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Designing Immersive Virtual Reality Environments for Supporting Patients at Home

Translating Input From Home Care Nurse Experts to Design Requirements

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Immersive virtual reality computer programs provide new experimental and treatment interventions that hold great promise for nursing. Immersive virtual reality uses sensory cues to represent real-world environments in a way that makes participants feel as if they are in a physical space different from the one in which they currently exist. As the acceptance of immersive virtual reality as a clinical and experimental tool has grown, so has the need to ensure that the context depicted in the environment mirrors both the sensory and the task requirements of the real-world situation. Here, we describe the use of nurse expert key informant group interviews to generate requirements that must be fulfilled in immersive virtual reality environments designed to evoke and engage participants in self-management tasks. An expert panel of four home care nurses participated in three sessions designed to elicit details of common home care challenges, frequency of variation, and typical participants. More than 20 potential scenarios were identified. The design team later used this information to create design requirements for two key scenarios and subsequently develop immersive virtual reality environments for use in research studies, mapping sensory and functional expectations to immersive virtual reality implementations. Challenges in mapping from key informant group findings to requirements are addressed.

KEY WORDS: Home care, Nursing informatics, Self-care, Virtual reality

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Funding was provided by an intramural grant from the National Institutes of Health, National Institute of Nursing Research, Bethesda, Maryland.

The authors have disclosed that they have no significant relationships with, or financial interest in, any commercial companies pertaining to this article.

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.cinjournal.com).

DOI: 10.1097/CIN.0000000000000895

In recent years, immersive virtual reality (IVR) has emerged as an efficient research instrument to study a variety of healthcare concerns and to create innovative interventions.[1,2] Designing realistic and relevant IVR environments is a challenging task that benefits from the knowledge and experience of expert key informants. This article describes how the staff of the Advanced Visualization Branch (AVB) of the National Institute of Nursing Research of the National Institutes of Health engaged expert home care nurses in the design of an IVR environment intended to support future studies of self-care management in the home and community. Immersive virtual reality is a computer technology using specialized devices designed to present visual and sensory cues that mimic real-world environments. Studies support IVR as a therapeutic intervention for a wide variety of health conditions and have demonstrated positive patient outcomes.[3–5] Clinical uses have focused primarily on education, exposure therapy, and sensory feedback for conditions such as chronic pain, anxiety, phobias, and eating disorders.[3–5] In health professional education, there is a growing use of IVR to teach complex procedures[6] as well as to study complex phenomena and treat patients.[7] The variety of uses for IVR makes it an important instrument to explore in the growing field of healthcare research and practice.

Recently, IVR has become more widely used in healthcare research and patient care because of the availability of consumer-grade, moderately priced technologies that can convey health-relevant sensory cues and physical space layouts. Immersive virtual reality enables the engagement of participants in simulated real-life activities, while affording researchers greater ability to control for external factors and testing conditions.[1] An IVR environment allows researchers to study real-world phenomenon without needing to accommodate for unstable, changing conditions found naturally in real-life. Immersive virtual reality allows for a controlled experimental condition to be tested systematically multiple times with the same participant or across participant groups.[8] Using IVR, researchers can assess changes in performance over time under the same experimental conditions.[9] One goal of utilizing IVR in patient care is to improve participants' ability to complete a complex task as if they are in real life, by creating a virtual environment where the participants feel immersed and present.[8] Immersive virtual reality has the potential to be highly beneficial in nursing research, as it may provide a way to safely and systematically study instrumental activities of daily living and self-care management in a realistic and adaptable environment. Importantly, creating IVR environments that effectively mimic real-world encounters and self-management challenges requires understanding of the everyday environments of the home and community. The process of translating these challenges to guide the design of immersive environments is called design requirements gathering and is the focus of this article.

Self-care Management and Health Outcomes

Successful self-care management is an important contributor to positive health outcomes. After leaving clinician-directed care in a hospital or rehabilitation facility and upon returning home, many patients with chronic illness struggle to find effective ways to manage their health within their everyday lives.[10,11] There are many factors that make it challenging for patients to understand clinician-prescribed treatment regimens and then to integrate these new or ongoing treatment plans into their daily routine.[12,13] Importantly, not understanding how to modify clinician-provided guidance into what is realistic in patients' homes can lead to gaps in self-care management.[14] Patients with chronic illness are often required to learn extensive and complicated information about their diagnosis and how it could change their ability to complete instrumental activities of daily living. Chronic illness treatment plans require a patient to learn how to manage medications, recognize and address symptoms, and create a routine that allows for illness management while also continuing their daily schedule alongside their treatment plan.[12,13,15] The combination of these factors can lead a patient to become overwhelmed and interfere with implementing their treatment plan. Realistic and familiar environments, experienced through IVR, may help advance nurse researchers' understanding of the challenges of self-care management in the home. This may also help researchers indicate points of interventions that could be delivered in vivo or through IVR.

A key challenge lies in the gap between patients' cognitive capacity for understanding clinician instructions and clinicians' expectations for the individual. Patients in one study on chronic illness reported being able to recall and state treatment expectations; however, they also reported a lack of understanding on how to perform some of the required self-care activities. As a result, they were less likely to adhere to recommendations and successfully perform self-care management activities.[12] This difference in understanding between a patient and clinician can result in unrealistic expectations for how patients are able to manage their chronic illness. Patients with chronic illness also report a misunderstanding in how their treatment plan can be affected by various factors in their life, including fitness levels and job responsibilities.[14] A patient's misunderstanding about how to incorporate a treatment plan into his/her daily-living activities can lead to frustration and impaired self-care management. It is possible that leveraging IVR for research would support the identification of clinical interventions that could mitigate failures during transition from clinician-directed care to self-care management and might also provide patients with a place to rehearse the self-care management behavior in a context familiar to where that behavior will be needed.

Home Care Nurse Experts as Key Informants

Self-care management in the home is a complex, unstructured activity influenced by many facets, including the clinical problem as understood by the patient, the tasks that must be addressed, and the physical environment within which these intersect. Obtaining expert nurse perspectives can provide a basis for generating design requirements for IVR and ultimately guide study design. Home care nurses, because of their intimate knowledge of the home living experiences of patients and common self-care management needs, are crucial to understanding patients' behaviors, challenges with self-care management, and adherence to treatment plans. Therefore, they serve as credible experts to inform IVR design requirements for research of patients with self-care management challenges. Home care nurses are responsible for ensuring that treatment plans can be implemented successfully into a patient's life.[16] Expert home care nurses recognize that each person's home life is unique and have developed the perspective that enables them to holistically evaluate each patient's unique environment to ensure successful self-care management. Understanding the barriers and facilitators of successful self-care management is crucial for helping patients become more able to self-manage their chronic illness. This understanding, gleaned from expert home care nurses as frontline stakeholders, provides useful guidance in designing IVR environments that support the future study and implementation of self-care management interventions.[17]

Group approaches, such as key informant interviews, are information-gathering methods that provide first-hand accounts of the field of interest.[18,19] Past studies on chronic illnesses have used these approaches to further understand the perspectives of patients and clinicians in establishing self-care treatment plans.[12,14] In this article, we report on a series of key informant group interview sessions comprised of experienced home care nurses who describe specific self-care management challenges patients face in managing their chronic illnesses in the home and community environment. The expertise of home care nurses helps IVR designers comprehend the challenges of self-care management in the context of chronic illness and obtain a unique perspective on the factors that are most supportive or detrimental to a patient's successful self-care management. Additionally, this expertise aids in the exploration of innovative technology, such as IVR, to assist in self-care management tasks in the future.

METHODOLOGY

The first step of this engineering design project was to gather design requirements that would inform the development of IVR environments intended to mitigate self-care challenges for individuals with chronic illness. We invited highly experienced home care nurses to participate in a series of key informant group interviews. Inclusion in this effort required that each participant was an advanced practice nurse at the master's degree level and had greater than 5 years of hands-on experience as a home care nurse serving a community of patients with complex chronic illness. Home care nurse leaders in the local community were contacted for referral to nurses who met the inclusion criteria. Six nurses who met the criteria were invited and four agreed to participate. The average length of home care experience for this cohort was 25 years. Nurse participants were offered a small honorarium as compensation for their time. Initially, two 90-minute sessions, via remote Cisco Webex Meetings, were held 4 weeks apart. A third follow-up session, via remote Cisco Webex Meetings, was held 7 months after completion of the second session. All three key informant interviews were led by an experienced nurse (D.M.G.) from the AVB development team. Data from these interviews were collected through detailed notes and audio recordings of the interview sessions. A detailed summary document was created from the session recordings, reviewed for accuracy by the key informants, and supplied to the AVB development team.

Key Informant Group Interviews

In the initial interview session, participants were introduced to the primary objectives of the AVB of the National Institute of Nursing Research. These objectives included the exploration of using IVR technology to improve self-care management tasks for patients with chronic illness and to explore sensory cueing for psychomotor performance in a digital environment of realistic clinical scenarios. To advance these objectives, our key informants were first presented with the logistics of the group interview process and their responsibilities as a member of the group. The key informants were not required to have knowledge of, or experience with, innovative technologies such as IVR. However, it was important for them to understand the connection between their expertise in home care nursing and the future research objectives of the AVB. Therefore, a brief overview of IVR technology was provided, and its future potential as a therapeutic intervention to improve patient health was reviewed. The key informants were shown a video, via a computer monitor in a first-person perspective, of a patient traversing a simulated IVR home environment (see Supplemental Digital Content 1, http://links.lww.com/CIN/A153). This prototype depicted the home-based locations of a diabetic person's self-care activity and demonstrated how a participant in an IVR environment could manipulate the items needed for self-care, such as those needed for self-administered insulin. The video demonstrated how a participant within an IVR environment could navigate by walking or using a technical teleport feature to jump quickly between certain key locations within the virtual home. The participant in the video used a point-and-click apparatus, which appeared as virtual hands, to pick up certain items such as medications and move/drop/throw them almost anywhere around the IVR home space.

Following the presentation of IVR as a newly emerging technology in healthcare, semistructured interviews using probes and open-ended questions were utilized to facilitate identification of common self-care management challenges faced by patients with chronic illness in the home environment (Table 1). Key informants were asked to describe common self-care management challenges that they had observed in their practice.

During the second key informant interview session, participants were asked to review the summary document from session 1 for accuracy, clarity, and further consideration. Additional probes and open-ended questions aimed to gather greater detail were posed to the group (Table 1). During this session, key informants were encouraged to

Table 1. Key Informant Interview Questions

Session	Interview Questions
1	Can you describe challenging clinical self-care management scenarios common in your practice? How frequently would you encounter this type of situation/challenge? How severe was the impact of this scenario on your patients' health? What interventions did you apply and how effective were they?
2	Can you discuss each scenario from session #1 in greater detail? What do you think may have caused this self-care task to fail? Why do you think your patients struggled with this task? What do you believe contributed to this task being challenging? Were there cognitive issues or environmental distractors which contributed to the challenges?
3	Can you describe in greater detail the contributing factors of these select challenging scenarios? Can you describe patient decisions in these scenarios that contribute to poor health outcomes?

identify and reach consensus on the most common and clinically consequential self-care management challenges observed in their home care practice. They were asked to prioritize and recommend which scenarios might have the greatest potential for improvement with the application of an innovative and potentially effective IVR intervention. The third and final key informant interview session was held 7 months after the second session. During this session, key informants were asked to validate and clarify in greater detail specific clinical scenarios (Table 1).

Analysis of Key Informant Interview Content

Audio recording content from the first two interview sessions were reviewed and consolidated into summary documents by the lead author. We used a topical analysis approach according to established engineering principles.[20] Two members of the development team (D.M.G., S.F.) reviewed the summaries, documenting key themes and repeated topics from each session. The results of this effort were then shared with the AVB technical design team for review and consideration. It was imperative to select scenarios that would have the potential for a positive clinical outcome for multiple patient populations and be amenable for development in IVR. As a result, the design team used clinical priorities and technical considerations as criteria to select the self-care management scenarios most amenable for development. The clinical criteria outlined below informed our design requirements and reflects the importance of the problems we aim to address.

- Common: The frequency of the challenge among patients with a specific chronic illness
- Significant: Likelihood that a behavior change associated with the scenario would improve the clinical outcomes for a patient and reduce healthcare system utilization
- Widespread: The extent to which the problem is found across multiple different patient populations

We used these clinical priorities to select a scenario that was common among patients with chronic illness, had a significant impact on the patients' health outcomes, and was not isolated to one patient type or disease state. Technical consideration for development of these clinical scenarios in IVR included whether sensory-rich IVR environments could support realistic execution of the psychomotor skills required to complete the task and could effectively reproduce relevant environmental conditions. We also considered whether well-known limitations of virtual reality (lack of haptics/tactile feedback, motion sickness, and the inability to explore fine motor movement) would be a detriment. The content from the key informant interviews provided guidance to develop IVR design specifications and requirements for sensory cueing in environments in which self-care management challenges arise, both within the home and larger community.

Workflow Analysis and Design Requirements

Utilizing information gathered from key informant interviews, the development team completed detailed workflow analyses for selected scenarios. Workflow analyses were developed from the first-person (patient) perspective and did not include potential caregivers. As part of this process, we outlined in detail the relevant stimulus, the order of the required steps to complete the selected tasks, and their interdependencies. Cognitive and behavioral requirements necessary to complete the tasks in a virtual environment were also included. From these detailed workflow analyses, we extracted design requirements to produce functional specifications for the planned IVR environments. These documents will frame the engineering development. The timeline of key informant interviews and the analysis procedures are outlined in Supplemental Digital Content 2 (see Supplemental Digital Content 2, http://links.lww.com/CIN/A154).

FINDINGS

Key Informant Group Interviews

During interview session 1, our key informants identified and validated clinical scenarios in which more than 20 self-care management challenges could be found in the daily lives of individuals with chronic illness (Table 2).

During interview session 2 and using the criteria listed in the methods section, the key informants reached consensus on seven of the scenarios that they thought had the most significant clinical consequence for their patients with chronic illness. A summary of details provided by key informants regarding each of these seven scenarios and a description of how they might be represented in IVR are found in Table 3.

Although all seven of the scenarios met the clinical criteria, the AVB research and development team identified two scenarios that also met the technical considerations. The team determined that these two scenarios were most likely to be effectively represented and evaluated in an IVR environment. We chose to explore grocery store food selection among patients with heart failure managing dietary restrictions and home-base complex medication management.

Food Selection According to a Dietary Restriction

From the key informant interviews, we learned that many patients with heart failure who suffer poor outcomes related to dietary sodium intake are often unaware that the foods selected during grocery shopping may not conform to their sodium restriction. Food selection while shopping with a dietary restriction requires a person to comprehend the relationship between the information on the nutritional label and their specific dietary restriction. Key informants encouraged us to explore the potential for an immersive virtual grocery shopping experience to improve food selection behaviors for these patients.

Table 2. Self-care Management Challenges Identified by Expert Home Care Nurses

Clinical Scenario	Self-care Management Challenge
Heart failure: dietary sodium restriction	Grocery shopping Meal planning Reading nutritional labels
Complex medication administration	Error free medication administration Use of pill box organizer
Ostomy care	Preparing for travel outside the home Changing the appliance Skin care
Diabetes: managing blood sugars	Choosing insulin administration items Preparing to leave the home Inspecting feet for skin defects
Chronic obstructive pulmonary disease (COPD): inhaler use	Breathing techniques Care of nebulizer equipment
COPD: portable O_2	Proper machinery usage Changing tank flow meter
Post-stroke mobility	Safely moving around your home Safely using the bathroom Using walker/cane Exercising
Postsurgical PleurX drains	Hygienic use/set up and clean up
Opioid overdose	Administration of nasal spray (Narcan) Coaching through treatment
Allergies	Auto injection for anaphylaxis
Disease related symptom management	Appropriate use of the emergency department
Behavioral Health	Daily living with depression, social isolation, loneliness, etc.

To begin the process, we created a workflow analysis of a grocery store shopping experience for a person with a dietary sodium restriction (Table 4). Cognitive and behavioral requirements for completing this task are included. This analysis was completed as if the patient, not the caregiver, were engaged in the shopping task. To maximize an IVR experience, we chose to focus on in-store shopping where an immersive virtual grocery store would facilitate observation of food selection and meal planning behaviors. In our workflow analysis, the "Stimulus" is the anticipated trigger that initiates a specific "Task." Content found in the "Visual Cues" column describes specific environmental assets needed to complete the task. These cues are in addition to standard grocery store stimuli that help to create a realistic IVR environment. "Cognitive Requirements" are the mental processes needed to understand the required task and how to perform it. "Behavioral Requirements" are actions required by the participant to complete the task.

Using the results of the grocery shopping workflow analysis, we created a design requirements document (Table 5). This document includes users' interactions within the IVR environment as well as the virtual objects, spatial layout, and environmental features required to study the self-care management scenarios of interest. Using the design requirements document, we were able to translate the workflow analysis results effectively into specific functional specifications for our engineering team to implement.

Complex Medication Administration in the Home

The key informants also related that ineffective home-based medication management skills are associated with increased healthcare utilization, including emergency department visits.[21] Our key informants described the use of a medication dispensing device called a "pill box" to assist patients and improve the consistency and accuracy of adhering to a complex medication regimen. A pill box in this context is a common device used to contain and organize medications needed for in-home medication management.[22] It requires the person to read instructions and sort, organize, count, and place a pill in the appropriate slot in anticipation of subsequent medication consumption. It requires organizing specific doses according to the day of the week, time of day, and aligning the organization with the physical characteristics of the pill box. We completed a workflow analysis outlining the use of a pill box within an IVR environment (Table 6).

According to our key informants, people often complete pill sorting activities in the kitchen. We considered what design elements would be required to study pill sorting in a virtual kitchen environment (Table 7). Some considerations included the need to manipulate small items within a virtual space, the need for environmental distractions common in a real-life house, and the need for realistic materials (like a pill box) so that a participant could easily recognize and relate to the object within the virtual space.

DISCUSSION

As part of the National Institute of Nursing Research, the AVB aims to advance nursing research in transitional home care with the use of IVR. To utilize IVR as a nursing research stimulus, it is important first to systematically develop an IVR environment that will facilitate the study of self-care management in the natural, everyday contexts of individuals with ongoing health concerns. Our long-term goals are to create IVR environments that can engage participants in these multisensory, image-intensive experiences and then evaluate the impact of these environments on health behavior. Researchers have reported that IVR technology holds great promise for both therapeutic and investigatory use in healthcare.[1,2] As reported by our key informants, innumerable home healthcare scenarios exist that could be the focus of IVR research when considering the challenges complex chronic medical conditions have on daily life. To identify common and complex self-care management scenarios that are difficult for patients to complete, and that may be amenable

Table 3. Selected Self-care Management Challenges and Potential IVR Research Scenarios

Clinical Scenario	Self-care Management Challenge	IVR Implementation Considerations
Food selection with heart failure	Many patients with heart failure live with dietary sodium restrictions. Despite the information provided by nurses to help patients make healthy choices, they often forget/forgo this information while shopping.	Repetitive practice shopping for a sodium-restricted diet in a grocery store.
Complex medication administration	Many chronically ill patients have complex medication administration regimens that are difficult to safely manage. Pill box organizers, as an intervention, are introduced and instructed by nurses, but the complex regimens have such variability that important steps are often overlooked or forgotten.	Demonstration and practice on how to accurately fill a medication pill box organizer according to prescription.
Ostomy care	Patients can be overwhelmed with the care of their ostomy. Challenges arise with how to change the appliance, care for their skin, and how to prepare to travel outside the home. Although products may vary, the sequencing of the task matters.	Demonstration and repetitive practice of the ostomy care tasks.
Diabetes: how to manage blood sugars	For diabetics, managing their blood sugars is a complex issue with potential life-threatening consequences if not adhered to consistently and properly.	Demonstration and practice of how to measure blood sugar, how to store and administer insulin, how to prepare to leave the house with insulin, and how to make healthy dietary choices.
Chronic obstructive pulmonary disease (COPD): inhaler use	Management of COPD requires regular and effective use of inhaler delivered medication. Proper use of respiratory inhalers requires coordinating breathing and sequencing. Nebulizer equipment must be properly cleaned to ensure the safety of its use.	Demonstration and repetitive practice of inhaler use and care of nebulizer equipment.
COPD: portable O_2	Patients with COPD may be asked to manage portable home oxygen. The simple mechanics of use, turning on and off, transferring from home tank to travel tank, and detaching flow meters cause tremendous anxiety as patients forget the instructions they have been given.	Demonstration and repetitive practice of portable O_2 mechanics.
Impaired mobility	Loss of independence because of impaired mobility is a very common scenario of home-bound persons with chronic illness. There are many skills for them to learn; how to safely transfer; how to use a cane; how to go up and down stairs; how to open a door while using a walker; how to weigh oneself while using a walker.	Demonstration and repetitive practice of mobility enhancement activities with correction cues.

to development in IVR environments, we engaged expert home healthcare nurses to provide information based on their knowledge and real-world experience. We applied a structured group interview process by which to extract a core set of home care situations that were important and challenging for patients and home care nurses. The perspectives of our key informant experts are consistent with those found in the literature regarding the challenges of people living with complex illness.[11,12,14,16,21–23] Using the information provided by our experts, the AVB chose two areas for initial exploration in IVR: food selection based on dietary restrictions while grocery shopping and medication management using a pillbox organizer. Once we identified clinical scenarios for development and future study, we created workflow analyses to define the design requirements and functional specifications as a development framework for the engineering team.

It is well established in the literature that attention to workflow in computer system development for healthcare is crucial because "it allows for clear definition of the problem space to be addressed,"[24] and various approaches to workflow analysis have been described.[24] Our workflow analysis framework was created to gather as much detail as possible to guide the design framework for our engineering team. In our analyses, we include users' potential cognitive demands and behavioral expressions in addition to more typical items such as the stimulus, the order of the tasks, and their interdependencies. The detail of our workflow analyses contributed to the creation of accurate and comprehensive design requirements. These requirements can be implemented in many ways, and through an iterative design and test model, we can create usable and realistic interfaces. We think other researchers can apply this model to identify other home healthcare scenarios and to provide a standardized way to communicate with technical staff.

As evidenced by the results of our workflow analyses, self-care management tasks for patients with chronic illness are complex and are complicated by the interplay among cognitive, behavioral, and environmental factors. Individual differences in cognitive skills such as attention, memory, reading, computational abilities, learning, organizing, and executing may interact with environmental influences (product labeling, store layout, cost, etc) to produce variability in the successful implementation of newly acquired healthcare behaviors. The multifactorial nature of these challenges makes it difficult to

Table 4. Workflow Analysis of Grocery Shopping With Dietary Sodium Restrictions

Stimulus	Task	Visual Cues	Cognitive Demands	Behavioral Expression
Enter grocery store	Begin shopping	Shopping list and cart, aisle/wall signs, store markers, food products on shelves Standard grocery layout	Ability to read and comprehend aisle/wall signs, store layout, shopping list	Choose a cart/basket Read shopping list Choose an aisle to begin shopping
Enter chosen food aisle	Find desired item(s) from the shopping list Choose the low/lowest sodium option for the desired item(s)	Product label with food of interest Product label may display "low sodium" Nutrition label with sodium level	Ability to translate food items on the shopping list to products on the shelf Ability to read/comprehend product and nutrition labels Understand the relationship between serving size and what they will realistically eat Determine if the sodium content/serving size is congruent with their dietary sodium restriction Determine if food product sodium level is realistic for personal daily sodium restriction	Locate product of interest on the shelf Read food product labels Read servings per container and serving size Read nutrition labels and locate/read sodium on the nutrition label Choose to purchase food item or not Place the food item in the shopping cart
Multiple food item options present on grocery shelves	Choose between multiple items of the same food category	Multiple food options on the grocery shelf with varied levels of dietary sodium	Determine which item has the lowest sodium content per serving or realistic one-time consumption Use working memory to compare nutritional information	View and compare multiple products at once Read and compare nutrition labels for multiple products Choose items based on sodium level restrictions
Completed shopping list	Review the contents of the shopping cart based on needs and dietary restrictions	Selected food products Check marks through all selected items on shopping list	Determine if the contents of the cart are in accordance with dietary restrictions Determine if the selected food products will allow for realistic meal preparations within dietary restrictions	Choose to purchase all food selections OR Choose to swap, change, or put back a product Go to checkout counter

evaluate improvement interventions. Immersive virtual reality environments are highly controllable, eliminate confounding variables, and allow for the quantifiable measurement of human behavior which can be calculated and stored for future analysis. Immersive virtual reality is convenient and economical for repeated-use cases, such as practice, therapy, or in place of venues that are not accessible to patients or caregivers.[1] These characteristics suggest that using IVR for research purposes will have significant advantages over similar studies in real-life environments. The use of IVR technology provides us with the potential to observe, evaluate, and understand specific factors of self-care management challenges and provides nurses with an additional research strategy for understanding patients' responses to these challenges.

Our IVR grocery store environment will facilitate observation of a person's food choice behavior and will allow us to obtain a quantitative measurement of one self-care management task in a controlled environment. We can use the IVR grocery store to manipulate the way self-care management information is disseminated and measure how it affects a patient's ability to care for themselves. Further, we can introduce distractions, stresses, and challenges that mimic real-world interruptions in a standardized manner. In this way, we can evaluate emotional as well as cognitive processes that influence completion of shopping tasks. With the capacity to observe participants' use of labels and, ultimately, the items purchased, it is possible to gain an understanding of how those individuals process information about sodium or other nutritional elements.

The accurate and sustained use of medication dispensing devices, such as a pill box, is a challenge for patients despite educational and demonstrative intervention by nurses.[23] Our IVR kitchen environment will simulate a pill box filling scenario so that the research team can study the physical, cognitive, and behavioral challenges associated with the proper use of this important device for safe, at-home medication administration. Conducting these studies in an IVR environment that affords stability, reproducibility, and familiarity may yield new insights and new interventions.

To study self-care management tasks in IVR, the environment must have the ability to support complex interactions between participants and objects in the environment.[9] The

Table 5. Design Requirements for IVR Grocery Store

Interactions With Virtual Reality Environment	Virtual Objects	Space Layout	Virtual Reality Environmental Features
Orient self in store; search/locate/choose a cart/basket Locate and read shopping list Choose an aisle to begin shopping	Shopping cart Shopping list	Shopping carts and baskets near the entrance of the virtual store	Select a tool to "pick up" a cart when near the cart area
Navigate throughout the store	Aisle signs, wall signs, store markers, food products on shelves	Standard grocery store layout	Readable directional and navigational signs Ability to display/highlight teleport landing location
Review shopping list Select item for search	Shopping list displayed on common device (cell phone, paper)	Shopping list accessible and viewable	Ability to scroll and select shopping list
Visual search for desired aisle Locate and enter the aisle containing the food product, move to a desired location in the aisle	Aisle signs, wall signs, store markers, food products on shelves	Standard grocery store layout	Ability to track head and eye movement for visual search data
Visual search for desired product Locate and move near desired food products	Food products with readable labels	Similar products grouped together in aisles and on shelves	Readable food product labels Movement functionality supports close contact between user and products
View and read educational materials on dietary restriction View and read instructional materials on how to read nutritional label	Readable text information Voiceover of instructional materials A "Proceed" button A "Need More Information" button	Neutral screen with informational text	Ability to select and enlarge instructional material Readable font/text size Audible text voiceover Ability to interact with and select button of choice Ability to display additional resources/information upon selecting "Need More Information"
Compare the nutritional values of similar food products: Highlight and select multiple products Read the food product labels Read servings per container and serving size Read nutrition labels side by side and locate/read sodium on the nutrition label Compare nutrition labels for multiple products Compare specific nutritional value to a user's dietary restriction	Selection tool, food products (with options that fall within dietary restriction), readable labels, shelves User's dietary restriction	Aisle layout allows user to get close to products for selection Shelf organization showing products within dietary restriction close to products not consistent with dietary restriction	Ability to interact with product Ability to view multiple nutritional labels simultaneously Ability to provide feedback related to dietary restriction Ability to enlarge nutritional labels
Select the desired product based on sodium level restrictions	Selection tool, food products	Aisle layout allows users to get close to the products to select	Ability to highlight and interact with the product Ability to enlarge the product
Place food selections in basket/cart Mark product as complete on shopping list	Shopping list, basket/cart, selected product	Basket or cart near user Viewable shopping list	Ability to highlight and interact (select and return) products
Choose to swap/change/return product to shelf (as needed) Mark product as returned or incomplete on shopping list	Shopping list, basket/cart, selected product	Basket or cart near the user Viewable shopping list	Ability to highlight and interact (select and return) product

(continues)

Table 5. Design Requirements for IVR Grocery Store, Continued

Interactions With Virtual Reality Environment	Virtual Objects	Space Layout	Virtual Reality Environmental Features
Navigate to checkout counter Review nutritional information provided during the checkout process Accept all selected products or return a specific product to the shelf	"Check out," "Return to Cart," "Return to Shelf," and "Accept" buttons Display of nutritional information ("Receipt") Checkout counters	Checkout counters at the front of the store	"Check out" button results in display of nutritional facts for all selected products "Return to Cart" button allows users to edit what products are in their cart/selected "Return to Shelf" button allows users to remove a product from their cart "Receipt" with readable nutritional information provided (feedback on whether the food product is consistent with dietary restriction) "Accept" button ends IVR experience

power of IVR for use in healthcare is not found solely in the technology, but rather in the partnership between the technology and the quality of the content in the environment.[7] For example, specific design requirements such as the ability to visually present nutrition labels may become a problem in virtual environments if the quality of the graphics is insufficient to read the label text. However, a participant's ability to read and interact with nutrition labels is essential to the study of dietary restricted shopping. Knowing these requirements and potential pitfalls enables the team to design multiple possible solutions that can be beta tested for optimization prior to study implementation.

In this phase of our work, we focused on the expert opinions and broad perspectives provided to us by home care

Table 6. Workflow Analysis for Complex Medication Management Using a Pill Box Organizer

Stimulus	Task	Visual Cues	Cognitive Demands	Behavioral Expression
New prescription medication arrives in the home	Organize medication pill bottles	Packages from pharmacy Full medication bottles	Ability to read and comprehend medication purpose and label instructions	Read medication name and label instructions Store medication in familiar location for use when needed
Availability of pill box organizers in the home	Choose to use pill box organizer	Pill box organizer Informational material on pill box use	Comprehend verbal and written instructions on the use of pill box Ability to translate instructions into action	Listen to verbal instructions Read written materials
Decision made to use pill box	Sort and organize medication into chambers	Pill box labels for days of week and time of day Pill box colors and chambers Pill bottle labels	Understand which medications are appropriate for organization into the pill box Translate prescription label info into sorting action Understand how to organize and sort pills into chambers	Select medications appropriate for the pill box Read prescription labels Match prescription day and time with the matching pill box chamber
Notification (alert) of upcoming medication admin time	Consume medication at the proper day/time	Notification mechanism (calendar, clock, phone alert, mealtime) Notification of medication status (taken/not taken)	Comprehend alert meaning Understand how to translate alert into action Comprehend relationship between current day/time with pill box chambers Understand the administration method for each medication Comprehend task completion status	Acknowledge alert and initiate actions Select the appropriate day/time pill box chamber Remove pills from the appropriate chamber Consume medication Update status indicating medication was consumed

Table 7. Design Requirements for an IVR Pill Box Organizer Task

Interactions With Virtual Reality Environment	Virtual Objects	Space Layout	Virtual Reality Environmental Features
Locate pill bottles/packages Retrieve pill bottles from storage location Choose destination for pill sorting activity Move medication to pill sorting location	Pill bottles and various medication packages (in varying colors, sizes, types) Kitchen cabinets, drawers, counters, shelves, containers, table, chairs, etc	Kitchen setting	Ability to open kitchen storage to locate medication packages Ability to select ("pick up") medication Ability to select destination for medication sorting Ability to move medications to sorting destination
Listen to verbal instructions or read written instructions on how to use a pill box organizer	Voiceover or readable text of instructional material about using a pill box A "Proceed" button A "Need More Information" button	Instructional pamphlets laid out on kitchen table or audio voice-over with closed caption	Ability to select and enlarge instructional material Readable font/text size Audible text voiceover Ability to interact with and select button of choice Ability to display additional resources/ information upon selecting "Need More Information"
Select one medication to sort into a pill box Read prescription label for sorting instructions **Repeat until all medications are sorted*	Variety of pill bottle options Table/surface to arrange pill bottle Readable pill bottle labels with administration instructions	Kitchen table at sitting height Pill bottles viewable on table Zoomed-in view of selected pill bottle labels	Ability to select pill bottle Ability to increase the size of the pill bottle label to ensure readability
Sort one dose amount into pill box chambers by matching prescription day and time with pill box chamber per label instructions **Repeat until all mediations from all pill bottles shown are sorted*	Various pills (shapes, colors, sizes) Kitchen table Pill box with chambers for 7 days of the week and multiple times of day Viewable administration instructions	Kitchen table with pill box, pills and instructions laid out on surface	Ability to select and move specific pill bottles/doses Ability to select a specific pill box chamber to open/close Ability to select specific pill box chamber to "accept" the chosen pill dose Ability to adjust the text size of administration instruction Ability to return to previous screen and select a new pill bottle for new sorting task
Acknowledge notification alert and initiate actions Select correct pill box chamber based on alert information Update alert status indicating medications were consumed	Clock with changing display of day, week, time of day Pill box with chambers for seven days of week/ multiple times of day	Viewable clock Pill box on table surface	Ability for the clock to display various administration times Ability for the clock to display alerts based on administration times Ability to select specific pill box chambers Ability for the clock to change the administration alert after each correct selection of pill box chamber

nurses with extensive experience in this field. We did not engage individual patients or other potential users of the environments. However, we recognize that this is a crucial next step in understanding these challenges and creating an IVR intervention that meets the diverse needs of our target user group. Input from a larger number of home care nurses in our key informant interviews could also have provided greater information on potential challenges that patients and caregivers face. We think that the process of engaging key informants in this work increases the likelihood of developing research environments that have practical implications for home healthcare nurses. Additionally, people with chronic illness often have formal and/or informal caregivers who assist with the activities highlighted in this article; therefore, they could conceivably benefit from simultaneous inclusion in the IVR environment. Our key informants were never explicitly asked about caregivers. Although we recognize that caregivers play an important role in the lives of many people with chronic illness, this scenario was beyond the scope of our current efforts.

We acknowledge that self-care challenges are multifaceted and therefore recognize that our workflow analyses are not fully comprehensive of the challenges we chose to explore. When creating our workflow analyses and design specification tables, we had to omit details that could require an interaction between multiple environments. Additionally, these workflows only incorporate one way to complete a task when there may be multiple alternatives. The limitations of our early work will be addressed during development and usability testing of the environments. The successful development of IVR environments for use with patients should incorporate user-centered design methods such as subject matter expert (key informant) interviews followed by the systematic integration of the subject matter expert knowledge into workflow analyses and design requirements. Subsequent efforts will include participatory design sessions, usability evaluation, and end-user feedback.

Although we are in the early stages of learning the possibilities of leveraging IVR for patient care in the home or community, utilizing an IVR environment in this domain possesses several opportunities.

Our future research efforts will evaluate how the IVR platform can be leveraged to improve health outcomes. We will explore the use of interactive simulations that represent common healthcare challenges in the homes of people with chronic illness. Using IVR, we will examine novel questions of disease-management and home-based nursing care in patients transitioning from acute care to outpatient environments.

Acknowledgments

The authors would like to acknowledge the team at the National Institute of Nursing Research, AVB for their participation and contribution to this work. Also, a very special thank you and recognition to the home care nurses whose clinical knowledge and expertise were essential to the overall quality and realism of the developing IVR environment.

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