

In this paper, we focus on how participants used the portion estimation interface, how they felt about using it, and how their self-efficacy and portion estimation abilities changed. We used logs of all participants except P5 because their logs were accidently erased during extraction from the device. We used the Data Package in Microsoft Excel for quantitative analysis of application usage logs. To determine accuracy of portion sizes recorded in meal logs, the primary author determined the ground truth of estimates using a combination of methods such as fiduciary marker, container sizes, and packaging information in corresponding meal photographs. The estimate was determined to be accurate if participants selected the portion size that was closest for the particular estimation aid they chose to use. For example, if they were recording 1.5 ounces and chose the hand estimation aid, a full-cupped hand was the closest (representing 2 ounces); whereas if they used the deck of cards estimation aid, half a deck was the closest (representing 1.5 ounces).

The qualitative data included participants' unstructured, written responses to the usability and self-efficacy instruments, and their reflections on their experience with the portion size estimation interface recorded during the interviews. Two researchers independently coded the data at the sentence level using Dedoose. Codes emerged through open and inductive processes, which the research team then iteratively refined to develop consensus. A total of 23 codes were initially generated, then grouped into the main themes described in this paper.

## RESULTS

A majority of the participants demonstrated sustained use of the application. Participants' literacy skills tested in NVS did not have any relationship with the usage of estimation module. Overall, participants found the estimation module easy to use and apply. Time and effort involved in using the module did not cause any concern. The major successes of the estimation module included its effectiveness in helping participants develop and practice portion estimation skills and learn knowledge. This led to improved self-efficacy and increased awareness of one's eating habits. Some of the challenges included lack of specific reference objects for some food items, and inapplicability of a certain class of reference objects to some participants.

### Application Usage

We classified participants into two groups according to their frequency of recordings with the portion estimation interface. The first group recorded an average of 8-9 portion sizes per day, and the second recorded an average of 3-4 portion sizes per day. This helped us define an active participant (marked with * in Table 1) as one who recorded at least six portion sizes on at least half of the study days.

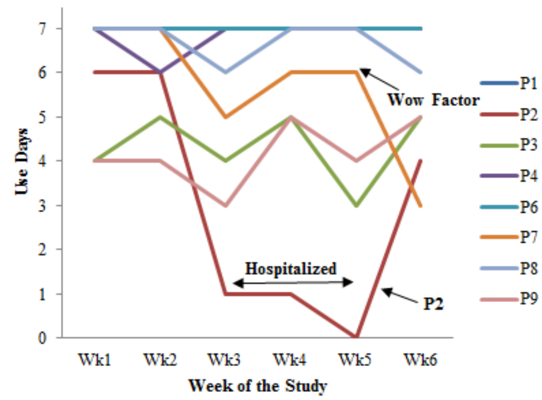


**Figure 3 © Beenish Chaudhry. Use Days by Week**

We also studied DIMA-P usage in terms of the number of days they used the application (use days) in each week of the study (Figure 3). Five participants showed a drop in use days in the third week. This corresponds to the time when the researcher stopped face-to-face meetings with the participants. Five participants increased usage in the last week, including P2 who did not use DIMA-P from week 3 to week 5 due to a hospital admission. One participant (P7) showed a significant decrease in the application use over the course of the study – a phenomenon known as the "wow factor" (Figure 3) [13]. Overall, even the most infrequent users used the application somewhat regularly during the study. Moreover, there was an increase in use days in the last week among most participants, suggesting incentives could have been a motive.

To understand how participants' daily interactions with the application changed over the course of the study, we used a quality of use metric also used in the original DIMA study [13]. A day was rated High (2) if more than one recording was made in a day, Medium (1) for only one recording, and Low (0) for no recording during the day. Based on weekly averages of the daily ratings, we found that four participants maintained high and two maintained low quality of use. The remaining two (one of them was P2) decreased their quality of use from high, in the first two weeks, to medium, in the final two weeks. The majority of participants had multiple interactions with DIMA-P every day during the study. This result is similar to the first pilot study, where there was no portion size estimation module.

### User Experience

From the usage logs, we learn that the recording time with DIMA-P was longer than with DIMA, 35.4 seconds versus 13.5 seconds. However, use days and quality of use metrics show that introducing portion estimation, which increased task completion time, did not significantly change the usage. From the usability questionnaire, we learn that, overall, participants found the application easy to use (Median=4; SD=0.97). They also found it easy to do portion size estimation with DIMA-P (Median=5; SD=0.73). They thought the information on the portion estimation interface easy to understand (Median=5; SD=0.53). Watching their dietary intake with DIMA-P was a satisfactory experience for most participants (Median= 4; SD=0.44). Finally, most participants were willing to use the application again (Median=4; SD=0.93), and also wanted to recommend it to others having trouble managing their diet (Median=4; SD=1.32).

### Portion Size Estimation Module's Usage

To understand how participants used the portion estimation interface, what they felt about using it, and how well it fulfilled their portion estimation needs, we describe the six key themes that emerged from participants' post-study comments about their experiences. We discuss each theme with supporting quotes from participants.

#### *Strategies in Selecting Aid Portions*

Participant developed metrics to ensure they were accurately interpreting the information on the estimation interfaces. Individual seemed to gravitate towards a small set of aids they wanted to apply based on three criteria:

*Flexibility:* an aid's ability to define a portion size even when it did not fit a food's shape or composition – "*Deck of cards was my gauge*" (P7†).

*Physical Availability:* an aid's availability in the physical world even when it was not difficult to imagine other presented aids. "*It was not difficult to imagine the size of baseball; but I did not want to do it. I just relied on my hands*" (P6*). "*If I am not sure how much I am eating, I would drop it in a measuring cup to check*" (P4*†).

*Relevance:* the number of times an aid was used or interacted with by the participant in the real world. The lesser an object's relevance to participants, the harder it was for them to create its mental image and find it useful. "*I have not looked at the hockey puck for a long time so I forget, and it becomes difficult to imagine*" (P2). "*For people who are not into sports, find something else to measure"* (P8*).

#### *Conflict between internal beliefs and external information*

Participants consistently reported a feeling of surprise or disbelief around what the application told them was a certain portion size. When first beginning to use the application, users identified a misalignment between their own beliefs around what a portion size of a food looked like and what the application told them. Many users aligned their beliefs with the application information and then reported integrating that knowledge into their practice – "*I was shocked to find out, it was different. My perception about values of different containers was not correct. Before you just drown it in gravy because it tastes good, but now you know how it is, you are taking in too much*" (P8*).

Participants described two processes that helped them reconcile the information provided in the application with their beliefs – performing confirmatory testing to check the accuracy of the application and continued application use. P2 used a physical version of the aid to confirm information in the application – "*it is not believable that the object is that much weight but when you look at the actual size of the object it becomes believable. I [had] not looked at the deck of cards for a long time so I forgot*." P5† used a scale to confirm the application's information – "*I had to weight it out ... to match the pictures on the screen*." Instead of conducting confirmatory testing, P1*† continued practicing with the application to develop confidence in the application's estimators – "*I had knowledge of certain sizes but I was not right; it helped me [to] practice*."

For a few participants, some images remained unbelievable after continuing to use the application. P2 had difficulty because the images of the objects were too unfamiliar to be deciphered properly. P2 pointed out that they could not believe "*an image [pointing to ¼ of cassette] is 0.25 ounce bread*." They admitted they were not able to identify the object in the image. P8* also reported having difficulty believing the application, even after continued use: "*Some of the portion sizes are not believable like I cannot believe that cheese about the size of 2 playing cards side by side is 1 ounce.*" P8* cited their disbelief of some of the estimators as their primary frustration with the application.

#### *Learning through application use*

Participants described three different ways that they gained knowledge and skills through using the application: 1) *specific, factual information*; 2) *practical skill-based knowledge*; and 3) *personal information about an individual's own behavior.*

During the post-study interview, some participants reported being able to learn specific factual information around what size different portion aids represented – "*5 crackers = ½ ounce; mini muffin = 3 ounces; fist = 1 cup*" (P8*) and "*I had knowledge of certain sizes but I was not right; it helped me practice what my dietitian always tells me to do; I remember 1 Golf ball = 1 ounce; Fist = 1 cup; Handful = ½ cup; deck of cards = 3 ounces of meat*" (P1*†) – and conversions between measurement units – "*show more comparisons like 4 tablespoons = 1/4 cup*" (P7†).

One thing that users appreciated greatly was the opportunity afforded by the application to practice their portion size estimation skills. Some participants wished they had more time to use the application, as they had just started learning to manage their health outcomes. "*The study should have been for at least 90 days. I think you see more changes* [in health outcomes i.e. inter-dialytic weight gain and portion estimation skills] *in this time period*" (P8*). Many suggested that they gained some level of skills that they would be able to take forward in their life, even without having the application or reference objects in their lives.

#### *Main Uses: Reference and Feedback*

Participants admitted that the applications helped them make choices when they were approaching limits. "*I slowed down when it was red and I tried to watch what I eating" (*P4*). However, participants noted that the application could have suggested specific foods or portion sizes based on their current intake: "*It needs to be dynamic and tell people how much to eat* [when they are close to their recommended limits]" (P3†).

Participants also admitted that the application helped them eat less and work towards their own specific goals. "*It taught me how to eat less*" (P1*†). "*Documenting helps you make better choices and how much to eat*" (P3†). Participants were also interested in seeing how consuming a certain portion size would affect their weight gain between two dialysis sessions: "*It should show how it* [a portion] *is going to change my weight*" (P7†).

#### *Limitations of the Estimation interface*

Participants thought the estimation interface needed to be more specific in identifying different scenarios - such as when different preparations of the same food could vary greatly. One individual reported, "*It just had too little options for cooking, like potato you can eat it mashed or cubed or fries. Some of the places, it was not enough options like candies come in so many different shapes and sizes. There is a very long candy and some potatoes are grown as finger potatoes*" (P8*). This was also an issue in home-prepared food versus restaurant food – "*I think choices need to be more definitive. For example, there are so many different sizes of hotdogs. I know at home they are small size but when you go to convenience store they are bigger*" (P3†). A better clarification of portion images was also desired. "*Some of the portion pictures need more explanation, for example the meat about the size of card deck is 3 ounces with bones or without bones"* (P2).

Another emergent concept was the time and effort to enter all the ingredients of a prepared meal to get more accurate feedback. "*Sometimes you eat so many things and then you have to think about portion size for each one of them and it becomes time consuming but I want to lose weight and want to track everything that I am eating"* (P1*†).

In our face-to-face contact during self-monitoring phase, several participants pointed out that they were having trouble maintaining their blood phosphorous levels. We note that these participants would have benefited from having phosphorous in the glance-able nutrient display – currently it is only shows fluid, sodium and potassium.

| Successes | Concerns/ Challenges |
|---|---|
| Flexibility of reference objects | Irrelevance/ unavailability of certain reference objects |
| Promotion of knowledge and learning with respect to portion size estimation | Mismatch between internal belief and external representation |
| An opportunity to practice skills and apply knowledge | Lack of specific reference objects for portion estimation with respect to prepared meals |
| Improvement in decision making and self-efficacy | Time and effort involved in estimating portion sizes |
| Awareness of one's own behaviors was promoted by real-time feedback | Limitations with respect to understanding/ managing overall personal health |

**Table 2. Estimation Module's Successes and Challenges**

#### *Portion Size Estimation Self-Efficacy*

During the post-study interviews, participants made comments that suggested an increase in their self-efficacy around measuring portion sizes and integrating portion size measurement into their eating practices. "*I knew about estimation aids from my dietitian but I never used them. This tool helped me practice what my dietitian always tells me to do*" (P1*†). Another concept emerged around participant's confidence in their knowledge of their own practices. "*I was already measuring my fluid but it helped me realize how quickly I ate 4 ounces of peanut butter"* (P3†), and "*It added a lot of knowledge. It showed me what the heck I was doing and how to do it better*" (P7†).

| Self-Efficacy in | Pre-Study | Post-Study |
|---|---|---|
| Estimating portion sizes in various situations | 4.13 (SD=1.17) | 4.60 (SD=0.92) |
| Using estimation aids and household containers | 3.33 (SD=1.25) | 4.56 (SD=0.90) |

**Table 3. Descriptive Statistics for Subscales of PSESES**

In their post-study reflections, participants pointed out that before the study, they thought they knew portion sizes. But during the study they learned that their perceptions were not necessarily accurate. "*Before I thought I could* [estimate portion sizes] *but I found out I could not*. *Like my idea of ½ cup was more than a fist*. *But now I know better*" (P8*). "*It helped me learn to do the right thing. I thought I could do it before but it makes more sense now*" (P9).

The mean score on both subscales of PSESES improved post-study. A paired t-test comparing pre and post-test responses to the PSESES questionnaire revealed a significant difference in participants' confidence in estimating portion sizes, $t(8) = 3.32$, $p=.011$, and their confidence in using estimation aids and household containers, $t(8) = 3.62$, $p =$

.004. These results, although with a small sample, support the finding that participants felt a greater sense of self-efficacy in estimating portion sizes and using estimation aids and household containers to support their assessment of portion size.

### Pre and Post Portion Size Estimation Tests

| | Pictures (Max=12) | | Measure (Max=10) | | Containers (Max=12) | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post |
| P1*† | 3 | 6 | 5 | 6 | 4 | 6 |
| P2 | 2 | 4 | 6 | 9 | 2 | 2 |
| P3† | 2 | 4 | 3 | 5 | 5 | 8 |
| P4*† | 3 | 6 | 6 | 4 | 3 | 6 |
| P5† | 5 | 6 | 3 | 1 | 3 | 4 |
| P6* | 6 | 6 | 5 | 6 | 5 | 5 |
| P7† | 4 | 5 | 4 | 4 | 4 | 4 |
| P8* | 2 | 6 | 6 | 5 | 2 | 4 |
| P9 | 2 | 5 | 6 | 5 | 1 | 3 |
| Mean | 3.22 | 5.22 | 4.89 | 5 | 3.22 | 4.67 |

**Table 4. Portion Estimation Test Scores**

Not only did participants increase confidence in estimating portion sizes, they also demonstrated increased accuracy in the portion size estimation tests. From the test scores (Table 4), we learn that eight participants improved their scores on *Pictures*, four improved on *Apportion* and six improved on *Containers*. Paired t-tests comparing participants' pre and post scores on the *Pictures* and *Containers* test revealed significant improvement in their ability to estimate portion sizes: $t(8) = 4.99$, $p < .001$, and $t(8) = 3.51$, $p < .001$, respectively. We found no significant change in participants' scores for the *Apportion* test, $t(8) = .48$, $p=.32$. The positive effect on the *Pictures* test, but not the *Apportion* test suggests participants became more skilled at estimating portion sizes of food once it was portioned out, however they still had difficulty in creating an amount of food matching a specified quantity.

### In Situ Estimation Accuracy

In comparing participants' portion size estimates for 600 food and 144 drink items, as recorded in the application, to the actual portion sizes based on the pictures they took, we found that participants accurately measured more than half of their portions, 58.2%. The inter-dialytic weight gain data helped us bolster the accuracy of these estimations. The in situ estimation accuracy of most food categories did not seem to change over the course of the study, except liquids and eggs that showed improvement over time. Participants had more difficulty measuring portion sizes of solid (69% correct) and amorphous foods (62%) compared to liquids (95%). Snacks (32%) and crackers (14%) had lowest percentage accuracies but they were also recorded infrequently (44 and 28 total recordings respectively). Moreover, also like earlier work [12], protein portions, such as meat pieces or slices represented the greatest challenge to participants, (36% accurate estimates) suggesting a need to focus on education and reference objects that effectively support the estimation of these items.

## DISCUSSION

In this section, we highlight novel conceptual understandings about health behavior change technologies and issues surrounding their in situ use based on our findings. We discuss how cognitive dissonance and manual logging can be leveraged in design for changing users' beliefs about health behaviors and empowering them to take greater control of their health. Finally, we discuss the importance of data triangulation in the evaluation of behavior change applications.

### Leveraging Cognitive Dissonance

At times, participants demonstrated disbelief when information on the estimation interface conflicted with their current knowledge. Festinger's Theory of Cognitive Dissonance [17] suggests that this mental inconsistency would put individuals in a state of psychological discomfort. The psychological discomfort would, in turn, prompt individuals to act in order to reconcile their contradictory beliefs. As Consolvo and colleagues summarized, users have four options for recourse when faced with this discomfort – changing their behavior, changing their knowledge, rationalizing the dissonance, or avoiding the information and situations that reinforce the dissonance [14].

In our study, participants primarily engaged in changing their knowledge in response to dissonance between information in the application and their current knowledge. This differs from much of the prior HCI research, where interventions have directly targeted behavior change by creating dissonance between users' behaviors and their beliefs [22, 7, 40]. When participants in our study were confronted with information inconsistent with their current knowledge or beliefs, many stopped to consider the information and actively engaged in reconciling their prior knowledge with the new information. For several, this took the form of testing, where participants used scales or physical objects to confirm what the application was telling them.

Although we found that the cognitive dissonance created through DIMA-P primarily had a positive effect, it is well documented that cognitive dissonance can also cause users to avoid situations that reinforce the psychological discomfort [7, 41]. Systems that create dissonance could alienate users and lead them to stop using the application or reduce their engagement with it [11]. P8 highlighted her disbelief of some portion size estimators as the one negative aspect of the application. Although this supports the idea that creating dissonance has the risk of engendering negative attitudes in users, ultimately P8 continued using the application throughout the study period and highlighted the way the new knowledge helped her in practice. In our case, users could reconcile this new knowledge by engaging physical versions of the estimators and scales to test the accuracy of the application. This helped them remain engaged with the application instead of abandoning it. Applications that aim to use cognitive dissonance as a method to support knowledge development or behavior change must provide users with the ability to reconcile dissonant information by integrating and supporting methods to verify application claims.

In addition to providing opportunities for users to confirm information in the application, prior research also suggests that facilitating expert or peer communication for users could help them resolve disbelief [28, 30]. Gaming could also be used as a strategy to educate users and present potentially dissonant information. The gaming element can increase engagement and comfort with new concepts - helping reduce the negative side effects of cognitive dissonance. Grimes-Parker's work on educating low SES populations about food is an example of this approach [21].

### Involving Users in Input

There has been an effort to develop systems that automate the process of collecting dietary information from users [9, 27, 48, 49] or estimating portion size through semi-automated methods [31]. Although this relieves the burden of entry and portion size estimation from users, which addresses a major barrier in long-term engagement with behavior change applications [45, 43], our research suggests that this may miss out on some of the most valuable learning opportunities for users. In our study, participants developed knowledge, skills, and self-efficacy around estimating portion sizes that transcended the application itself. Almost all of this development came from the process of entering food into the application and using the aid to estimate portion sizes. Automated portion size systems would take these learning opportunities away from users, disempowering them from developing their own skills in portion size estimation. For low literacy users, this is especially problematic, as these kinds of foundational skills are valuable for use in everyday life.

Other researchers have identified the process of logging health behaviors in self-monitoring applications as a key moment for learning, reflection, and awareness raising [8, 15, 37]. When users are removed from the logging process, feedback can be out of context and there are missed opportunities for just-in-time feedback. Similar to this prior research, our work challenges the idea that we should automate the logging of behaviors and instead suggests that we should develop systems to make entry more engaging and valuable for users. By actively engaging users in the process of entering their food and estimating their portion sizes, we enhanced their self-efficacy and provided them with knowledge and skills that could be applied outside the application. Previous research has used just-in-time feedback when behaviors are logged and game progression as ways to promote self-logging and make it a valuable experience for users [39]. More work should be done to explore ways to make the self-logging process more valuable and engaging for users.

### Data Triangulation

We aimed to target self-efficacy and portion size estimation skills by designing features that supported two out of three behavioral health constructs of ITHBC (a) foster knowledge and beliefs, and (b) enhance self-regulation skills and abilities. Our analysis of pre and post-study tests shows that participants' self-efficacy of portion size estimation, and their knowledge and skills around portion size estimation have improved. However, on analyzing in-situ meal recordings we found that participants were inconsistent in their ability to translate their knowledge and skills into accurate portion size estimations for different types of food in everyday life. The theory postulates that improving these two constructs should impact health behaviors. Our results highlight a gap between theory and practice, uncovered only through data triangulation.

One possible problem with DIMA-P was the lack of support for the social facilitation construct of ITHBC. If participants had obtained feedback on their in-situ portion size estimates over the course of the study, it is possible that they could have self-identified shortcomings in their techniques and consequently rectified them. Prior work has found that peer or expert feedback on one's diet can help improve people awareness of their dietary intake [30, 52].

Other research has used data triangulation to find gaps between theory and practice [30] and inconsistencies in people's perceptions and behaviors [38]. Indeed, Klasnja and colleagues suggest that early stage HCI research in behavior change technologies should focus on efficacy evaluations and studies that help gain deeper understanding of people's technology use [25]. We join them in their suggestion by adding that data triangulation (especially with in-situ data) is critical for understanding the nuances in people's use of technology, and for uncovering future research directions.

## LIMITATIONS

While we acknowledge that a sample size of 7-9 people is small, Klasnja and colleagues argue that piloting an early research interface in a long study with fewer participants makes better sense in uncovering errors [25]. The smaller sample size helped us looked at specific design issues and needs of the participants in more detail. Moreover, we only had one view of meal photographs that might have affected our assessment of participants' accuracy of estimation.

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