Perspective View Displays and User Performance

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ABSTRACT

Consoles that use three-dimensional (3-D) perspective views on flat screens to display data seem to provide a natural, increasingly affordable solution for situational awareness tasks. However, the empirical evidence supporting the use of 3-D displays is decidedly mixed. Across an array of tasks, a number of studies have found benefits for 3-D perspective over two-dimensional (2-D) views, while other studies have found rough parity, and still other studies have found 2-D superior to 3-D. Interestingly, many realistic military tasks have complex demands that require both types of views at different points in time. This paper investigates an interface concept called "orient and operate," which employs the advantages of both 2-D and 3-D displays.

INTRODUCTION

Objects and scenes displayed on a flat screen from a 30- to 60-degree perspective viewing angle can convey three-dimensional (3-D) structure and shape. They are increasingly being used in military and civilian occupations such as air warfare, command and control, air traffic control, piloting, and meteorological forecasting. However, they have not been shown to be effective for all tasks. Comparisons between two-dimensional (2-D) (top-down, side) and 3-D (perspective) displays in the literature on a variety of tasks have found mixed results.* Several factors have been proposed to account for the differences (see, e.g., [9, 12, and 19]). In an attempt to identify and evaluate the factors important to the effectiveness of the viewing angle, we developed a series of experimental tasks using simple block stimuli (see Figure 1, left) viewed on a non-stereo display. We found that 3-D views were superior for tasks that required understanding the shapes of the blocks, but that 2-D views were superior for tasks that required judging the precise relative position between the blocks and another object (a ball) in the scene [20]. In these experiments, the 3-D view was from 30 degrees with shading, and the 2-D views were from the top, the front, and the side.

We then extended these findings to more complex and naturalistic terrain stimuli. Participants were shown a 7- by 9-mile piece of terrain in either 2-D or 3-D (see Figure 1, right) and asked to perform tasks that required either shape understanding or judging relative position. We again found that 3-D views were superior for the shape understanding tasks, and 2-D views were superior for relative position judgment tasks [21 and 22]. In these experiments, the 3-D view was from 45 degrees with shading, and the 2-D view was a topographic map with color-coded contour lines.

Interestingly, many realistic military tasks have complex demands that require both types of views at different points in time. For these tasks, we propose an interface concept called "orient and operate," which employs the advantages of both 2-D and perspective view displays. A 3-D view can be used initially to orient or obtain an understanding of the layout of

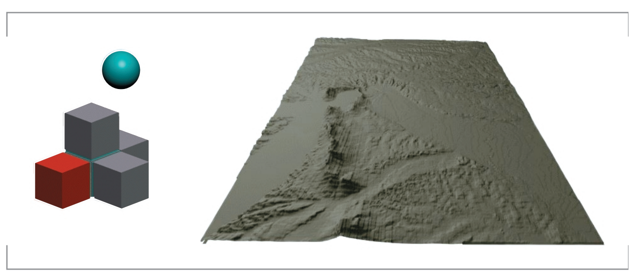

FIGURE 1. Simple block stimuli and terrain stimuli shown in 3-D perspective views.

*A number of studies have found benefits for 3-D perspective over 2-D [1, 2, 3, 4, and 5]. Other studies have found rough parity or different results on different measures or tasks [6, 7, 8, 9, 10, 11, and 12] and still other studies have found 2-D superior to 3-D [13, 14, 15, 16, 17, and 18].

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14. ABSTRACT
Consoles that use three-dimensional (3-D) perspective views on flat screens to display data seem to provide a natural, increasingly affordable solution for situational awareness tasks. However, the empirical evidence supporting the use of 3-D displays is decidedly mixed. Across an array of tasks, a number of studies have found benefits for 3-D perspective over two-dimensional (2-D) views, while other studies have found rough parity, and still other studies have found 2-D superior to 3-D. Interestingly, many realistic military tasks have complex demands that require both types of views at different points in time. This paper investigates an interface concept called "orient and operate," which employs the advantages of both 2-D and 3-D displays.

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background topography and the shape of objects in a scene. Then, a 2-D view can be used to operate on the objects, such as moving them around on the background.

THE GEOMETRY OF 2-D AND 3-D VIEWS

Before continuing, it is useful to understand the basic geometric and functional differences between 2-D views and 3-D views.* One reason 3-D views are good for understanding the general shape of objects and the layout of a scene is that all three spatial dimensions of an object can be seen within a single, integrated view [23]. With a single, integrated view, the user does not need to switch among and integrate information from separate 2-D views to obtain an understanding of the three-dimensional shape of an object or scene. Another reason why 3-D views are good for understanding shape is that natural cues to depth, such as shading, relative size, and texture, can be readily added to an image. Adding these cues can increase the salience of depth in the scene and thereby enhance the sense of a three-dimensional shape. Stereo and motion can also be used to aid the perception of depth,† though these are less commonly used.

One problem for 2-D and 3-D views is that information along the line of sight from the observer into the scene cannot be represented. The reason is that all of the information along a line of sight between the object in the displayed world and the viewer must be represented by the same pixel in a display. In a 2-D top-down or "plan" view, the x and y dimensions are represented faithfully, while the z dimension is lost entirely (see Figure 2). Actually, the x and y dimensions are scaled down in the plan view. "Represented faithfully" means that this scaling is a linear transformation that preserves angles and relative distances in the x-y ground plane so that, for example, parallel lines remain parallel. In the 3-D view, all three spatial dimensions are represented, but the line-of-sight ambiguity remains. Instead of losing one dimension entirely, all three dimensions are foreshortened. The effect of this ambiguity can be seen in Figure 1 (left) where the location of the ball cannot be determined: Is it floating in back of the figure, or is it floating toward the front of the figure?

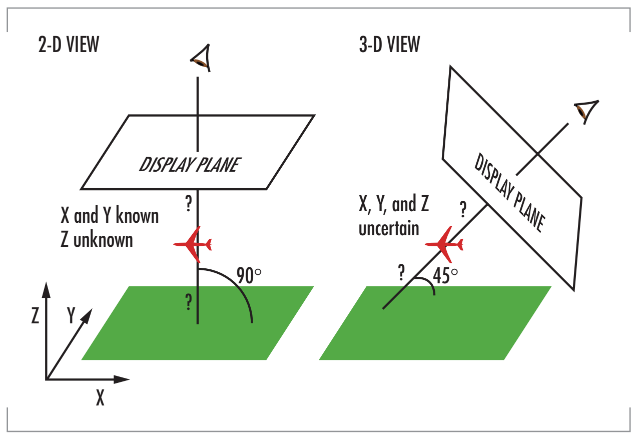


FIGURE 2. Line-of-sight ambiguity makes the location of the aircraft uncertain in different ways, depending on the viewing angle.

A further problem for 3-D views is distortion in the representation of distances and angles. Some distortions result from foreshortening, which increases as the viewing angle drops from directly top-down to ground level. This distortion can cause the sides of a square to appear shortened and the right angles to appear acute or obtuse, as seen in Figure 2. Other distortions result from perspective projection, which causes distances in the x and z dimensions to scale linearly (i.e., a linear perspective), but distances in the y dimension to scale nonlinearly. Due to this distortion, parallel lines appear to converge toward the vanishing point, as can be seen in Figure 1 (right). Perspective projection is, in fact, a cue to depth, but it works by distorting distances and angles. It can make depth more salient in an image, but at the price of making precise measurements more difficult.

* Sedgwick [24] provides a thorough description of 3-D views and perceptions of space.

† See our report [25] for a description of depth cues.

Antenna Placement Experiment

FIGURE 3. Side-by-side condition from antenna experiment: 3-D perspective view map (left) and 2-D top-down topographic view map (right).

Here, we will discuss an experiment that evaluates our interface concept of "orient and operate" using a relatively detailed operational military task. In this experiment, participants were shown a terrain map that contained two fixed antennas (a source and terminal), several enemy unit locations, and a set of antennas to be placed on the map to establish line-of-sight communications. The task was to create a chain of antennas across the map to connect the source and terminal antennas. The antennas had to be within line of sight of each other while remaining concealed from the enemy units. Participants positioned antennas simultaneously out of sight of the enemy, but in line of sight and range of other antennas, thereby creating a chain of antennas across the map. One group of participants viewed only the 2-D topographic map. Another group received only the 3-D view, and a third group received both views, side by side. In the side-by-side condition, the two views were visible to the participant on separate monitors: a 3-D "orient" view and a 2-D "operate" view (see Figure 3). The antennas were constantly visible on both views, even as they moved, so participants could look at either view at their discretion. Participants were timed to complete a series of nine problems.

It was not entirely clear which type of view would prove better for making these precision judgments. In previous work [21], we used line-of-sight judgments as a shape understanding task and found that 3-D views were superior. Participants viewed a terrain segment in either a 2-D top-down topographic view or a 3-D perspective view and judged whether or not there was a line of sight between two points on the terrain. This task appeared to require only a very general gestalt understanding of the terrain—whether a large mountain or range of hills was obstructing the line-of-sight view. In contrast, placing antennas on a map to create an unbroken chain of line-of-sight communications while keeping them out of sight of enemy units may require judgments that are far more precise.

We found that performance with 2-D maps was, in fact, much better than performance with 3-D maps. Our interpretation is that routing of antennas requires placements of units just in or out of lines of sight, and these precise judgments are facilitated by the 2-D view with its faithful representation of space. Interestingly, performance in the side-by-side condition proved to be even better than performance in the 2-D condition. Our interpretation is that some aspects of the antenna task, namely, orientation aspects, were still better performed in 3-D.

We investigated this interpretation in a follow-on experiment. From observations of participants, we found that the 3-D views appeared to be useful at various points throughout the task to help interpret the 2-D topographic views, and that the 3-D views were especially important toward the beginning of the task for determining a basic route. We believe that the ability of the 3-D views to naturally and easily convey shape makes them useful for finding canyons and hills that could be used to build a route through the terrain. This idea fits with our concept of "orient and operate," wherein the user first orients to a scene using a 3-D view and then switches to a 2-D view to perform fine-tuned operations on the scene.

In the follow-on experiment, called "pick-a-path," participants were shown three potential routes across the terrain for constructing their chain of antennas (see Figure 4). One of the three routes was much more promising than the other two, in that it followed canyons and skirted hilltops to remain out of enemy lines of sight. Participants were shown the terrain and routes in either 3-D perspective views or 2-D topographic views. "Pick-a-path" performance was found to be much faster for the 3-D perspective views than for the 2-D views.

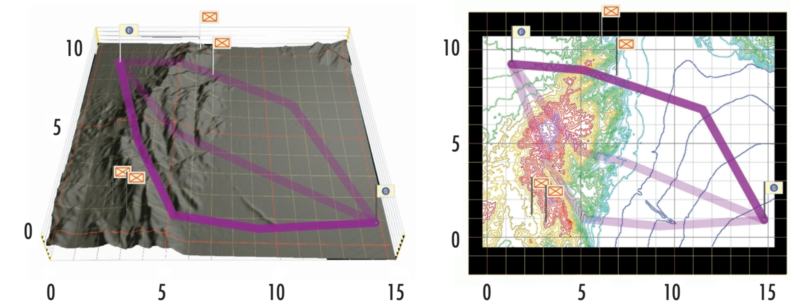
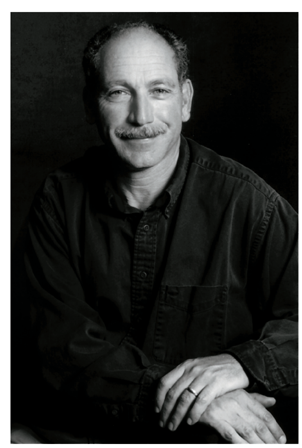


FIGURE 4. An example 3-D map and the equivalent 2-D map from "pick-a-path."

We concluded that the ability to select a path on a terrain map depends not only on the viewing perspective (e.g., 2-D, 3-D), but also on how precise the route needs to be. Initial path planning benefited from a 3-D view while the actual routing of the antennas benefited from a 2-D view. The 3-D view was better able to convey terrain shapes, and the 2-D view was better able to convey where two objects needed to be placed to solve the tactical problem. We recommend using 3-D for initial path planning and 2-D for object placement, supporting our "orient and operate" display design paradigm: Users should orient to a scene using a 3-D perspective view and then operate on the objects in the scene using a 2-D view.

Further supporting "orient and operate," we found that participants performed the best when provided with both 2-D and 3-D views. However, the effect was of small magnitude, and we believe that more improvement is possible. Placing views side by side may not be sufficient for creating an effective suite of displays. Moving from one view to the other requires considerable re-orientation to the scene by the user. Methods are needed for improving the correspondences between objects in the views that alleviate the effects of re-orientation. The concept of visual momentum [26] may offer ideas, such as the use of natural and artificial landmarks, for improving the correspondence. Investigation of these and other concepts is currently underway.

Our antenna placement experiments extended our program of research on how to improve perception of object shape, position, and location to a more complex and applied operational domain. In this domain, we found considerable support for our basic distinction for using 3-D perspective views for shape understanding and for using 2-D views to judge relative position of objects. Applying this framework, we are currently building several "orient and operate" prototypes for use in real-world military display systems.



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