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A Comparative Analysis of Four Navigation Aids on User Performance in Single User Virtual Environment

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Abstract

In virtual environments (VEs), whether collaborative or single-user, numerous interaction strategies have been developed to facilitate task execution. However, due to the diverse nature of tasks and applications in VEs, these interaction techniques often vary significantly and lack standardization. Consequently, there are no universally accepted or well-organized interaction techniques that can be effectively applied across all VEs. This limitation becomes especially evident in Single User Virtual Environments (SUVEs), where effective communication modalities are essential for task execution. Despite their importance, there has been limited research on systematically comparing communication modalities such as arrows-casting, textual guidance, audio cues, and 3D Map-Liner (3DML) to assess their impact on user performance during task completion in SUVEs. This study aims to address the above gap by evaluating user performance with different communication modalities in SUVEs. Specifically, it compares the effectiveness of arrows-casting, textual guidance, audio cues, and 3DML for task execution in a VE designed for assembly tasks. A virtual environment was developed where the Dijkstra algorithm was implemented to calculate the shortest distance, ensuring optimized navigation. To conduct the study, 20 undergraduate students were selected to test these navigational aids. The results highlight that arrows-casting demonstrated the highest user performance among the tested modalities, while audio navigation aids showed the lowest performance. The findings of this study provide valuable insights into the design and selection of communication modalities in SUVEs. The superior performance of arrows-casting suggests that visual navigation aids are particularly effective in guiding users during task execution. On the other hand, the low performance of audio navigation aids indicates the need for further refinement and integration of audio cues in VEs. These results can inform the development of more efficient and user-friendly navigation aids, contributing to improved task completion and overall user experience in VEs. Additionally, the methodology and findings can serve as a foundation for future research on interaction techniques and task optimization in diverse virtual environments.

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1 Introduction

Virtual Reality (VR) is a digitally generated environment that promptly response to user input, representing real world interactions. A Virtual environment (VE) refers to computer-simulated 3D world. The VR Technology finds applications in diverse areas like social and environmental sustainability, training, teaching and training for education perspective, Road-Crossing sustainability in fleeting moments of space and time, rehabilitation, aeronautics assembly, surgery, aviation, entertainment, computer aided design in engineering, Google streetview in an online wayfinding and military training [1–8]. Various navigation, selection, and manipulation techniques and devices are used for interaction in VR. In spatial tasks involving navigation, the awareness modality are used, which decrease the mental load while working in the VR [9]. Navigational modalities in virtual reality are appealing for interaction within virtual environments, as they offer valuable support for task execution in a straightforward manner. Recent studies indicate that cognitive aids can reduce the mental load on users, but they may also reduce active exploration, potentially impacting performance in VE.

In SUVE different interaction modalities for navigation are used. Like in the real world environment interaction, in virtual environment the users change and organize their position, co-presence, and sense of presence according to their behaviors in there surrounding area to enhance their interaction [10]. In SUVE, different guidelines such as visual (Arrows, Lighting, Map, Arrows-casting etc.), acoustics, landmarks are used to navigate in the environment. The awareness and communications aids like 3 Dimensional Map with Linear (3DML), arrows-casting, Acoustic and Visual are used for navigation in VE for the purpose of increasing user's performance. 3DML serves as a navigational tool by drawing a line from the user's starting point to their target location on a map, simplifying navigation within a virtual environment. Also the new navigational modality i.e. arrows-casting is used to make the navigation easy for user in the VE. In the arrows-casting aid of navigation a clear red path along with arrows for direction is shown to the users of the environments from the source to destination [11–13]. Also the navigational aids i.e. textual and audio are also used for providing assistance in the VE to enhance the users' performance in VE. There also exist a number of other approaches and guidelines to assist users in the VE and CVE like you-are-here maps, the process of mapping landmarks, utilizing mobile navigation tools, and employing other orientation devices [14].

In this paper the effect of 3DML, audio, arrows-casting and along with the textual navigation aids on user performance in SUVE is evaluated and analyzed quantitatively to check the completion time and reported the number of errors of making the combination of word "UNIVERSITY" for assembly in SUVE. This research seeks a deeper understanding of how these modalities improve user performance in VE and to conclude the most efficient aids in term of user performance in VE. Two hypotheses are proposed:

- **Hypothesis 1:** The selection of interaction aids influences user performance in SUVE.
- **Hypothesis 2:** From the given navigational aids in SUVE i.e. (Textual, 3DML, Arrows-casting, and audio) which one increase user performance?

The related Work/ Background Studies are discussed in section 2 of the paper. Section 3 presents the experimentation and analysis conducted to assess users' evaluated in terms of performance and realism based on various navigation aids, including audio, 3DML, text, and arrow casting. Section 4 discusses the conclusion and outlines future work.

2 Background Studies

Navigation in VEs includes exploring and finding pathways. When a user navigates within a VE, both his body and viewpoint are directed to a specific location in the virtual world. It is harder to explore VEs as compared to exploring a physical world. For instance, gates and doorways are used in physical world to move to a point-of-interest. Users in such a real space measure distances for navigation. However, VE does not impose such restrictions as a user can go to any destination at once from his present location. The user is teleported immediately to desired location only by referencing that location on a map within a VE. Moreover, users exploit peripheral information as references that reduce their cognitive load during navigation in the physical world. In contrary, users have few cues for understanding and exploring the virtual world. Therefore, the user's spatial ability and environment related navigational awareness make navigation hard within VEs[23]. Some of the following Navigational aids are used in VEs.

2.1 Visual Aids

Visual metaphors are key communication tools in VEs. An easily comprehensible communication channel can be established by users with simple visual metaphors for efficient use of VEs. Visual metaphors in VEs provide immediate user responses. Manipulating objects parameters such as orientation, position, color, scale, etc. are used as visual guides in VEs to achieve not only communication objective but also enable users can display their activities and actions to other active peers. Visual aids appear highly effective when used for teaching purposes as these aids help enhance memory retention than other conventional teaching methods [15]. Few navigational aids include maps, arrows, audio, and textual aids which are central features in VEs as par as navigation is concerned. These aids act as assistive tools that enable users to understand and interact with the VE.

2.1.1 Map

Maps provide a top-down view of the virtual space, helping users orient them within the environment and understand the layout. They often show key landmarks and can be interactive, allowing users to plot courses or see their current locations in real time. Maps also assist in spatial reasoning, which can be crucial for tasks that involve navigating complex spaces. Arrows are often used as directional cues that guide users through the virtual space. They can point out the path to an objective or indicate the direction of important locations or items. Arrows can be particularly helpful in instructional or training VEs, where they can lead users through procedures or toward areas that require their attention. They simplify navigation by providing clear visual cues that can be followed with minimal cognitive load. Textual aids, such as labels and instructions, are crucial for clarification and providing information that might not be immediately obvious from the visual and audio information. Text can be used to label areas within the VE or to provide narrative context that guides the user through a storyline or a sequence of tasks. Audio cues can be 3D spatial sounds that help users locate things that are not currently in their field of vision, or narrative instructions that guide users on where to go next. Sounds can also provide environmental context that aids in navigation, such as the sound of water indicating a nearby virtual river. Textual aids contribute to comprehension and retention of information. They can also be instrumental for users with hearing impairments or in situations where audio is not a viable option [16]. The research study proposed by Savino et al., in which the participants had explore actual and virtual spaces by using smartphone-based navigation apps together with paper maps which demonstrates that VR environments represent a suitable alternative to actual testing locations for navigation methods which may lead to better pedestrian navigation systems within VR platforms [17].

Searching in VEs can be accomplished with the help of maps as users are provided survey knowledge which is not available when exploring the VE [18]. Map alignment is a key map design aspect. To accomplish mental rotation tasks, where rotation angle and objects matching time are linearly related, map alignment helps reducing cognitive load while performing object-matching task [19]. More time is consumed when participants match objects in case of no map alignment. A landmark-based map acts as a usual way to navigate and form three-dimensional information [20]. Decision is making such as whether to change direction can be efficiently made with landmarks which eventually lead to minimum exploration errors and faster decision making [21]. A verbal navigation aid based on landmark developed for an urban game environment offered superior spatial learning than mini-map while the proposed landmark-based aid is less effective for navigational purpose than mini-map [22].

2.1.2 Arrows

Arrows as navigational aids guided cars on way to their destinations in a VE [23]. A fixed-screen arrow for navigation assisted mechanics to locate targets within virtual world. In a 3D VE, arrows are employed for path exploration and navigation to reach to a point-of-interest [24].

Directional arrows are a type of arrows which specify direction for users to navigate inside VE as shown in Figure 1 [25]. A user can draw as many directional arrows to find the path and accomplish the task within VE. It is helpful for navigation but increasing the numbers of directional arrows within VE may effects the immersion of VE, hence negatively affects users' performance in VE [26]. To handle this problem the directional arrows must disappears after performing the task.

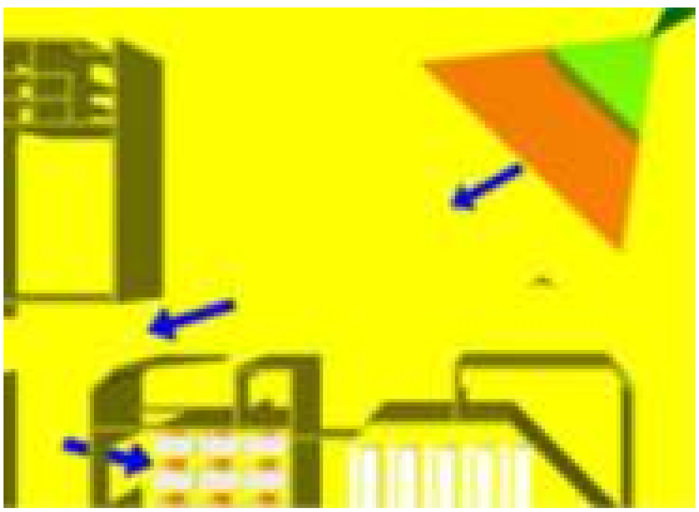

Figure 1. Arrows Based Navigation

2.1.3 Textual Aids

Textual aid is a type of visual aid where textual information is displayed within the user's working environment which help them in navigation. During construction of the building to provide training to the masons, Sampaio et al. [27] developed an environment in which the visual simulation was used which consist of 23 phases. For each stage a textual form was developed containing information about the construction of a wall.

The VLab developed by Sabagh et al. [28] is a web-based virtual learning environment designed for chemistry students. The students are facilitated with the help of chat window for sending text messages including queries, explanation of the task, and coordination and communication.

This research study of examining virtual semantic landmarks in Mixed Reality-based indoor environments developed both the system and conducted an essential user study to determine how these landmarks affect spatial knowledge acquisition during navigation. The user study incorporated the Microsoft HoloLens untethered device for showing iconic holograms representing semantic landmarks. Sketch maps together with landmark positioning assignments and interviews were utilized in the user study to both evaluate acquired spatial knowledge and gather recommendations for MR navigation interface advance [29].

In the skill integrated project [30], the users of the environments were trained about the task and sub task with visual aids consisting of multiple graphical windows that show all steps of the process involved. Signals in the form of textual aids were used in multimedia application as mention in Albus, Vogt et al. [31], which investigates the learning effects based on the outcomes of the users working in the environment.

2.2 Audio

Audio can enhance immersion and make the experience more engaging. Moreover, for users who may have visual impairments, audio can be a primary means of navigation. Audio-based aid in VEs enables users to accomplish tasks in shorter time when evaluated against textual aid [32]. This form of cues is important for teleconferences and other online social meetings. When a tracking system renders 3D audio signals as per users' positions, high emersion and real feeling can be achieved within the VE. Researchers have extensively researched the function that audio cues perform in guiding VR navigation. Users successfully navigate virtual spaces using sounds as spatial information during the evaluation described in "Soundspace VR: Spatial Navigation Using Sound in Virtual Reality." The findings indicate that adding audio cues as a method to improve spatial perception and explore virtual spaces more efficiently within virtual reality scenarios [33, 34].

An application like Skype or phone call audio is used as a mean for the exchange of information. Talk is virtually represented by "mouth". The mouth opens when users speech reached to some certain value i.e. amplitude threshold.

Mohammed Nour Al- Halabi used audio modality for the evaluation and efficiency of Audio-visual distraction techniques, such as "audio-visual (AV) eyeglasses" and "virtual reality (VR) box or a tablet," are used to investigate anxiety in pediatric patients. VirtuNav [35] is a 3 Dimensional Computerized Model that provides a haptic-enabled Virtual Reality (VR) environment with audio facility, which help visual impaired peoples to explore indoor location like hospital or class rooms.

The study proposed by Semibati et al., determined whether audio-visual route assistance would reverse the adverse effects of visual-only or auditory-only GPS navigation systems. The research evidence proves that merged audio together with video indicators help improve spatial memory alongside navigation performance throughout immersive VR systems [36, 37]

3 Experimentation

For experimental results generation the four cognitive aids i.e. Textual, Audio, 3DML and Arrows-casting were used for navigation to check and compared users' performance in a SUVE.

3.1 Environment

A virtual environment was created where various cube-shaped objects were randomly positioned in different rooms. Users' task was to locate these objects within the virtual environment and bring them to a designated central room for assembling the word "UNIVERSITY", as illustrated in Figure 2. Four navigational aids were employed to complete the assembly task.

- C1 : 3 Dimension Map with Linear (3DML)
- C2 : Audio
- C3 : Textual
- C4 : Arrows casting

Figure 2. Single user virtual environment used for evaluation

The weighted graph of the VE having different object to complete the assembly task is shown in Figure 3. Objects (letter) are denoted by the circles lying in different rooms, the distance is presented in positive numerical values, and CR is the place where the assembly task is completed called central room. START represents the user's initial position from which navigation begins in the virtual environment.

In weight of the edges are also mentioned in Figure 3.

To represent the finite graph (Figure 3) the adjacency matrix is used. The adjacent vertices are shown in positive numerical value and non-adjacent vertices are zero.

In the virtual environment as depicted in figure 3 many paths exist to pick object. For example their exist two paths from START to object V in the environment i.e.

Path 1:

$$\text{START} \rightarrow A \rightarrow B \rightarrow C \rightarrow F \rightarrow G \rightarrow V$$

Path 2:

$$\text{START} \rightarrow O \rightarrow M \rightarrow K \rightarrow J \rightarrow H \rightarrow G \rightarrow V$$

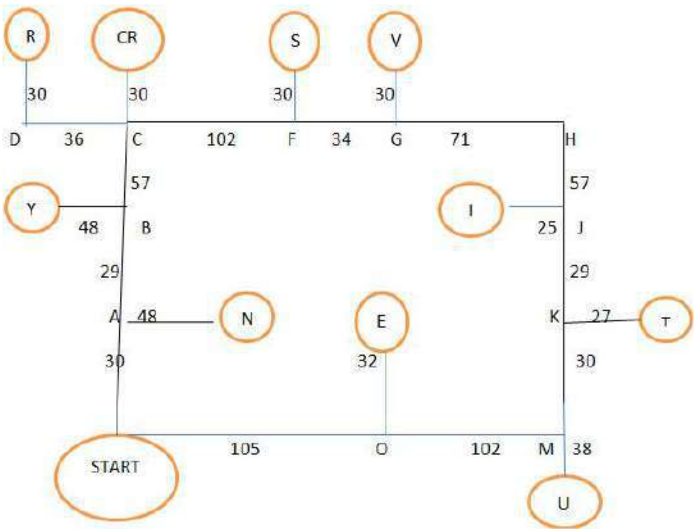

Figure 3. VE objects and their weights

Accordingly, other objects paths in figure 3 can be calculated between any two vertices. Path matrix give us help of finding the shortest route from the source to destination with the help of well-known single-source shortest path algorithm, such as Dijkstra's. Using Dijkstra's algorithm with the four given parameters, the optimal path is determined for cognitive aids from C1 to C4 for the user to complete the assembly task. For example, to make the "UNIVERSITY" word from the randomly placed object inside rooms in the virtual environment., After picking up the object "U", the user will transport it to the central room utilizing one of the cognitive aids (C1 to C4). These aids signal when the object 'U' has been picked up and assist to locate the next object, "N". The same procedure is followed for the remaining objects to complete the assembly task of forming the word "UNIVERSITY".

3.2 Experimental Structure

For the experimentation process a virtual environment wad developed and installed on laptop having core i7 CPU, 8GB RAM and having a graphic card. For interaction with the synthetic object in virtual environment traditional input device i.e. Keyboard was used. Four navigational aids mentioned in C1, C2, C3 and C4 were used. The environment was developed utilizing C++ language and also the OpenGL libraries were utilized for the coding. For acoustic communication in the VE the "Sound Tap Audio Streaming Recorder" software was also ustilized. Dijkstra's algorithm was employed to determine the shortest path from a single source i.e. from the users' current position to their target position in VE under each condition. The Dijkstra's algorithms shortest route calculation was made based on the path matrix. For the purpose of conducting and evaluating the system developed for assembling the word "UNIVERSITY", forty different undergraduate students were selected. From given sample of 40 students, we excluded fifteen students, whom were not familiar with the basic knowledge of the operating computer system. Also five (5) more were excluded due to their visual impairment. The remaining twenty (20) students having their ages from 21 to 30 whom were keenly interested in the experimental process were finally selected. A brief overview about the VE and the task was given to the student. To make the users familiar with the environments i.e. objects and four navigational aids used in the system, a pre-trial was performed.

To make the users familiar with the environments i.e. objects and four navigational aids used in the system, a pre-trial was performed. The duration taken to complete the task and the mistakes made by students during the process experimental process were noted. Also for students' feedback during the experimental process, a post questionnaire was distributed.

3.3 Task

Different Objects randomly placed in the virtual constructed environment in separated rooms. The students searched the object and brought them to the central room in the VE To complete the assembly of the word "UNIVERSITY", the given four conditions were used for navigation accordingly based on Dijkstra's algorithm. The sequence of the navigation aids i.e. from C1 to C4 was changed to the students during the experimental process. The configurations of the given condition for navigation were: $C2 - C3 - C4 - C1$, $C1 - C2 - C3 - C4$, $C2 - C1 - C3 - C4$, and $C2 - C3 - C1 - C4$ for C1. Similarly for the remaining followed the same procedures.

3.4 Navigating Mechanism

3.4.1 3 Dimensional Map with Linear Based Navigation

To conduct the experiment to check the user performance for assembling the word "UNIVERSITY" using a cognitive navigational aid of 3 Dimensional Map with Linear (3DML) mechanism, A 3D map is created using C++ and the OpenGL libraries. (shown in Figure 4). In this approach when the user start the experiment and the environment is displayed to him/her then the “U” object start blinking in the map and in themap a line is drawn from his/her current position to the object “U” in map which shows the user that object “U” should be picked up. In 3DML the line drawn based on Dijikstra’s algorithm of using the path matrix. When the user pick up the object “U” in the VE then in 3DML modality shows a line which reached to the destination such as central room in the VE. The users will pick up the object to the (CR) central room. The next object i.e. of making the word “UNIVERSITY” the object ’N’ starts blinking in the 3DML. A line is drawn from the user’s current position to object "N" based on Dijkstra’s algorithm. Once object "N" is picked up, object "I" starts blinking, and the same procedure is followed for picking and releasing each object. This process is repeated for all objects in the virtual environment (VE) until the assembly task is completed of making the word “UNIVERSITY” is completed.

Figure 4. 3DML navigation aid

3.4.2 Audio Based Navigation

In the cognitive navigational modality of audio, the participant in the experimental process move in the virtual environment to search the objects to complete the word "UNIVERSITY" assembly, users search for the starting object "U". While navigating in the virtual environment (VE), audio aids are used to guide them. Messages such as "See Right", "See Left", "Go Forward", and "See Behind" are communicated to assist in locating and picking up the object "U." via audio aid (see Figure 5). When the users picked up the object “U” then he/she start navigation towards central room. Whenever he/she release the object in central room then via audio aid to search the next object “N” is communicated to him/her. The same process is used for the rest of object picking and releasing until the completion of the word “UNIVERSITY”.

Figure 5. Audio based navigation

3.4.3 Textual Based Navigation

In the cognitive navigational modality of textual, the participant in the experimental process move in the virtual environment to search the objects and complete the word “UNIVERSITY” assembly. The users search the starting object ’U’. During navigating in the VE the textual aid is used to guide him/her in the environment. The messages in the form “See Left”, “see behind”, “see Right”, and “Go Front” for picking the object ’U’ is communicated via textual aid (see Figure 6). When the users picked up the object “U” then he/she start navigation towards central room. Whenever he/she release the object in central room then via textual aid to search the next object “N” is communicated to him/her. The same process is used for the rest of object picking and releasing until the completion “UNIVERSITY” word assembly.

3.4.4 Arrows-Casting Based Navigation

In the cognitive navigational modality of arrows-casting, the participant in the experimental process move in the virtual environment to search the objects to complete word “UNIVERSITY” assembly. During

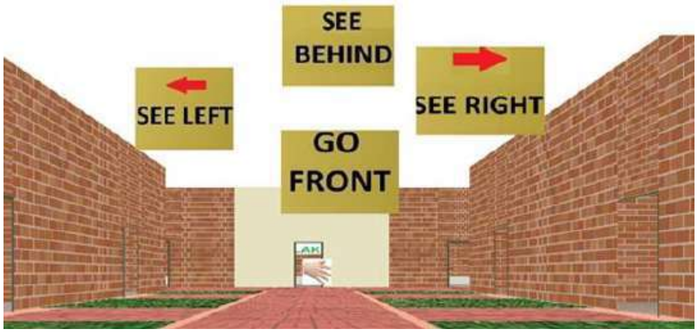

Figure 6. Textual navigation aid

navigating in the VE to search and pick the object "U" a red path with arrow is shown to user starting from their current position towards their destination i.e. object "U". Whenever users of the experiment picked up object "U" then a red path with arrow is displayed to him/her up to central room which shows that take the object to Central Room (CR). When users release object "U" in the central room, a red path with arrows is displayed leading to the next object, "N." Using the arrows-casting navigation aid, users navigate through the environment to reach object "N". After picking up object "N," users bring it to the central room, and the process continues until the assembly of "UNIVERSITY" is completed. This type of navigation in the virtual environment (VE) is based on arrows-casting, as illustrated in Figure 7.

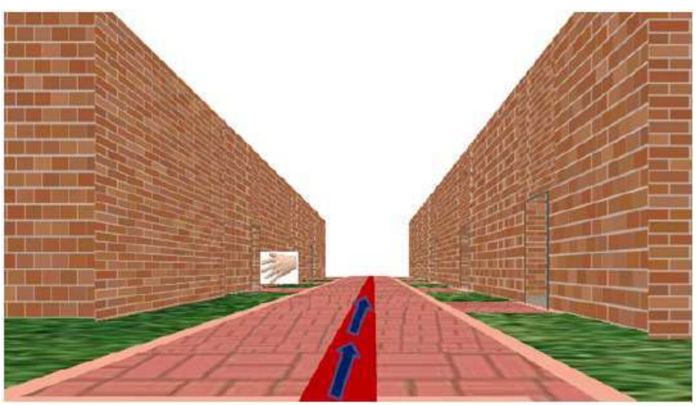

Figure 7. Arrows-casting based navigation

3.5 Experimental Results and Analysis

3.5.1 Task Completion Time Analysis

Task completion time is an important measure for calculating users' efficiency in VE. Using assembly task, the performance of users in term of task completion time was checked with four navigational aids i.e. C1 to C4 in SUVE. The repeated ANNOVA statistical test was performed to compared the results and calculate p value for each navigation aids in SUVE. The results shows significant difference i.e. ($F (3, 19) = 3.56$, $p = 0.038$ ($p < 0.05$) for the four navigational aids in SUVE. The navigational aid C1 (3DML) has 828 sec as mean task completion time with standard deviations (STD) of 53.72. Similarly the navigational aids C2(Audio) , C3 (Textual) and C4 (Arrow-casting) has 990.48 seconds with standard deviation of 70.51, 1044.73 seconds with TSD of 70.76 and 519.3 of 62.59 STD respectively. Figure 8 shows the mean task completion time and their standard derivation value for each navigational aid. The final experimental results shows that C4 (Arrows-casting) in term of task completion time comparatively enhance users' performance as shown in Figure 8. Also from the "Tukey-Kramer post hoc analysis" results shows that the task completion time of the navigational aids i.e. the C2 and C3 (mean = 990.4833333 seconds, mean= 1044.733333) time and ($p = 0.004$), and C1 (mean = 519.3, mean = 828) ($p = 0.004$), C1 and C2 conditions (mean = 828, mean = 990.4833333) ($p = 0.562$), C1 and C3 (mean = 828, mean = 1044.733333) ($p = 0.916$), C4 and C2 (mean = 519.3, mean = 990.4833333) ($p = 0.291$), C4 and C3 (mean = 519.3, mean = 1044.733333) ($p = 0.526$) are significantly low.

3.5.2 Errors Analysis

In VE, picking wrong object or placing the object in wrong position by the users is counted as errors. While conducted the experiment in VE the errors of the users were counted in all four conditions such as C1 to C4. The results analysis of Global error are summarized as shown in Figure 9. Using the C1 (3DML) users has the average of 0.54 errors and STD of 0.38. Similarly for C2 (audio), the users made 1.58 errors having STD of 0.58. In C3 (Textual), users made 1.18 errors with standard deviation of 0.44 in SUVE. In C4

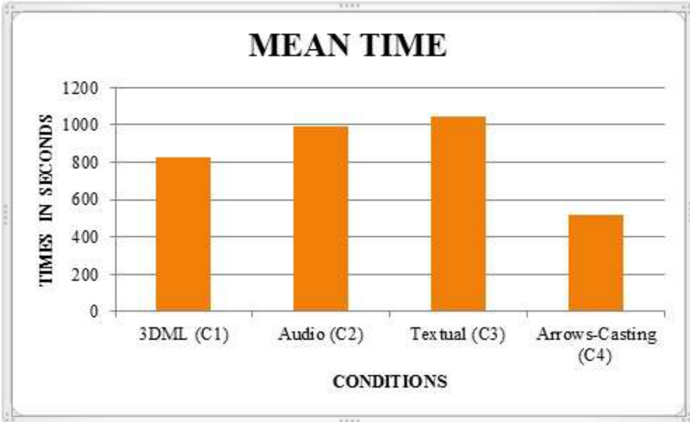

Figure 8. Task completion time

(Arrows-casting) modality the users made 1.10 errors with standard deviation of 0.47 in performing the assembly task. The results show that C1 has better in term of number of errors made by the users in SUVE which has fewer errors than C2, C3 and C4. In addition the numbers of errors are less in arrows-casting, textual and audio respectively. The "Tukey-Kramer post hoc" analysis shows that errors in C1 and C2 ($p = 0.786$), C1 and C3 ($p = 0.95$), C1 and C4 ($p = 0.965$), C2 and C3 ($p = 0.975$), C2 and C4 ($p = 0.935$), C3 and C4 ($p = 0.99$) are significantly low in assembly task completion in SUVE.

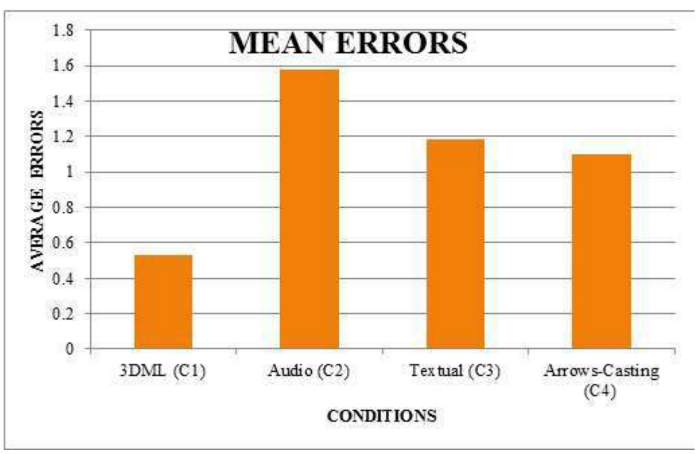

Figure 9. Errors in task completion time

3.5.3 Subjective Assessment

In this section responses collected via the following questionnaire (see table 3) are analyzed. The user choose option from C1 = 3DML, C2 = Audio, C3 = Textual, C4 = Arrows – Casting.

Table 1. Questionnaire-based survey

S.No	QUESTIONS
1	Which navigational aids mentioned from C1 to C4 affect more on human efficiency and behavior in terms of users' performance in a SUVE?
2	During the task execution, which navigation modality do you find the most appropriate?
3	In which conditions (C1 to C4) is task completion difficult?
4	On the basis of user precedence in terms of task completion in VE, which cognitive navigational aids (C1 to C4) are helpful and useful?
5	Organize the navigation modalities in terms of your involvement during task execution in VE.
6	In terms of motivation during the experiment, which navigation modality do you prefer more?

The users feedback based on the Table 1 questioners are analyzed and shown in Table 2.

Table 2. Statistical assessment of users' feedback

Q. No	3DML	Audio	Textual	Arrows-Casting
1	30%	11%	19%	40%
2	44%	8%	15%	33%
3	10%	55%	30%	5%
4	31%	12%	13%	44%
5	40%	10%	20%	30%
6	55%	8%	18%	19%

The choice of users' feedback for question 1 in term of users efficiency and behaviors is 40 % for arrows-casting. The choice of users for question 2, to find the most appropriate navigational aids is 3DML (44%). As far as Question 3 is concerned, the task completion is most difficult in audio navigational aid which is observed by 55% users. In response to question 4 the helpful and useful navigational aids is arrows-casting (44%) suggested by the users in questioners survey. 3DML navigational aid is preferred by most of the users i.e. 40% as compared to other navigational aids while recording their response to the involvement of users in experimental activity as specified in question 5. Similarly for in response to question 6 to measure the effectiveness of motivational level 3DML is preferred 55% of the users.

To check the specified six parameters (i.e. Friendliness, Intuitiveness, perturbation, efficiency, stress and fatigue) in VE, users were given a questionnaire with subjective rate the four aids i.e. C1 to C4 in Likert scale of the 7-Points collected from users are shown in Table 3.

Table 3. Mean scores and p-values

Q	3DML	Audio	Textual	Arrows-Casting
Perturbation	6	4.8	5.1	6.4
	P = 0.0046			
Stress	5.01	3.5	4.1	6.5
	P = 0.0032			
Fatigue	6.45	4.3	5.2	6.7
	P = 0.0054			
Intuitiveness	6.4	6	6.6	6.9
	P = 0.0076			
Efficiency	5.7	4.9	5.22	6.25
	P = 0.0088			
Friendliness	6.82	5.7	6	6.88
	P = 0.02344			

The analysis shows that the users are less perturbing in arrows-casting based aid in SUVE. There values in the likert scale are 6, 4.8, 5.1 and 6.4 for C1 to C4 respectively. As for as "Stress" is concerned while navigating in SUVE, the C2 and C3 were rated more stressed as compared to C1 and C4 aids. Their recorded data in Likert scale were 5.01, 3.5, 4.1 and 6.5 values for C1, C2, C3 and C4 respectively. Moreover, C4 was rated high in the 7-points scale than C1 in stress based subjective ratings. The users become more tiring in C2 and C3 navigational aids as compared

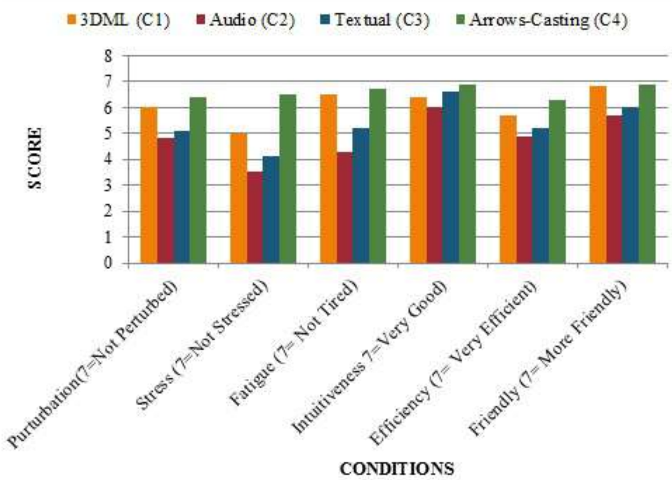

Figure 10. Average results of users feedback: six parameters (i.e. Friendliness, intuitiveness, perturbation, efficiency, stress and fatigue)

to C1 and C4. Their values are 4.3 for C2, 5.2 for C3 6.45 for C1 and 6.7 for C4 navigation. Further, we performed analysis on the subjective feedback collected from the users regarding "Friendliness" "Intuitiveness" and "Efficiency" of navigation aids in SUVE of under 7-points Likert scale, where for "Intuitiveness" 6.4, 6, 6.6 and 6.9 for C1, C2, C3 and C4 respectively. The "Efficiency" scores are 5.7 for 3DML, 4.9 for C2, 5.22 for C3, and 6.25 for C4.

The "Friendliness" ratings for the navigation aids are 6.82 for C1, 5.7 for C2, 6 for C3, and 6.88 for C4. As illustrated in Figure 10, the analysis reveals that C2 and C3 were rated as less user-friendly, less intuitive, and less efficient compared to the other conditions. In contrast, C1 and C4 received higher ratings on this 7-point scale across the six subjective metrics. The subjective ratings — Friendliness, Stress, Perturbation, Efficiency, Fatigue, and Intuitiveness — yielded p-values of 0.02344, 0.0032, 0.0046, 0.0088, 0.0054, and 0.0076 respectively, indicating statistical significance. Based on users' preferences, the most preferred navigation aids for SUVE task completion are C4, C1, C3, and C2 in that order.

4 Conclusion and Future Direction

In this study presents the results of an experimental investigation aimed at assessing the impact of 3D interaction cognitive aids on user performance in a Single User Virtual Environment (SUVE). A SUVE was created to conduct experiments evaluating the effects of cognitive aids—3DML, audio, textual, and arrows-casting—on user performance within a building. We compared the navigation aids C1, C2, C3, and C4 for performing the assembly task of forming the word "UNIVERSITY." The experimental results showed that with C1 and the C4 navigational aids the users' performance were better than C2 and C3 aids in VE. Overall analysis of the results showed that in C4 (arrows-casting) navigation modality to complete the task in VE the users performed better than others modalities i.e. C2 (Audio), C3 (Textual) and C1 (3DML). Also the users of the VE to perform the experiment found that C1 (3DML) navigational modality is more natural than others modalities and it can be combined with them. The final results align with the study's hypotheses: "The choice of 3D interaction aid significantly affects user performance in a SUVE (Hypothesis 1)" and "3DML and arrows-casting are more effective in terms of user performance compared to audio and visual metaphors (Hypothesis 2)." In the future, these aids—3DML, textual, arrows-casting, and audio, will be combined to evaluate users' performance in a Single User Virtual Environment (SUVE). Also their effects on users performance in a VE will be checked when the users switch between theses aids dynamically. The future work shall also consider evaluating the efficiency and easiness of these four navigational aids from user perspective in immersive environment using 3D interfaces.

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6 Compliance with Ethical Standards

6.1 Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

6.2 Ethical approval:

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Author Contributions

Sohail Ghani: Conceptualization, Methodology, Software **Shah Khalid**: Supervision, Data curation, Writing- Original draft preparation. **Aftab Alam**: Supervision, Investigation. **Muhammad Salam**: Reviewing. **Fakhrud Din**: Software Validation. **Nasir Rashid**: Reviewing and Editing

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