Influence of indirect vision and virtual reality training under varying manned/unmanned interfaces in a complex search-and-shoot simulation

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Abstract. In the real-world, manned and unmanned vehicles may be used for a number of applications. Visual technologies like indirect visual display (IVD) and virtual reality (VR) have been used to train operators in both manned and unmanned environments. The main objective of this research was to evaluate the effectiveness of manned and unmanned interfaces in IVD and VR display designs. Using an underwater search-and-shoot scenario, we developed two variations in display designs (IVD and VR) and two variations in type of interface-based training (manned and unmanned). A total of 60 subjects participated in the experiment, where 30 subjects were randomly assigned to simulations in IVD and the rest in VR. In both the simulations, 15 randomly selected participants executed the manned interface first and the remaining 15 executed the unmanned interface first. Results revealed that the subjects performed better in VR compared to IVD, and also performed better when they executed the unmanned interface first. We highlight the implications of our results for training personnel in scenarios involving manned and unmanned operations in IVD and VR interfaces.

Keywords: Virtual Reality · Indirect Visual Displays · Human Factors · Manned interface · Unmanned interface · NASA - TLX

1 Introduction

With the continuous evolution of technology, our capability to sense environments at a distance has grown exponentially over the last two or three decades [1]. Unmanned systems are one contemporary technical instantiation of this evolutionary vector in extending human perception action capabilities [2]. According to [2], the central problem of unmanned system development is not the feasibility and creation of the hardware, but the human factors issues in the assimilation of the relevant sensory inputs, the processing of information pertinent to user specified goals, and the translation of the user's subsequent decisions into effective action [2].

There has been a dramatic surge in the use of unmanned systems in military organizations around the world [3]. This surge has led to human factors research to understand human performance while monitoring and controlling unmanned vehicles [3]. Unmanned systems can be very difficult to control [4]. There are a number of documented human related problems when operating UUVs, including problems with perception, underwater navigation and orientation, interface design and situation awareness [4-6]. Perceptual issues have been long standing problem in unmanned systems, whereby the human operators are removed from the immediate environment. Operator is deprived of sensory cues, but must make navigational and control movements, and mission related decisions on sensor imagery that can lack resolution, color, field of view and depth perception [7]. Situation awareness issues for the human operator when supervising an unmanned underwater system can be far greater than surface and air unmanned systems due to constraints on perception and restricted communications available underwater [8]. Decision making in these situations, are hindered due to impoverished sensory information, attentional resource limits, task, and environmental stressors [2]. Most researchers agree that humans are needed to control or supervise the unmanned system, but what kind of knowledge, skills, and abilities they should possess has not been decided [2]. According to [2], for manned aircrafts, there are pre-selection criteria such as intelligence tests and medical examinations, but there are no pre-selection criteria for unmanned systems whatsoever.

Furthermore, since the past few years, indirect visual displays (IVDs) and virtual reality (VR) have been used as a means of training and assessing individuals in complex and dynamic tasks [10]. Indirect visual displays help in supporting full spectrum, 360-degree local area awareness operations, both remote and immersive [10]. Indirect vision systems were initially designed as tools to support mobility and means to assess and enhance situation awareness of the operator [21]. But due to the presence of three-dimensional objects in the environment, and the absence of localized acoustics detection [21], a technology shift to immersive VR has been recommended by researchers [10,11], especially in training and assessment. According to [10], VR is the use of computer modeling and simulation to enable a person to interact with an artificial three-dimensional visual or other sensory environment. Virtual Reality allows the possibility for the individual to "dive" into the virtual world that allows the individual to build a better mental model of the scene, freely and seamlessly move around the virtual scene, and examine its descriptors from all possible perspectives [11]. Virtual environments are supposed to be more effective than other digital approaches with respect to the acquisition of several abilities [11]. Although these technologies are used to support human operations, an understanding of the issues related to cognitive and ergonomic challenges and how these interfaces enable better tactical thinking and decision-making is lacking in literature.

Instance-based learning theory (IBLT) [9], a theory of how individuals make decisions from experience, has elucidated decision-making in complex tasks very well. According to IBLT, decision-making is a five-step process: recognition of the situation, the judgment based in experience, choices among options based upon judgments, execution of chosen actions (decision-making), and feedback to those experiences that led to the chosen actions [9]. Hence, as per IBLT, when the complexity and the constraints in the task is higher, the decision-maker would be able to collect and store more experiences during training in the task. This collection of experiences would allow the decision-maker to get a better mental representation of the objective to be achieved and subsequently enhance decision-making [9]. Hence, owing to its enhanced telepresence and better immersivity, we expect that the VR simulation would help the individual to create a better mental model of the scenario and the objectives to be achieved. This in turn, would create more experiences in his/her's memory, which would lead to better performance due to optimal utilization of cognitive resources. We also hypothesize that unmanned interface-based training would lead to better performance. That is because the unmanned interface provides unconstraint visual conditions to human players.

In what follows, we investigate the implications of four simulations that differ in their display designs and type of interface-based training on human performance and cognitive workload. Then, we detail results and discuss the applications of our results on decision-making in the real world.

2 Materials and Methods

In this section, we describe an experiment to investigate the influence of an IVD/VR design involving unmanned/manned interfaces on one's decision-making performance.

2.1 Participants

A total of 60 participants (35 males and 25 females; mean age: 21.7 years, SD = 2.23 years) at the Indian Institute of Technology (IIT) Mandi, Himachal Pradesh, India took part in this study. The study was approved by an ethics committee at IIT Mandi. Participation was voluntary and a written consent was taken from all participants before they began the experiment. Fifty-four participants were right-handed. All participants had normal or corrected-to-normal vision, and no one reported any history of neurological disorders. All participants were from science, technology, engineering, or mathematics backgrounds. Seventy-two percent of participants reported that they had not experienced virtual reality before. All the participants received a flat payment of INR 50 for their participation in the study. They could also earn a performance-based incentive of INR 30 per successful simulation (a successful simulation is the one in which a participant is able to achieve all simulation objectives within a defined time period).

Fig. 1. The overhead map of the naval terrain designed in Unity3D. The blue spheres indicate the three headquarters in the simulation. The small red spheres indicated the enemies and the big red sphere indicated the position of the player.

2.2 The underwater search-and-shoot simulation

An underwater based virtual search-and-shoot simulation was designed using Unity3D version 5.4.1 [12], and the avatars of the enemy submarines and the manned/unmanned interfaces were designed using Blender animation [13]. Figure 1 shows the overhead map of the terrain, with three headquarters located at different coordinates in the terrain. We followed the evolutionary prototyping SDLC model [14] in developing the simulation. As shown in Figure 2(a), one of the display design was a typical first-person-shooter based IVD, providing a live-video feed with a horizontal field of view of 120° to the operator (which is comparable to the horizontal view of a healthy human being). The other was a VR design, catering to an artificial 3D environment, as shown in Figure 2(b). In addition to the variation in the display designs, variations in the computer interfaces were also introduced: a manned interface (as shown in Figure 3(a)) and an unmanned interface (as shown in Figure 3(b)). Table 1 shows the human factors issues introduced in the unmanned and the manned simulation. We introduced some physical and ergonomic changes in both the simulations in order to enforce realistic cognitive constraints in decision-making on the individual. The enemy submarines were positioned in such a way that all the headquarters contained approximately equal number of opponents guarding it. The participants' objective was to destroy all enemy submarines and protect all the naval headquarters within a specified time period (10 minutes). The participant's health was initialized to 100. Participants possessed a missile launcher for offense, consisting of 50 missiles.

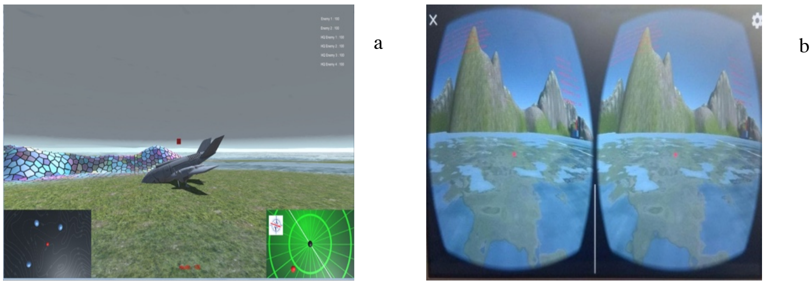


Fig. 2. The display design variations in the simulation (a) Simulation in an indirect visual display (b) Simulation in immersive mobile VR

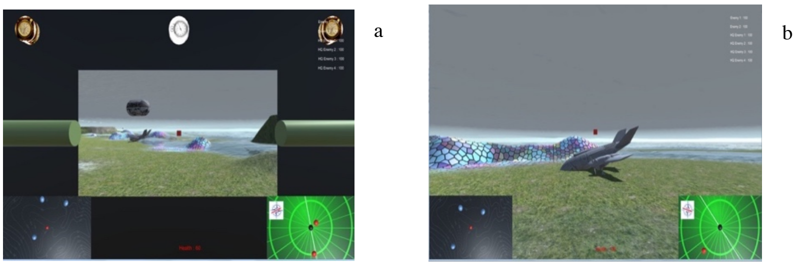


Fig. 3. The different interfaces designed for the experiment (a) the manned interface (b) the unmanned interface

Table 1. Variation in the human factors issues in the computer interfaces in the simulation

Attribute	Manned Simulation	Unmanned Simulation
Embedded Periscope View	Yes	No
Latency of response buttons	200 milliseconds	800 milliseconds
Delay in video transmission	15 frames	30 frames
Controls	Extreme™ 3D Scan Pro	Mouse and Keyboard

One enemy could be killed in 5 missiles, and the player submarine could be destroyed with 12 missile hits. The total number of enemies in the simulation was kept to six. All enemies' health was initialized to 100. Two sub-types of enemy submarines were created: aggressive and defensive. The aggressive enemy submarine was programmed in a way so that they would pursue the player submarine relentlessly and try to shoot it down. The defensive enemy submarine would try to defend itself by dodging the player's attacks by moving in a random direction when under fire. These submarines were programmed to be offensive towards the three-naval headquarters, and they would start firing their missiles towards the headquarters as soon as they were in its vicinity. As shown in Figure 2(a), we also implemented a SONAR sensor in both IVD and VR in the bottom right-side of the interface to enable the participants track the enemy submarines' suggestive positions. The SONAR sensor would detect the targets if it came under the radius of 50 units (in Unity3D calibration) from the center point (the black sphere in the Figure was suggestive of the player submarine's position). In addition, as shown in Figure 2(a), the location of the three headquarters and the position of the player submarine relative to the headquarters were also shown in the bottom-left part of the interface. The IVD simulation was executed in a 21.5-inch HP desktop monitor, at a resolution of 1920 x 1080 pixel with noise-canceling headphones worn by the participant for receiving audio stimulus in a well-lit room. The participants used an Extreme^{TM} 3D Pro joystick [15] for navigating and shooting in the manned simulation. Participants used a keyboard and a mouse for navigating and shooting respectively in the unmanned simulation. The VR simulation was executed using a mobile-based android system, through a 5.5-inch Xiaomi Redmi Note 3 smartphone [16] and My VR goggles [17], rendering a 120° horizontal field of view of the virtual environment. The participants used a DOMO MagicKey Bluetooth controller [18] to navigate and shoot in the VR simulation.

2.3 Experiment Design

In a lab-based setting, all the 60 subjects executed both the manned and unmanned interfaces (within-subjects) across both the IVD (N = 30) and VR (N = 30) designs (between-subjects). Within each display design (IVD or VR), half of the participants were given manned interface-based training first, and the other half were imparted unmanned interface-based training first. Behavioral measures like number of submarines destroyed and the total time taken to complete the simulation were recorded. In addition, various cognitive measures like the computerized version of the NASA-TLX [16] and simulator sickness questionnaire (SSQ) [17] were also recorded. The NASA-TLX questionnaire was recorded after every simulation executed by the participant. Owing to better telepresence and higher immersivity, we hypothesized that the performance would be better in the immersive VR design compared to the IVD design. Since unmanned interfaces produced an unconstraint view of surroundings, we expected an optimal transfer of cognitive skills in the unmanned interface-based training compared to the manned interface-based training.

3 Results

We carried out one-way ANOVAs to compare the effect of display design (IVD, VR) and type of interface-based training (manned, unmanned) on all the cognitive and behavioral descriptors mentioned above.

3.1 Performance measures

As shown in Figure 4(a), the percentage of enemy submarines destroyed were significantly higher in the VR design compared to IVD design (VR: 63% > IVD: 52%; F (1, 58) = 11.04, p = 0.002, r = 0.84). As shown in Figure 4(b), time taken to complete the simulation was significantly higher in the VR design compared to the IVD design (VR: 267s > IVD: 201s; F (1, 58) = 7.41, p = 0.008, r = 0.88). Overall, these results show that the VR design led to superior participant performance compared to the IVD design.

Next, as shown in Figure 5(a), the percentage of enemy submarines destroyed were significantly lower when the manned interface was presented first compared to when the manned interface was presented second (Manned first (MF): 43% < Manned second (MS): 61%; F (1, 58) = 49.45, p = 0.0001, r = 0.53). Second, as shown in Figure 5(b), the time taken to complete the task was significantly lower when the manned interface was presented first compared to when the manned interface was presented second (MF: 195s < MS: 256s, F (1, 58) = 12.02, p = 0.001, r = 0.83).

Furthermore, as shown in Figure 5(c), the percentage of enemy submarines destroyed were significantly lower when the unmanned interface was presented first compared to when the unmanned interface was presented second (Unmanned first (UF): 44% < Unmanned second (US): 54%; F (1, 58) = 10.35, p = 0.002, r = 0.84). Second, the time taken to complete the task was significantly lower when the unmanned interface was presented first compared to when the unmanned interface was presented second (UF: 190s < US: 249s, F (1, 58) = 13.29, p < 0.0001, r = 0.81; see Figure 5d).

A two-way ANOVA was conducted that examined the effect of display design and the type of interface-based training on the differences in the percentage of enemy submarines destroyed (see Figure 6). As shown in Figure 6, a two-way ANOVA revealed a statistically significant interaction between the display design and the interface-based training order on the difference in the percentage of enemy submarines destroyed (F (1, 56) = 4.48, p = 0.039, η^2 = 0.074). Overall, as per our expectation, the unmanned training was much superior to the manned training in both IVD and VR design. However, the difference between unmanned and manned training was much less in the IVD design compared to the VR design.

3.2 Cognitive measures

Next, we analyzed the NASA-TLX self-reported scores. The self-reported mental demand was significantly higher in the VR design compared to IVD design (VR: 6.63 > IVD: 5.00; F (1, 58) = 13.42, p = 0.001, r = 0.81) as shown in Figure 7(a). However, as shown in Figure 7(b), the participants also revealed significantly higher performance satisfaction in the VR design compared to IVD design (VR: 6.12 > IVD: 4.86; F (1, 58) = 11.2, p = 0.001, r = 0.84). As shown in Figure 8(a) and 8(b), the mental demand was higher when the manned and unmanned interfaces were presented first compared to when they were presented second (MF: 6.73 > MS: 5.13, F (1, 58) =

16.71, $p = 0.0001$, $r = 0.77$; UF: 6.4 > US: 5.3, F (1, 58) = 7.13, $p = 0.01$, $r = 0.59$). In VR display and unmanned first training, the two-tailed Pearson correlation between the time taken and the nausea-related symptoms (in SSQ) was significant ($r = 0.624$, $p < 0.05$).

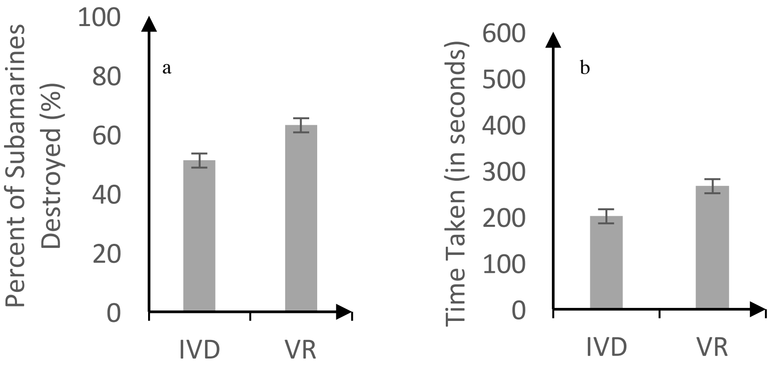
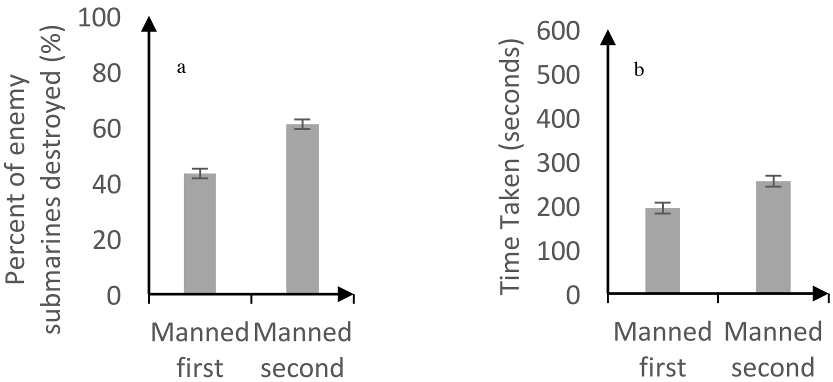


Fig. 4. Means and standard errors obtained in different display designs for time taken (a) and number of submarines destroyed (in percentage) (b).



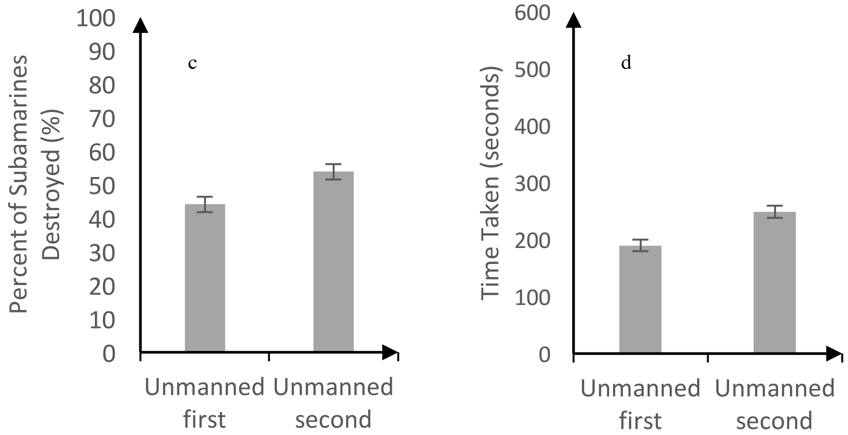


Fig. 5. Means and standard errors obtained in manned and unmanned interface-based training order (first or second). The number of enemy submarines destroyed (a) and the time taken (b) in manned interfaces. The number of enemy submarines destroyed (c) and time taken (d) in unmanned interfaces.

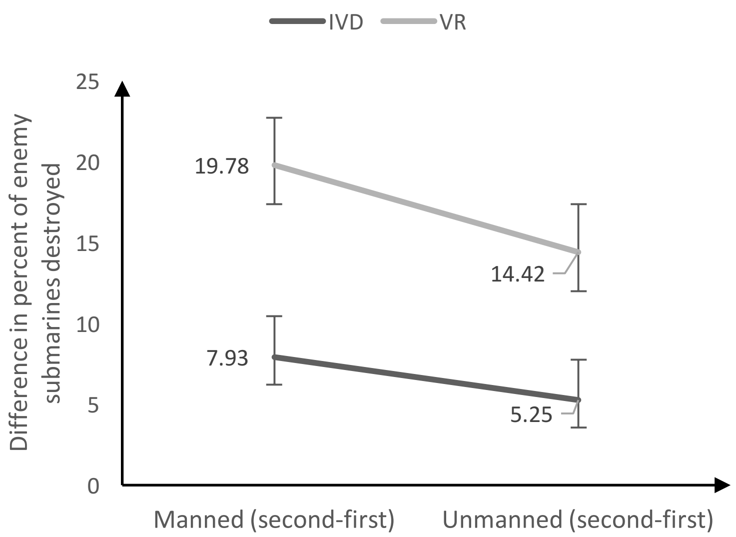


Fig. 6. Means and standard deviations of the difference in the percentage of enemy submarines destroyed due to interfaced-based training order (Manned second – Manned first, Unmanned second – Unmanned first) and display design (IVD, VR)

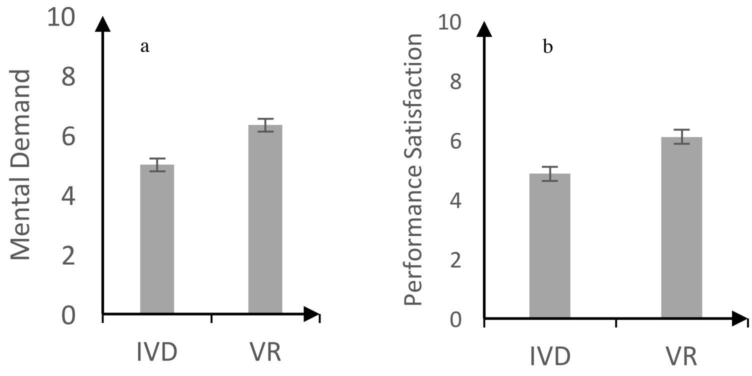


Fig. 7. Means and standard errors in IVD and VR display design for self-reported mental demand (a) and self-reported performance satisfaction (b).

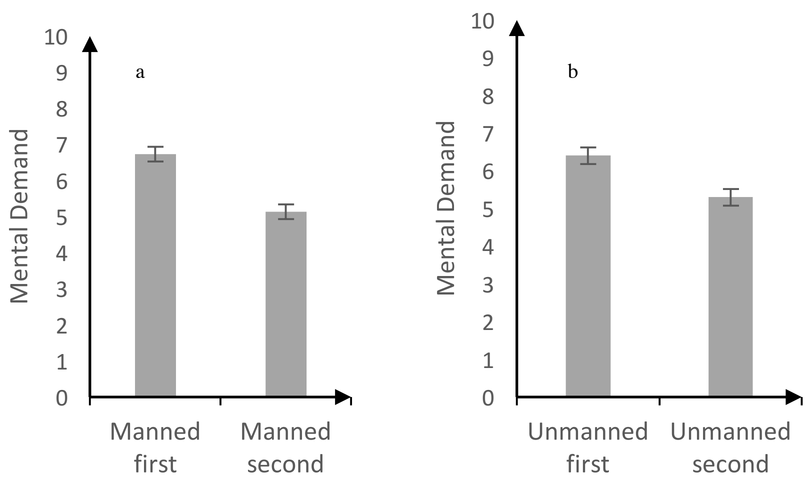


Fig. 8. Means and standard errors in interface-based training order for self-reported mental demand (a) and self-reported performance satisfaction (b).

4 Discussion

In this experiment, we evaluated the cognitive and behavioral implications of indirect vision and virtual reality display designs under varying manned/unmanned interfaces in a complex underwater search-and-shoot simulation. Results revealed that the participants performed better in the VR design compared to the IVD simulation and performed better in unmanned training compared to manned training. These results were found to be consistent with [11], where it was articulated that immersive VR enabled the participants to build a mental model of the simulation by seamlessly moving around the virtual world. Also, our results are in agreement with [19], where individuals were able to maximize their efficiency in comprehending the information conveyed in the virtual environments.

Our results on display design and interface training can also be explained by IBLT [9]. As per IBLT, situations that create more instances about the environment in decision-maker's memory would help to make good decisions. In agreement with this explanation, the unmanned training design provided an unconstraint training environment, which led to the creation of more instances in an individual's memory. These instances possibly lead to better performance. In fact, in agreement with IBLT, the VR design also led to an unconstraint perception of our environment causing it to produce enhanced performance. This explanation is supported by the self-reported mental demand score, which was higher in the VR design compared to the IVD design. Thus, more information availability and higher channelization of cognitive resources due to mental demand increased the information-processing speed from the instances created in memory.

Our results have important implications for decision-making in manned and unmanned operations as well as different display designs. Based upon our results, unconstraint training involving VR and unmanned scenarios seems to be the most potent in improving performance. Thus, it is advisable to train personnel in complex real-world applications using VR designs and unconstraint interfaces.

5 Conclusions

The results of our experiment indicate that VR design offers numerous advantages over the IVD design in complex decision-making scenarios. Also, our experiment proved that training individuals in unmanned (unconstraint) interfaces leads to efficient performance in a complex task compared to manned (constraint) interfaces. We expect to use these conclusions as a means of creating effective training environments for military personnel.

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