VIRTUAL REALITY AND 2D INTERFACES:
A COMPARISON OF VISUAL SEARCH TASK PERFORMANCE

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Airborne surveillance operations present challenging environments for tactical operators and for the technologies that support these activities. Information from multiple sources is currently presented on 2D displays, but the influx of data has made it difficult to represent this information using traditional technologies. Recent innovations in VR have laid the groundwork for a promising solution to this problem by allowing users to immerse themselves in 3D representations of the real world with embodied tracking capabilities. The present research examined the feasibility of transitioning two common tactical operator tasks from a 2D to a 3D/VR user interface. Naive participants searched for targets amongst a set of non-targets on a traditional 2D interface and on a custom-built VR interface rendered on an Oculus Rift. Participants reported a target's geographical coordinates or the distance between two targets. Search difficulty and search specificity were manipulated. Results and future directions are discussed.

Airborne surveillance operations require the visual integration of multiple streams of data from ground, air, and maritime sources. The ever-increasing availability of real-time sensor data, fused track data, and environmental data has surpassed the capability of traditional 2D displays to provide the operator with a coherent visual representation of the operational environment. Consequently, the operator must devote considerable mental effort to navigate multiple layers of cluttered displays in order to maintain effective situation awareness. The limitations of 2D displays have accelerated the need to develop human machine interfaces that can leverage recent innovations in virtual reality (VR) and augmented reality (AR) technologies.

A potential benefit of VR/AR interfaces is that the user can view and interact with one-to-one mappings of an environment in virtual 3D space (VR) or with synthetically rendered/enhanced objects in the environment itself (AR). This offloads the operator's task of mentally re-mapping a 2D plan-view to encompass a vertical dimension (e.g., Carswell & Wickens, 1987; Wickens, Merwin, & Lin, 1994). The benefits of 3D over 2D visualization have also been shown in the context of "tunnel in the sky" displays (Haskell & Wickens, 1993) and for conflict avoidance on air traffic displays (Ellis, McGreevy & Hitchcock, 1987). There is, however, evidence showing that 2D displays are *better* than 3D displays in certain contexts (e.g., Boyer, Campbell, May, Merwin, & Wickens, 1995; O'Brien & Wickens, 1997; Tham & Wickens, 1993; Wickens & May, 1994). One limitation of many 3D displays is that they only provide the user with one viewpoint, which can result in closer objects obscuring distant objects (e.g., Ellis et al., 1987). The immersiveness of VR interfaces circumvents this problem by providing the user with a potentially infinite number of viewpoints.

The purpose of the present work was to examine the impact of a 3D/VR user interface on tasks that are representative of what a tactical operator would commonly perform using a 2D interface. To this end, participants performed a visual search task in which they were to locate target objects amongst distractors. Participants reported a target's <u>location</u> (latitude, longitude or altitude) or the <u>distance</u> between two targets. Participants performed these tasks using an in-house prototype 3D/VR interface and a commercial-off-the-shelf 2D interface. The difficulty of the search task was manipulated by having either 1~~8~~ or 36 objects in the search environment. Further, search specificity was manipulated by providing the target object's domain (airborne, surface, sub-surface), its classification (friendly, neutral, enemy), or by not providing any domain/classification information. An object's domain was visually represented in 2D/3D as a triangle/pyramid, square/cube, or circle/sphere for airborne, surface, or sub-surface objects, respectively. An object's classification was visually represented by the object's color – green, yellow, or red for friendly, neutral, or enemy objects, respectively.

It was hypothesized that the one-to-one mapping of the search environment provided by the 3D display, coupled with the ability to change viewpoints in VR (i.e., participants could move along the x, y and z-axes) would yield better performance than the 2D display. It was further hypothesized that the performance benefit when using the 3D/VR interface would be magnified for difficult searches. It was also hypothesized that the anticipated benefits of the 3D/VR would be more evident when the target object's domain (air, surface, sub-surface) was specified because the vertical separation of the objects can be visually represented in 3D/VR, but not in 2D.

Method

Participants

A total of 17 Carleton University undergraduate students (12 females) participated in exchange for $20. All participants had normal or corrected-to-normal visual acuity and normal color vision. Three participants were unable to complete the experiment due to VR-induced motion sickness and were therefore excluded from the sample.

Design

A 2 (Interface: 2D vs. 3D/VR) x 2 (Search Difficulty: 18 objects vs. 36 objects) x 3 (Search Specification: No Specification vs. Domain Specified vs. Classification Specified) repeated measures design was used. Interface was blocked and counterbalanced across participants. Search difficulty and search specification were mixed factors, with the six conditions created by crossing these two factors randomly presented with the constraint that there were an equal number of trials per condition. A total of 72 trials were presented – 36 in the 2D condition and 36 in the 3D/VR condition.

Apparatus and Stimuli

2D interface. The operational enviroment – a surface area of approximately 150 km^2 off of the coast of Halifax – and search instructions were displayed on two LCD monitors with a 1920 x 1200 resolution. An overhead plan-view of the search environment (see Figure 1, left panel) was shown on one monitor while the search instructions (e.g., "What is the altitude of object ID #1?") and a countdown timer were displayed on the other monitor. Input devices were a standard Microsoft keyboard and mouse. The visuals and user interface were driven by VR Forces (Version 4.4) software produced by VT MÄK. The environment was populated with 18 or 36 objects, depending on the search difficulty for that trial, that were represented as icons created by crossing three shapes (triangle, square, circle) with three colors (green, yellow, red). Each object was labeled with a unique numerical identifier (i.e., the digits 1 to 18/36), which was located adjacent to the icon. The countdown timer appeared with the search instructions and started at a predetermined time based on the task and search difficulty. If time elapsed, the message "TIMEOUT" was displayed and a buzzer sounded.

3D/VR interface. The same computer used in the 2D interface condition was used to render the search environment on an Oculus Rift CV1 head-mounted VR display (see Figure 1, right panel), which tracked participants' head movements such that the environment was always in view. The field of view was approximately 110° vertically and horizontally. A Leap Motion hand tracker was affixed to the front of the Oculus Rift and used IR tracking technology to fit a kinematic model to the user's hands in order to track and visually represent hand/finger movement in real time. Input devices consisted of a SpaceNavigator 3Dconnexion 3D mouse, which allowed users to move along the x, y, and z-axes in 3D space and a virtual number pad. The visuals and user interface were controlled by custom in-house software built on the Unreal gaming engine platform (Version 4.13). The objects in the search environment were volumetric equivalents of the icons in the 2D condition. The size of the objects was scaled according to the distance between the participant's current location and the object. The search instructions and countdown timer were identical to those in the 2D condition, but were displayed on a virtual screen that was located on the right side of the search environment and maintained a set size and position relative to the participant's current location.

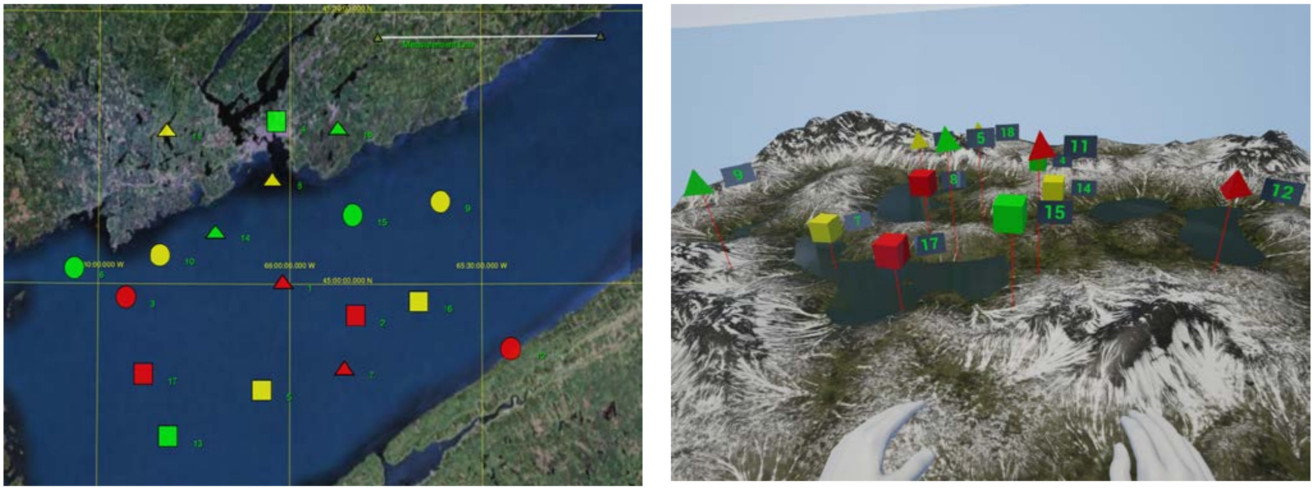

Figure 1. Search environment in the 2D conidition (left) and in the 3D/VR condition (right)

Procedure. The 3D/VR condition consisted of a 10-minute training session to familiarize participants with the VR-specific apparatus, 12 practice trials, and 36 experimental trials. The 2D condition consisted of 12 practice trials and 36 experimental trials. Half of the participants received the 3D/VR condition followed by the 2D condition and the other half received the reverse order. Trials began with the presentation of the search task instructions, which specified the target object's unique identifying number, the target object's domain or classification (except on no-specification trials), and whether the participant was to report the target object's latitude, longitude, altitude or distance from another target object. Participants entered their responses on the keyboard's number pad in the 2D interface condition or on the virtual number pad in the 3D/VR interface condition. Correct responses always consisted of four digits.

In the 2D interface condition, participants accessed an object's location by clicking on the target object, which activated a drop-down menu. Participants selected an option on this menu that activated a secondary menu that displayed the target object's location. To find the distance between two objects, participants clicked on the two target objects and then used the mouse to drag and drop the end points of a distance measurement tool onto the activated targets. Participants then right clicked the measurement line, which activated pop-up menu that displayed the line's current length (i.e., distance between the two targets).

In the 3D/VR interface condition, participants accessed an object's location by fixating on an object, which activated a blue halo that surrounded the object, and then clicked the 3D mouse to activate a pop-up menu that displayed the object's location. To find the distance between two objects, participants fixated on the first target and clicked the 3D mouse to activate it and then fixated on the second target object and activated it. Participants then made a "pinch" gesture with their left hand on a target, which activated a distance finder tool, signalled by the appearance of a blue sphere that was displayed in the participant's virtual left hand. While maintaining the pinch gesture, participants used the mouse to move to the second target. Participants then "dropped" the distance finder (i.e., the blue sphere) on the target by releasing the pinch gesture. A measurement line connecting the two target objects then appeared, with the distance displayed above the line.

Results

Three participants were unable to complete the experiment due to VR-induced motion sickness. Their data were eliminated from all further analyses, which reduced the sample to n=14. Additionally, 3.5% of the trials were flagged as mistrials due to data collection failure and were therefore eliminated from the analyses.

The remaining data were analyzed using a 2 (Interface) x 2 (Search Difficulty) x 3 (Search Specification) repeated measures ANOVA.

Activation Response Times

Activation response times were measured as the time between the onset of the search instructions and the activation of the target (location task) or targets (distance task). Only correct response times were included in the analysis.

Location task. The main effect of interface was not significant, $F(1, 13) = 2.17$, $p > .15$, nor was the main effect of search specification, $F(2, 26) = 1.03$, $p > .35$. The main effect of search difficulty was significant, $F(1, 13) = 27.56$, $p < .001$, with faster responses on 18-object trials (M=5.67 s) than on 36-object trials (M=8.82 s). The interface by search difficulty interaction was not significant (F<1). As shown in Figure 2 (left panel), the interface by search specification interaction was significant, $F(2, 26) = 7.62$, $p < .005$. This interaction was driven by domain-specified targets being activated significantly slower than non-specified and classification-specified targets in the 2D interface condition, but being activated faster in the 3D/VR condition.

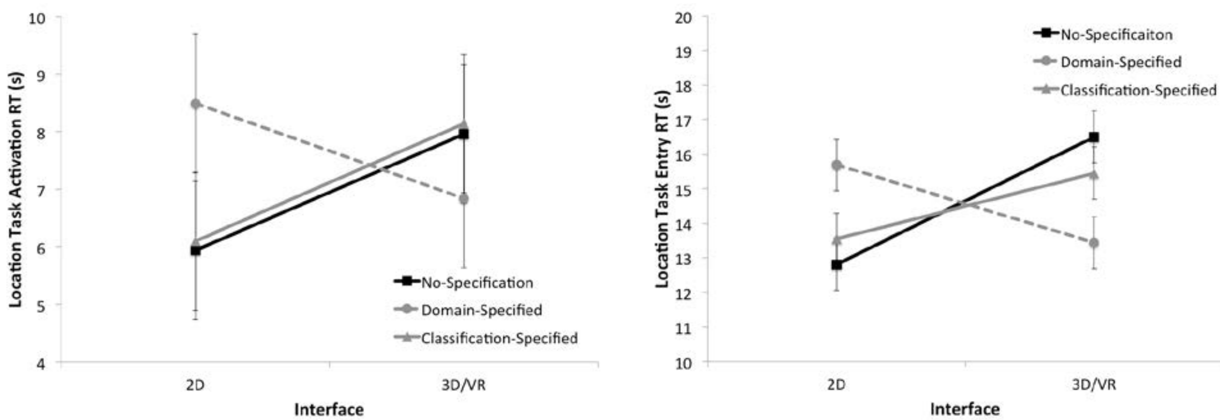

Figure 2. Location task activation response times (left panel) and entry response times (right panel) as a function of interface and search specification with 95% confidence intervals.

Distance task. There was a significant main effect of interface, $F(1,13) = 19.38$, $p < .005$, with faster responses in the 2D interface condition (M=9.72 s) than in the 3D/VR interface condition (M=13.82 s). The main effect of search difficulty was also significant, $F(1, 13) = 42.01$, $p < .001$, with faster responses on 18-object trials (M=8.71 s) than on 36-object trials (M=14.82 s). The main effect of search specification was not significant (F<1), nor were the interface by search specification or interface by search difficulty interactions (Fs<1).

Entry Response Times

Entry response times were measured as the time between the onset of the search instructions and the entry of the 4-digit target object location or distance. Only correct response times were included in the analysis.

Location task. Neither the main effect of interface (F<1) nor the main effect of search specification, $F(2, 26) = 2.26$, $p > .10$, were significant. The main effect of difficulty was significant, $F(1, 13) = 35.67$, $p < .001$, with faster responses on 18-object trials (M=13.26 s) than on 36-object trials (M=15.88 s). The interface by search difficulty interaction was not significant (F<1). As shown in Figure 2 (right panel), the interface by search specification interaction was significant, $F(2, 26) = 6.72$, $p < .005$. As in the location task activation response time data, this interaction is caused by significantly slower responses on domain-specified trials than on no-specification and classification-specified trials in the 2D condition, but significantly faster responses in the 3D/VR condition.

Distance task. The main effect of interface was not significant, $F(1, 13) = 1.54$, $p > .20$. The main effect of search specification was marginally significant, $F(2, 26) = 3.28$, $p < .06$, with slower responses on domain-specified trials (M=29.14 s) than on no-specification (M=27.04 s) or classification-specified (27.34 s) trials. The main effect of difficulty was also significant, $F(1, 13) = 127.74$, $p < .001$, with faster responses on 18-object trials (M=23.83 s) than on 36-object trials (31.84 s). There was a marginally significant interface by search specification interaction, $F(2, 26) = 3.24$, $p < .06$ (Figure 3, left panel). Entry response times were significantly slower on domain-specified trials than on no-specification and classification-specified trials in the 2D condition, but did not differ in the 3D/VR condition. The interface by difficulty interaction was also marginally significant, $F(1, 13) = 3.29$, $p < .10$ (Figure 3, right panel), with faster entry response times in 2D than in 3D/VR for 18-object searches, but not for 36-object searches.

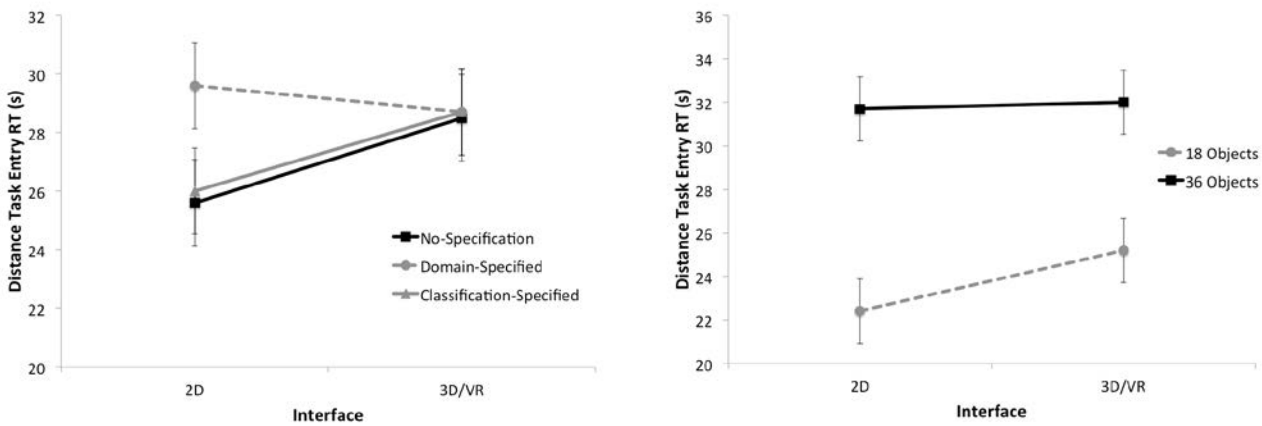

Figure 3. Distance task entry response times as a function of (left panel) interface and search specification and (right panel) interface and search difficulty with 95% confidence intervals.

Accuracy

Accuracy was recorded as binary data (correct vs. incorrect). In order for a trial to be deemed correct, the participant had to enter their 4-digit response before the trial timed-out and the response had to match the target's true location or distance value.

Location task. The main effects of interface and search specification were not significant ($Fs<1$). There was a marginally significant main effect of difficulty, $F(1, 12) = 4.11$, $p < .07$, with higher accuracy on 18-object trials (97.4%) than on 36-object trials (94.7%). Neither the interface by search specification interaction, $F(2, 24) = 1.12$, $p > .30$ nor the interface by difficulty interaction ($F<1$) were significant.

Distance task. The main effect of interface was not significant, $F(1, 11) = 1.80$, $p > .20$. The main effects of search specification and difficulty were not significant ($Fs<1$). Neither the interface by search specification interaction, $F(2, 22) = 1.28$, $p > .25$, nor the interface by difficulty interaction ($F<1$) were significant.

Discussion

The key finding is that the current implementation of a 3D/VR user interface did not yield many performance advantages over a traditional 2D interface on a visual search task that required the user to report a target's location or the distance between two targets. However, one observed advantage of 3D/VR over 2D is that the 3D/VR interface allowed users to find and query targets faster when the target's domain (airborne, surface, sub-surface) was known (see Figure 2). This finding supports the hypothesis that the visual separation of vertically disparate objects in 3D/VR helps the user effectively constrain their search to include only relevant objects.

The search difficulty manipulation had a robust and consistent effect on performance. In contrast, search specification typically did not influence performance, which indicates that overall, participants were not using the additional information provided in domain-specified or classification-specified trials to help guide their searches. One explanation for this finding is that participants simply ignored this supplementary information when searching for the target because its unique numeric identifier was sufficient. In order to encourage participants to use this additional information, the search instructions in subsequent experiments will be modified such that the target's number will be enclosed in a circle, triangle, or square to indicate its domain or will be colored green, yellow, or red to indicate its classification.

The fact that there are many experimental differences between the 2D and 3D/VR interfaces besides the dimensionality of the search environment and how the user interacts with it makes it impossible to pinpoint why the 3D/VR interface did not yield the anticipated benefits. As a starting point, it was clear that many participants struggled with the 3D/VR interface apparatus, including the 3D mouse and the virtual number pad. Future experiments will therefore attempt to level the playing field by having participants in the 2D condition view the display on a Oculus Rift, navigate using the 3D mouse, and respond using a virtual number pad. It is anticipated that the continual refinement of the 3D/VR interface's usability, coupled with the elimination key experimental confounds between interface conditions will provide a clearer picture of the benefits of immersive visualization technologies.

Acknowledgements

This research is supported by General Dynamics Mission Systems Canada and by an Ontario Centres of Excellence grant awarded to C.H. We would like to acknowledge Danielle Krukowski for her assistance with data collection.

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