

A Study of Real-time Information on User Behaviors during Search and Rescue (SAR) Training of Firefighters

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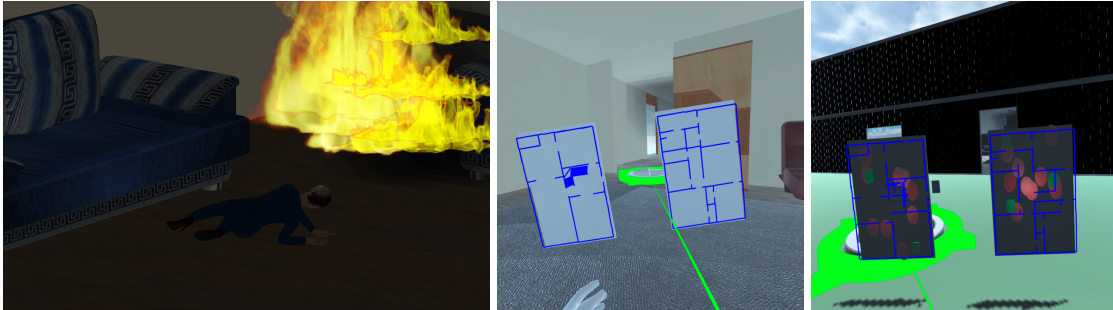


Fig. 1. Example scenes of SAR training with fire and smoke simulations that are automatic controlled. We offer options of virtual maps with static (middle) and real-time (right) information.

Abstract—Search and rescue (SAR) is an essential skill for many first responders including firefighters. With the new development of technologies on environmental sensing, we are now equipped with the new capability of utilizing real-time information from a fire scene to assist SAR tasks. This work is to explore the effects of immersive maps, that collect information automatically from the environment including human and building structures, on user behaviors during SAR operations. We have developed a VR prototype system for SAR training with controlled fire scenes and information collections. We also designed and performed a user study focusing on the factors of information amount in an immersive map and danger degree of SAR tasks. We have summarized a set of user behaviors from our study, and captured their features with statistical data analysis. Our results confirm the advantages of real-time information for SAR tasks and differences of user behaviors under dangerous situations. Our results also demonstrate the potential of studying user behaviors with virtual training and deriving insights to design effective training programs.

Index Terms—Search and Rescue, Virtual Reality, User Behavior Analysis, Immersive Visualization

1 INTRODUCTION

Firefighting is important but dangerous. It is listed among the top 10 most dangerous jobs in the United States. According to US Fire Administration, in 2015, there were 1,345,500 fires, which caused 3,280 deaths, 15,700 injuries, and \$14.3 billion loss. Abundant evidence suggests that limitations in cognition, ineffective communication, and poor decision making have caused high risks and resulted in huge casualties, such as at Mann Gulch and South Canyon [28, 29].

A variety of new technologies for both hardware and software have been developed to assist firefighting. For hardware, wireless sensing techniques provide new ways to capture and process various real-time information, including the status of human beings, buildings and fires. Drones and robots are also developed to assist tasks under dangerous situations [9]. For software, monitoring and communication systems, often with artificial intelligence algorithms embedded, have been designed to improve situation awareness and communication [1]. The training for firefighters in VR also provides an opportunity to experience various dangerous situations [2, 7, 24, 31], improve decision making [18], and evaluate the impact of new stimulus [31].

However, due to the dramatic differences between new technologies and traditional approaches, it is still not clear how new technologies affect user behaviors and if new technologies actually improve user performances [23, 30]. For example, the decisions of firefighters are often

based on their previous experiences [12], will they and to what extent choose to utilize real-time information compared to their experiences? This work aims to examine the effects of real-time information on user behaviors during dangerous search and rescue (SAR) operations with VR simulations, as the VR and AR have been shown as effective tools to study various user behaviors [3, 10, 16]. Similar to [30], our results can be used to guide the design and evaluation of training programs for firefighters.

To study the effects of real-time information, we have first developed a VR training system which uses a multi-level approach to generate controlled fire scenes in a set of residential buildings. We also design immersive maps with both static information from the 3D environment, and real-time information collected from the simulated environments about the dynamic locations of fires and of persons to be rescued. The immersive maps can be brought to the virtual environments, providing the opportunity for users to analyze situations of the environment and people at any location.

We have designed and performed a user study to explore the user behaviors from the SAR training system under different dangerous conditions. We focus on two independent variables – the information level represented by virtual maps and the danger degree of the environment controlled by our fire simulations. Our approach collects detailed behavior records and performs data analysis to explore the usage of real-time information in VR. We analyze the statistical features from the diverse set of user behaviors, and explore the correlations between internal and external behaviors with quantitative approaches.

Our results confirm the advantage of real-time information for SAR tasks and demonstrate its effects on the changes of locomotion behaviors and usages of virtual maps. We have also identified several consistent correlations between the overall performance and user behaviors. Our findings about user behaviors under different danger degrees

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and information levels in the supporting virtual training systems provide insights for designing effective intelligent immersive systems for SAR-related tasks.

2 RELATED WORK

We briefly summarize the previous work on VR/AR for training, studies of user behaviors, immersive visualization in VR/AR, and real-time monitoring/planning.

2.1 VR/AR for Training

VR Training is the digital simulation of lifelike scenarios for training purposes. Trainees enter a 360° active learning environment using a head-mounted device and experience sights and sounds that dissolve the barrier between virtual and actual realities [6]. As a good example, Jaikyoung et al. [13] proposed a firefighter training platform using the virtual environment. They adopted AR and VR techniques to achieve an immersive virtual environment where trainees were able to navigate the environment, command other firefighters, and see realistic fire and smoke. Trainers could monitor the behaviors of trainees as they react to changes to maintain their safeties. Pongsagon et al. [27] also performed a similar virtual experience to provide information concerning fire incidents and helped trainers to deal with realistic critical situations. As another example, Maximilian et al. [19] challenged the efficiency of VR headsets in training health care professionals, finding that traditional training methods were more effective and efficient. Although the results showed that it took health professionals longer to perform a task in VR, the resulting learning effect was much higher and VR-training was more cost-effective than traditional training.

Related to the effectiveness of VR simulations, Paul et al. [21] performed a study on head-worn devices on EMS staff to examine how helpful and sufficient AR technology could be. The researchers used the observations and feedback of EMS staff to improve the realism of training scenarios and enhance communication between different care providers. Jonas et al. [8] provided paramedic emergency simulation with focus on anaphylactic shock, which was rare to occur in a real life conditions. Their platform demonstrated that Virtual Reality could be applied in vocational training. In a different development, Clint et al. [34] introduced a SAR platform consisting of a wearable computer interface for dogs to work more transparently and effectively with their handlers while conducting SAR missions. Jimmy et al. [25] also performed a similar experiment on SAR dogs using wearable devices to improve their effectiveness in the field. By locating the position of survivors and sending these data to the dog handlers, first responders could safely approach the location to perform further operations. Another good example of VR training is a platform developed by Etienne et al. to train mine personnel to experience activities and processes that could be encountered in the day to day operations at a mining site [26].

Our work also uses VR to provide a realistic training environment where users can experience different fire scenes and practice SAR operations. The main difference is that we focus on capturing user behaviors during the training and perform a comprehensive set of analyses to explore visualization features and behavior profiles that can be summarized and used to improve VR training.

2.2 VR/AR for User Behaviors

User behaviors have been studied in a number of research fields including both cognitive and computer sciences. While some types of behaviors such as user interactions with advertisement online can be studied with data collected automatically, many studies require participants to perform specific tasks and record their behaviors with intrusive methods, such as cameras and EEGs. Compared to these methods, the data collection of user behaviors with VR and AR are restricted to the head and hands (which can be expanded with additional methods such as motion sensors), raise fewer privacy concerns and do not require post-processing to deidentify users in recordings.

Researchers using VR and AR have studied a diverse set of user behaviors, including motion sickness levels [33], work force attrition [20] and emotion and reactions of participants [3, 10, 16]. VR and AR have also been used to study user behaviors [11, 32]. For instance VR was

used to analyze the movement and gestures of athletes to improve training. Alberto et al. [4] presented a VR-based training system to teach basketball to beginners by analyzing their movement and providing them with ad hoc cues that are not available in the real world. Lin et al. compared co-located and situated real-time visualizations in basketball free-throw training, demonstrating that real-time visual feedback helped athletes to refine subsequent shots and focus on body form [14].

2.3 Real-time Monitoring and Planning for First Responders

With the fast development of sensing techniques, many buildings improve their ‘smart levels’ with the installation of various monitoring and sensing devices. Such devices, through information collection, aggregation, and analysis, can provide valuable real-time to first responders such as firefighters. For example, Seo et al. [22] designed a system that allowed indoor UAV and pre-installed sensors to work together to detect the approximate location of workers in a building on fire. Similar approaches for gas leak or fire hazard detection in buildings have been proposed, using multi-hop wireless networks [5]. The propose of this approach is to have access to training in a realistic situation of an entirely configurable environment. Our work simulates the results of current sensing technology to acquire a set of live information that can be delivered to first responders in real-time. While such products are not available yet, the results of this study can inform their design.

3 OVERVIEW

Since the focus of our study is real-time information for SAR tasks under dangerous situations, we design our experiments for participants to experience and perform the SAR tasks with fires and smoke inside residential buildings. With a VR simulation system, we record details of changes from both the environments and participants, including motions of their heads, hands and bodies, so that we can further measure several types of user behaviors and explore their decision making processes. Our work shows that user behaviors can be captured and analyzed to reflect changes of psychological factors or processes of decision makings.

For our user study, we identify two independent variables: the information available in the virtual map supporting the tasks and the danger degrees of the tasks caused by the fires and smoke. For each variable, we design three scales with the information level and danger degree increasing gradually. Specifically, the information levels contain a map with just the building shape, a map with only static information, and a map with both static and dynamic information about the fires and persons to be rescued. The danger degrees cover a baseline for a relatively safe situation where participants can still see through the rooms, a medium level, and a challenge situation where participants can hardly see things in distance due to the fires and smoke in the building, simulating real SAR scenes of firefighters.

Based on our knowledge of SAR from first responders, we expect that the user behaviors are affected by both information levels and danger degrees. We expect to find consistent behaviors among participants and unique strategies from individuals as well. Specifically, we have made the following hypotheses:

(H1) Several types of user behaviors are affected by the extent to which the situation is dangerous.

(H2) The availability of virtual maps is helpful to SAR. Additionally, real-time information may lead to better performance compared to static information.

(H3) Combining both variables, real-time information is more likely to affect behaviors of participants under the more dangerous situations.

In the following, we first describe our VR simulation system in Section 4 and then the details of our user study in Section 5.

4 VR SIMULATION OF SAR TRAINING

To support our designed study, we have developed a system for SAR training of firefighters in VR. We have three main goals to achieve with this simulation system:

- Supports participants to perform SAR tasks, simulates the real-time data collection process from several wireless sensors, and automatically saves detailed user records.
- Produces virtual environments with fires and smoke at different assigned danger levels, simulating real fire scenes. We generate a linear scale to control the danger simulations – the minimum value representing safe environments with high visibility and no fires/smoke, and the maximum value representing the most dangerous environments with low visibility and multiple fire/smoke simulations.
- Provides virtual maps, which accumulate data from wireless sensors on maps and allow participants to observe real-time information at any location in the environments.

The following describes the technical details of three components of our system, building construction, fire simulation, and generation of virtual maps respectively, for creating various rescue scenes with different danger degrees. We also provide the interaction methods and implementation information of our system.

4.1 Construction of Building Environments

To focus on the two independent variables of our study, we keep the virtual environments for all the trials in a consistent style. It is also important to use a different environment for each trial to avoid the possibility of participants remembering the routes. While buildings vary from basic residential to complex commercial types, we choose a common type of SAR tasks – residential housing with two floors. We create a number of buildings for our user study by keeping their external shapes the same, so that all buildings have the same sizes of areas for search. The internal structures of the buildings are all different, through simulating example blueprints of residential houses from public websites. We also add a set of furniture in the buildings manually to create living rooms, bedrooms, offices, dining rooms, and bathrooms. The Figure 2 shows two examples of our building models. They have similar appearances and the same search areas, but different internal structures.

4.2 Simulation of Fire Scenes

To simulate various fire and smoke effects, we use a multi-level structure that composes different types of basic particle systems. As shown in Figure 3, the basic particle systems include 3 levels for fires (tiny, medium and large) and 1 level for smoke. The fire effects are mainly controlled through a combination of the 3 fire systems, e.g. a small fire simulation may include 3 tiny and 2 medium systems, and a large fire simulation may include 2 tiny, 3 medium and 3 large systems. Similarly, several smoke systems are added to simulate effects from light fogs to thick black smokes from burning.

In addition, we adjust the parameters of particle systems automatically based on their desired danger degrees. For higher degrees, we use more particles and larger particles (10-100 particles, 2-5 scales), longer durations (3-10 seconds), and faster projection speeds. To ensure interactive rendering speed of the system on standalone devices like Oculus Quest, we use relatively small numbers of particle systems. Specifically, the danger degrees in our study involve 3 to 10 fire locations, each with several to dozens of particle systems. They can be increased for devices like Oculus Rift. The fire systems inside each simulation are randomly distributed around the simulation seed position, with larger areas for higher danger degrees. The controls of smoke systems focus on the particle numbers and colors – light colors for small simulations and dark colors for large simulations.

To generate different scenes, we control the generation of multiple fire simulations through alternating the danger degrees. All the key parameters, including the number of simulations (small for lower levels), number of particle systems, and distances to the player (far away for lower levels), are adjusted automatically with linear equations between the assigned value ranges. Small random numbers are added to create variations of the fire and smoke simulations without affecting the overall visual effects. This process ensures that we can generate different fire scenes with the controlled danger degrees.

4.3 Automatic Generation of Virtual Maps

We generate virtual maps to simulate the effects of real-time environmental sensing. Our virtual maps have three components for each floor of the building, a base plane, the floor plan, and real-time locations of the player, targets to be rescued and fires. The base plane is a blank plane which captures the shape of the building. It is the same for all the buildings. The floor plan is automatically generated by locating all the wall objects in the building, and rendered as lines directly on the base plane. The real-time locations are rendered as basic shapes (red circles for fires, and rectangles for the player and targets) with different colors, as shown in Figure 4.

For the two floors, we choose the pair view to avoid overlapping issue of 3D maps – the map for the first floor is on the left, and the second floor on the right. While there are other design options on the virtual maps [15, 17], we simplify the choices to focus on the types of real-time information in this study.

4.4 Interaction and System Implementation

Our system provides the interaction functions to show or hide the virtual maps during the study with a button on the left controller. As shown in Figure 4, the virtual map is always placed on the front of the left hand, so participants can raise the left hand to view the map and drop the hand to observe the environment. Participants can also place the map on the side to view the map and environment simultaneously. Since the large fires simulate very dark environments as in real scenes, we also add a spot light to each floor map to ensure its visibility in dark scenes.

For movement, we have compared the functions of teleportation and character control. In piloting, we found that free movement by character control, under our simulations of fires and smokes, was more likely to cause motion sickness especially for participants without VR or gaming experiences. Therefore, we only allow teleportation for movement, but participants can teleport to any location inside and outside of the building.

For SAR tasks, we add animated persons (targets) that the participants need to rescue at various locations in the building. The rescue interaction is simplified – once the participant walks close to a target, our system identifies the event of collision detection and marks the target as rescued. The person is then automatically removed from the scene.

To assist the user study, we use a button 'Y' on the controller for participants to execute the study. Depending on the time that the button is pressed, our system switches to the first or next trial by automatically loading the scenes with different buildings and fire simulations, and finishes the data recording process after all trials are finished.

Our prototype system is built with Unity and C# and deployed on Oculus Quest and Rift. As described in each system component, we maintain an interactive system speed for all the trials.

5 USER STUDY

With the simulation system, we have performed a user study and we describe the details of the study in this Section.

5.1 Materials

For each of the two independent variables, information level and danger degree, we cover 3 levels and therefore there are in total 9 trials. Specifically, the three danger degrees include an easy degree where only 3 locations are on fire and the visibility inside the building is high, a hard degree where dozens of locations are on fire and the visibility is low (simulating videos from fire departments), and a medium degree in between. The three information levels cover a base level of virtual map with only the building shape, a medium level with the floor plans – static information, and a high level with both static and real-time information of fires, targets and participants. Figures 1 and 5 show several example snapshots with different combinations from the two variables.

To reduce the effects from other factors, we randomize the order of different building models and the fire/smoke locations in each trial. As described in the system component of building construction, all the



Fig. 2. Example building models used in the study. All our models have the same sizes and styles, but different internal structures, to avoid factors related to the buildings.

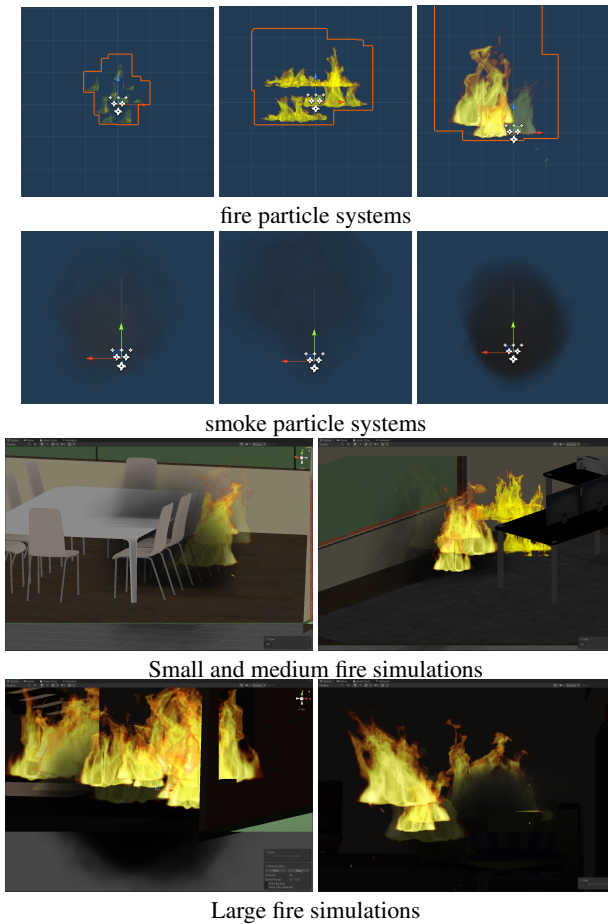
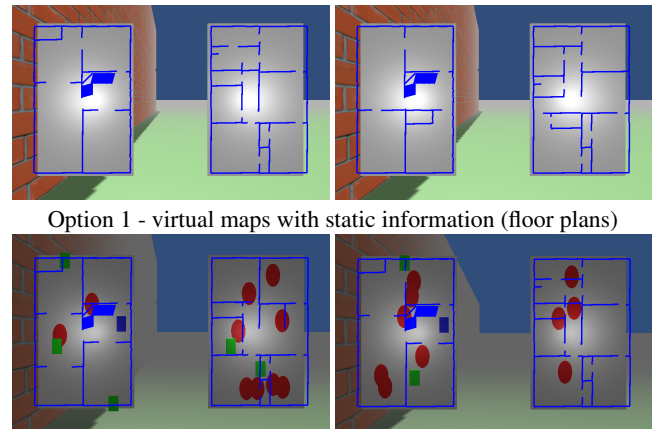


Fig. 3. Simulations of fire scenes are generated automatically with a hierarchy of basic fire and smoke particle systems, based on pre-assigned danger degrees.



Option 1 - virtual maps with static information (floor plans)
Option 2 - virtual maps with both static and real-time information (red circle for fire positions, green box for target positions, and blue box for participant position)

Fig. 4. Virtual maps automatically generated from the environments, simulating data collection with wireless sensing. Besides these two options, we also have a baseline case with no information.

buildings have the same search areas and 2 floors, but different internal structures.

5.2 Participants

Participants ($N = 9$) were male (7) and female (2) college students and faculty members between the ages of 20 - 50 years (the average age was 32). Four were computer science majors and five are non-CS majors. None of participants had previous experience as first responders.

5.3 Procedure and Tasks

The tasks for all the trials are the same – SAR in a building on fire. The participants are informed that there are 5 targets to be rescued in each trial, and they should try to rescue all 5 targets unless they feel their own lives are in danger.

Before the study, all participants first took a practice session in a 2-floor building similar to the ones used in the trials. They were asked to practice the teleport, rescue, and map functions of the system. There was no time limit on the practice session, and participants decided when they were ready.

During the study, we assigned the danger degrees to change from easy to hard. Since none of the participants had previous experiences as first responders, this order was thought to help participants get familiar

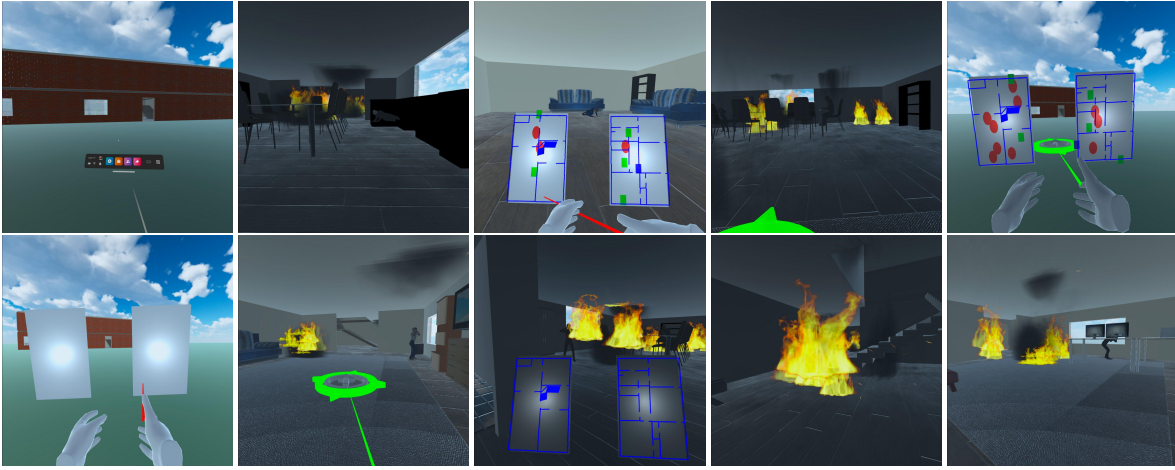


Fig. 5. Example snapshots taken from Oculus Quest show different danger degrees and information levels of our trials.

with SAR tasks in fire scenes and avoid panic when faced with the hard danger degree, which might be overwhelming for some participants if came first.

The order of the information in the virtual maps was randomized, each danger degree covered each of the 3 information levels once and only once. The random ordering minimized carry over effects of the visualization experienced on user performance across trials.

After the study, the participants were asked to leave comments and suggestions freely. We summarize the results together with our data analysis and discuss the suggestions from participants in Section 5.

5.4 Data Collection

Our VR system automatically records the following data for every frame of rendering, around 20 records per second.

- Status of the system, including trial number, target status (rescued or not), map status (being shown or hidden by participants).
- Status of the participant, including 3D location of participants, view direction, and 3D locations of left and right hands.
- Time stamp of the record.

6 DATA ANALYSIS AND RESULTS

Since our user study is designed based on analysis of user behaviors under different conditions of the SAR tasks, we start our data analysis from a set of basic metrics for quantifying external user behaviors. We also explore the correlations among different types of user behaviors and use them to reflect on both factors of information level and danger degree. At the end, we summarize the results based on our hypothesis and discuss the limitations and potential improvements.

6.1 Characterize User Behaviors

We summarize the user behaviors that are useful to and identifiable from our user study, since our participants have diverse technology backgrounds related to VR, gaming and visualization, and preferences on performing SAR tasks. To differentiate these behaviors, we divide them into the following two categories, summarizing factors related to performance and external factors about the physical movements and interactions.

The first category is the performance of SAR tasks, which can be measured directly by the results or indirectly by the statistics of user behaviors.

- Result of SAR task – Measured by the number of rescued persons or ratio over the total number of targets.
- Duration of SAR task – Measured by the time stamps from the start of a trial and the end, which is determined by participants.

- Navigation efficiency – Measured by the ratio of the distance a participant has moved and the distance between the starting position and the rescued target.

The second category is the physical behaviors that are involved in our study. These metrics are computed for each time stamp throughout the trials. First, locomotion is the dominant factor during SAR, therefore we summarize several metrics to describe the related behaviors, including the teleportation, moving speed, and repeated distance. The locomotion behaviors may reflect the backgrounds of participants on VR and gaming, and our data analysis in the next section shows that they play an important role on the performances and even the strategies of SAR tasks. Second, we also measure the frequency of view rotations and hand movements, as they are two typical physical behaviors to reveal complex internal behaviors. Third, we include the factor of map status from our simulation system, which records if participants choose to show the virtual maps or not. The higher frequencies of using virtual maps or not (free navigation) suggests different SAR strategies of participants.

- Average distance of teleportation – The teleport function is a common operation for 3D gaming, and it may suggest a locomotion feature of participants and if the participant is familiar of 3D operations in VR.
- Frequency of teleportation – Similar to above.
- Repeated distance – Measured by the similarity of continuous movement to identify if a participant repeatedly visits similar locations back and forth.
- Moving speed – Measured by the changes of 3D locations, similar purpose to above.
- Frequency of view rotation – Measured by differences of continuous view angles.
- Frequency of hand movements – Measured by the 3D locations of left and right hands.
- Frequency of showing maps – Recorded by the system, suggesting the preference of a participant between using virtual maps and free navigation.

Figure 6 illustrates the statistics of 8 factors from our study. We can clearly identify different groups from participants, e.g. user I is very good at majority metrics and user A is not familiar of VR/gaming (confirmed by the post interview). The metrics suggest sub-groups of participants that can guide the interpretation of user behaviors.

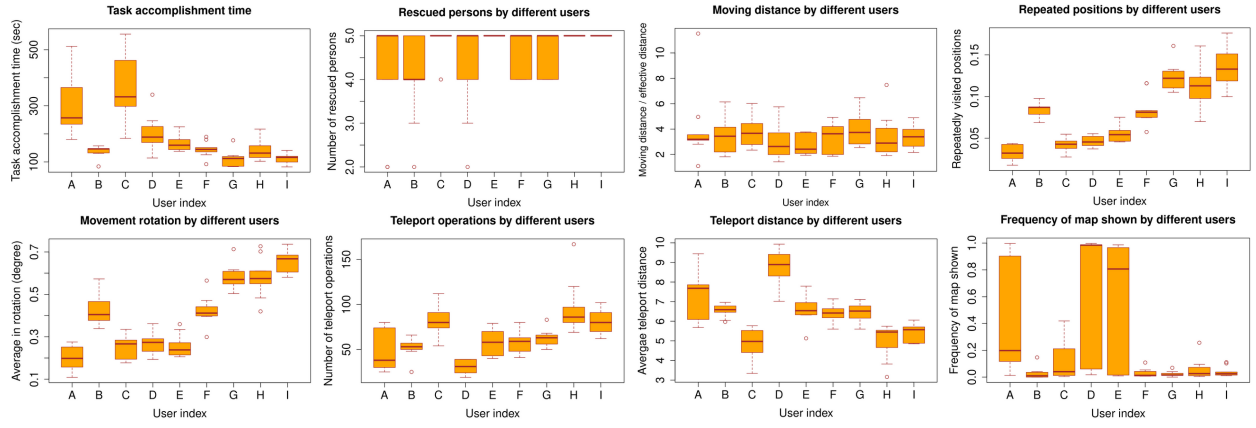


Fig. 6. The metrics of basic behaviors for characterizing user profiles. They are combined in our data analysis to explain different behaviors and explore behavior correlations.

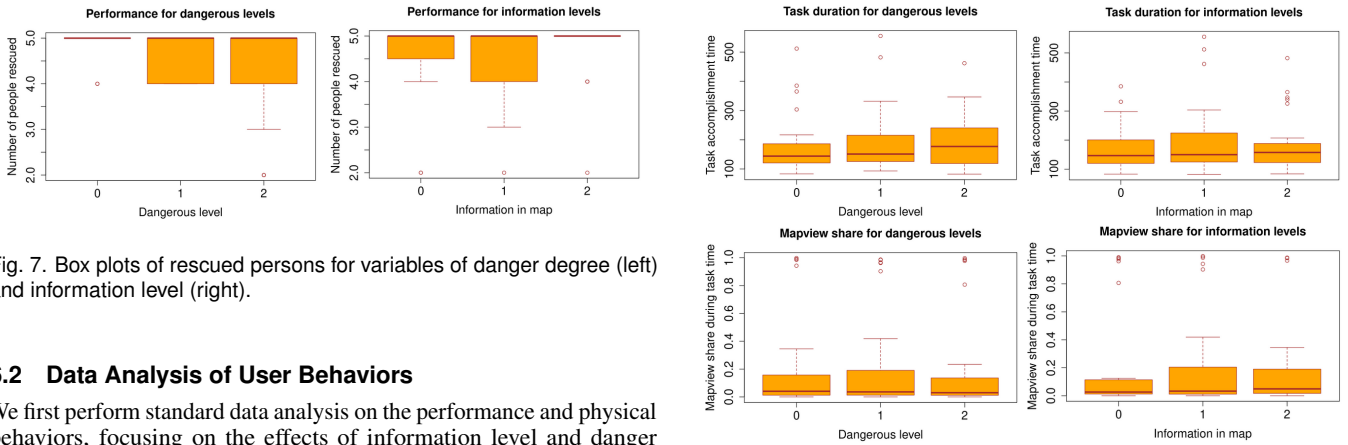


Fig. 7. Box plots of rescued persons for variables of danger degree (left) and information level (right).

6.2 Data Analysis of User Behaviors

We first perform standard data analysis on the performance and physical behaviors, focusing on the effects of information level and danger degree from different aspects of user performance.

As the average numbers of rescued people shown in Figure 7, all the average aggregated numbers are above 4.5 out of 5, indicating that majority of participants have finished the tasks successfully. We use the scale of 0, 1, 2 to represent the easy, medium, hard degrees of danger. For the variable of danger degree, we summarize the data from all the trials with the same danger degree but different information level. As expected, the rescue numbers drop when the danger level increases. All participants have performed very well for the least dangerous level. We find the two worst performances from all participants are both from the most dangerous level, which is the main reason for the low aggregated result. Among the participants, 6 out of 9 users still achieved good results. The remaining 3 users only rescued half of the targets, and they all reported low level of comfort with dangerous situations in VR.

The rescue results for the information level are mixed. The scale of 0, 1, 2 is used to represent the three information level - maps with the building shapes, maps with floorplans, maps with all information. As shown in Figure 7 (right), the level 2 receives the highest score, and the level 1 receives the lowest. The level 2 is shown to be statistically significant better, while the levels 0 and 1 are not. It suggests that the level 1 with only the floor map is often not helpful or attractive for participants since it does not show the real-time location of the participant. The participants still need to identify their locations based on the structural properties such as doors or windows. The key differences between levels 1 and 2 are the real-time locations of participants, fires, and rescued persons, which affect SAR results significantly.

The task completion duration varies from about 20 minutes to 1 hour, shown in Figure 8. For the variable of danger degree, the average completion time increases slightly. This is consistent with our design, as the fires and smokes with higher danger degrees are more severe, making the SAR tasks more challenging to complete. The effect of danger on completion durations may be tempered by the order of trials,

Fig. 8. The completion times and status of maps.

since we always start with the lowest danger degrees. Participants may get more familiar with the SAR tasks for higher degrees and be able to complete the tasks faster compared to other ordering of trials.

The completion time is also related to the decision making process of participants – people tend to act quickly under dangerous situations for both self-protection and safety of targets [12]. The slight drop of completion times for the most dangerous level is likely to be caused by some participants ending the trials before rescuing all targets (some participants save only half of the targets). From our post interview with participants, there are two possible reasons – either they could not find or reach the remaining targets under the dangerous situations, or they felt that their own lives were in danger so they had to leave.

We further combined the factors of information level and the durations that the maps are chosen to be visible. As Figure 8 (second row, right) shows, the average completion time increases slightly, but not statistically significant. This result is consistent with the fact that the increase of information level takes more time for participants to digest. The results of map viewing time increase obviously for the information level 1 (0.28) and 2 (0.33), compared to the level 0 (0.025). It is clear that participants tended to use information when available, and the use of virtual maps only increases the completion times slightly.

6.3 Connecting Different User Behaviors

Based on the previous results, we also explore the connections among different types of user behaviors. We summarize our results from the following aspects of performance and strategy.

Performance and Locomotion Behaviors. From our results, we can identify the dependency of SAR performances on the locomotion

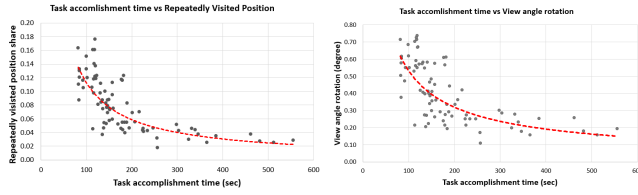


Fig. 9. The correspondence of repeated distance and view rotation with the completion time.

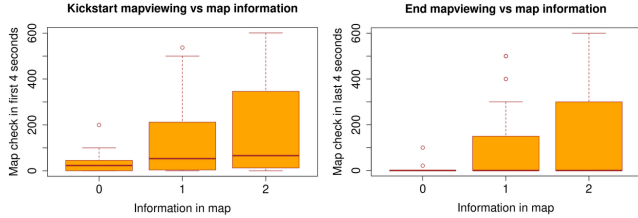


Fig. 10. Differences in map viewing at different stages of SAR.

behaviors. First, participants with better locomotion records, including large teleportation distances and faster moving speed, generally achieve better performance. Their completion times increase much less and their performance records are much better under dangerous situations than other participants. Figure 9 shows the dependency of the completion time on two metrics, repeated distance and view rotation, respectively. The fitting curves show that they are inversely proportional, indicating that these two behaviors are plausible factors for automatic performance prediction.

SAR Strategies and User Behaviors. While strategies are high-level user behaviors, we perform interactive exploration to show that they can be learned from detailed behavior records. The results can be useful in addition to general strategies and demonstrate their advantages on specific use cases. The metrics about the teleport functions, rotations, and repeatedly visited positions throughout the trials demonstrate different strategies – some participants (G, H, and I) with good gaming backgrounds looked around frequently. At the same time, they seldom referred to the map, which led them to visit the same locations for multiple times to double check the progress. Another type of participants (A, D, and E) depended heavily on the map to guide their movement. They avoided unnecessary rotation or duplicate visits to the same locations to improve their SAR efficiency.

The accuracy of a virtual map becomes an interesting topic to explore. When the virtual maps did not match the environment perfectly, some participants chose to not use the map completely, while other participants still tried to get useful information out of the map, reflected by frequent view switches between the map and environment. There were cases when targets were hidden in the dark during the most dangerous levels. In these cases, the majority participants who rescued these targets have the map shown frequently.

We focus data analysis on different stages of SAR tasks. Specifically, we perform similar data analysis for the phases when each SAR task starts and ends. We have found obvious differences on the use of virtual maps. As shown in Figure 10, some participants check out the maps right after a new task starts, and this number increases as more information is provided in the map. The trend is similar for the ending phase. Among the 3 participants who used maps frequently, 2 of them (C 2.98, D 2.76, and average is 3.44) achieve the best navigation efficiency.

6.4 Summary of Results

Related to our hypotheses for the study, we summarize our results as follows.

H1. Our results confirm this hypothesis that several types of behaviors, including moving, rotation, interaction, and number of rescued people, are all affected by the level of danger of the task. We also

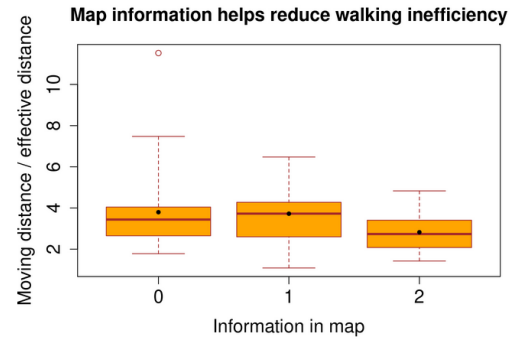


Fig. 11. Real-time information reduces walking inefficiency in VR with the lowest moved distances.

show the correlations between several pairs of behaviors, e.g. inverse relationships between completion time with repeated distance and view rotation (Figure 9).

H2. Our results confirm this hypothesis that virtual maps are helpful for SAR tasks. There are statistically significant differences between the number of people rescued and information level/danger degree (Figure 7). The real-time information (information level 2 with average 2.82) is the mostly effective option (Figure 11). The static information (information level 1 with average 3.79) is found to be comparable to the basic information (information level 0 with average 3.72).

H3. Our results are consistent with this hypothesis that real-time information is more likely to affect behaviors of participants during the most dangerous situations. We observe “outlier” behaviors, such as not completing the SAR tasks, are more frequent on the most dangerous level. The information levels 1 and 2, if the real-time locations are included, affect SAR results as well (Figure 7).

7 CONCLUSION AND FUTURE WORK

In this work, we study the effects of real-time information and immersive maps on user behaviors during SAR tasks in VR simulations. We have developed a VR training system with automatic fire simulations to control danger degrees of the environments and adjust information levels of virtual maps. We perform quantitative data analysis with a diverse set of behavior records from our simulation system. We have also explored the relationships among different types of behaviors, and discussed the strategies and preferences of participants. Our results reveal the behavior differences among the participants and confirm our hypothesis that real-time information is helpful to SAR tasks. The results also suggest useful information for the design of intelligent training systems from the aspects of interface design based on external physical behaviors.

In this simulation system, we mainly use visual effects of fire simulations to control the danger degrees of SAR tasks. We are interested in adding sound effects of fires and persons for a more complete VR experience. We are also interested in analyzing additional internal human behaviors during the SAR tasks with the 3D information of the environment, especially the strategies to handle dangerous situations, so that we can design different types of virtual maps and adjust the contents automatically according to the situations and needs of users. At the end, we plan to use our behavior analysis results to design a machine learning model to capture the profiles of behaviors and generate adaptive information to suit the user needs and preferences for the best performances.

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