Published in final edited form as:

Appl Ergon. 2020 January ; 82: 102912. doi:10.1016/j.apergo.2019.102912.

The Desktop, or the Top of the Desk? The relative usefulness of household features for personal health information management

Anna F. Jolliff^{1,2}, Peter Hoonakker^{3,4}, Kevin Ponto^{4,6}, Ross Tredinnick⁴, Gail Casper^{4,5}, Thomas Martell¹, Nicole E. Werner¹

¹Department of Industrial and Systems Engineering, University of Wisconsin-Madison

²Department of Counseling Psychology, University of Wisconsin-Madison

³Center for Quality and Productivity Improvement, University of Wisconsin-Madison

⁴Wisconsin Institute for Discovery, Madison, WI

⁵School of Nursing, University of Wisconsin-Madison

⁶School of Human Ecology, University of Wisconsin-Madison

Abstract

Sixty percent of the US population manages at least one chronic illness. For these patients, personal health information management (PHIM) is an integral part of daily life, and largely occurs within the home. However, the way in which the home supports PHIM has not been systematically investigated. The present study examined how members of the diabetic population use features of the home environment to support PHIM. Participants ($N=60$) explored a simulated home environment, the VR CAVE, and identified the most useful features for performing three examples of PHIM tasks. The computer was perceived as the most useful feature for PHIM. However, perceived usefulness of features varied based on the PHIM task performed and the rooms in which features appeared. We conclude that a detailed study of the affordances of features is necessary to ease the burden of managing chronic illness, particularly diabetes mellitus, in the sociotechnical system of the home.

Keywords

Personal health information management; sociotechnical systems; chronic illness; virtual reality

1.0 Introduction

1.1 Managing chronic illness at home

Some of the most critical aspects of healthcare are performed in the home environment. This is particularly true for patients managing chronic illness. In 2014, those managing at least

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

one chronic condition represented 60% of the US population, and 42% managed more than one (Ward, Schiller, & Goodman, 2014). Managing chronic illness often demands strict and detailed at-home regimens and activities called self-management. A subset of self-management, personal health information management (PHIM), refers to the work of managing one's health information (MacGregor & Wathen, 2014). This work can be understood both behaviorally and cognitively, with actions such as storing, organizing, monitoring, and seeking out health-related information. For patients managing chronic illnesses such as arthritis, coronary heart disease, and – in the case of the present research – diabetes mellitus, PHIM is an integral part of daily life (Ancker et al., 2015). To both understand and meet the needs of the growing population managing chronic illness at home, we must better understand the work of PHIM (Cheng, Hootman, Murphy, Langmaid, & Helmich, 2010; Ward et al., 2014).

Previously, the work of PHIM has been called “invisible,” in that it occurs in the home “behind closed doors” and often goes unrecognized by healthcare providers (Ancker et al., 2015). In recent years, significant strides have been made to understand PHIM, with the performance of PHIM at home receiving increased attention. Although research has expanded our knowledge of how PHIM is performed at home, relatively little is known about the contextual influence of the environment itself (Mickelson, Unertl, & Holden, 2016) (Aarhus & Ballegaard, 2010). And yet, central to an understanding of patient work is an understanding of the environmental context in which that work occurs (Moray, 1994; Wilson, 2000).

1.2 Studying PHIM in context

Both PHIM tasks and the home environments in which these tasks occur are variable and complex. PHIM may include diverse tasks such as medication management, gathering information online, remembering medical appointments, verbally sharing information, and recording lab values, for example. Variations in the home environment include, for example: the layout of the home, which may allow for privacy; the lighting of the home, which may permit easily reading a medication bottle or finding a syringe; the size of the home, which may dictate whether PHIM is performed all in one place, or spread throughout the house; the availability of storage, which could affect whether a home is organized or cluttered; and the household furniture present, which may or may not support actions related to PHIM (Moen & Brennan, 2005) (Werner, Jolliff, Casper, Martell, & Ponto, 2018). Understanding these highly variable activities across variable environments is no easy task.

1.2.1 Designing to support PHIM in context—The variable environment of the home can be understood as a complex sociotechnical system (STS) (Carayon et al., 2006; Holden et al., 2013; Holden, Schubert, & Mickelson, 2015; Unruh & Pratt, 2007). STS theory describes an interdependent work system of spaces, objects, people, and tasks, that perform processes to produce outcomes. For all patients managing health information at home, PHIM is the product of many interactions within a complex STS (Holden et al., 2015). Moen and Brennan (2005), for example, showed how the strategies employed by community dwellers to manage PHIM interact with both the specific task at hand and household spaces.

Tools and technologies are an integral component to sociotechnical systems, and have great potential to ease the burden of PHIM (Mickelson, Willis, & Holden, 2015) (Palen & Aaløkke, 2006). Evidence suggests that health information technology (HIT), specifically, has the potential to support PHIM at home (National Research Council, 2011). However, HIT solutions are often created with little attention to the context in which they will be used or the actors who will use them (Or & Karsh, 2009) (Zayas-Caban & Dixon, 2010) (Zayas-Cabán & Valdez, 2012) (Lucero et al., 2012) (Piras & Zanutto, 2011) (Kim et al., 2009). For example, a wheelchair may be significantly less useful in a split-level home. As another example, some populations may find a digital calendar to be less visible, convenient, or intuitive than a wall calendar. We currently lack evidence-based guidance for the development of HIT that considers the interactions between end user characteristics and the context of the home environment.

1.2.2 Affordances of household features—As Moen and Brennan (2005) found, features of spaces and objects shape a person's PHIM strategies. The real or perceived properties which determine how a space or object may be used are that feature's *affordances* (Norman, 1988). Affordances may include the capacity to provide *storage* (as in a drawer), hazard resistance (as in a child-proof pillbox), or communication (as in a computer or telephone). Affordances occur not only in isolated features, but also emerge within a complex system of interacting features. For example, a drawer that appears in the bathroom may offer more privacy than one which appears in the kitchen. As such, affordances ought not be studied in isolation, but rather in relation to other features. This makes naturalistic home environments an ideal setting in which to study affordances.

1.2.3 The sociotechnical system in the context of diabetes mellitus—The peculiarities of specific chronic illnesses inevitably shape the sociotechnical systems in which they are managed. The tools, tasks, organizational structure, and environments which support one illness may be entirely different from those which support another. Patients with diabetes manage unique daily tasks such as monitoring blood sugar values, managing an array of medications, and recalling medical appointments. Insulin, a vital tool for managing blood sugar levels, may require safe refrigeration. Further, it may be necessary to keep an insulin pen close at hand for emergencies, yet simultaneously out of reach of young children. As another example, a Bluetooth-enabled glucometer may require private storage, yet remain within sufficient proximity to a computer that is used by multiple actors. Many diabetics require convenient places to store “sharps,” or used needles. We might speculate that a diabetic-friendly sociotechnical system would offer safe, accessible, and discreet solutions to illness management; however, research is needed to investigate these speculations, and to determine how features of the home might support or hinder the management of diabetes.

1.2.4 Barriers to studying PHIM in context—Conducting research in home environments presents unique challenges. Researchers are typically limited in the time they can spend in a home, constrained in the number of visits to a single home, and further constrained to a total number of homes due to travel or cost limitations (Marquard, Moen, & Brennan, 2006; Valdez et al., 2014; Zayas-Caban, 2012; Zayas-Cabán & Valdez, 2012). In

addition, home assessment is time consuming and typically necessitates expert evaluation of the environment, which can add to time and cost barriers (Carlsson et al., 2008).

Immersive 3D environments present an alternative means to study PHIM in context while circumventing these barriers. The present study used a simulated home environment, the CAVE automatic virtual environment (VR CAVE), to systematically examine PHIM within virtual recreations of actual home environments (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992) (Brennan, Ponto, Casper, Tredinnick, & Broecker, 2015) (Werner et al., 2018). These recreations provided a 3D perspective and enabled participants to freely explore the simulated environment. The use of a highly realistic virtual environment allows for the authenticity and degree of engagement seen in real world settings, while avoiding the aforementioned barriers (Drews & Bakdash, 2013) (Rooksby, 2013; Sanderson & Grundgeiger, 2015).

1.3 Objectives

The objective of the present study is to better understand how members of the diabetic population use the specific features of their home environment to support PHIM. Specifically, we are interested in which features are understood as useful. Notably, we understand “usefulness” as a term that implies perception or point of view, and as such use it here as a relative rather than absolute construct. With that in mind, our research questions were as follows: 1) What features in the home environment are most useful for PHIM for those managing diabetes mellitus? 2) Are there differences in the usefulness of features across the different PHIM tasks performed by those with diabetes mellitus? And 3) do participants with diabetes mellitus perceive different features in the physical environment to be more or less useful when they are located in different spaces in the home?

2.0 Methods

The present study is the fourth subproject (SP4) of a parent project, vizHOME, the goal of which is to understand how the home environment facilitates or presents a barrier to PHIM. The vizHOME study was approved by the Institutional Review Board.

2.1 Participants

Eligible participants were people 18 years of age or older who had been diagnosed with diabetes mellitus. Participants were recruited through advertising in healthcare facilities and public libraries, as well as referral by endocrine clinic staff. Participants had to be able to read and write English. Sixty participants ($N=60$) completed the VR CAVE home assessment phase of the study.

The mean age of the participants was 58.3 years ($SD=15.67$). The youngest and oldest participants were 20 and 86 respectively, yielding a range of 66 years. Self-reported gender indicated 32 male and 28 female participants. Forty-six participants identified as white; nine as black; two as Asian; and three as more than one race. Two participants reported Hispanic or Latino ethnicity.

2.2 Apparatus

Accurate 3D virtual replicas of 20 actual household interiors were created using a LiDAR (Light Detection and Ranging) scanner. These virtual replicas were projected on six 9'6"x9'6" sides of the VR CAVE (the ceiling, the floor, and the four walls) at a resolution of 1920x1920 pixels per side, resulting in a submillimeter accurate representations of the 20 home environments. While in the VR CAVE, participants wore stereoscopic 3-D glasses which also served as a head tracker. As participants moved freely about the rendered environment, the virtual models updated based on user's location and direction of gaze. Participants experienced the space and the features within it from a natural, right-sized immersive perspective, creating what is called a sense of presence (Sanchez-Vives & Slater, 2005).

The study team used the results of the third subproject within the larger parent project to determine the features that participants identified as most useful for PHIM (Werner et al. 2016). Features that were found to be the most useful in this subproject were subsequently made available in the VR CAVE in the present project (see Appendix A for the full list of features). These features were surrounded in the cave by virtual "boxes," which indicated to participants that these features were available to be selected, or "tagged" (See Figures 1–5 in Appendix B for examples).

2.3 Task

For each of three PHIM tasks described below, participants were transported through a series of five non-contiguous rooms and were asked to identify the two most useful features for performing each task in each room. Participants were allowed up to 15 minutes per task to complete this. The three tasks were as follows (*italics added*):

Task 1: Medication investigation—You have just developed a rash and are concerned it may be related to a medication you recently started taking. What boxed feature in this room would be most useful to you for *finding out if the rash could be a side effect of this medication*?

Task 2: Appointment reminders—You are having an outpatient surgical procedure. In preparation for the surgery, you have been scheduled for 5 appointments for preoperative teaching and care at different locations. What boxed feature of this room would be most useful to you for *setting up a reminder for yourself or someone else in your household to help you recall the appointment*?

Task 3: Checking and recording blood sugar values—Your clinician told you that you should check your blood sugar four times per day and record the values until your next visit. What boxed feature of this room would be most useful to you for *checking your blood sugar and recording the value*?

2.4 Procedure

The project director developed presentation slides with a script-driven audio component to ensure standardized orientation of the participants to the vizHOME project, training for the

home assessment task, and special equipment used to collect data in the VR environment (including stereoscopic 3-D glasses and the wand for navigating and tagging features). This orientation occurred prior to participants completing the tasks.

Virtual renderings of selected rooms (living room, kitchen, bedroom, bathroom and den) within 10 homes representing four home types (detached, semi-detached, multi-unit, mobile) were viewed. To avoid redundancy, room, task, and sequence combinations were randomized and checked for errors by project researchers. Participants were randomly assigned to these combinations. Each sequence of five rooms per task were sampled from five different virtual homes.

Scripts were used at each step of the process to ensure a consistent procedure. During each PHIM task, a research assistant served as a “guide” and documented feature selection within each room. A technical assistant ran the VR CAVE, solved technical issues, and recorded time in the VR CAVE. Participant comments were audio-recorded as they selected features in the VR CAVE. After completing all PHIM tasks, participants exited the VR CAVE and completed surveys which measured simulation sickness, workload, and demographic information. Participants received \$100 upon completion of their participation.

2.5 Measures

To measure their experience of the task in the virtual world, participants completed the NASA Task Load Index (TLX) (Hart & Staveland, 1988) and the Simulation Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilenthal, 1993). The NASA TLX measures workload across six domains, including mental demands, physical demands, temporal demands, own performance, effort, and frustration. The SSQ contains 16 items which measure general discomfort (including nausea), disorientation (including dizziness), and oculomotor factors (including eyestrain). Both the NASA TLX and the SSQ were scored according to recommended scoring conventions.

2.6 Data Analysis

Every time a participant tagged a feature as useful for a PHIM task, this data was recorded both by the computer system and manually by the research assistant. Manual documentation enabled the recording of participant tags that were not contained in the feature list. Three primary data elements were analyzed for the current research questions and organized in frequency tables. These tables (see Tables 1–5) depict a feature’s actual and possible selection, as well as the percentage of tags across tasks, per task, and per room. Frequency values were calculated as follows:

2.5.1 Total actual tags—Total actual tags was the label assigned to the total number of times a participant tagged a given feature as one of the two most useful features in a given room. For example, if cabinets were tagged as one of the two most useful features in a room a total of 100 times (across all participants combined), they earned 100 total actual tags.

2.5.2 Total possible tags—Total possible tags was the total number of times a participant *could have* tagged a given feature as one of the two most useful features in a

room. In other words, if cabinets appeared in the same room as a participant 200 times, cabinets earned 200 total possible tags. Importantly, if the same feature appeared multiple times in a given room (e.g., if the kitchen contained two distinct sets of cabinets), this was only counted as one appearance of cabinets.

2.5.3 Percentage tagged—Percentage tagged was calculated by dividing the total actual tags by the total possible tags. That is, a cabinet that was tagged as one of the two most useful features in a room 100 times, but appeared in a room 200 times, would earn the percentage tagged of $100/200$, or 50%.

3.0 Results

Results of the SSQ showed that simulation scores were quite low, indicating little simulation sickness associated with navigating the VR CAVE. On a scale from 0–12, the mean score was .33. Results of the NASA TLX showed that few participants experienced a high workload while completing the tasks in the CAVE. Across 60 participants, the mean workload score was 23.9 on a scale from 0–100, which places it in the 10th percentile for difficulty based on a meta-analysis of 1000 NASA TLX scores in over 200 publications (Grier, 2015).

Each of the three primary research questions is addressed below, supplemented by a table depicting results.

Research Question 1: Usefulness of Features Across Tasks

Our first research question inquired about the features in the home that participants found to be most useful. We found that, across the three different PHIM tasks, the five most useful features were the computer, end table, nightstand, desk, and dining table (Table 1). That is, when participants had the option to tag one of these features as useful, they frequently did, choosing these features over other “taggable” options.

Research Question 2: Relative Usefulness of Features by Task

Our second research question inquired about whether there are differences in perceived usefulness of items between different PHIM tasks. Our results suggest that there are differences in perceived usefulness of items between tasks as described below.

Task 1: Medication Investigation—For the task of investigating potential side effects of a medication, we found that the computer, the cabinet, the end table, the desk, and the drawer were selected as the five most useful features (Table 2).

Task 2: Appointment reminders—For the task of setting up multiple medical appointment reminders, we found that the five most useful features were the calendar, the computer, refrigerator artifacts, the nightstand, and end table (Table 3). Refrigerator artifacts may include items such as appointment cards, calendars, and post-it notes.

Task 3: Checking and recording blood sugar values—We found that for the task of checking and recording blood sugar values four times daily, the five most useful features were the nightstand, dining table, end table, dresser top, and desk (Table 4).

Research Question 3: Relative Usefulness of Features by Room

Our third research question inquired as to whether participants perceive different features in the home environment to be more or less useful depending on where they are located in the home. The data suggest that there are differences in the perceived usefulness of features between rooms (Table 5). For example, the computer was the most useful feature in the den and master bedroom, but it was the second most useful in the living room. The calendar was the most useful feature in the kitchen, but it was the fifth most useful in the master bath. It should be noted that the analyses compensate for those rarely occurring feature placements (e.g., a calendar in a master bath) by looking at the likelihood a feature is selected only when it was possible to select.

4.0 Discussion

Our research questions inquired about the perceived usefulness of different features across PHIM tasks, the usefulness of features between tasks, and the usefulness of features as they appeared in different spaces within the home. We found that the computer was perceived as the most useful household feature overall for PHIM. However, the perceived usefulness of features, including the computer, varied based on the PHIM task performed and the rooms in which features appeared. Our findings suggest that the usefulness of different features for PHIM is the result both of these features' intrinsic affordances, and their affordances in relation to the broader sociotechnical system of the home. We conclude that a detailed study of the affordances important for PHIM is necessary to designing tools and creating environments which ease the burden of managing chronic illness, particularly diabetes, in the home.

In the present study, the three items selected as the most useful across PHIM tasks were the computer, the nightstand, and the end table. These findings build on existing work highlighting the importance of features' affordances for supporting PHIM (Werner et al. 2016). Werner and colleagues outlined 14 different types of affordances of household features that can support PHIM. Examples of these affordances are the capacity for *storage* (characteristic of shelves or a cabinet), being *transportable* (a purse, a cellphone) or being an *information repository* (a calendar, an address book). In this study, two of the three most useful features overall – the nightstand and the end table – shared certain affordances in common, while the third and most useful – the computer – contained unique affordances.

Unlike end tables and nightstands, computers offer the affordance of *content presentation*. Computers, for example, can display lab results or billing information via online personal health records (PHRs). Also unlike end tables and nightstands, computers enable *communication* via e-mail, patient portals, and other messaging applications. Third, computers provide *cognitive support*, insofar as the information sought out may aid in health-related decision making. All three features – computers, end tables, and nightstands –

have the capacity to serve as *information repositories*. In the context of PHIM, this means that all three features may be used to store information related to one's health.

Unlike computers, end tables and nightstands – the other two features found to be most useful for PHIM – are *protective* of physical objects and *hazard-resistant*. Their drawers can be used to store objects such as medication bottles or syringes out of sight and out of harm's way. Notably, four out of the five most useful items overall offered the affordances of *physical support* and *storage*, or the abilities to physically hold and maintain other features. This suggests that these affordances are useful for PHIM. However, given that computers were still rated as the most useful overall, it may be that the unique digital affordances of computers outweigh their lack of affordances related to the physical storage or protection of objects.

Our findings pertaining to the essential role of the computer have implications for the design of health information technology. Our results show how ubiquitous the computer has become in the performance of PHIM at home. Especially since the introduction of PHR, computers have become more important for storing medical information, scheduling appointments, and communicating with healthcare providers. Based on analysis of the Health Information National Trends Surveys, Ford et al. (Ford, Hesse, & Huerta, 2016) forecast that adoption of PHRs will increase beyond 75% in 2020. The acknowledgment of the importance of the computer to PHIM is relatively new. Merely 10 years ago, a study by Zayas-Caban (2010; 2012) suggested that computers' role was less important, overshadowed by physical objects such as file cabinets, calendars, and cupboards.

However, results of this study also show that the usefulness of the computer, along with all other household features, is highly dependent on the PHIM task at hand. This is demonstrated in Table 6, which summarizes the usefulness of features between tasks.

For task 1 (medication investigation), the unique affordances of the computer competed with those of nondigital features such as the cabinet and end table. Notably, all features share the affordance of *information repository*, which is understandably necessary for the investigation of a medication. While information regarding a medication might be sought in pill boxes or pharmacy inserts, stored in cabinets and end tables, more participants reported that they would seek out this information digitally. Perhaps participants used the computer to consult medication information in their PHR, e-mail their healthcare team regarding the medication, or independently conduct research online.

Similarly, the options for creating appointment reminders fall into one of two categories: digital or non-digital reminders. Participants were most likely to state that these reminders would be created nondigitally on wall calendars, and second most likely to seek out the aid of computers for this task. Calendars and computers share the affordances of *content presentation* and *alert/cue*. That is, these features not only relay content, but relay a prompt to take an action. However, unlike physical calendars, computers first require activation on the part of the end user to display cues, and are often located in less central spaces in the home. This may help to explain our observation that, for the task of recalling appointments, computers were surpassed by physical calendars in usefulness.

The only task for which the computer was not one of the five most important features was that of checking and recording blood sugar. Rather, the nightstand, the dining table, the end table, the dresser top, and the desk were the five most useful features for this task. Importantly, all five of these features provide *physical support*, or the capacity to display objects. Physical support increases an object's ease of access, which may be particularly useful for important tasks repeated multiple times per day in different locations (Casper et al. 2016). Nightstands, end tables, and desks also contain affordances of *storage* and *protection*, given that they typically contain drawers. These affordances may be important for the task of measuring blood sugar, which typically requires additional objects and devices, some of which require protection (glucometer, lancets). Our findings with regard to Task 3 highlight the fact that, despite the importance of computers, much of PHIM remains a nondigital process grounded in physical context.

A third major finding was that the perceived usefulness of features seemed to vary based on the room in which the feature was located. This finding can be explained by understanding the home as a sociotechnical system, in which the usefulness of features does not occur in isolation but, rather, emerges from interactions between system elements (Holden et al., 2013) (Holden, Valdez, Schubert, Thompson, & Hundt, 2017). The patient work system describes four interacting system components which shape patient work, including person, tasks, tools, and context (including physical-spatial, social-cultural, and organizational). In the present study, individual features interacted with the physical-spatial context to influence usefulness. For example, computers in the den were rated as useful 25.4% more frequently than computers in the living room. As another example, cabinets in the master bath were tagged as one of the two most useful items in the room 45.5% of the time, as opposed to only 18.3% of the time when cabinets appeared in the living room.

Task characteristics also influenced the interaction between features and their physical-spatial context. For example, computers support a variety of tasks, some which may require privacy, and privacy is influenced by the physical-spatial context of the home. This may further explain why, in our study, a computer in the den – a relatively private room – was rated as useful significantly more often than a computer in the living room – a room which is typically not private. The task for which the computer was rated as most useful – investigating a rash associated with a medication – is a task for which a person might desire privacy.

The sociotechnical system also contains *persons* and their *socio-cultural contexts*. Characteristics of individuals and groups of individuals shape the way in which PHIM is performed. Socio-cultural norms may explain why, for example, cabinets were rated as significantly more useful in the bathroom than the living room. While cabinets in the bathroom normatively hold medications, ointments, and other health-related items, cabinets in living rooms may hold items unrelated to health. Additionally, factors related to person (for example, age, ability status, or comorbid conditions) may influence the way in which the environment supports PHIM.

This study took place in a virtual environment rather than real homes. Although the virtual environments were highly accurate projections of actual homes, they were never the

participants' actual homes. As such, participants' responses tell us only how they would manage PHIM in a house like that which they explored, rather than in the home in which they currently live. Participants' lack of familiarity with the houses in the VR CAVE, and the nuances of the specific design and arrangement of information in the VR CAVE, may have directed certain behaviors within it that would not be present in the participants' own environment. On the other hand, it may be that, even in an unfamiliar environment, people prefer to conduct their PHIM activities in the same way they would at home and using the same features. For example, participants who at home would use their nightstand as a flat surface to record blood sugar values might be similarly inclined to do this in the (unfamiliar) VR CAVE. Future research should investigate not only the ways in which participants' actual homes differ from virtual homes, but how their behavior is similar to or different across these real and virtual contexts.

Limitations

The 20 homes in the present study were carefully selected to represent socioeconomic strata; mobile homes, apartments, condominiums, and single family homes (detached and semidetached) were sampled here. However, we do not expect that our results are generalizable to all populations dwelling in all different types of homes.

It is also important to acknowledge a caveat to the discussion of usefulness *across* tasks. The three PHIM tasks in this study – investigating the side effects of a medication, checking and recording blood sugar, and setting up appointment reminders – were each highly different from each other. Together, these tasks represent a range of PHIM tasks, but do not represent the full spectrum of PHIM as performed by those with diabetes mellitus. Furthermore, the management of specific illnesses rarely occurs in isolation, and often shares both cognitive and physical space with other health concerns or conditions. Future research ought might explore a wider range of PHIM tasks related to diabetes mellitus, as well as those unrelated; further, how might the home environment support or hinder the management of multiple illnesses simultaneously?

It should last be noted that our data about the usefulness of features are constrained by the existing interior of the virtual home. Because these were replicas of real homes, items like Smartphones, tablets, or glucometers were not always visible. These items may have been stowed out of sight, or may have been absent from the home entirely. Thus, participants could not have tagged these items, and information on their relative usefulness for PHIM is not available. Given that features with similar affordances to smartphones and tablets (for example, computers and calendars) were frequently tagged as useful for PHIM, future research ought to include features such as these in analyses.

Conclusion

The findings of the present study pertain to a sample of the work performed by those managing diabetes mellitus at home. These findings may be used to extract and distill design requirements for the features and arrangements of spaces which may be conducive to PHIM among those managing diabetes. However, design requirements can be reasonably expected

to deviate across contexts and individuals. As such, designs which support PHIM should be targeted yet adaptable.

Our findings suggest that the affordances of features contribute to their usefulness for PHIM. Furthermore, affordances may be perceived differently depending on the task at hand and the room in which features appear. Future work ought to investigate in context the precise affordances of features that help determine their usefulness. For example, the present research compared the affordances of computers versus nondigital tools. At times, digital mediums enhance or simplify PHIM performance, while at others nondigital mediums may be preferred for PHIM. A nuanced study of affordances will most effectively inform the design of PHIM tools, in the context where those tools will be used: the home environment.

Acknowledgments

Acknowledgements and Funding Sources

This work was supported by the Agency for Healthcare Research and Quality under Grant number R01HS022548 (www.vizhome.org). The project was also supported by the Clinical and Translational Science Award (CTSA) program, through the National Institutes of Health (NIH) National Center for Advancing Translational Sciences (NCATS), [Grant UL1TR002373]. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Agency for Healthcare Research and Quality.

Appendix A

Complete list of features across rooms

cabinet

calendar

coffee table

computer

counter

desk

dining table

drawer

dresser

dresser top

end table

nightstand

refrigerator artifact (e.g., appointment cards, calendars, post-it notes)

shelf

Appendix B

Images of each room type in the CAVE with taggable features boxed and labeled

Figure 1.
Master bedroom

Figure 2.
Kitchen

Figure 3.
Den

Figure 4.
Living Room

Figure 5.
Bathroom

References

- Aarhus R, & Ballegaard SA (2010). Negotiating boundaries: managing disease at home. Paper presented at the Proceedings of the SIGCHI conference on Human Factors in Computing Systems.
- Ancker JS, Witteman HO, Hafeez B, Provencher T, Van de Graaf M, & Wei E (2015). The invisible work of personal health information management among people with multiple chronic conditions: qualitative interview study among patients and providers. *Journal of medical Internet research*, 17(6), e137. [PubMed: 26043709]
- Brennan PF, Ponto K, Casper G, Tredinnick R, & Broecker M (2015). Virtualizing living and working spaces: Proof of concept for a biomedical space-replication methodology. *Journal of biomedical informatics*, 57, 53–61. [PubMed: 26173040]

- Carayon P, Hundt AS, Karsh B, Gurses A, Alvarado C, Smith M, & Brennan PF (2006). Work system design for patient safety: the SEIPS model. *Quality and Safety in Health Care*, 15(suppl 1), i50–i58. [PubMed: 17142610]
- Carlsson G, Schilling O, Slaug B, Fänge A, Ståhl A, Nygren C, & Iwarsson S (2008). Toward a Screening Tool for Housing Accessibility Problems: A Reduced Version of the Housing Enabler. *Journal of Applied Gerontology*, 28(1), 59–80. doi:10.1177/0733464808315293
- Cheng Y, Hootman J, Murphy L, Langmaid G, & Helmich C (2010). Prevalence of doctor-diagnosed arthritis and arthritis-attributable activity limitation-United States, 2007–2009. *Morbidity and mortality weekly report*, 59(39), 1261–1265. [PubMed: 20930703]
- Cruz-Neira C, Sandin DJ, DeFanti TA, Kenyon RV, & Hart JC (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM*, 35(6), 64–73.
- Drews FA, & Bakdash JZ (2013). Simulation training in health care. *Reviews of Human Factors and Ergonomics*, 8(1), 191–234.
- Ford EW, Hesse BW, & Huerta TR (2016). Personal Health Record Use in the United States: Forecasting Future Adoption Levels. *Journal of Medical Internet Research*, 18(3), e73. doi:10.2196/jmir.4973 [PubMed: 27030105]
- Grier RA (2015, 9). How high is high? A meta-analysis of NASA-TLX global workload scores. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 59, No. 1, pp. 1727–1731). Sage CA: Los Angeles, CA: SAGE Publications.
- Hart SG, & Staveland LE (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology* (Vol. 52, pp. 139–183). North-Holland.
- Holden RJ, Carayon P, Gurses AP, Hoonakker PLT, Hundt AS, Ozok AA, & Rivera-Rodriguez AJ (2013). SEIPS 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients. *Ergonomics*, 1–18. doi:10.1080/00140139.2013.838643
- Holden RJ, Schubert CC, & Mickelson RS (2015). The patient work system: An analysis of self-care performance barriers among elderly heart failure patients and their informal caregivers. *Applied ergonomics*, 47, 133–150. [PubMed: 25479983]
- Holden RJ, Valdez RS, Schubert CC, Thompson MJ, & Hundt AS (2017). Macroergonomic factors in the patient work system: examining the context of patients with chronic illness. *Ergonomics*, 60(1), 26–43. doi:10.1080/00140139.2016.1168529 [PubMed: 27164171]
- Kennedy RS, Lane NE, Berbaum KS, & Lilienthal MG (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, 3(3), 203–220.
- Kim E-H, Stolyar A, Lober WB, Herbaugh AL, Shinstrom SE, Zierler BK, ... Kim Y (2009). Challenges to using an electronic personal health record by a low-income elderly population. *Journal of medical Internet research*, 11(4).
- Lucero RJ, Sheehan B, Yen P-Y, Velez O, Nobile-Hernandez DL, Tiase VL, & Bakken S (2012). Developing self-management tools with vulnerable populations for use in personal health information management systems. Paper presented at the NI 2012: 11th International Congress on Nursing Informatics, June 23–27, 2012, Montreal, Canada.
- MacGregor JC, & Wathen CN (2014). My health is not a job’: a qualitative exploration of personal health management and imperatives of the ‘new public health. *BMC public health*, 14(1), 726. [PubMed: 25030501]
- Marquard JL, Moen A, & Brennan PF (2006). Photographic data--An untapped resource to explore complex phenomena such as health information management in the household (HIMH). *Stud Health Technol Inform*, 122, 58–62. [PubMed: 17102218]
- Mickelson RS, Unertl KM, & Holden RJ (2016). Medication Management: The Macro-cognitive Workflow of Older Adults With Heart Failure. *JMIR Human Factors*, 3(2).
- Mickelson RS, Willis M, & Holden RJ (2015). Medication-related cognitive artifacts used by older adults with heart failure. *Health policy and technology*, 4(4), 387–398. [PubMed: 26855882]
- Moen A, & Brennan PF (2005). Health@ Home: the work of health information management in the household (HIMH): implications for consumer health informatics (CHI) innovations. *Journal of the American Medical Informatics Association*, 12(6), 648–656. [PubMed: 16049230]

- Moray N (1994). "De Maximis Non Curat Lex" or how Context Reduces Science to Art in the Practice of Human Factors. Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.
- National Research Council (NRC). (2011). Health Care Comes Home: The Human Factors. Retrieved from Washington, DC:
- Norman DA (1988). The psychology of everyday things(The design of everyday things): Basic Books.
- Or CKL, & Karsh BT (2009). A systematic review of patient acceptance of consumer health information technology. *J Am Med Inform Assoc*, 16, 550–560. [PubMed: 19390112]
- Palen L, & Aaløkke S (2006). Of pill boxes and piano benches: home-made methods for managing medication. Paper presented at the Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work.
- Piras EM, & Zanutto A (2011). Emotions and personal health information management: some implications for design. Paper presented at the MIE.
- Rooksby J (2013). Wild in the laboratory: a discussion of plans and situated actions. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 20(3), 19.
- Sanchez-Vives MV, & Slater M (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience*, 6(4), 332–339. [PubMed: 15803164]
- Sanderson PM, & Grundgeiger T (2015). How do interruptions affect clinician performance in healthcare? Negotiating fidelity, control, and potential generalizability in the search for answers. *International Journal of Human-Computer Studies*, 79, 85–96.
- Unruh KT, & Pratt W (2007). Patients as actors: the patient's role in detecting, preventing, and recovering from medical errors. *International Journal of Medical Informatics*, 76, S236–S244. [PubMed: 16829180]
- Valdez RS, Holden RJ, Hundt AS, Marquard JL, Montague E, Nathan-Roberts D, & Or CK (2014). The Work and Work Systems of Patients: A New Frontier for Macroergonomics in Health Care. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 58(1), 708–712. doi:10.1177/1541931214581165
- Ward BW, Schiller JS, & Goodman RA (2014). Multiple chronic conditions among us adults: A 2012 update. *Preventing Chronic Disease*, 11.
- Werner NE, Carayon P, Casper GR, Hoonakker PLT, Arnott Smith C, Brennan PF (2016). Affordances of household features important for personal health information management: designing consumer health information technology for the home. In Mollo V and Falzon P (Ed), *Proceedings of the Healthcare Systems Ergonomics and Patient Safety Conference Toulouse, France, October 5–7, 2016*, pp. 390–394.
- Werner NE, Jolliff AF, Casper G, Martell T, & Ponto K (2018). Home is where the head is: a distributed cognition account of personal health information management in the home among those with chronic illness. *Ergonomics*, 61(8), 1065–1078. [PubMed: 29402181]
- Wilson JR (2000). Fundamentals of ergonomics in theory and practice. *Applied ergonomics*, 31(6), 557–567. [PubMed: 11132041]
- Zayas-Caban T (2012). Health information management in the home: a human factors assessment. *Work*, 41(3), 315–328. doi:10.3233/wor-2012-1306 [PubMed: 22398501]
- Zayas-Caban T, & Dixon BE (2010). Considerations for the design of safe and effective consumer health IT applications in the home. *Qual Saf Health Care*, 19((Suppl 3)), i61–i67. [PubMed: 20959321]
- Zayas-Cabán T, & Valdez RS (2012). Human Factors and Ergonomics in Home Care In Carayon P (Ed.), *Handbook of Human Factors and Ergonomics in Health Care and Patient Safety* (2 ed., pp. 743–762). Boca Raton, FL: CRC Press.

Highlights

- Across PHIM tasks, the computer was perceived as the most useful feature for PHIM
- The perceived usefulness of features varied based on the PHIM task performed
- The perceived usefulness of features varied based on the room in which they appeared

Table 1.

Usefulness of Features Across Tasks.

Feature	Total actual tags	Total possible tags	Percentage tagged
Computer	181	301	60.13
End table	120	241	49.79
Nightstand	57	119	47.90
Desk	51	120	42.50
Dining table	73	180	40.56

Table 2.

Usefulness of features for Task 1, investigating the side effects of a medication.

Feature	Total actual tags	Total possible tags	Percentage tagged
Computer	74	97	76.29
Cabinet	75	158	47.47
End table	33	79	41.77
Desk	15	37	40.54
Drawer	88	225	39.11

Table 3.

Usefulness of features for Task 2, recalling appointments.

Feature	Total actual tags	Total possible tags	Percentage tagged
Calendar	77	117	65.81
Computer	53	85	62.35
Refrigerator	37	60	61.67
artifact			
Nightstand	19	36	52.78
End table	43	84	51.19

Table 4.

Usefulness of features for Task 3, checking and recording blood sugar.

Feature	Total actual tags	Total possible tags	Percentage tagged
Nightstand	25	42	59.52
Dining table	35	60	58.33
End table	44	78	56.41
Dresser top	10	20	50.00
Desk	24	49	48.98

Table 5.

Usefulness of features by room.

Room	Feature	Total actual tags	Total possible tags	Percentage tagged
Den	Computer	88	120	73.33
	Drawer	77	119	64.71
	Desk	51	120	42.50
	Shelf	59	180	32.78
	Cabinet	0	0	0.00
Kitchen	Calendar	55	120	45.83
	Dining table	73	180	40.56
	Refrigerator artifact	66	180	36.67
	Cabinet	52	180	28.89
	Counter	43	180	23.89
Living Room	End table	115	180	63.89
	Computer	58	121	47.93
	Shelf	24	61	39.34
	Coffee table	46	119	38.66
	Cabinet	22	121	18.18
Master Bath	Drawer	61	119	51.26
	Cabinet	85	179	47.49
	Counter	60	179	33.52
	Shelf	55	179	30.73
	Calendar	12	61	19.67
Master Bedroom	Computer	35	60	58.33
	Nightstand	57	119	47.90
	Shelf	67	180	37.22
	Dresser top	19	58	32.76
	Calendar	39	121	32.23

Table 6:

Summary of Usefulness of Features Between Tasks.

Medication Investigation	Establishing Appointment Reminders	Checking and recoding blood sugars
Computer (76%)	Calendar (66%)	Nightstand (60%)
Cabinet (48%)	Computer (62%)	Dining table (58%)
End table (42%)	Refrigerator (62%)	End table (56%)
Desk (41%)	Nightstand (53%)	Dresser top (50%)
Drawer (39%)	End table (51%)	Desk (49%)