

United States Air Force Research Laboratory

MEASURING VISUOSPATIAL WORKING MEMORY USING PATH VISUALIZATION

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14. ABSTRACT The term visuospatial working memory (VSWM) refers to a set of cognitive processes that people use to visualize spatial configurations. VSWM is involved in most spatial solving. It may be crucial for Uninhabited Aerial Vehicle operators because they must hold in memory spatial information that would normally be visible from a panoramic cockpit view. This paper describes a new technique called Path Visualization (PV) for measuring VSWM. The PV paradigm yields accuracy and response-time data that can be used to quantify various aspects of human spatial visualization.					
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MEASURING VISUOSPATIAL WORKING MEMORY USING PATH VISUALIZATION

Introduction

The term *visuospatial working memory* (VSWM) refers to a set of cognitive processes that people use to visualize spatial configurations. VSWM is not typically viewed as permanent visual memory, but rather as a temporary workspace for visuospatial computations. VSWM processes can be experimentally distinguished from the processes that support working memory for verbal materials (e.g., Logie, 1994; Smith & Jonides, 1997). VSWM is said to be involved in virtually all spatial problem solving; everything from designing a product to visualizing a route to the airport. It may be particularly crucial for operators of Uninhabited Aerial Vehicles (UAVs) because they control the aircraft from a Ground Control Station, so they must visualize their flight path plus the positions of many objects (terrain, threats, other aircraft, reconnaissance objectives, etc.), without the benefit of a panoramic view from the cockpit.

Much remains to be understood about VSWM. We need to know how much information it can hold; what causes loss of information from it; how information in it can be organized (3D egocentric, 2D map, 3D allocentric, or some other); and what operations (e.g. rotation, expansion, scanning) can be performed on this information. To shed light on these issues, we need ways to study VSWM objectively.

This paper describes a new technique called Path Visualization (PV) for obtaining quantitative information about VSWM. The PV paradigm yields an accuracy-and response-time-based quantification of the mental “space” in which human spatial visualization takes place.

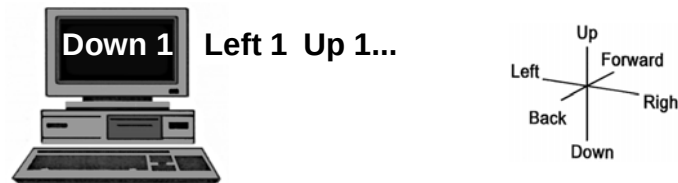
THE PATH VISUALIZATION TASK

It is difficult to find objective measures of any mental operation. The nonverbal, ephemeral qualities of spatial visualizations make them particularly elusive. Path Visualization is an objective method that seems to avoid at least one potential measurement pitfall. In the PV paradigm, observers do not merely reproduce a sequence of visual stimuli, as is sometimes the case for tests of visual short-term memory. Such tests allow the possibility that stimuli could be encoded and recalled in a way that does not require an explicitly spatial representation (for example, verbal rehearsal). In contrast, the PV task forces the observer to perform a spatial computation on the stimulus sequence if he or she is to respond accurately. This computation requires a spatial representation of multiple locations in a complex path.

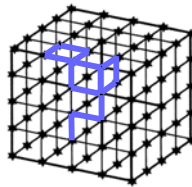
In the PV task, people try to visualize paths that are described piece-by-piece within an imaginary space (Figure 1). The space is typically a 5 x 5 x 5 three-dimensional cube-shaped grid. Paths start at the center of this grid. Each path consists of a series of segments. Each segment consists of a direction and a distance, where distances are given in units on the imaginary grid. Segment descriptions can be given using synthetic speech,

as text on a monitor, as arrows or lines in a diagram, or as a visual depiction of virtual self-motion. In the standard PV task, text or speech descriptions are used, and distances are always one unit. Directions can be fixed with respect to the axes of the grid, or they can be described with respect to an observer moving along the path. For example, the fixed (absolute) segment descriptions for a short square path which returns to its origin at the center would be: Forward 1 unit; Left 1 unit; Back 1 unit; Right 1 unit. The relative (ego-referenced) segment descriptions for this same path would be Forward 1, Left 1, Left 1, Left 1.

1. Participant views or hears a description of a path segment...



2. ...mentally adds the segment to a path in imaginary 5x5x5 space..



- 3...decides if the new segment intersects with the existing path, and indicates the decision with a keypress

Figure 1. General description of the Path Visualization task.

On each trial, a single 15-segment path is presented. Before initiating a trial, the study participant must have his/her left index finger on the Left-Arrow key (not the numeric keypad) and his/her right index finger on the Right-Arrow key. A trial is initiated by pressing the keypad Enter key with the little finger of the right hand. Then a sequence of 15 segment descriptions is presented. Each segment description is displayed for 2 s. The participant's task is to mentally construct a path using these segment descriptions, adding each new segment to the path as it is presented.

To verify the accuracy of the participant's visualized path, after each segment is presented, he/she must press a key as quickly as possible indicating whether or not the new segment intersected with any previously presented part of the path. The participant must press the Left-Arrow key if he/she believes that the endpoint of the segment just presented did not revisit (intersect) any location from any of the previously presented segments, including the central starting location. Pressing the right arrow key indicates the belief that the endpoint of the most recent segment did revisit one of the locations that are part of the path presented so far. If either key is pressed during the display of the segment, the reaction time and accuracy of the keypress is recorded and the segment display continues until the 2-s display time has elapsed. If no key is pressed, the response

is scored as a timeout. Whether or not a key is pressed, the next segment of the path is presented after the prior display has been shown for 2 s and a 133-ms blank screen has been presented. After all 15 segments have been presented, a feedback screen appears, giving information about reaction time and accuracy for the trial. This information includes mean reaction times for correctly identified intersections, correctly identified non-intersections, intersections missed, and non-intersections incorrectly identified as intersections (false alarms). Pressing the Enter key initiates the next trial.

The PV task is similar to some existing methods (e.g., Attneave & Curlee, 1983; Barshi & Healy, 2002; Brooks, 1968; Carlson & Sohn, 2000; Diwadkar, Carpenter & Just, 2000; Kerr, 1987, 1993; Vecchi & Girelli, 1998) in that it requires participants to keep track of changes in the position of a point in a two-dimensional or three-dimensional array of locations. However, success at Path Visualization requires more than tracking a single point, which could possibly be accomplished using some mathematical recoding rather than visualization. In PV, both the current end position *and* the prior path must be held in memory in order to determine whether an intersection has occurred.

Many variations of the PV task are possible. Comparing performance on different variations can shed light on various issues in the modeling of human spatial visualization. Here are four examples of issues currently being addressed using the PV task:

Are 2D and 3D Representations Handled the Same Way in Visuospatial Working Memory?

A controversial issue in the study of spatial visualization is the dimensionality of the mental representation. At one extreme is the notion that somewhere in the brain there exists a three-dimensional analog projection area for representing 3D space. The other extreme is the idea that spatial information is represented propositionally, in much the same way as nonspatial information (e.g., Hinton, 1979). A popular middle ground, at least for visuospatial imagery, has been various kinds of array-like theories, c.f., Kosslyn (1980, 1994), in which an analog 2D projection area suffices for both 2D and 3D information. Additional possibilities (including a Marr-like 2½-D sketch) have also been proposed (Pinker, 1988). It is also possible that representations of 2D and 3D space use different mechanisms, and therefore might be distinct abilities. Indeed Cornoldi, Cortesi and Preti (1991), using the Kerr (1987) location tracking task, showed that congenitally blind participants are as good as sighted participants in tracking 2D location, but the blind have particular difficulty tracking locations in three dimensions.

Evidence potentially relevant to this issue can be obtained by comparing performance on different kinds of paths in the PV task. Paths can be restricted to lie on horizontal, coronal or sagittal planes so that working memory for 2D versus 3D structures can be assessed. Planar paths can be embedded among 3D paths so that participants will not know before the end of the path whether it is 2D or 3D. Therefore any differences in performance between 2D and 3D paths are unlikely to be due to the selection of different strategies. Of course, differences in performance for 2D and 3D paths must be interpreted in the light of differences in connectivity (max. of 4 for 2D; 6 for 3D,

assuming orthogonal directions), and other possible differences in the characteristics of random paths generated in 2D vs 3D.

Do Ego-Referenced and Fixed-Coordinate Descriptions Use the Same Spatial Memory System?

As noted earlier, paths in the PV task can be described using fixed-coordinate descriptors, in which the labels "up," "down," "right," etc., always refer to the same directions in an external coordinate system, or ego-referenced descriptors, in which the labels are relative to an imaginary observer moving along the path. These two kinds of descriptors are related to two different representations of space. In the context of the PV task, an egocentric representation means that the participant's mental viewpoint is along the path, whereas in an allocentric representation, the path is viewed from somewhere else (for example, looking down from above). There is no logically necessary connection between types of path descriptors and types of spatial representations; one can perform mental transformations to obtain either kind of representation from either kind of descriptor. There is, however, a strong natural correspondence between ego-referenced descriptors and an egocentric representation, and between fixed-coordinate descriptors and allocentric representation.

Both egocentric and allocentric representation are critical to the ability to navigate in the world, but they are quite different. Egocentric representation arises naturally when moving through space; allocentric representation is natural for a map-like depiction. There is neurophysiological evidence that the brain constructs both kinds of representation, each in a different area (O'Keefe, 1992; Stein, 1992). This functional and physiological differentiation suggests that there may be separate systems for egocentric and allocentric spatial computations, and thus, perhaps, separate abilities.

The PV task can be given with either fixed-coordinate or ego-referenced path descriptors. Since all other aspects of the task are the same with either descriptor type, PV provides a clean comparison of performance given path descriptors from different frames of reference.

Are Different Parts of Visualized Space Equally Well Represented?

All of visualized space may not be equally well represented. There may be differences in representation between near and far, or upper and lower parts of a visualized 3D space. It is also possible that some individuals show evidence of "spatial-image scotomas," areas of imagined space that may not be well represented, perhaps akin to the visual neglect shown by patients with parietal damage. The homogeneous metric character of the PV task makes it possible to look for such effects in a normal population. Given a sufficient number of trials per participant, mean response time and accuracy can be computed for different regions of 3D mental image space.

How Does Linguistically Described Space Differ From Visually Experienced Space?

UAV pilots typically experience the space traversed by the aircraft via a video feed. Flying using the video feed, when the camera is locked to the direction of flight, is similar to flying a PC flight simulation game. The pilot is looking at a 30-degree field-of-view scene displayed on a monitor. The pilot may also hear aspects of space described in radio communications.

Experienced space (the video feed) might be processed in the brain by an episodic memory system in which visual details and impressions of speed and distance are preserved. Linguistically-described space might be encoded differently. How might the representations of these two sources of spatial information differ? Are capacity limits different in the two representations? Do they use different rules of organization? Are the patterns of likely spatial errors different? Do they reflect the same individual spatial abilities?

To address these issues, one must have a way of presenting the same spatial information, requiring the same response, in both linguistic and visual-motion forms, and without confounding effects of specific knowledge or strategies. This can be accomplished using the PV task because the same paths can be presented using either linguistic descriptions (c.f., Franklin & Tversky, 1992) or a visually rich virtual fly-through.

CONCLUSION

The Path Visualization task provides an objective method for studying temporary, complex spatial constructions in visuospatial working memory. It provides both accuracy and response-time data under different visualization conditions and for different regions of 2D and 3D visualization space. Information about current research using the PV task and software for presenting various PV conditions can be obtained by contacting the author.

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