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Using Virtual Reality to Inform Fall Risk Prevention in Patient Rooms

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Author Note: Saaransh Vatsa holds an MS in Entertainment Arts and Engineering from the University of Utah and his contributions to the project were to program rooms in VR for evaluation, create an integrated environment for mixed reality and collect data from VR object interactions during tracking. Other authors contributed to conceptualization, methods, study data collection, analyses and interpretation. This study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of The University of Utah (protocol identification code IRB_00099410). Sara McCormick provided project administration.

Abstract: Despite decades of effort and research into preventing patient falls, there is a paucity of evidence about how the design of patient rooms influences falls. Controlled experiments with patients are difficult in a hospital room largely due to privacy concerns and the inability to manipulate the environment for research. Virtual reality (VR) technology enables us to simulate how users will interact within an environment without the need for building the physical environment. VR can present a variety of scenarios to a user and allows for interaction with both virtual and physical objects. We use VR to create an immersive environment of a hospital room to investigate the effects of patient bed orientation, toilet room location, toilet and wash basin position, grab bar location and use of an IV pole during patient ambulation between the bed and the toilet. Participants were fitted with a Valve Index Head Mounted Display (HMD), two Valve Index controllers, and three HTC VIVE Trackers on the sacrum and two feet and on an IV pole. Final IK (ROOTMOTION) asset was used in Unity to mimic the participants' movement with a manikin. Virtual collision boxes were created for all of the virtual objects in the VR room to evaluate how clearance and object placement effects movement and stability. Traditional hospital rooms were modeled based on architectural drawings and pictures from patient rooms. An additional room was configured by altering traditional room design features to evaluate the effect of distances between objects, toilet room door types and general room layout. This VR study is part of a multi-year project that aims to better understand how patient room design influences patient ergonomics and safety during ambulation. Repositioning furniture in the room and designing contact points along the pathway to provide continuous support can reduce moments of instability without compromising the utility of a patient room to provide care.

Keywords: patient falls, virtual reality, posture estimation, ergonomic training

1. Introduction

Virtual Reality (VR) is emerging as a versatile tool to study movement disorders for rehabilitation, evaluate performance during gait to falls and assess workplace environments for hazards among many other uses (Donath, Rössler, & Faude, 2016; Weber, Barr, Gough, & van den Berg, 2020). Despite the vast amount of research using VR, little has been done to evaluate how using VR could inform design decisions to protect patients from falling during hospital room ambulation, including patient transfers from the bed to toilet. Patient falls in healthcare negatively affect patient outcomes, resulting in increased morbidity, length of stay, and reduced quality of life. Unnecessary falls incur significant financial costs to both patients and the healthcare system. There has been an increase in patient falls in hospitals and other health care facilities of 46% per 1000 patient days in the past 60 years (Weil, 2015). An estimated one-third of these falls are preventable (Cameron et al., 2018). Safety interventions have been proposed and studied yet fall rates continue to be unacceptably high and are even increasing (Hsiao, 2016; Tricco et al., 2017).

Despite the substantial research studying hospital falls, their prevention remains difficult. A major challenge in the study of hospital falls is the complex environment and difficulty creating a realistic laboratory experience to evaluate patient-room interactions. VR research aims to create realistic and safe experiences that allow users to naturally interact in an immersive space which enables the study of behaviors and physical movements and to easily change an environment to study

Figure 1. Fully furnished virtual hospital room environment that was designed in Unity to evaluate user interaction and safety in simulated patient tasks.

various objectives (e.g., toileting, bed entry/egress, sit-to-stand). We explore this possibility to study patient-room interactions in an immersive VR with the addition of physical objects for interactions (Figure 1). This paper represents one part of a multi-year research initiative to better understand how to design a patient room to increase patient safety during in room ambulation.

1.1 Prior Supporting Work

Patient room designs were evaluated using a predictive risk algorithm (Novin, Taylor, Hermans, & Merryweather, 2021) and a form of mixed reality (MR). Our previous work has described new risk assessment algorithms that we have developed to optimize room layout with the goal of fall prevention. Briefly, this method estimates the fall risk associated with a room by considering multiple design factors (e.g., lighting, flooring type, door type (swinging or sliding), and furniture). The layout of furniture and medical equipment in hospital rooms influences the safety of patients (Hignett & Lu, 2007). Other studies have shown the importance of considering the patients' physical surroundings to reduce the risk of falls (Alert, 2015). Our additional work has demonstrated the capability of using an optimization method in a manner conceptually similar to computerized layout planning to reduce the risk of falls (Chaeibakhsh, Novin, Hermans, Merryweather, & Kuntz, 2021).

Another challenge with evaluating VR users during simulation is tracking the body and its relationship to the physical and VR environment. To better understand these interactions, we use tools developed for VR systems that are capable of predicting inverse kinematics (IK) using tracking data from the Head-Mounted Display (HMD), hand controllers and VIVE Trackers to provide accurate position and orientation data (Homayounpour, Butter, Vasta, & Merryweather, 2021). The position and orientation data from VR trackers allow for manikin tracking by solving the IK to represent a user's movement and posture during interactions within the virtual environment. Data from manikin position are used to detect collisions with virtual objects and determine whether contact was made or not. Ultimately these data are used to establish metrics and quantify performance within different environments.

2. Methods

We developed a VR testing platform in Unity (Unity Technologies) to enable the study of users in a hospital environment to understand how design factors in a room layout affect user performance and fall potential. The work presented here summarized a feasibility study in preparation for a full user study with n=10 participants. The research was

Figure 1. (Left) Image of mixed reality trials using virtual display and physical objects for creating immersive experience within a hospital room modeled after existing room architecture. (Right) A virtual environment with collision boxes highlighted on the hospital bed side rail for collecting proximity data during immersion.

conducted in compliance with the University of Utah Institutional Review Board (IRB_00099410). In a series of different phases, from participatory activities with architects and hospital managers, to user studies to evaluate how interacting with different object features (i.e., height, grasp, movability) with various supporting objects and perturbations resulted in changes to stability, we created a virtual environment to validate the project's purpose to understand patient fall risk in a hospital room from these early phases and test the safety of a room during toileting. Following user feedback from a study investigating 13 room layouts modeled after existing hospital rooms (Figure 2 (Left)), we adapted and redesigned a novel room environment for this study (Piatkowski, Taylor et al. 2021). Custom textures for the walls and other surfaces in the room were designed to ensure the expectations of the person was natural. We created and enhanced lightmaps to ensure realistic lighting in the room and populated the rooms with active props including a hospital bed, overbed table, patient chair, sofa, IV pole, doors, toilet, sink, charting station, and TV according to the position of the objects in the physical rooms. Users are able to interact with virtual objects and receive visual and haptic feedback through the headset and hand controllers. We also added light switches and emergency call switches.

Data collection scripts were coded for objects of interest to collect information about the user's behavior while interacting with room objects and we added realistic grab bars that provided the illusion of support in the simulation with proper hand poses to enhance immersion. Collision boxes were created for objects depending on size and potential contact points that provided the time and position of contact with the IK manikin as illustrated in Figure 2 (Right).

Data were captured within Unity to derive performance metrics and to assess temporal characteristics of steps, turning, time with contact, supporting time and general balance. An assessment of user interaction during the VR experience was conducted to further enhance the utility of the VR testing environment for the purpose of evaluating architectural design decisions, object and furniture placement and the effect on mobility during bed to toilet ambulation without assistance.

We simulated four different scenarios that represented frequent patient tasks in a hospital room. A single participant was asked, in random order to complete the following tasks: Exit the Bed on Right or Left Side (2), Navigate the Room to Toilet, Enter the Toilet Room via a swinging door or a sliding (barn style) Door (2), Sit on the Toilet and Return to the Bed. Position data were recorded from the VR trackers and collisions with the virtual objects were identified and tagged using the custom scripts mentioned previously.

Proximity Alert to object: Bed Frame L Upper
Body Part involved: HandColliderLeft
Distance between objects: 0.1437314
Collision at time: 8.683333
Proximity Duration: 0.01666641

Proximity Alert to object: Bed Frame L Upper
Body Part involved: HandColliderLeft
Distance between objects: 0.1472847
Collision at time: 8.766667
Proximity Duration: 0.03333378

Proximity Alert to object: Bed Frame L Upper
Body Part involved: HandColliderRight
Distance between objects: 0.367054
Collision at time: 8.941668
Proximity Duration: 0.208334

Figure 2. Example results from data collection script during VR trials. Units are in meters for distance and seconds for Collision time and Proximity duration.

3. Results

The VR study environment created an immersive experience with the flexibility to evaluate user experiences with different room layouts and clearances. For example, when the user contacted the grab bar near the toilet, the accuracy of the location of contact on the object improved when multiple collision boxes were used.

A dataset of proximity alerts is generated that includes information to assess performance and user-environment interaction with virtual and physical objects. These proximity alerts identify the frame when contact is made between the virtual human and the virtual objects in the environment that have been defined using collision boxes. An example output from the recorded data is shown in Figure 3. The alert provides information about which object was contacted, how far away from the user the object was located and the duration of time of the contact. The data from these alerts and the spatial data recorded using the VR trackers are displayed in Figure 4. From the spatial data, it is clear that a different motion is required to exit the bed from the right vs. the left side and the operation of the door into the toilet room modified the movement pattern. Further, these data were summarized in Table 1 to show the differences between spatial/temporal values from the tasks.

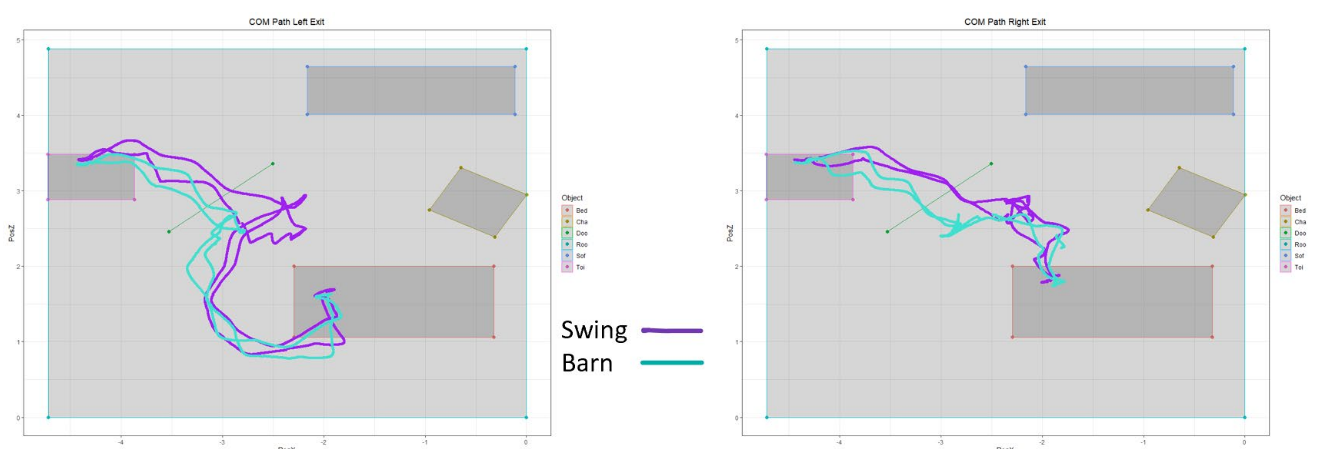

Figure 3. Example results from data collected using the VR scripts. The shaded regions in the room represent different objects. The participant started at the hospital bed and navigated through the room from either the right or left side of the bed. The colored lines represent the location of the center of mass, approximated by the VR tracker located on the pelvis of the participant, and show the change in movement during toilet room door operation.

Table 1. Spatial/Temporal metrics computed for each of the four task scenarios simulated in the VR hospital room environment

	Right Swing Door	**Right Barn Door**	**Left Swing Door**	**Left Barn Door**
Distance (m)	10.2	10.3	15.5	12.4
Task Duration (s)	44.5	42.5	69.8	51.8

With these values, we can assess the influence of design decisions related to object clearances, such as ADA compliant rooms compared to standard rooms, object locations, including handrails and grab bars, the influence of door operation (e.g., swing, sliding, double door) and general room layout. These values are recorded without complications from using traditional optical motion tracking and less immersive and exclusively physical testing environments.

There are some limitations to using VR in ergonomics assessments to inform physical design. The degree of immersion affects physical performance and some physical interactions cannot be fully simulated using VR and haptics alone. However, VR has been shown to be an effective means for producing realistic physical responses, including perception while working at height (Simeonov, Hsiao et al. 2005). Future work is needed to compare VR derived interaction with physical interactions. We will also include multi-player VR to evaluate clearance requirements and considerations for the scenario where patients are assisted by a caregiver during bed entry/egress and toileting.

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5. References

Alert, S. E. (2015). Preventing falls and fall-related injuries in health care facilities. *The Joint Commission, 55*, 1-55.

Cameron, I. D., Dyer, S. M., Panagoda, C. E., Murray, G. R., Hill, K. D., Cumming, R. G., & Kerse, N. (2018). Interventions for preventing falls in older people in care facilities and hospitals. *Cochrane database of systematic reviews*(9).

Chaeibakhsh, S., Novin, R. S., Hermans, T., Merryweather, A., & Kuntz, A. (2021). Optimizing Hospital Room Layout to Reduce the Risk of Patient Falls. *arXiv preprint arXiv:2101.03210*.

Donath, L., Rössler, R., & Faude, O. (2016). Effects of virtual reality training (exergaming) compared to alternative exercise training and passive control on standing balance and functional mobility in healthy community-dwelling seniors: a meta-analytical review. *Sports medicine, 46*(9), 1293-1309.

Hignett, S., & Lu, J. (2007). Evaluation of critical care space requirements for three frequent and high-risk tasks. *Critical care nursing clinics of North America, 19*(2), 167-175.

Homayounpour, M., Butter, D., Vasta, S., & Merryweather, A. (2021). *Validation of an Inverse Kinematic VR Manikin in Seated Tasks: Application in Ergonomics Training.* Paper presented at the Congress of the International Ergonomics Association.

Hsiao, H. (2016). *Fall prevention and protection: Principles, guidelines, and practices*: CRC Press.

Novin, R. S., Taylor, E., Hermans, T., & Merryweather, A. (2021). Development of a novel computational model for evaluating fall risk in patient room design. *HERD: Health Environments Research & Design Journal, 14*(2), 350-367.

Piatkowski, M., E. Taylor, B. Wong, D. Taylor, K. B. Foreman and A. Merryweather (2021). "Designing a Patient Room as a Fall Protection Strategy: The Perspectives of Healthcare Design Experts." International Journal of Environmental Research and Public Health **18**(16): 8769.

Simeonov, P. I., H. Hsiao, B. W. Dotson and D. E. Ammons (2005). "Height effects in real and virtual environments." Human Factors 47(2): 430-438.

Tricco, A. C., Thomas, S. M., Veroniki, A. A., Hamid, J. S., Cogo, E., Strifler, L., . . . MacDonald, H. (2017). Comparisons of interventions for preventing falls in older adults: a systematic review and meta-analysis. *Jama, 318*(17), 1687-1699.

Weber, H., Barr, C., Gough, C., & Van Den Berg, M. (2020). How Commercially Available Virtual Reality–Based Interventions Are Delivered and Reported in Gait, Posture, and Balance Rehabilitation: A Systematic Review. *Physical therapy, 100*(10), 1805-1815.

Weil, T. P. (2015). Patient falls in hospitals: an increasing problem. *Geriatric Nursing, 36*(5), 342-347.