Effects of Transparency Level, Controller Type, and Visual Degradation on Performance using Augmented Reality and Synthetic Vision

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ABSTRACT

Augmented reality application development must overcome human factors issues such as occlusion handling, transparency optimization, user interface selection, and adapting information displays to tasks and environments. The current research investigated the effects of transparency level, controller type, and degraded visual conditions on speed and usability. The experiment used a novel battlefield visualization application that blends augmented reality and synthetic vision. *Method:* Participants were required to use the application to discover and mark targets by placing icons on the synthetic vision layer. In the first study, participants used an Xbox controller to mark targets on either a high or low degraded visual environment scene, with the opacity of the camera sensor set to 0%, 30%, 70%, or 100%. For the second study, participants used either an Xbox controller, a mouse, or speech recognition to mark targets on a low or high degraded visual environment scene. *Results:* In Experiment 1, participants were fastest in the 30% opacity condition, regardless of degradation. In Experiment 2, participants were fastest in the 30% opacity condition, with no significant difference between Xbox and mouse, except in the highly degraded condition. In the highly degraded condition, participants were faster with the Xbox controller. *Discussion:* Results suggest an interaction between visual degradation and transparency and controller type. Users found the greatest benefit when using transparency adaptively according to task. Future studies should measure accuracy to determine the effects of semi-transparency and degraded visual conditions on depth perception.

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INTRODUCTION

Efforts to develop and refine augmented reality applications for the military have increased significantly over recent decades. Major systems include the Battlefield Augmented Reality System, Augmented Reality Command Control Communicate Coordinate, Tactical Augmented Reality, and Fused Augmented Realities with Synthetic Vision (FAR/SV) (Crane, Proaps, Benasutti, & Bliss, 2018; You et al., 2017). Augmented reality offers unique benefits to soldiers on complex, modern battlefields, such as increased situation awareness, reduced cognitive load (e.g. by reducing attention switching and facilitating visual search), and improved navigation and communication (Livingston et al., 2003; Lu, Duh, Feiner, & Zhao, 2014; Picaud, 2019). However, some challenges must still be overcome before any of these systems are ready for operational use. These include preventing information overload and managing occlusion handling (You et al., 2017).

Augmented reality overlays task-relevant information, such as navigation waypoints, headings, hazards, and other computer-generated graphics, onto a real-world view. This has been found to improve performance in a wide range of domains (Furstenau et al., 2008; Liu et al., 2010). Head-mounted displays are the preferred AR platform for the battlefield because they are hands-free and heads-up, which reduces attention switching and cognitive workload and increases reaction times (Liu & Wen, 2004; Wickens & Long, 1995). A major drawback of head-mounted displays is reduced field of view; however, synthetic vision may be used to extend the field of view by supplementing the typical view with a three-dimensional simulation of the environment. AR applications can also suffer from information overload, especially in battlefield applications, due to the high amount of relevant information that can be displayed to the user. Two ways to reduce information overload are information filtering and information clustering. FAR/SV filters information by providing different information displays for different tasks and clustering information geospatially. Doing so takes advantage of the cognitive benefits of display conformity and the proximity principle (Viertler, Krammer, & Hajek, 2015). Conformal graphics overlay, and move with, relevant objects in the environment, thus adhering to Gestalt grouping principles such as proximity, common fate, and good continuation (Ververs & Wickens, 1998). This reduces cognitive load by reducing eye movements and attention switching (Wickens & Long, 1994). If they are applied inconsistently or haphazardly, AR graphics present the risk of occluding important environmental objects. FAR/SV handles occlusion by stabilizing clusters of graphics and varying their distance from the object, an approach successfully used by Tatzgern (2015). Additionally, the AR graphics are semi-transparent, so they do not completely obscure objects in the environment. Unfortunately, semi-transparent displays may raise other issues, such as altered depth perception and foreground-background perceptual conflict (Ellis & Menges, 1998; Livingston, Ai, & Decker, 2009).

Transparency

FAR/SV is an example of a multi-layer display; it includes a 3D SV view of the environment, a real-world camera feed from an unmanned aerial system (UAS), and augmented reality information graphics, each displayed on their own layer. The transparency of the SV and AR layers can be manipulated independently. The user can increase the opacity of the SV layer. For example, if the real-world view is degraded, the user could increase its transparency to focus in on a real-world object. Similarly, the transparency of the AR graphics layer can be independently adjusted. However, semi-transparent graphic overlays can reduce depth perception and decrease discrimination of foreground and background objects (Ellis & Menges, 1998; Gupta, 2004). Empirically-based recommendations for transparency level vary widely (Bartram & Stone, 2011; Harrison, Kurtenbach, & Vicente, 1995). Some researchers have found that transparency greater than 50% results in significant perceptual degradation (Jäckel, 2013), whereas others found that transparency below 50% significantly reduced background object visibility (Gutwin, Dyck, & Fedak, 2003). Such conflicting results suggest that optimal transparency levels may be task or environment dependent. Allowing the user to adjust the transparency as needed is one solution, but may be disruptive while performing tasks (Levy, Rafaeli, & Ariel, 2016). Interruptions and task switching can degrade encoding of visual information and reduce change detection (McCarley et al., 2004). Such lapses could have disastrous consequences on the battlefield.

Degraded Visual Environments

Choosing an optimal transparency level is particularly important when the real-world view is obscured due to degraded visual conditions. The SV environment must be opaque enough to compensate for the degraded conditions, without obscuring real-world objects and events. Similarly, relevant AR information must still be visible without detracting from SV/real world visibility. Degraded visual environments are of particular concern on the battlefield because they occur commonly, can give the enemy an advantage, and may lower performance and decision-making (Knights & Mello, 2017; Narayanaswami, Gandhe, & Mehra, 2010; Nicolaou & McKnight, 2006). However, little attention has been paid to the impact of degraded visual conditions on AR applications. The current study investigated whether degraded visual conditions impacted the effects of transparency or controller type to predict performance. To simulate a degraded visual environment, we reduced color saturation, added horizontal lines (simulating low-quality camera feed), and added mud splatter across the sensor camera screen.

Controllers

In addition to information visualization, user interaction is key to a successful AR application. Controllers include Xbox-type controllers, mouse controllers, and natural controllers such as speech and gesture. X-box type controllers translate small controller movements to large movements in the program environment; such translation may demand considerable cognitive effort by users (Rogers, Bowman, & Oliver, 2015). Mouse controllers typically produce identical results in the environment to the user’s inputs. Speech and gesture are considered intuitive controllers, but are difficult to implement in an AR application. Speech is not well suited to spatial control within an interface (Zinchenko, Wu, & Song, 2017). Gesture control is slow and unwieldy due to lack of haptic feedback in an AR environment (Long & Bliss, 2016; Rogers et al., 2015). Empirical results of controller evaluations vary, with some researchers supporting Xbox-type controllers and other researchers supporting mouse controls (MacKenzie & Soukoreff, 2003; Rupp, Oppold, & McConnell, 2013). Additionally, it is not known whether the most effective controller type may differ depending on environmental or task conditions. For example, hands-free interfacing is extremely valuable in a battlefield environment, although speech has been found to be significantly slower and less accurate than other interface methods (Chandarana, Meszaros, Trujillo, & Allen, 2017). Speech has also been found to reduce workload (Helmke, Ohneiser, Mühlhausen, & Weis, 2016).

PURPOSE

Augmented reality (AR) application development faces the challenge of balancing key information visualization with users’ cognitive and interaction constraints. The current paper describes an investigation of transparency implementation and controller type on user’s task performance speed and subjective usability ratings across degraded and non-degraded environments. The task performed required visual search and object marking.

PARTICIPANTS

Overall, data were collected from 17 participants (10 women) between the ages of 18 and 43 (M = 22.353; Mode = 19; SE = 1.519). All participants were Old Dominion University (ODU) students who received research credit through ODU’s psychology research participation system (SONA). Students reported using computers an average of 29.765 hours per week (SE = 1.519). Students reported playing games an average of 6.706 hours per week (SE = 1.567), most often playing first person shooter and sports games. Students also had experience with several control devices (M = 18.118 hrs/wk; SE = 5.602), such as keyboard, touchscreen, and Xbox controllers. Five participants reported using robotic devices between one and five years, including remote control cars, drones, and robotics kits. One participant was enlisted in the United States Marine Corps, and reported in-depth knowledge and first-hand experience with UAVs.

MATERIALS

The task consisted of marking vehicles, buildings, or people using the FAR/SV application. Scenarios were created in FAR/SV v.1.4.6, running on an Alienware laptop with Windows 10 64bit. The FAR/SV application featured controls for flying a simulated drone and adjusting the drone's camera. The scenarios simulated a drone flying a preset flight path over a city, with three waypoints per scenario. Participants were instructed to pause at each waypoint to place a marker. The marker menu allowed the user to mark objects in the environment using standard military symbols (MIL-STD-2525). A vehicle, building, or object was placed near each waypoint on the synthetic terrain. The controllers consisted of an Xbox One controller, speech recognition, and mouse/keyboard. Speech recognition was programmed to recognize a preset list of commands, which were given to the participants. The mouse controller was used to select menus, and the arrow keys on the keyboard were used in conjunction with the mouse to control the sensor camera.

MEASURES

Subjective system usability was measured with the System Usability Scale (SUS) (Brooke, 1996). The SUS includes ten questions related to both positive and negative system traits. Participants respond to questions using a five-point Likert-type scale (1 = strongly disagree; 5 = strongly agree). For example, "I think that I would like to use this system frequently" reflects a positive system trait and "I found the system very cumbersome to use" reflects a negative system trait. Each item was rescored to reflect a four-point scale and converted to a raw score that falls between 0 and 100. The SUS has been found to be highly reliable across administrations ($\alpha = .92$) (Sauro, 2016).

To assess overall performance, experimenters observed and made notes about participant behaviors during tasks completed within each scenario. While experimenters observed performance, participants talked through their actions, including errors or situations in which they needed prompts (i.e., think aloud protocol).

The research team was specifically interested in the speed of marker placement under varying levels of visual conditions and camera transparencies. Researchers measured marker placement speed with a stopwatch. Time began when participants started the process to open the radial menu (Speech: Saying the word "Place," Xbox: Pressing A, Mouse: Right clicking the screen). Time ended when the marker radial menu was no longer visible on the screen (Speech: After saying "Confirm," Xbox: After pressing A to confirm checkmark, Mouse: After clicking the checkmark [Figure 4]).

PROCEDURE

All procedures received approval from ODU's Institutional Review Board (IRB) before any data were collected. Participants entered the lab and sat at the desktop computer hosting FAR/SV. Before testing began, participants read and signed an informed consent form outlining any risks associated with participation. Participants completed a demographics questionnaire before an experimenter explained the usability testing procedures.

Participants completed a one-minute familiarization scenario in manual mode during which they completed tasks required for each session. During the familiarization session, researchers provided a visual aid for the placement of MIL-STD-2525 icons for all three placement methods. An experimenter prompted the participants to complete various tasks on their own before providing additional training or feedback. All participants completed the following tasks during the familiarization scenario:

1 Moved through main menus to begin Mission Rehearsal with the Xbox controller,
2 used the zoom function of the sensor camera with the Xbox controller,
3 placed one MIL-STD-2525 icon using speech recognition, the mouse, and the Xbox controller, and
4 deleted an icon with the mouse and Xbox controller.

Participants completed multiple scenarios. The scenarios contained flight waypoints for the drone to follow with autopilot and various objects to place such as vehicles, buildings, and people. All participants completed each task by:

1 Playing the scenario,

2. flying to each waypoint along a pre-planned waypoint route,
3. pausing the scenario to search the area at each waypoint,
4. using the sensor camera to search the area, and
5. placing a MIL-STD-2525 icon to mark any visible entities in the environment.

STUDY 1

PURPOSE

The first study investigated the effects of transparency and degraded visual conditions on task performance speed. Participants completed a simulated reconnaissance task on a laptop computer by viewing feed from a simulated drone flying a preset path, using the sensor camera to search the area, and placing an icon to identify the location of simulated humans in the environment. AR development efforts have failed to establish an optimal transparency level for overlaid graphics. This study investigated the degree to which task performance varied under different levels of degraded visual conditions.

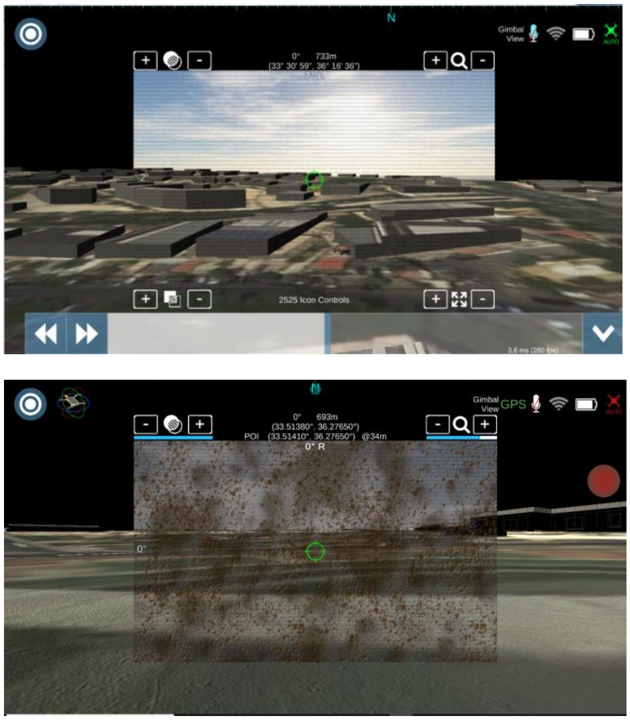

Figure 1. Example of fully opaque (0% transparency) sensor camera under low (top) and high (bottom) degradation.

METHOD

This experiment used a 2 x 3 within-subjects design. The independent variables were degraded visual conditions (2 levels: High and Low) and sensor camera transparency (3 levels: 30%, 70% [Figure 3] and 100% [Figure 2] camera opacity). All participants also completed a scenario that served as a control group with no camera (or 0% opacity; Figure 1) in which no degraded conditions would be visible. Transparency levels were divided into four categories based on the percentage of sensor camera visualization opacity that overlapped the synthetic terrain. For example, in the 30% opacity condition, the center of the screen would show 30% sensor camera visualizations overlapping the synthetic terrain (Figure 3). No sensor camera feed was provided in the 0% condition and the fully opaque sensor camera feed was provided in the 100% condition.

Figure 2. Example of sensor camera with no camera feed (SVA only; 100% transparency).

Seven participants completed seven scenarios with an Xbox One controller. The presentation of degraded visual conditions was counterbalanced. Within the high and low visual conditions, transparency levels were randomly presented to each participant. Therefore, each participant completed scenarios across all transparency levels for the high and the low degraded conditions. Participants placed three markers during each trial for a total of 21 markers. Participants' speed in placing markers, and usability ratings of FAR/SV, were collected to compare these conditions. We measured marker placement speed with a stopwatch. Time began when participants started the process to open the radial menu (Speech: Saying the word "Place," Xbox: Pressing A, Mouse: Right clicking the screen). Time ended when the marker radial menu was no longer visible on the screen (Speech: After saying "Confirm"; Xbox: After pressing A to confirm checkmark; Mouse: After clicking the checkmark; Figure 4).

RESULTS

On average, participants spent the most time placing markers with the Xbox controller under degraded conditions in the 70% opacity condition (Figure 5). There was no difference in placement time between transparency levels. Participants spent longer placing markers in the highly degraded condition compared to the low degraded condition, although this difference did not reach significance ($p = .099$, $\eta^2 = .331$). Individual variability in performance was also highest for degraded conditions in the 70% and 100% opacity levels, possibly due to the increased visibility of mud splatter on the simulated camera blocking the view of the environment. Participants rated system usability highest under the 0% opacity condition. Furthermore, SUS scores exceeded the threshold for acceptability (>68, Sauro, 2015), across all conditions. Oddly, SUS scores were higher in the degraded ($M = 78.5$) than in the clear ($M = 70.5$) condition. This could relate to Schaefer, Chen, Szalma, and Hancock's (2016) findings that users exhibit greater confidence in an automated system if they perceive the degraded imagery as difficult to analyze.

Figure 3. Example of sensor camera 30% (top) and 70% (bottom) opacity under high degraded conditions.

Figure 4. Example of radial menu for marker placement with on-screen instructions.

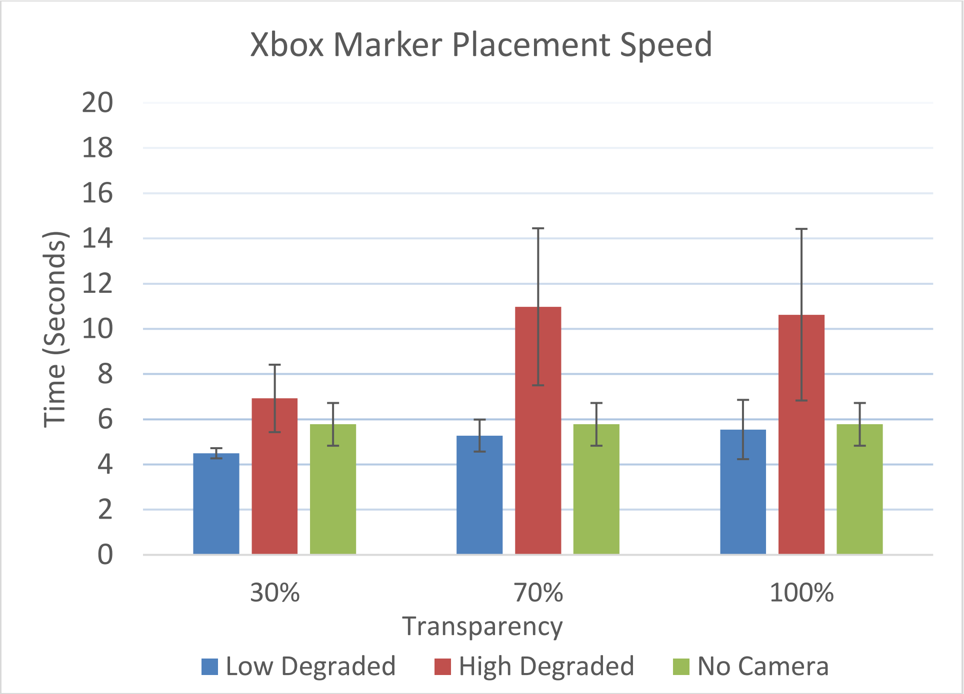

Figure 5. Means and standard errors for Xbox marker placement time (in seconds) as a function of degraded sensor camera visualizations and transparency.

STUDY 2

PURPOSE

The second study compared the effects of controller type and visual degradation on task performance speed. Little attention has been paid to controller type, with current AR applications varying from speech to eye tracking to touch-screens. Controller choice will vary depending on the platform used (e.g. iPad or HMD), and whether the user's hands are free. However, some controllers (e.g. speech) require less cognitive and physical effort than others (e.g. gesture). This experiment compared keyboard/mouse, speech recognition/keyboard, and Xbox One controllers. The primary goal was to determine whether degraded visual conditions affect control preference or task performance speed. Additionally, participants were free to adjust transparency as desired during this study. This allowed the research team to compare the objective performance data from Study 1 with users' transparency preferences in Study 2.

METHOD

As with Experiment 1, this experiment used a 2 x 3 within-subjects design. The independent variables were marker placement method (3 conditions: Speech, Mouse, and Xbox) and degraded sensor camera visualizations (2 levels: High and Low). Camera visualizations were degraded by reducing the color saturation, adding horizontal lines, and adding mud splatter across the sensor camera screen. In the low degraded condition, the horizontal lines were visible and the color was 50% unsaturated. In the high degraded condition, the horizontal lines were visible, the color was 100% unsaturated, and there was mud splatter covering 70% of the screen. The color saturation settings were programmed into the FAR/SV application for the purpose of this experiment.

Ten participants completed six scenarios. The presentation of marker placement method was counterbalanced. High and low visual conditions were randomly presented within each marker placement method presentation. Therefore, each participant completed one high and one low degraded condition for each marker placement method. Participants placed three markers in each trial for a total of 18 markers.

RESULTS

On average, participants spent more time placing markers in the highly degraded visual conditions across all marker placement methods compared to low degraded conditions, although this difference did not reach significance (Figure 6). Participants completed marker placement fastest with the mouse under low degraded visual conditions (M = 7.86), and slowest with speech under highly degraded conditions (M = 30.70). Across visual conditions, participants spent significantly more time placing markers using speech recognition (M = 28.16) than the Xbox (M = 10.23) or mouse (M = 14.18), $p < .01$, $\eta^2 = .854$. Although this was likely influenced by speech recognition errors, such as having to speak a command multiple times before it was recognized, we instructed participants to use the Xbox controller instead if participants had 5 failed attempts at speech. There was also more individual variability in marker placement speed when using speech recognition. Participants adjusted the transparency depending on the nature of the task, usually choosing either 0% or 100% opacity. It seems likely that participants found the 30% and 70% levels more visually confusing. Participants preferred to search the area using the sensor camera, then increase the SV opacity while marking the objects. Participants rated system usability higher for Xbox and mouse, exceeding the acceptability threshold (M = 73.75), than for speech, which fell just below the acceptability threshold (M = 60.83). They felt most confident when using the Xbox controller, and reported the most need for technical support when using speech.

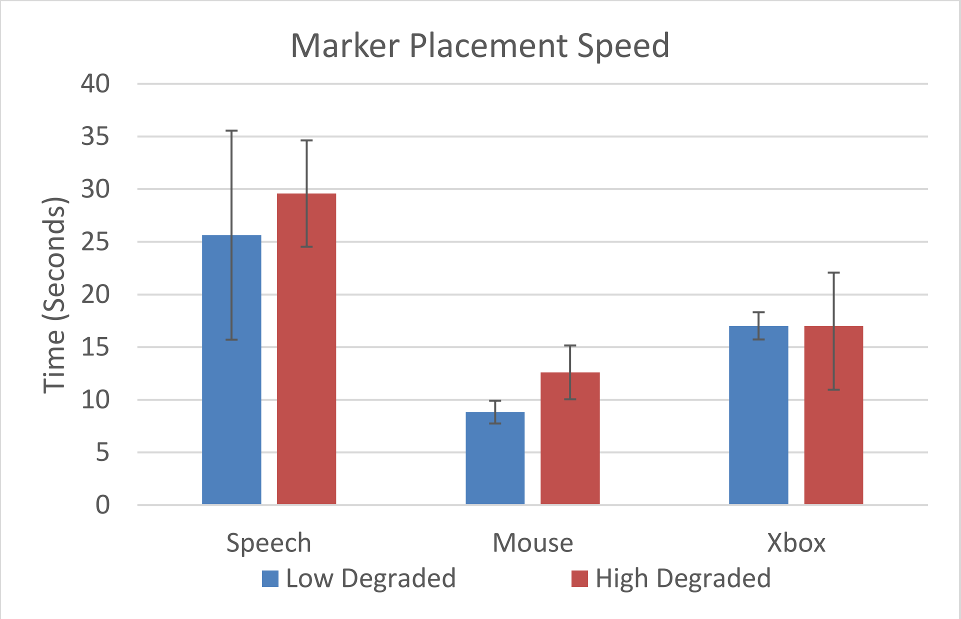

Figure 6. Means and standard errors for marker placement time (in seconds) as a function of marker placement method (3 levels: Speech, Mouse, and Xbox) and degraded sensor camera visualizations (2 levels: High and low degraded conditions).

DISCUSSION

The results suggest a significant effect of transparency, controller type, and degraded visual conditions on performance and perceived usability. Speed did not differ significantly across transparency levels. This agrees with Gutwin, Dych, and Fedak's findings (2003), suggesting that object occlusions due to degraded conditions or AR graphics has a greater effect on performance than perceptual conflicts due to semi-transparency. When participants were free to adjust transparency, they chose to use 100% opacity to locate objects, and 0% opacity to mark them on the synthetic terrain. Considering objective results from the first study and behavioral results from the second, the best course of action appears to be adaptable transparency that adjusts to either 0% or 100% depending on degraded environmental conditions and task. When video feed is necessary to complete a task, opacity should be 100%. When the task can be completed on the synthetic terrain, opacity should be 0%.

Participants were significantly slower placing markers when using speech. There was no significant difference between mouse and Xbox controller on speed. However, participants were slower with the mouse, but not the Xbox, in the highly degraded condition. This suggests an interaction of controller type and environmental conditions, such that the Xbox may be preferable in variable environmental/task conditions (although we had insufficient power, due to our low sample size, to test for an interaction directly). Participants were much faster placing markers with the Xbox (5-10 seconds) when transparency was fixed than when transparency was adjustable (10-17 seconds). This suggests that adjusting the transparency was very disruptive, which agrees with Levy, Rafaeli, and Ariel's findings (2016). Future research should consider the effect of such disruptive user-adjustable controls on change detection and visual information encoding.

For both Study 1 and Study 2, participants were slower placing markers in the highly degraded visual condition; but neither difference reached significance.

Participants found the synthetic vision easier to work with compared to the camera feed, even when degradation was low. They also preferred the Xbox to either mouse or speech controls. These results agree with the performance-based results discussed above. SUS scores were higher after placing markers in the degraded condition than after the clear condition. This may relate to the construct of trust in automation, with some (Schaefer et al., 2016) suggesting that degraded imagery may increase users' trust in automation.

One limitation of this study is that we did not measure marker placement accuracy. Future studies should consider accuracy, as this could help measure the effects of semi-transparency and degraded visual conditions on depth perception.

CONCLUSION

Transparency and controller type interact to predict performance in degraded environments. Additionally, user-adjustable transparency must be carefully considered in light of the task domain, because it entails drawbacks as well as advantages. Based on our findings, we believe that the best approach is to adjust transparency automatically based on the function being performed. We also recommend the use of Xbox-style controllers, except in situations where user interface must be hands-free. Future research should consider accuracy and workload as additional measures of the effects of transparency and controller type on performance.

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