VIEWPOINT TETHERING IN COMPLEX TERRAIN NAVIGATION AND AWARENESS

Matthew Lamb and J. G. Hollands
Defence Research & Development Canada - Toronto
Toronto, Ontario, Canada

Twelve participants navigated a simulated vehicle across complex virtual terrain using five different display viewpoints: egocentric, dynamic tether, rigid tether, three-dimensional (3D) exocentric, and two-dimensional (2D) exocentric. While navigating, participants had to avoid being seen by simulated enemy units. After the navigation task, participants' spatial awareness was assessed using a recognition task. The egocentric display was more effective than exocentric displays (2D or 3D) for navigation, and the exocentric displays were more effective than egocentric for time seen during navigation and the recognition task. The tethered displays generally produced intermediate results, but minimized the time during which the participant's avatar was visible to enemy positions. In summary, it would appear that the tether facilitated spatial awareness involving knowledge of locations of interest with respect to one's own position while navigating.

INTRODUCTION

The integration of data from local and regional sensors will provide remotely operated vehicle (ROV) operators with reconstructed two-dimensional (2D) and three-dimensional (3D) visual representations of complex terrain. Virtual or augmented reality visualizations allow the use of viewpoints that would not normally be feasible in reality. Designers are then faced with the choice of optimal viewpoint parameters that maximize human performance.

It is widely accepted that the nature of the task dictates the best viewpoint on geographic terrain. Tasks involving shape understanding are best performed with 3D viewpoints because all three dimensions are integrated into one representation (St. John, Cowen, Smallman, & Oonk, 2001). 2D viewpoints are best for tasks judging relative position, due to the distortions associated with 3D viewpoints (St. John et al., 2001; Wickens, Thomas, & Young, 2000). For navigation and wayfinding, local guidance is best performed from an egocentric perspective, while global spatial awareness tasks should be carried out with an exocentric, fixed viewpoint showing most or all of the terrain (Wickens & Hollands, 2000).

Although the optimal viewpoint is task dependent, switching between multiple displays can be disorientating. The *tethered* viewpoint commonly used in computer gaming has been proposed as one solution (Colquhoun & Milgram, 2000; Wickens & Prevett, 1995). A tethered view couples the viewpoint to the avatar's position and orientation, but typically is higher up and behind the avatar, showing more of the terrain. In this sense, it provides visual momentum by providing a view that incorporates egocentric and exocentric qualities. There is some evidence in support of the tethered concept: Wang and Milgram (2001) found that a tethered display produced better performance than an egocentric display for aerial navigation, and Wickens and Prevett found advantages with a tether-like display (versus egocentric) for spatial awareness.

However, a rigid tether violates the principle of motion compatibility. As the operator directs the avatar to the right, the virtual world moves to the left. The rigid tether also behaves like a compensatory tracking system (Colquhoun & Milgram, 2000) and produces a rather jerky motion especially with a longer tether because any small angular change in heading of the avatar produces a large displacement of the virtual camera.

A dynamic tether (equivalent to a non-rigid, dynamic mass spring damper system) creates a display incorporating both compensatory and pursuit tracking attributes and may reduce the motion compatibility problem. The net effect is a smoother motion as the avatar moves through the environment, because the non-rigid dynamics mean that abrupt changes in heading produce a slightly lagged motion of the camera that nullifies small abrupt heading changes. However, Wang and Milgram (2001) did not find any advantage to the dynamic tether over a rigid tether for six-degrees-of-freedom (DOF) aerial navigation.

Ground-based navigation differs from aerial navigation in that the operator is only controlling one rotational DOF, yaw. Yu and Andre (1999) used an arcade-driving simulator to evaluate four different viewpoints. A tethered viewpoint slightly removed from the vehicle provided the best navigation and situational awareness. However, this driving task differs in several fundamental ways from off-road navigation in complex terrain.

We examined the effect of viewpoint on controlling a vehicle navigating complex terrain, and on concurrent and subsequent spatial awareness. Five viewpoints were used (see Figure 1): egocentric, rigid tether, dynamic tether, 3D exocentric (perspective view on terrain but viewpoint does not change with vehicular position), and a 2D exocentric map (God's eye view). We predicted that navigational performance would be better in the egocentric over either exocentric view because the egocentric display provides well-learned egomotion cues commonly available as one navigates through an environment, either in vehicle or on foot (Wickens & Hollands, 2000). We also predicted that the tethered display would be more effective than the exocentric displays for navigation, and as effective as the egocentric display. Finally, we predicted that navigational performance would be better with dynamic than rigid tethering, reducing the motion compatibility problem and allowing pursuit tracking.

To assess spatial awareness during navigation, while participants navigated between waypoints they were instructed to avoid being seen by enemy units. The time that the tank was seen from at least one of the enemy positions was recorded. After each trial, observers had to choose the terrain just navigated from a set of distractor terrains. Given that both of these spatial awareness tasks require a sense of the global characteristics of the terrain, we predicted the opposite order of effectiveness: exocentric worse than egocentric, with the tethered display as effective as the exocentric display. We did not predict any effect for dynamic (versus rigid) tethering for these tasks.

We measured each participant's map reading ability using the Map Reading Test (Goerger, 1998). This test was designed to determine if an individual can read the terrain features on a map and associate them with real-world terrain features. We were interested in determining if map-reading ability affected performance on the navigation and spatial awareness tasks.

METHOD

Participants

12 (7 female, 5 male) volunteers, aged 20-50, with normal or corrected-to-normal vision were recruited from DRDC Toronto and the nearby community. Participants were financially compensated for their participation.

Stimuli and Apparatus

Stimuli were presented on a 50.8 cm (20") diagonal LCD display. Graphics were rendered using C++ and Open GL on a Windows 2000 workstation with a 3Dlabs Wildcat III 6110 graphics card. Eleven terrain maps were created from digital elevation data using Multigen Paradigm Creator software (1 terrain for familiarization + 10 for experimental trials). Vector topographical lines were created for each terrain model. The avatar was a three-dimensional model of a tank, controlled by a joystick. Blue spheres on poles represented waypoints; cubes on poles represented enemy positions.

These terrain maps were shown using five viewpoints (egocentric, rigid and dynamic tether, 3D exocentric and 2D exocentric). Three status bars representing line of sight from enemy positions were shown in the upper left of the display. A heading indicator was placed at the bottom of the display. Figure 1 shows examples of the five display types with sample terrain.

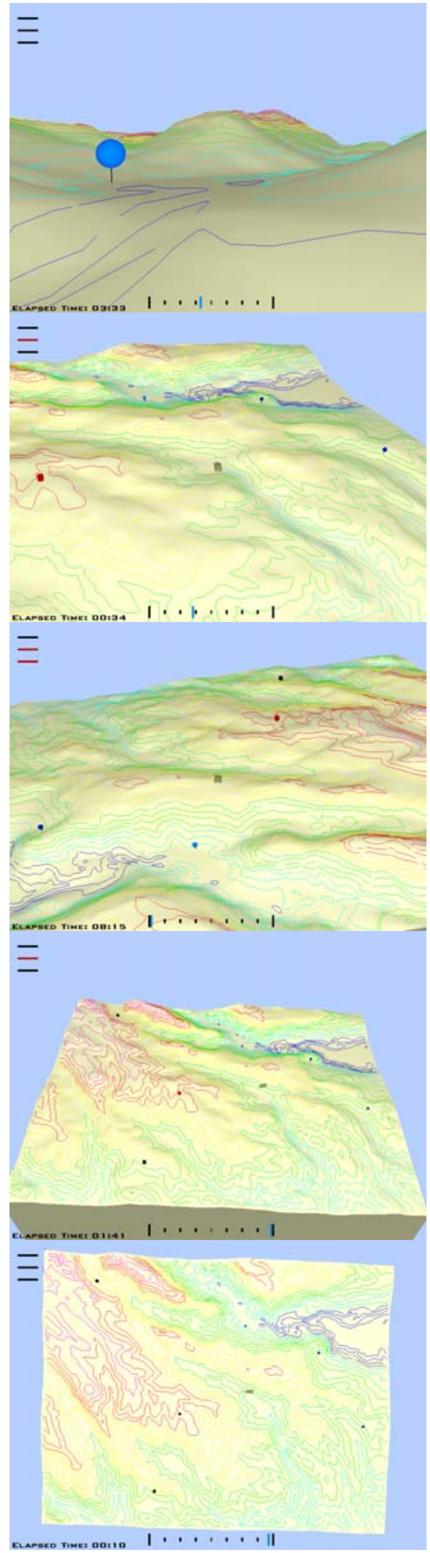

Figure 1. Example views of each display type. Top to bottom: egocentric, dynamic tether, rigid tether, 3D exocentric, 2D exocentric.

Design and Procedure

Each participant completed three one-hour sessions over a maximum of four days. In the first session, participants completed the Map Reading Test and then performed a familiarization task in which they explored the five display conditions (2D exocentric, 3D exocentric, rigid tether, dynamic tether, and egocentric), the joystick, and the general environment. Written and oral instructions were provided to the participant.

For the experimental trials, each of the 10 terrains had 2 point scenarios, leading to 20 trials for each of the five conditions, or 100 trials in total. The 100 trials were run in 5 blocks of 20 randomly selected trials. Block 1 was run on the first day, Blocks 2 and 3 on the second, and Blocks 4 and 5 on the third. Thus, the order of trials was completely random, with each participant having a different random order, and the order of conditions was also randomized.

For the navigation task, the participant was instructed to drive the avatar between waypoints as quickly as possible, while remaining out of sight of enemy positions. The shape of the terrain controlled the avatar's speed. Moving the joystick left and right controlled the yaw rotation, the former rotating the avatar clockwise, the latter rotating counter clockwise.

When the tank entered the line of sight of an enemy position, the enemy cube's color changed and corresponding status bar changed from black to red. The heading indicator indicated the direction of the next waypoint in the tank's forward 180-degree field of view.

The avatar's position was sampled approximately every 100 ms. The task commenced 2 s after the simulation had loaded. The trial ended once the third waypoint had been reached. Lengths of path were necessarily correlated with time data (longer paths took more time to traverse) and are therefore not reported here.

The amount of time the tank was within the sight of any enemy position was recorded and this *time-seen* measure was used to assess concurrent spatial awareness. A four-alternative forced choice (4AFC) *recognition task* followed the completion of each trial by providing rotating images of four terrains. Participants were required to choose which terrain they traversed in the navigation task. Response time (RT) and accuracy were recorded. Participants were debriefed at the end of the experiment.

RESULTS

Performance Measures

For each performance measure, a mean score was computed for each participant in each condition. These means were submitted to a one-way within-subjects analysis of variance (ANOVA) in each case. Planned comparisons were computed on those orthogonal contrasts relevant to predictions. Figure 2 depicts the mean values for each measure, and associated within-subjects standard error values.

Display type affected navigation time, $F(4,44) = 6.94$, $MSE = 10.4$, $p < .001$. Navigation time was less for the egocentric than exocentric displays, $F(1,11) = 8.20$, $MSE = 23.49$, $p < .05$. Although navigation time for tethered displays was less than for exocentric, the difference only approached conventional significance levels, $F(1,11) = 2.84$, $MSE = 8.70$, $p < .13$. Navigation time was less for the egocentric than the tethered conditions, $F(1,11) = 5.70$, $MSE = 16.90$, $p < .05$. There was no difference in navigation time between rigid and dynamic tethers, $F < 1$.

Display type affected time seen, $F(4,44) = 8.09$, $MSE = 1.55$, $p < .0001$. Time seen was less for exocentric than egocentric displays, $F(1,11) = 6.65$, $MSE = 2.40$, $p < .05$. Time seen was less for tethered than egocentric, $F(1,11) = 18.91$, $MSE = 2.48$, $p < .005$, and exocentric displays, $F(1,11) = 7.65$, $MSE = 1.60$, $p < .05$. There was no difference in time seen between rigid and dynamic tethers, $F < 1$.

Display type affected recognition accuracy, $F(4,44) = 28.57$, $MSE = 0.0129$, $p < .0001$. Accuracy was greater for the exocentric than egocentric displays, $F(1,11) = 103.52$, $MSE = 0.0138$, $p < .0001$. Accuracy was greater for tethered than egocentric displays, $F(1,11) = 26.91$, $MSE = 0.0164$, $p < .0005$. Accuracy was greater for exocentric than tethered displays, $F(1,11) = 25.00$, $MSE = 0.0169$, $p < .0005$.

Display type affected RT, $F(4,44) = 2.98$, $MSE = 1.295$, $p < .05$. RTs were shorter for exocentric than egocentric displays, although the difference failed to reach conventional significance levels, $F(1,11) = 1.57$, $MSE = 3.243$, $p < .25$. There was no difference in RT between tethered and egocentric displays, $F < 1$. RTs were shorter for exocentric than tethered displays, $F(1,11) = 8.42$, $MSE = 1.702$, $p < .05$.

Map Reading Test

A map reading test score was obtained for each participant. These scores were correlated with each performance measure averaged over all conditions, and within each condition. No correlation reached conventional significance levels ($p > .05$ in all cases).

DISCUSSION

As predicted, the egocentric display was more effective than exocentric displays (2D or 3D) for navigation, and the exocentric displays were more effective than egocentric for spatial awareness, both for time seen during navigation and the recognition task (significantly for accuracy; not significantly for RT). This result is in keeping with a large literature contrasting the relative benefits of egocentric and exocentric displays for navigation and spatial awareness tasks (e.g., St. John et al., 2001; Wickens & Hollands, 2000).

The tethered displays generally produced intermediate results. For navigation, they were less effective than the egocentric display and roughly equivalent to the exocentric displays. For spatial awareness recognition the tethered displays were more effective than the egocentric display, but less effective than the exocentric displays.

More importantly however, the tethered displays were the most effective displays for spatial awareness using the time-seen measure. Not only were the tethered displays more

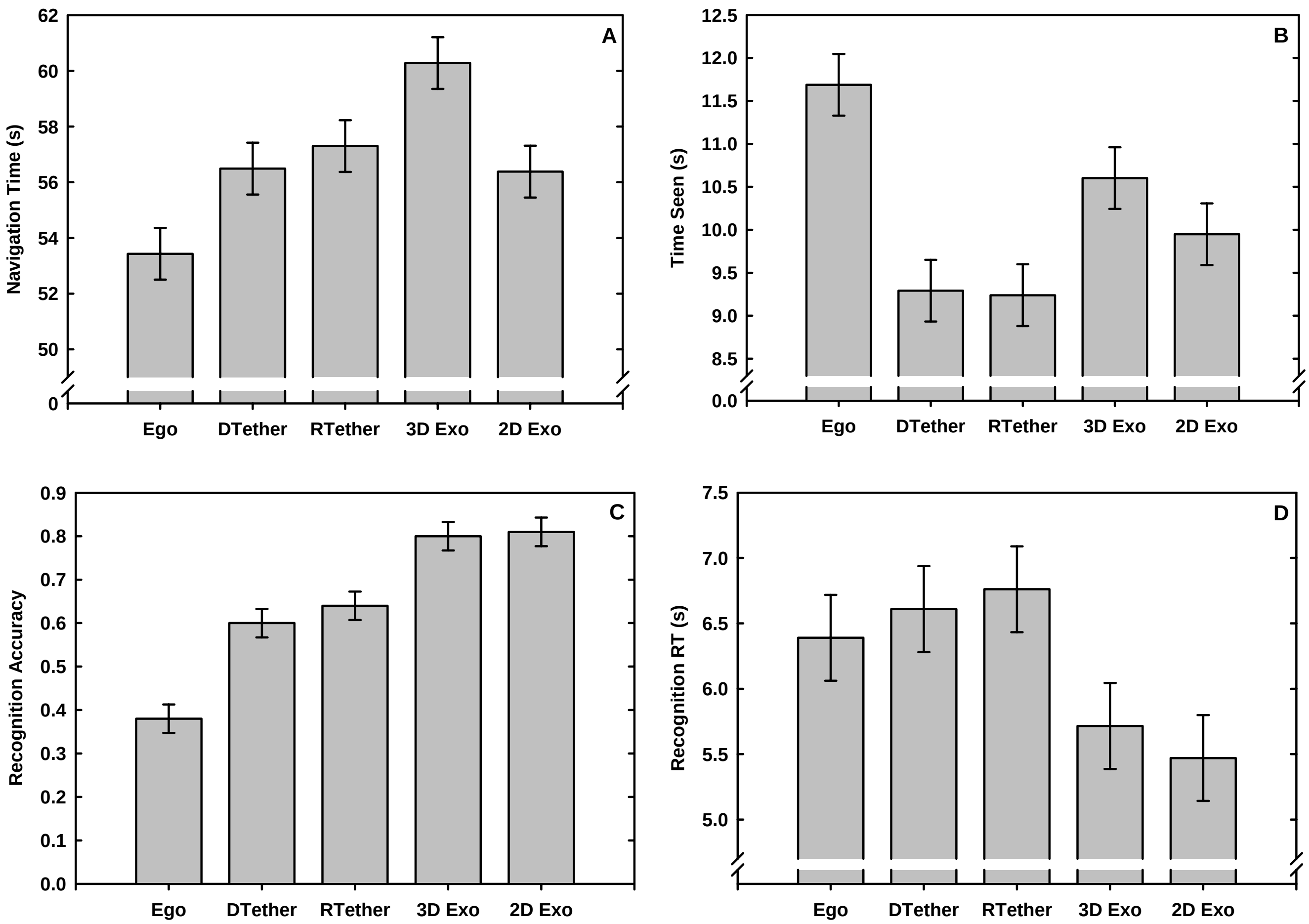

Figure 2. Mean and standard error values for the four measures: a) Navigation Time; b) Time Seen; c) Recognition Accuracy; d) Recognition RT. Ego = Egocentric; DTether = Dynamic Tether; RTether = Rigid Tether; 3D Exo = 3D Exocentric; 2D Exo = 2D Exocentric.

effective than the egocentric display, they were also more effective than the exocentric displays. Use of the tether minimized the time during which the participant's avatar was visible to enemy positions.

We obtained no effect of tether dynamics in the navigation task. Wang and Milgram (2001) also did not find a performance advantage, although they found that their subjects preferred the dynamic over the rigid tether. The display problems associated with the rigid tether may not be evidenced until certain levels of fatigue are reached. Performance benefits for the dynamic tether may therefore be difficult to demonstrate in short experimental sessions.

Our participants' map reading abilities did not affect their performance on these tasks. Thus, the obtained results appear independent of spatial ability. Although we did not assess whether our participants had any specialized training in navigation (e.g., orienteering) we speculate that participants having such training would have scored higher on the map reading test. Thus we think it unlikely that specialized navigation training would have affected the pattern of results we observed.

The order of conditions was randomized in this experiment. This meant we could not eliminate the possibility of asymmetric transfer effects. We plan to examine this in future research by using a between-subjects design.

In summary, it would appear that the tether was useful in spatial awareness involving knowledge of locations of interest with respect to one's own position while navigating. In this sense, perhaps our results help to identify a navigation task whose performance is dissociated from conventional exocentric spatial awareness and egomotion. The tethered display may be the most effective display for this type of egocentric spatial awareness task.

ACKNOWLEDGMENTS

The authors thank Kevin Trinh for conducting analyses and preparing the graphs.

REFERENCES

Colquhoun, H., & Milgram, P. (2000). Dynamic Tethering for Enhanced Remote Control and Navigation. In

Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting (pp. 146-149). Santa Monica, CA: Human Factors and Ergonomics Society.

Goerger, S. R. (1998). *Spatial knowledge acquisition and transfer from virtual to natural environments for dismounted land navigation.* Unpublished Master's thesis, Naval Postgraduate School, Monterey, CA.

St. John, M., Cowen, M. B., Smallman, H. S., & Oonk, H. M. (2001). The use of 2D and 3D displays for shape-understanding versus relative –position tasks. *Human Factors, 43,* 79-98.

Wang, W., & Milgram, P. (2001). Dynamic viewpoint tethering for navigation in large-scale virtual environments. In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp. 1862-1866). Santa Monica, CA: Human Factors and Ergonomics Society.

Wickens, C. D., & Hollands, J. G. (2000). *Engineering psychology and human performance* (3rd Ed.). Upper Saddle River, NJ: Prentice-Hall.

Wickens, C. D., & Prevett, T. T. (1995). Exploring the dimensions of egocentricity in aircraft navigation displays. *Journal of Experimental Psychology: Applied, 1,* 110-135.

Wickens, C. D., Thomas, L. C., & Young, R. (2000). Frames of reference for the display of battlefield information: Judgment-display dependencies. *Human Factors, 42,* 660-675.

Yu, P.C., & Andre, A.D., (1999). A simulator evaluation of four perspective scene viewpoints. In *Proceedings of the Silicon Valley Ergonomics Conference and Exposition-ErgoCon 99* (pp. 233-242).