VISUAL MOMENTUM AND TASK SWITCHING WITH 2D AND 3D DISPLAYS OF GEOGRAPHIC TERRAIN

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We were interested in determining if the visual momentum provided by gradual transition between two- and three-dimensional (2D and 3D) views of geographic terrain aided task switching. Twenty-two participants made judgments about the properties of two points placed on 2D or 3D displays of terrain. Participants performed the tasks in pairs of trials, switching tasks and displays between trials. On half the trials (continuous transition), the display dynamically rotated in depth from one display format to the other. On the other half (discrete transition), participants were immediately shown the alternate display format. The results showed that response time after transition was less for the continuous condition, and that accuracy was greater for the continuous condition, especially for the 3D display. We argue that this was because the continuous transition provided improved visual momentum between consecutive displays, and recommend the use of dynamic transition when switching views on geographic terrain.

INTRODUCTION

A topic that has received little attention with respect to tactical displays is the role of *visual momentum* in user-computer interaction, or the user's ability to extract and integrate data from multiple consecutive display windows (Woods, 1984). Some methods proposed for improving visual momentum include placing perceptual landmarks across displays, overlapping consecutive representations, or spatially representing the relationship among the displays (Woods, 1984). Another method involves gradually transforming one display into another. We were interested in determining if the visual momentum provided by gradual transition helped people when they switched tasks.

There is benefit to allowing multiple views on geographic terrain, and therefore both two- and three-dimensional (2D and 3D) display formats should be made available to an observer, such as a military commander or geological engineer. This is because the effectiveness of 2D and 3D displays of geographic terrain depends on the judgment task (for a summary, see Wickens & Hollands, 2000). 2D renderings are generally useful for judging relative position, because the normal viewing angles minimize distortion, while the advantage of 3D views is in shape and layout understanding, because they integrate all three dimensions and allow for features otherwise invisible in 2D view to be depicted (St. John, Cowen, Smallman, & Oonk, 2001; Wickens & Thomas, 2000). This implies that to perform these various types of tasks, the observer will need multiple views.

The military observer also needs to switch tasks frequently when monitoring a battlespace. While the display can be changed to match the task at hand, the actual transition from one display to another may still be difficult. Abruptly changing frames of reference (changing views from 2D to 3D and vice versa) can cause disorientation. To alleviate this problem, a gradual transition between 2D and 3D perspectives incorporating animation of viewpoint during task switching may be effective.

Hollands and Ivanovic (2002) addressed the issue of whether gradual transition in viewpoint (e.g., from 2D topographic map to 3D terrain viewed from a 45 degree angle) improved task performance relative to discrete transition. To do this, they used two tasks developed by St. John et al. (2001). Tasks required the participant to judge whether one ground location was visible from another (*A-See-B* Task), or which one of two points was of higher altitude (*A-Hi-B* Task). The St. John et al. results showed that the A-See-B task was performed better with a 3D display, whereas the A-Hi-B Task was performed better with a 2D topographic map.

With respect to tasks and displays, the Hollands and Ivanovic (2002) experiment was a replication of St. John et al. (2001), Experiments 4 and 5. However, Hollands and Ivanovic had participants switch tasks across trials to determine whether knowledge of terrain obtained when performing one task in the first trial affected performance in a different task on the subsequent trial. On half the trial pairs, there was a continuous rotation of the space from 2D to 3D views (or vice versa); on the other half, a blank screen was shown for the equivalent duration (about 3 s). They found that the transition improved performance, reducing response time without sacrificing accuracy. However, the 3-

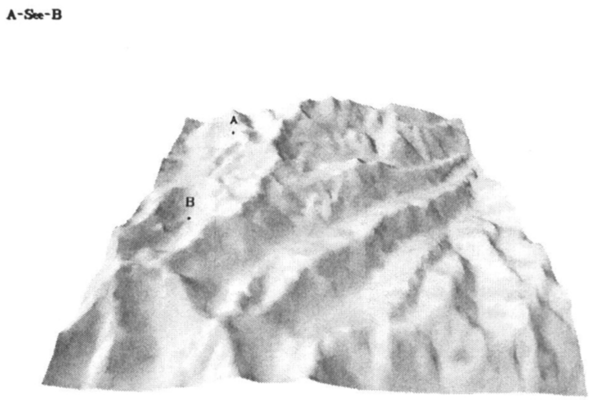

Figure 1. Example of 3D display used in experiment.

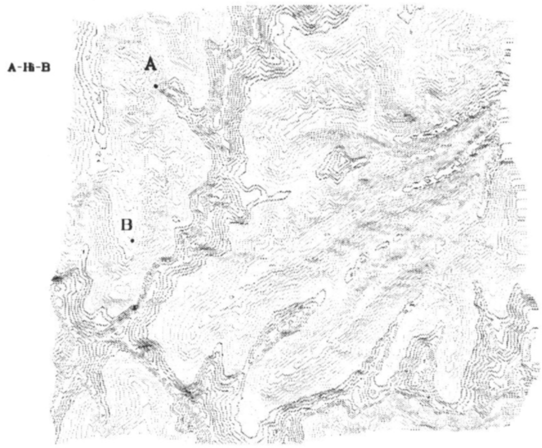

Figure 2. Example of 2D display used in experiment.

second blank screen in the discrete transition condition may have led to participants forgetting terrain information shown on the first trial. This possibility would mean that better performance in the continuous condition was not due to better visual momentum but rather due to an artifact of the control condition.

In the current experiment, we changed the control condition used by Hollands and Ivanovic (2002) so that the display for the second trial was shown immediately following the first to eliminate this possibility. If the advantage for continuous transition obtained by Hollands and Ivanovic was not obtained, this would imply that their results were due to participants forgetting terrain information while the blank screen was shown. In contrast, if the advantage for continuous transition was a result of visual momentum, then the results should still obtain when there is no blank screen in the control condition.

METHOD

Participants

We ran 22 participants (12 male and 10 female), aged 18 to 53 with normal or corrected-to-normal vision, recruited from DRDC Toronto and the nearby community. Participants were financially compensated for their participation.

Stimuli and Apparatus

Ten terrain models were created from Digital Terrain Elevation Data (DTED) of regions of Wyoming using Creator/TerrainPro (Multigen-Paradigm, 2001a) modelling tools. Each model represented a 13351 m x 11288 m area. In general, 2D and 3D displays were constructed to resemble those used by St. John et al. (2001). The Vega visual simulation system (MultiGen-Paradigm, 2001b) was used to render each terrain model as a 3D display, and an example is shown in Figure 1. The 3D display depicted the terrain model at a viewing angle of 45 degrees with respect to the ground plane. MICRODEM (Microcomputer Digital Elevation Models, Guth, 2001) was used to create a 2D display with coloured contour lines (see Figure 2 for an example).

Pairs of A and B points were randomly selected for each terrain model, with the following constraints. The distance between points in a pair was at least 2000 m, and points were separated in altitude by at least 500 m. To avoid selecting a point near the model edge, the points were selected from a central 11600 m x 10600 m area. Four pairs of points were selected for each terrain and each pair satisfied a specific task condition. For half the A-B pairs, point B could be seen from point A (A-See-B-Yes pairs). For the other half (A-See-B-No pairs), point B could not be seen from point A. For half the A-See-B-Yes pairs, point A was higher than point B, and for the other half, point B was higher. The same was true for A-See-B-No pairs. The terrain models and pair locations were the same for both transition conditions.

The experiment was conducted in a room with dimmed lighting to accentuate visibility and contrast. The stimuli were presented on a 21" (53 cm) Hitachi SuperScan 814 monitor at 1280 x 1024 resolution, and keystrokes and response times were

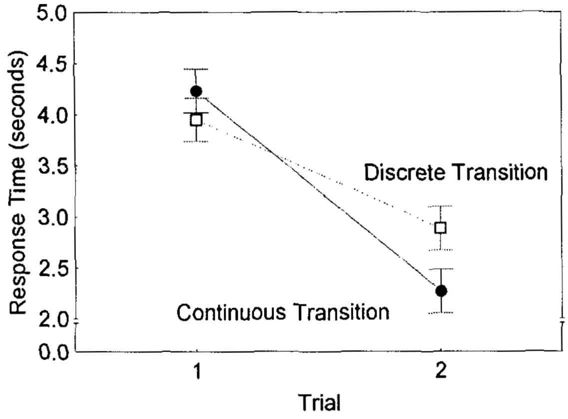

Figure 3. Response time in seconds as a function of transition and trial in pair. Error bars indicate the within-subjects standard error of the mean (Loftus & Masson, 1994) in all graphs.

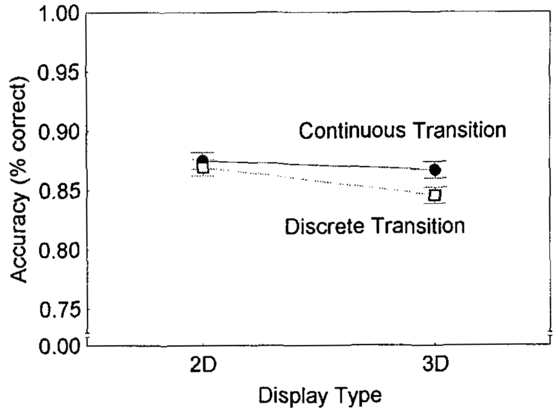

Figure 4. Accuracy (proportion correct) as a function of transition and display type.

collected by a Windows NT graphics workstation. Participants sat at a comfortable viewing distance.

Design and Procedure

The experiment had a 2 x 2 x 2 x 2 within-subjects design with display (2D vs. 3D), task (A-See-B vs. A-Hi-B), transition (continuous vs. discrete), and trial (1st vs. 2nd) as independent variables. Dependent measures were response time and accuracy (proportion correct).

Each participant read a brief description of the experiment and signed an informed consent form. General questions about the experimental design were answered. Participants performed two tasks. In the *A-Hi-B* task, participants indicated whether point A was higher than point B. In the *A-See-B* task, participants indicated whether they could see point B if they were standing at point A. There was one block of practice trials with a unique terrain model prior to each transition condition.

Participants performed the tasks in trial pairs. The terrain model and A-B points were the same within each trial pair. For each pair, there was a switch in the display type across trials from 2D to 3D (or vice-versa), and a simultaneous task switch, leading to 4 possible sequences of displays and tasks. As noted above, there were four pairs of A-B points for each terrain model, resulting in 16 unique combinations of trial pairs for each of the 10 terrain models, or 160 trials pairs in total. These 160 trial pairs were arranged in 4 blocks (40 trials per block).

To create each block, a set of 4 trial pairs was chosen randomly without replacement for each of the 10 terrain models, with the constraint that one combination of four A-B pairs was included. The order of the terrain models was randomized within blocks. The ordering of terrain models and trial pairs across blocks was unique for every participant.

There were 160 trial pairs (identical with respect to order of terrain model and trial pairs) for each transition condition. In the *continuous transition* condition, the viewpoint continuously rotated from a position centered directly above the terrain (2D) to a point such that the angle between ground level and the line of sight with respect to the geographic center of the terrain was 45 degrees (3D) from the first trial to the second (vice versa for 3D to 2D). The height of the viewpoint above the terrain was constant. A fade-in/fade-out process occurred prior to the rotation when transitioning from the 2D display to the 3D model viewed from above. Fading occurred after the rotation when transitioning from 3D to 2D. Shading was added when fading into the 3D display (and removed when fading out the 3D display). The rotation took approximately 3 seconds. The A-B points were visible during the transition.

In the *discrete transition* condition, the terrain model was shown sequentially: first using the 2D display, and then the 3D display (or vice versa). There was no visible delay between the views. The order of transition conditions was counterbalanced across participants. In the discrete condition, the display and task prompt for the second trial was shown immediately after the participant responded to the first trial.

At the start of each trial, a task prompt ("A-See-B" or "A-Hi-B") was shown at the same time as the terrain (see Figures 1 and 2). Response time (RT) was measured from display onset until the participant responded. On the second trial in the continuous condition, the task prompt appeared when the terrain had finished rotating. In this case, RT was measured from the time the task prompt was displayed until the participant responded.

Each pair of trials was initiated by pressing the space bar. The participant's response on the first trial initiated the transition. For each trial in the pair, the participant responded by pressing a key marked "Y" or "N" (the "1" or "2" key on the numeric keypad), and the participant was asked to respond as quickly and accurately as possible.

The experiment took about 90 minutes to complete. At the conclusion of the experiment, the experimenter thanked and debriefed the participant, and answered questions.

RESULTS

Response Time

A mean RT for accurate trials was computed for each participant in each condition. These data were submitted to a 2 x 2 x 2 x 2 within-subjects analysis of variance (ANOVA) with transition, task, display, and trial serving as independent variables. Continuous transition produced shorter RTs than discrete transition for the second trial in a pair (but not the first), $F(1,21) = 18.61$, $MSE = 0.953$, $p < .0005$. Mean values are shown in Figure 3. RTs were shorter with the 3D than the 2D display, but this difference was greater for the A-See-B task (4.13 s for 2D vs. 2.96 s for 3D), than the A-Hi-B task (3.28 s for 2D and 2.97 s for 3D), $F(1, 21) = 55.59$, $MSE = 0.283$, $p < .0001$.

Accuracy

Each trial was scored as correct or incorrect. The proportion of correct trials was computed for each participant in each condition. These data were submitted to a 2 x 2 x 2 x 2 within-subjects ANOVA. Continuous transition produced greater accuracy than discrete transition, $F(1, 21) = 6.52$, $MSE = 0.0025$, $p < .05$, although the continuous advantage was larger for the 3D display, $F(1, 21) = 5.45$, $MSE = 0.001$, $p < .05$. Mean values are shown in Figure 4. Accuracy for the A-See-B task was higher with the 3D display, but accuracy for the A-Hi-B task was higher with the 2D display, especially on the first trial, $F(1, 21) = 6.90$, $MSE = 0.0016$, $p < .05$. Mean values are shown in Figure 5.

DISCUSSION

As observers switched tasks and display formats, a continuous transition improved performance relative to the discrete condition. Participants were faster on the second trial of the pair

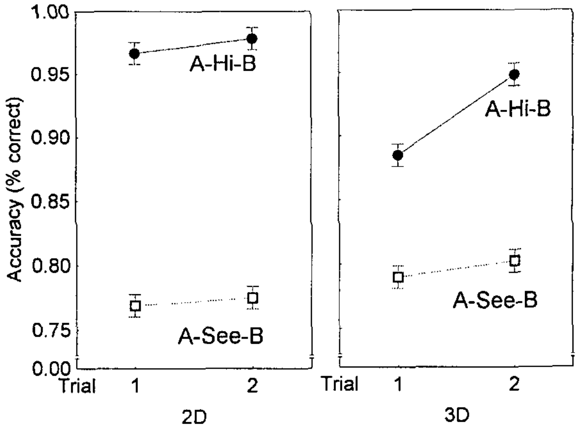

Figure 5. Accuracy (proportion correct) as a function of task, display, and trial in pair.

with the continuous transition. Presumably, this was because the transition provided improved visual momentum between consecutive displays. Accuracy was generally higher with continuous transition, both before and after transition. This meant that there was no evidence of a speed-accuracy tradeoff with respect to this effect--accuracy was higher after the continuous transition.

Why was accuracy also better with continuous transition on Trial 1 (before the transition)? Observers made judgments about each terrain map multiple times in sequence within a block. Perhaps the continuous transition helped observers build and maintain a mental representation of each terrain over the sequence. The continuous transition was especially beneficial for judgment accuracy with 3D displays. The accuracy results also replicated the St. John et al. (2001) results showing a 2D advantage for the A-Hi-B task but a 3D advantage for the A-See-B task.

In future work we plan to examine the effect of changing the points while keeping the terrain model constant. This will provide some insight into the question of whether it is the general terrain or the points in relation to the terrain that is better preserved with dynamic transition. Other possibilities include looking at the different types of smooth transition available, and examining how other visual momentum methods can be applied to the visualization of terrain. We also note the possibility that the current method may have provided an advantage for the continuous case, in that the transition itself may have served as a sort of "preview" of task-relevant information not available in the discrete condition. We plan to examine this possibility by providing similar preview for the discrete case.

Regardless, the current results show that advantages for continuous transition obtained by Hollands and Ivanovic (2002) were not an artifact of the blank screen delay that they used. In combination with the results obtained by Hollands and Ivanovic, the current results indicate that dynamic transition should assist the observer in a multi-task environment. This may be useful in the design of future command and control and command post systems. The use of dynamic transition is therefore recommended when commanders are viewing multiple display windows over time. The results should also have implications for other domains, such as geographic information systems and virtual environments.

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