Task Switching with 2D and 3D Displays of Geographic Terrain: The Role of Visual Momentum

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ABSTRACT

We were interested in determining if the visual momentum provided by gradual transition between 2D and 3D views of geographic terrain aided task switching. Forty-two participants made judgments about the properties of two points placed on terrain depicted as 2D or 3D displays. 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), a blank screen was shown for the same duration. The results showed that performance improved more for the continuous transition than the discrete transition condition. We argue that this was because the transition provided improved visual momentum between consecutive displays, and recommend the use of dynamic transition when commanders are viewing multiple display windows over time.

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.

For geographic terrain, there is benefit to allowing multiple views of a battlespace, and therefore both 2D and 3D display formats should be made available to the commander. 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 commander will need multiple views.

The commander 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.

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Objectives and Prediction

Our experiment addressed the issue of whether gradual transition in viewpoint (e.g., from 2D topographic map to 3D terrain viewed from a 45 degree angle) improves task performance relative to discrete transition. To do this, we 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, our experiment was a replication of the St. John et al. (2001) experiments (in particular, their Experiments 4 and 5). However, in our experiment, we had participants switch tasks across trials to determine whether knowledge of terrain obtained when performing one task in the first trial affected performance on a different task in the subsequent trial. On half the trial pairs, there was a continuous rotation of the space from 2D to 3D views; on the other half, a blank screen was shown. We predicted that the transition would improve performance by providing visual momentum as our participants switched from one task to the other.

METHOD

Participants

We ran 42 participants (22 male and 20 female), aged 19-49 yrs, 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 different 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 x 11288 m^2 area. Pairs of A and B points were randomly selected for each terrain model, with the following constraints. The points were separated in altitude by 500 m. The distance between points was more than 2000 m. To avoid picking points near the model edge, points were selected from a central 11600 x 10600 m^2 area. 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 of 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. Two pairs of points meeting these constraints were chosen, resulting in 8 pairs of A-B points for each terrain model. The terrain models and pair locations were the same for both transition conditions.

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. MICRODEM (Microcomputer Digital Elevation Models, Guth, 2001) was used to create a 2D display for each of the 10 terrain models with coloured contour lines (see Figure 2 for an example). A 2D and 3D display depicting each of the 8 A-B pairs was constructed for each terrain model, resulting in 16 different displays per terrain model. Each location in a pair was represented by a point superimposed on the map labelled A or B.

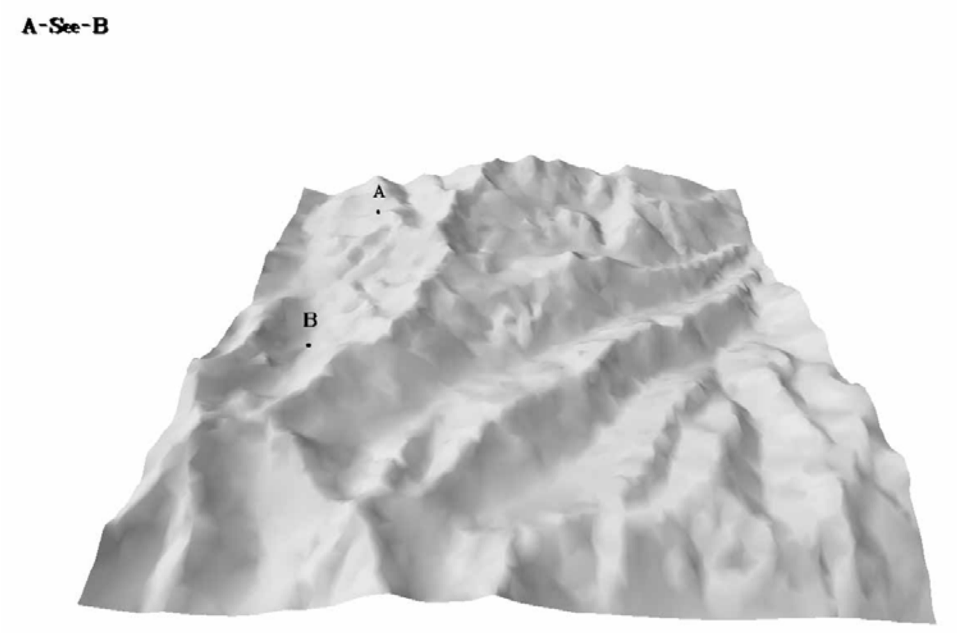

Figure 1: Example of 3D Display Used in Experiment.

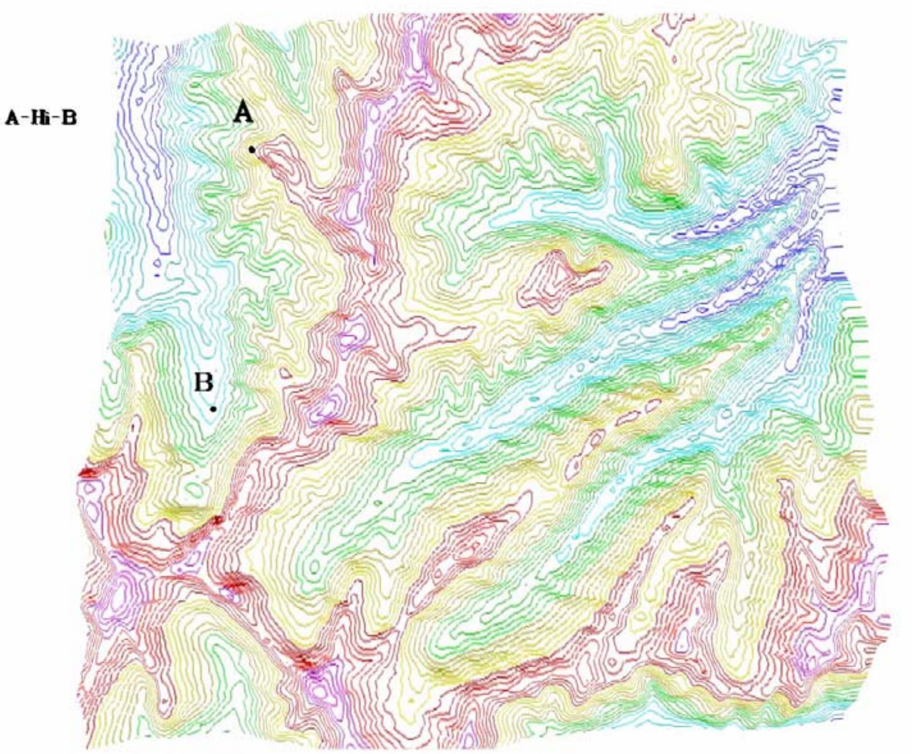

Figure 2: Example of 2D Display Used in Experiment.

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 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-High-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 which of two points, A or B, was higher. In the A-See-B task, participants indicated whether they could see point B if they were standing at point A. Participants performed each task with both 2D and 3D displays. Participants performed one block of practice trials with a unique terrain model prior to the session for each transition condition.

Participants performed the tasks in pairs of trials. 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 8 pairs of A-B points for each terrain model, two pairs for each possible response sequence (YY, YN, NY, NN). For each terrain model, we assigned the first A-B pair to trial pairs 1-8 as shown in Table 1, and the second pair to trial pairs 9-16.

Thus, the 16 trial pairs shown in Table 1 were used for each of the 10 terrain models, creating 160 trial pairs. 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 the 2nd trial of one pair was not identical to the 1st trial of the next pair). 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.

Table 1: Trial-Pair Combinations for Each Terrain Model

Trial Pair	Trial 1	Response Type	Trial 2	Response Type
1	2D A-see-B	Y	3D A-hi-B	Y
2	2D A-see-B	Y	3D A-hi-B	N
3	2D A-see-B	N	3D A-hi-B	Y
4	2D A-see-B	N	3D A-hi-B	N
5	3D A-hi-B	Y	2D A-see-B	Y
6	3D A-hi-B	N	2D A-see-B	Y
7	3D A-hi-B	Y	2D A-see-B	N
8	3D A-hi-B	N	2D A-see-B	N
9	2D A-hi-B	Y	3D A-see-B	Y
10	2D A-hi-B	Y	3D A-see-B	N
11	2D A-hi-B	N	3D A-see-B	Y
12	2D A-hi-B	N	3D A-see-B	N
13	3D A-see-B	Y	2D A-hi-B	Y
14	3D A-see-B	N	2D A-hi-B	Y
15	3D A-see-B	Y	2D A-hi-B	N
16	3D A-see-B	N	2D A-hi-B	N

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 terrain model gradually rotated in depth from the 2D to the 3D display (or vice versa) from the first trial to the second. The 3D display depicted the terrain model at a viewing angle of 45 degrees with respect to the ground plain. The rotation took approximately 3 seconds. In the *discrete transition* condition, the terrain model was shown sequentially: first using the 2D display, and then the 3D display (or vice versa). A blank screen was shown between the two views for a duration equivalent to the animated rotation in the continuous transition condition. The order of continuous and discrete transition conditions was counterbalanced across participants.

For both transition conditions, 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 1½ hours to complete, including breaks between blocks of trials. At the conclusion of the experiment, the experimenter thanked and debriefed the participant, and answered the participant's questions.

RESULTS

Response Time

A mean response time for accurate trials was computed for each participant in each condition. (The response time was calculated as the elapsed time from the start of each trial to the participant's key press and did not include the time for the rotation of the terrain model in the continuous transition condition). These data were submitted to a 2 x 2 x 2 x 2 within-subjects analysis of variance (ANOVA) with transition, task, view, and trial serving as independent variables. For brevity we report here only those effects involving transition. Continuous transition produced shorter response times than discrete transition for the second trial in a pair (but not the first), $F(1,41) = 65.17$, $MS_e = 1.08$, $p < .0001$. Mean values are shown in Figure 3. Continuous transition shortened response times more for the A-See-B task (3.58 s for continuous vs. 4.50 s for discrete) than the A-Hi-B task (3.20 s for continuous vs. 3.83 s for discrete), $F(1,41) = 4.34$, $MS_e = 0.79$, $p < .05$.

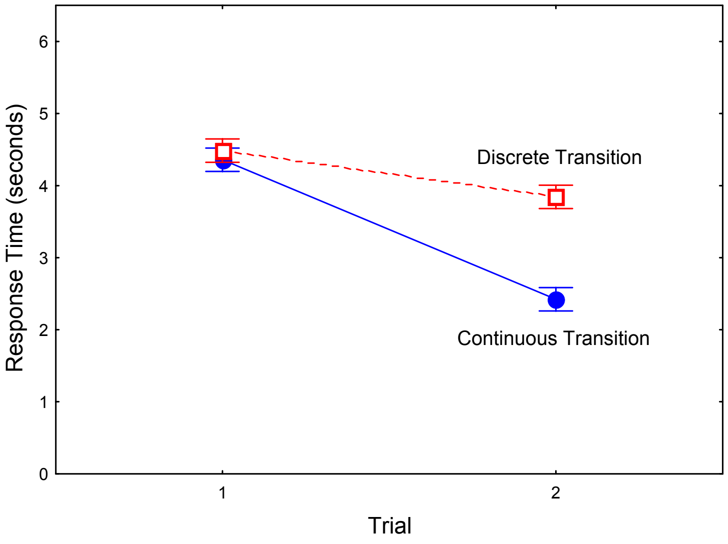

Figure 3: Response time in seconds as a function of transition and trial in pair. Error bars indicate the within-subjects standard error of the mean (Loftus & Masson, 1994).

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 with transition, task, view, and trial serving as independent variables. Again we report only those effects involving transition. As shown in Figure 4, continuous transition produced greater accuracy than discrete transition for the second trial in a pair (but not for the first), although the effect just failed to reach conventional significance levels, $F(1,41) = 3.77$, $MS_e = 0.0017$, $p = .059$. Continuous transition increased accuracy for the A-Hi-B task (.94 for continuous vs. .92 for discrete) but not for the A-See-B task (.73 for continuous vs. .74 for discrete), $F(1,41) = 7.02$, $MS_e = 0.0037$, $p < .05$.

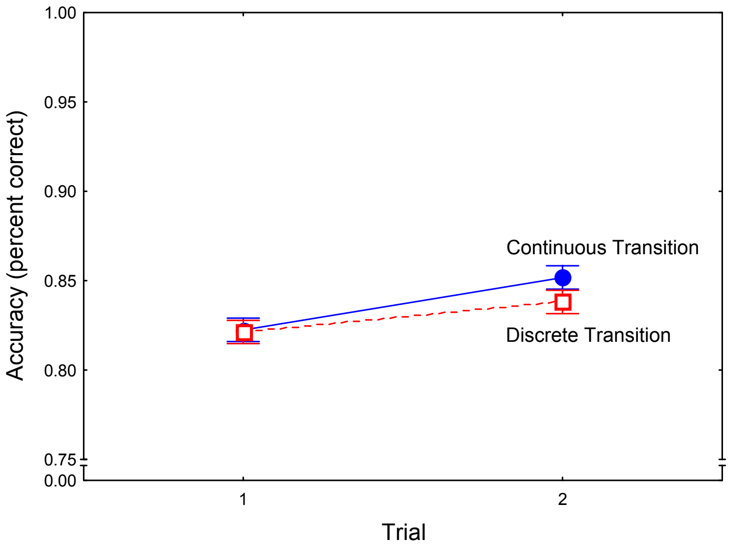

Figure 4: Accuracy (proportion correct) as a function of transition and trial in pair. Error bars indicate the within-subjects standard error of the mean (Loftus & Masson, 1994).

DISCUSSION

In the experiment, participants made a pair of judgments about geographic terrain. For each trial pair, there was a switch in the display type across trials from 2D to 3D (or vice-versa), and a simultaneous task switch, with all four possible combinations of displays and tasks used. In the continuous transition condition, participants viewed a dynamic rotation from a 2D topographic map to a 3D perspective rendering of the same terrain (or vice versa). As predicted, the results showed that a continuous transition between the display types improved performance on the trial after transition relative to the discrete condition. Participants were faster and there was a trend toward greater accuracy on the second trial of the pair with the continuous transition. Presumably, this was because the transition provided improved visual momentum between consecutive displays.

The response time advantage for continuous transition was true regardless of task, although it was greater for the A-See-B task. An accuracy advantage for continuous transition was only observed for the A-Hi-B task. We were surprised that no accuracy advantage of continuous transition was evident for A-See-B, although participants were faster with continuous transition in that task. Continuous transition may help in maintaining the location of the A-B points with respect to the terrain, speeding processing, but not aiding the accuracy of the judgment because that would further depend upon the height of the intervening terrain.

The results indicate that dynamic transition between different views on terrain should assist the commander 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.

It is possible that because participants viewed the terrain model longer in the dynamic transition condition, the extra viewing time provided an advantage. We doubt that this is the case because participants had unlimited time to view the terrain on each trial. However, as a check we are running an experiment where the time spent viewing the terrain is equalized in continuous and discrete transition conditions. We also plan to investigate whether further rotating the geographic terrain model so that the viewpoint is in alignment with the A-B axis assists in performing the A-See-B task, and whether the dynamic transition provided by visual momentum is still useful in this context.

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SYMPOSIA DISCUSSION – PAPER NO: 19

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Comment:
Col. Johansen has an intuitive desire for a flexible display. Zooming into a location while leaving the context around the outside of the display was an example of implementing visual momentum in the display.

Question:
What was the reason for not placing the view on the ground at either point A or B?

Author's Response:
This was done in order to try to replicate an earlier experiment so that results could be compared. Future work will look at a greater degree of immersion. It will be interesting to see how close to the actual view point of the position does the user have to be before it is obvious whether one point can be seen from the other, or which is at a higher altitude.

Question:
Could the user be shown both the 2D and 3D views at once and given the ability to choose which view to use for which task?

Author's Response:
There is some advantage to showing both displays, but there is the issue of mapping from one to the other.

Comment:
Visual momentum is about the transformation crutch, it does not have to be dynamic in time.

Comment:
There are individual skills related to understanding a 3D display. The experience and training the user has had will influence the ability to interpret the display. In this experiment, users self reported on their ability to navigate. It was interesting that those people who rated themselves higher in that ability actually rated higher in the continuous rotation.