Virtual Reality as a Methodological Tool to assess Disaster Preparedness

DeeDee Bennett Gayle
University at Albany, SUNY
dmbennett@albany.edu

Salimah LaForce
Georgia Institute of Technology
salimah@cacp.gatech.edu

Xiaojun Yuan
University at Albany, SUNY
xyuan@albany.edu

Mahsa Goodarzi
University at Albany, SUNY
mgoodarzi@albany.edu

Mwarumba Mwavita
Minnesota State University, Mankato
mwarumba.mwavita@mnsu.edu

ABSTRACT

While disaster preparedness is known as a force multiplier to reduce impacts for individuals, there is limited research or practice to measure the influence of preparedness activities. Most metrics focus on how many people received preparedness information or how many pamphlets were distributed. This study outlines a project to use virtual reality to measure preparedness among the public. Focused initially on older adults, the goal is to create a game that can be used on multiple populations, which will collect data about preparedness activities. The tool will be used in an experimental design to assist in further refinement. The mixed method experiment includes surveys, field study with the VR headsets, and observational data. Once complete the game will be useful for researchers or practitioners needed actionable data regarding the preparedness practices of individuals and households.

Keywords

Virtual Reality, Gamification, Disaster Preparedness, Older Adults,

INTRODUCTION

Among the most challenging issues in emergency management is understanding and predicting protective action decision-making among vulnerable populations. While the threats from natural hazards cannot be eliminated, research to reduce vulnerability and increase community resilience is critical to the overall resilience of our nation. There are several groups considered more vulnerable during disasters. These include marginalized racial and ethnic minorities, people with disabilities, low-income households, and older adults, among others (Wisner, 2014; Kendra and Watchendorf 2023; Dadson et al 2024). The efforts undertaken in this study focus on testing and advancing decision-making theories to prepare for disaster by one specific vulnerable group - older adults.

In vivo research on the human impacts of disasters has a long history of challenges regarding ethical considerations for quick response research. For example, overburdening recent survivors, potentially adding to their distress, and researchers' presence draining much-needed housing resources in the impacted area. Most disaster decision-making studies require that investigators rely on secondary data available long after the fact or collect perishable data from survivors in the aftermath of a disaster. Few studies have explored protective action decision-making using a user-centered experimental design. Disaster research conducted as an experimental design has occurred during an actual disaster, which also encountered ethical controversies (Bennett Gayle et al., 2021). Therefore, this study makes a methodological contribution to advance disaster research using Virtual Reality (VR) to conduct experiments on decision-making during two types of disasters. It uses VR to advance research methodologies and reduce the critical ethical concerns faced during quick response research.

BACKGROUND

Older adults are among our most vulnerable to and more likely to be displaced by disasters (Kendra & Wachtendorf, 2024). They are at greater risk than all other age groups during disasters, particularly in planning, preparedness, and awareness (Adams et al., 2021; Bell et al., 2021; Carpenter & Yoon, 2015). Exacerbating disaster vulnerability, older Americans are expected to reside in places that may be more affected by climate change, including coastal zones and large metropolitan areas (Gamble et al., 2013). Shelter-in-place (SIP) orders have contributed to an increase in elder abuse and victimization in congregate facilities (Elman et al., 2020). Also, older adults are more vulnerable during heatwaves and winter weather events (Loughnan et al., 2015; Gascoigne et al., 2010; Rudge & Gilchrist, 2005). During flooding scenarios, they may be reluctant to leave due to social connections in the area (Brockie & Miller, 2017). Similarly, there is evidence that few older adults develop plans for evacuation from a hurricane because of their social connections (Coronese et al., 2019). Furthermore, while the number of older adults (> 65 yrs.) is projected to rapidly increase over the next few years, so too are the frequency and intensity of hazards attributed to climate change (AghaKouchak et al., 2020; Coronese et al., 2019). From 2006 to 2016, there was a 33% increase in the U.S. population of individuals aged 65 years and older (Census Bureau, 2018). By 2040, the number of older adults is expected to increase from 49.2 million to 82.3 million, representing nearly 22% of the population (Census Bureau, 2018). Similarly, the cost, frequency, and intensity of disasters (specifically from natural hazards) has increased in scale, occurring more often and causing more damage (USA Facts Team, 2024). Older adults living alone or with low income often need more assistance during evacuation.

Age-related normative changes in perception, attention, memory, text comprehension, and decision-making can affect the processing of hazard information (Mayhorn, 2005). Research supports the hypothesis that older adults are more vulnerable due to age-graded cognitive decline and the need for social support (Adams et al., 2021; H. Kim & Zakour, 2017; Mayhorn, 2005). However, there is a way forward to mitigate such challenges. Carpenter and Yoon's (2011) study on the relationship between aging and consumer decision-making concluded that prior knowledge and experience could improve decision-making and help older adults overcome limitations imposed by age-graded cognitive declines (Carpenter & Yoon, 2015). Awareness of and preparedness for a disaster can reduce vulnerability (Arimura et al., 2020). Therefore, considerations for older adults must be included at every disaster planning stage to mitigate the likelihood of disparate outcomes. This study investigates the decision-making factors of older adults across two hazard types to advance disaster theories and concepts on decision making, preparedness, and the protective action responses of vulnerable populations.

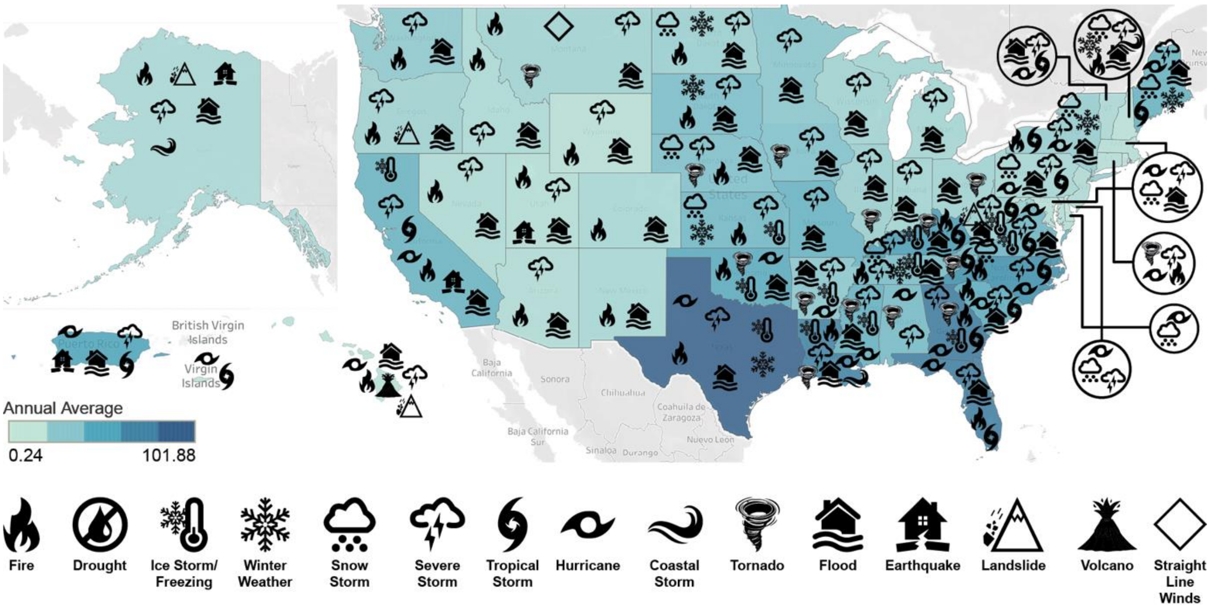

Figure 11: Annual Average Disaster Type in United States, 2015-2025, Based on FEMA Disaster Declaration Summary Data

The concept of differences in decision-making across hazards has been studied (Stapelberg, 2008; Terti et al., 2019), albeit from the perspective of emergency planners. Recent studies have begun to notice the differences in the cognitive risk perception process for individuals across hazards (Wu et al., 2024). These studies focused on compounding disasters, where two or more hazards, such as a hurricane during COVID-19 social distancing, occur simultaneously. While the reality of compounding disasters is a real concern for various locations, so is the possibility of more frequent disasters in one area or cascading disasters (where one hazard's impact causes another hazard, such as the earthquake, tsunami, and nuclear incident in Japan 2011). In the United States, most states are prone to more than one type of natural hazard, see Figure 1. Given early data on differences in risk perception for compounding disasters, it is imperative that we fully understand any differences in decision-making across various hazards. This study will identify the decision-making factors of older adults during different hazards (older adults >65 years old). In emergency management, most recommended protective measures fall into one or two broad categories, shelter-in-place (SIP) or evacuation. SIP includes orders to remain in your home, car, or workplace (e.g., chemical incidents, earthquakes, winter weather) or go to an emergency shelter in/near your home or neighborhood (e.g., tornado). Evacuation protective measures typically recommend people leave the affected or soon-to-be-affected area entirely (e.g., hurricanes, severe flooding, wildfires). There are situations when people cannot evacuate, and then measures are undertaken to shelter nearby, usually in a congregate care facility such as an emergency shelter. These two protective measures were the cause of conflicting risk perception in other studies (Wu et al., 2024).

Finally, one of the limitations of studies that have examined decision-making by older adults is that they typically use informants (caregivers and healthcare professionals) as the subjects, not older adults. The few disaster studies focused on older adult decision-making lamented the significant knowledge gap (Campbell, 2019; Fountain et al., 2019; Tuohy et al., 2014). Therefore, the ongoing research presented in this paper has two objectives: 1) Expand the body of knowledge regarding disaster methodologies and theories in disaster research, information science, and decision-making by conducting experiments with older adults in the United States and 2) Expand upon through the testing of theories from disaster science, information science, social science, and psychological science regarding (a) whether there are individual differences (i.e., varying responses) based on the type of hazard (Protective Action Decision-Making Model (PADM), (b) the acceptance of using VR as a preparedness tool (Technology Acceptance Model (TAM), (c) the implications of intersectional vulnerabilities on disaster-related decision-making (Social Vulnerability Theory(SVT), and (d) the role of affect/emotion in disaster decision-making (Cognitive Experiential Self-Theory (CEST). To that end we are testing four research questions:

- RQ1 Using the PADM framework and Social Vulnerability Theory, are there decision-making variations among older adults in response to different hazards?
- RQ2: Using the PADM framework and Social Vulnerability Theory, are there differences in protective action among different aged adults?
- RQ3: Using CEST, are better protective action decisions made when they are emotion-focused?
- RQ4: Testing the TAM theory; what is the feasibility of VR for improving disaster preparedness for older adults?

METHODOLOGY

Experimental designs have been previously employed in disaster research. Many studies have focused on disaster exercises and training, primarily for disaster-related professionals (Coles et al., 2016; Ghezeljeh et al., 2019; Linardi, 2016; Powell & Thompson, 2016; Stratton, 2019). As discussed above, disaster research conducted as an experimental design during an actual disaster has led to ethical controversies. The feasibility of onsite disaster experiments is also problematic. For one, researchers need to serendipitously be in the location pre- and post-disaster and secure consent with the same human subjects (Linardi, 2016; Powell & Thompson, 2016).

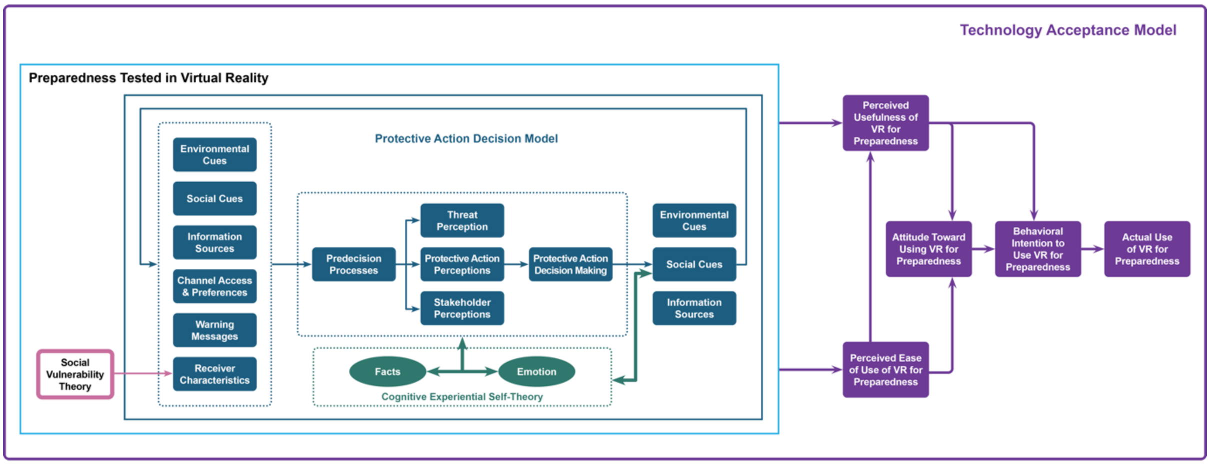

Figure 2: Depiction of the theoretical testing design for the study (adapted from Lindell & Perry, 2004; Epstein 2008; Davis 1989)

However, a completely innovative approach uses a VR-enabled experimental design to relay and collect information across multiple simulated sources (communications devices, environmental cues, social cues, etc.) in a home environment. As a result, PRO-ACTIVE will advance the understanding of using VR for 1) data collection in disaster science, 2) data collection among older adults, and 3) improving disaster preparedness and decision-making among the public. This project is the first to contribute to the body of research to advance VR as a method to collect data and analyze the decision-making and behavior of older adults in response to multiple hazards. The findings are anticipated to apply to various fields, including the science of decision-making, risk perception, geriatrics, psychology, and information, among others, as well as practical applications for departments of emergency management and public health to improve the public's resilience to disaster events.

The hypotheses are tested using a mixed-methods approach using experiments, observation, and surveys. PRO-ACTIVE has two study objectives: 1) Expand the body of knowledge regarding disaster methodologies by conducting within group experiments and surveys with older adults in the United States, and (2) Test the TAM by conducting between group experiments with older adult participants who received the experimental tutorial condition.

OLDER ADULTS AND VIRTUAL REALITY

VR has been found to have positive benefits among users related to mental health and for older adults. Training in VR increased the retention of information and task performance in both novices and more experienced workers (Manca et al., 2013) and in memory encoding and recall of newly learned routes in both older adults and young adults (Lokka et al., 2018). Further, VR has been found to improve the interview skills of people with schizophrenia and increase the length of their employment (Smith et al., 2015). In the health domain, VR use with older adults was shown to be efficacious in the treatment of people who are at risk of falling (Rendon et al., 2012), to increase cognitive functioning (Chan et al., 2010), and to improve muscle strength and control (J. Kim et al., 2013). Finally, there is research to suggest the benefits of using VR as a research tool. The strengths include internal validity and, thus, replicability, ecological validity, and transferability to in vivo practices. Further, VR supports participant safety, flexible/adaptive environments that are highly controllable, immediate and real-time feedback, and objective and precise measurements of behavior and psychophysiological states (Kinateder et al., 2015). Therefore the research design used in this study also conforms to safety and ethical guidelines for using VR with older adult populations (Brown et al., 2022) and is flexible enough to adjust as needed.

VR DEVELOPMENT

This project is capitalizing on the advances in and advantages of VR training by applying it to improving preparedness, risk perception, and protective action decision-making in older adults. The collection of such perishable data during disasters has typically been investigated during quick response research, where researchers visit recently impacted locations to interview or survey survivors (Stallings, 2003). This practice has long been criticized for its ethical implications, including heightened distress or trauma among participants, unfair expectations of the participants, and the lack of reciprocity for long-term fieldwork (Browne & Peek, 2014; Norris, 2006; Van Brown, 2020). The research undertaken through the PRO-ACTIVE project would typically require quick-response research approaches in the aftermath of a disaster. The use of VR eliminates this requirement and reduces the ethical issue of heightened distress or trauma among participants. Given that the participants are not actively going through the response and recovery of a real disaster, VR does not place any unfair expectations on the participants during such events. Additionally, given there is no need for the research team to travel to an impacted area to carry out this research, the extra ethical consideration regarding the lack of reciprocity for the community (as well as the participants) is also eliminated. Finally, given that the proposed measure of decision-making is for two different disasters among the same participants, using VR is one of the few approaches that will allow for this study's experimental design.

VR can teach specific functions in a stress-free environment (Ghali et al., 2012). Training in VR has emerged as a tool across many domains, including health maintenance, rehabilitation, education, workplace training, diversity and inclusion, and emergency management. As such, this project's innovation extends disaster methodology by using VR in an experiment focused on individual preparedness and response. The use of VR has been used in other disaster studies. In the emergency management and response context, Dethridge and Quinn (2016) examined media's role in community responses to a disaster by exploring how communication technology may allow new relationships between community groups and emergency agencies (Dethridge & Quinn, 2016). In Japan, VR has been used to improve disaster awareness and evacuation and for training (Ooi et al., 2019; Takeichi et al., 2020). While VR has been used as a research and training tool, its application in disaster research has focused on emergency response professionals, not the public. Few studies have explored emergency communications and protective action decision-making using an experimental design focusing on older adults; even fewer have used VR.

CURRENT PROGRESS

Our team, in collaboration with industry partners, is in the process of refining software developed by students using environments such as Unity, an intuitive VR development platform (Jerald et al., 2014). The collaboration will guarantee the ability to use the software for testing the research approaches and providing methodological contributions in the disaster setting. Utilizing commonly available 3D assets, software plugins, and other development assets will decrease development time and costs. A virtual environment will enable rapid iteration through the development process and provide maximum ability to adjust the simulation based on the needs of the researchers. The use of the two UAlbany gaming courses increases the marketability of the students via exposure to STEM experiences and skill building. Our classes are always full, and we hold multiple sections. During the capstone the students are learning about user interface, environment design, interaction, style guides, and accessibility features within the game environment.

We plan to begin our recruitment in summer 2025. We intend for all participants to use VR in a seated position and have no more than 5-8 minutes per VR session. Therefore, we are testing out the environment. Using Meta Quest Pro. The final product will be easily administered by technical and non-technical individuals using software that can be supported through the project's lifecycle and beta-tested by UAlbany students. The final product (i.e., end of project period) can be adapted for use by federal, state, and local emergency management agencies for use in their efforts to improve the preparedness of their populace.

The scene within the VR space is a home environment allowing us to test variables related to the PADM (RQ1); users will be able to walk around virtually and enjoy what looks like an animated household space. To keep it simple, we have opted for a one-bedroom apartment with space for a bed, bath, kitchen, and living space. The game objects include furniture, lights, TV, cell phone, general kitchen appliances, and preparedness kit items dispersed about the environment in appropriate places. Users are able to see outdoors through the windows. The components (for the game objects) determine the position, rotation, and scale of the objects; only reasonable objects will be able to rotate 360°, such as the cell phone or television remote. The VR space will be primarily animated; however, some real clips will be used for the television. The screenshot images in Figure 2 are shown without the use of our style guide to develop a more comfortable, age-appropriate feel for the home.

Figure 2: Screenshots of the VR Environment

The PADM factors are being used to identify the data collection undertaken in VR to determine decision making differences among older adults in reaction to various types of emergency information inputs. VR allows our team to use an experimental design with two distinct disaster scenarios and examine cues that relate to older adults' trust of information sources such as the Emergency Alert System through televised media, environmental cues, or Wireless Emergency Alert through a cell phone. Within the home environment, we will investigate attention to the different cues based on eye gaze data to determine the order of events as well as collect data on both response time to the initial indication of threat (e.g., acknowledgment of the emergency message) and elapsed time, the actual time it takes participants to exhibit the behavior that aligns with the appropriate protective action (e.g., prepare to evacuate).

The variables of the PADM model are being used to determine the difference in response based on the hazard type. To streamline the refinement of the VR environment and data collection, only pertinent PADM elements, such as environmental cues, social cues, information sources, channels, and actions undertaken, will be presented, captured, and differentiated in the environment. The environmental cues, social cues, warning messaging content, and available modes to receive information will remain constant for all participants. Participant actions will be captured through the VR, including the priority of what they attend to in the environment (collected via eye-gaze technology), intermediate actions, and the time taken to arrive at a decision (elapsed time). The outcome variable is the protective action taken for each type of hazard. We will capture posttest participant perceptions of the protective action requested, the stakeholders disseminating the messages, their risk assessment, and information about their behavioral response.

The pre and post-test survey questions are designed to assist us with testing the TAM and social vulnerability. Pre-test questions will include demographic information for us to accurately assess the receiver characteristics. The post-test questions are designed to pick up response to perceived ease of use and behavioral intention to use. The post-test questions will also ask about changes in behavior in real life. For the overall experiment, we anticipate including a second post-test survey 6 months after the participant experienced the VR environment. Within the overall design we have a within-subject experiment to examine the difference in priorities for preparing across two different hazards. However, we also include between-subjects design to test the CEST and the influence of the VR tutorial on preparedness knowledge.

LIMITATIONS AND FUTURE RESEARCH

Our study has limitations. First, the task scenario was confined to a one-bedroom apartment layout, which included designated spaces for a bed, bathroom, kitchen, and living area. This setting may not fully represent the various living environments of older adults. Second, the types of hazards selected for the study were limited, which may not capture the diverse risks that arise in real-world settings. Last, our current participant pool consisted exclusively of older adults, in which they may or may not have the same experiences as other populations. In the future, we plan to explore different residential layouts, a broader range of hazards, and other populations to test with others and refine as needed. Our immediate next step is to compare how older and younger adults use the VR platform in a within-subject experimental design.

To that end, we will rely on robust causal inference techniques such as regression discontinuity or difference in differences design. These will allow us to derive statistically significant relationships between different demographics or sub-populations with their emotional or decision-making profiles. Additionally, such inferences will enhance our capability to more accurately apply machine-learning methods to experiment results. These existing relationships will allow us to uncover meaningful associations or confirm existing hypotheses. Supervised models, such as classifiers (Neural classifiers, Support Vector Machines, Random Forests), can facilitate behavior prediction about stated preferences, perceptions, and attitudes. Unsupervised models, e.g., clustering, on the other hand, can explore hidden patterns in the data.

CONCLUSIONS

This study examines how older adults make decisions when faced with two different types of hazards. The goal is to improve our understanding of disaster preparedness, decision-making, and protective actions, especially for older adults. By examining how older adults assess risks and respond to disaster situations, it contributes methodologically by using Virtual Reality (VR) to create realistic disaster scenarios.

ACKNOWLEDGMENTS

We thank the reviewers of this work and would like to acknowledge this material is based upon work supported by the National Science Foundation under grant #2425223.

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