Visuospatial Processing and Learning Effects in Virtual Reality Based Mental Rotation and Navigational Tasks

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Abstract. Visuospatial function and performance in interactions between humans and computers involve the human identification and manipulation of computer generated stimuli and their location. The impact of learning on mental rotation has been demonstrated in studies relating everyday spatial activities and spatial abilities. An aspect of visuospatial learning in virtual environments that has not been widely studied is the impact of threat on learning in a navigational task. In fact, to our knowledge, the combined assessment of learning during mental rotation trials and learning in an ecologically valid virtual reality-based navigational environment (that has both high and low threat zones) has not been adequately studied. Results followed expectation: 1) learning occurred in the virtual reality based mental rotation test. Although there was a relation between route learning and practice, a primacy effect was observed as participants performed more poorly when going from the first zone to the last.

Keywords: Visuospatial Processing, Learning, Virtual Reality, Mental Rotation: Navigation.

1 Introduction

Visuospatial function and performance in interactions between humans and computers involve the human identification and manipulation of computer generated stimuli and their location. A number of neuropsychological studies have found that visuospatial tasks activate different cortical areas such as the Broadmann area V5, superior parietal lobule, parieto-occipital junction and premotor areas [1]. One measure of visuospatial processing in the human-computer-interaction literature is performance on virtual reality based mental rotation [2], which can be enhanced through practice [3]. The impact of learning on mental rotation has been demonstrated in studies relating everyday spatial activities and spatial abilities. Newcombe, Bandura, and Taylor [4] found a substantial positive relationship between a visuospatial relations test and a number of daily spatial activities. Quaiser-Pohl and Lehmann [5] found significant relationships among visually mediated sport activities, computer activities, and mental rotation. Quaiser-Pohl et al [6]

D. Harris (Ed.): EPCE/HCII 2013, Part I, LNAI 8019, pp. 75–83, 2013.

also found a relationship of action-and-simulation-playing with MRT performance. These studies point to the malleability of visuospatial abilities and their relation to both experimental practice and everyday (non-laboratory) learning.

1.1 Virtual Reality Based Navigation

Assessment of navigation-based learning and memory has been of interest to neuropsychologists for many years and has been broadly studied over the past four decades by researchers concerned with the neurobiological bases of learning and memory [7]. A great deal of this research has focused on assessing the navigation performance of rats and mice in the Morris water navigation task (MWT; [8], [9]). While immersed in the MWT animals are trained to locate a hidden escape platform submerged in a circular pool of opaque water. A virtual reality version of the Morris water task (VMWT) has been developed for assessment of human navigational ability [10-12]. Of note, the VMWT has proven useful in studying spatial learning theories [11], [12]. Virtual reality based navigation has been suggested as representative of real-world functioning [13-15]. Navigation, like mental rotation, has been shown to be impacted by learning. Walker and Lindsay [16] assessed the visuospatial domain through the use of virtual reality based navigation with a virtual auditory display—finding an overall improvement in performance from one navigation map to the next. This learning or practice effect mimics the sort of learning effects found in mental rotation performance.

1.2 Impact of Threat on Cognitive Performance within Virtual Environments

An aspect of visuospatial learning in virtual environments that has not been widely studied is the impact of threat on learning in a navigational task. Stress related responses to threat are important because associations have been found among increased stress, cortisol, and poor learning/memory in both rodents [17] and humans [18]. When a user is immersed in a virtual environment, they can be systematically exposed to specific feared stimuli within a contextually relevant setting [19], [20]. Further, virtual reality environments allow for optimal arousal identification and classification [21]. This modality of virtual reality exposure comports well with the emotion-processing model, which holds that the fear network must be activated through confrontation with threatening stimuli and that new, incompatible information must be added into the emotional network [22], [23].

1.3 Research Aims

To our knowledge, the combined assessment of learning during mental rotation trials and learning in an ecologically valid virtual reality-based navigational environment (that has both high and low threat zones) has not been adequately studied. Our aims were to 1) attempt to replicate prior findings that learning occurs in a virtual reality based mental rotation test; 2) assess whether navigational learning occurred in a virtual simulation of a Middle Eastern city; and 3) assess the impact of threatening stimuli presented while subjects navigated a three dimensional virtual environment.

2 Methods

2.1 Participants

Subjects included 49 undergraduate students (18 males and 31 females) between the ages of 18 and 25 took part in the University of Southern California's Institutional Review Board approved study. Strict exclusion criteria were enforced so as to minimize the possible confounding effects of additional factors known to adversely impact a person's ability to process information, including psychiatric (e.g., mental retardation, psychotic disorders, diagnosed learning disabilities, attention-deficit/hyperactivity disorder, and bipolar disorders, as well as substance-related disorders within 2 years of evaluation) and neurologic (e.g., seizure disorders, closed head injuries with loss of consciousness greater than 15 minutes, and neoplastic diseases) conditions.

2.2 Procedure

Virtual reality spatial rotation: After informed consent was obtained, basic demographic information, computer experience and usage, and spatial activities history were recorded. Next, a previously validated (see Parsons et al., 2004 [2]) neuropsychological measure of virtual reality spatial rotation (VRSR) was used. The VRSR assessment and training system was designed to present a target stimulus (TS) that consists of a specific configuration of 3D blocks within a virtual environment. The stimuli appear as "hologram-like" three-dimensional objects floating above the projection screen (see Figure 1).

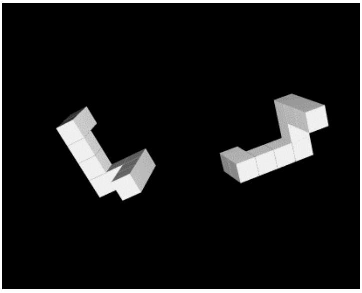

Fig. 1. Virtual reality spatial rotation

After presentation of TS, the participant is presented with the same set of blocks (working stimuli; WS) that needs to be rotated to the orientation of the target and then superimposed within it. The participant manipulates the WS by grasping and moving a sphere shaped "cyberprop" which contains a tracking device. The motion of the sphere is imparted upon the WS. Upon successful superimposition of the WS and TS a "correct" feedback tone is presented and the next trial begins. The new WS appears attached to the sphere (user's hand), and a new TS appears. In this mode of interaction, users do not need to press any buttons or select objects. The WS simply appears attached to the sphere for users to manipulate [2].

*Virtual Reality Navigation Task***:** The virtual navigation task utilized herein was that of a virtual Middle Eastern city, which included a route-learning and navigation simulation to assess landmark and route knowledge of the newly experienced VE. Participants were led along a predefined path through a virtual Middle Eastern city by a group of virtual military service personnel serving as guides. The guides led participants through six zones alternating between high and low environmental threat levels. During the high threat zones, participants experienced an ambush situation in which bombs, gunfire, screams and other visual and auditory forms of threat were present, whereas none of these stimuli were presented in the low threat zones. Upon reaching the end of this initial tour through the city, participants were instructed to navigate back to the starting point following the same path taken during the initial tour. Participants were to pass through each zone in reverse order until reaching the original starting point. If the participant strayed too far from the path, which was quantified as the distance it would take to walk for 10 seconds in a perpendicular direction from the original path, an arrow appeared in the corner of the screen that assisted the participant in finding his or her way back to the original path. During the navigation task, there were no longer any threatening stimuli presented in the high threat zones. The navigation task ended when the participant crossed the zone 1 marker.

The virtual environment depicting an Iraqi city was presented to participants with use of an eMagin Z800 head mounted display complete with head tracking capabilities to allow the participant to explore the environment freely. The virtual environment was created using graphic assets from the Virtual Reality Cognitive Performance Assessment Test [24], [25], using the Gamebryo graphics engine to create the environment. A tactile transducer floor was utilized to enhance the ecological validity of the VE by making explosions and other high threat stimuli feel more lifelike [26]. Auditory stimuli were presented with a Logitech surround sound system. Participants experienced the VE while residing in an acoustic dampening chamber, which had the added benefit of creating a dark environment to remove any peripheral visual stimuli that were not associated with the VE, resulting in increased immersive qualities of the simulation.

Fig. 2. Examples of high (left) and low (right) threat zones

3 Results

As expected, learning occurred in the virtual reality based mental rotation test. There was a significant learning curve with an attendant difference in performance from Trial 1 to Trial 24 (t=5.27; p<.01). Responses elicited by the variations in threat were

Table 1. Descriptives for Virtual reality navigation task

	Minimum	Maximum	Mean	SD
Seconds in Zones				
High Threat				
Zone 1	53.01	186.65	71.48	25.28
Zone 2	12.56	186.71	76.67	24.90
Zone 3	53.59	147.85	80.82	23.52
Low Threat				
Zone 1	55.54	111.45	64.30	11.04
Zone 2	42.29	138.18	75.42	16.99
Zone 3	21.30	183.10	67.74	23.97
Route Deviations				
High Threat				
Zone 1	.24	97.73	31.98	23.16
Zone 2	.22	410.77	57.31	80.02
Zone 3	1.43	358.14	71.8830	80.68
Low Threat				
Zone 1	.25	204.17	32.92	32.49
Zone 2	.17	869.85	71.90	137.21
Zone 3	.14	485.34	58.99	91.86
#Arrow Prompts				
High Threat				
Zone 1	0.00	42.00	10.87	11.68
Zone 2	0.00	35.00	8.89	8.97
Zone 3	0.00	100.00	20.85	23.56
Low Threat				
Zone 1	0.00	71.00	7.44	13.72
Zone 2	0.00	56.00	15.91	14.93
Zone 3	0.00	74.00	12.93	21.41

used to predict an outcome measure related to participants' performance navigating along the newly learned route in the novel virtual Middle Eastern city. Specifically, we looked at: 1) Time in zones; 2) Number of route deviations; and 3) Number of computer-generated prompts (arrows) to reorient the user (see Table 1).

Although there was a relation between route learning and practice, a primacy effect was observed as participants performed more poorly when going from the first zone to the last:

1. Time in Zones: comparing the first and last zone (Mean = 13.26; Standard Deviation = 17.61; Standard Error of the Mean = 2.51; t=4.36; p<.01)
2. Route Deviations (Mean = 38.95; Standard Deviation =93.18; Standard Error of the Mean = 13.59; t=2.87; p<.01)
3. Computer Reorientations (Mean = 13.40; Standard Deviation = 31.31; Standard Error of the Mean = 4.47; t=2.98; p<.01).
4. The impact of threat level on learning was most notable for its impact on Time in Zones: This was evidenced by the fact that subjects had decreased learning in the high threat zones (Mean = 21507; Standard Deviation = 59476; Standard Error of the Mean = 8496; t= 2.53; p<.01).

4 Discussion

A primary focus of this study was upon visuospatial function and performance in interactions between humans and computers that involve the human identification and manipulation of computer generated stimuli and their location. Our goal was to combine assessment of learning during mental rotation trials and learning in an ecologically valid virtual reality-based navigational environment (that has both high and low threat zones).

We were able to replicate prior findings that learning occurs in a virtual reality based mental rotation test. A number of researchers have found that repeat exposures to even a two-dimensional test leads to a rather marked increase in performance [27], [28], [29]. [30]. The learning effects have practical and theoretical implications. The practical aspect, in terms of experimental design, is best illustrated by reference to Hampson's observation that the expected effect of period phase on spatial performance did not materialize in a within-subject design, as opposed to a between subjects design [29]. Hampson attributed this to the learning effects for tasks and this concern can be extended to the MRT as well. It should be pointed out that the extreme responsiveness of MRT performance to learning contrasts sharply to some other behaviors in which sex differences between males and females have been found, such as a fine motor task. No gender differences were found for the VRSR. From our theoretical perspective, VRSR stimuli represent an increase in the complexity of a stimulus (from 2D to 3D) and results in an increase in the cognitive load (working memory) of the task. We consider our data on a perceptual continuum with stimuli and tasks increasing in complexity to match "spatial conditions." As a result, working memory load seems to increase steadily with stimulus complexity, due to task demands. Therefore we assert that the relation between stimulus complexity and task demand reflects a functional relationship between stimulus complexity and the load of working memory for these stimuli. We argue that stimulus complexity provides a parsimonious theoretical framework for understanding the differences between these tasks with full realization that interpretations are variegated by one's working heuristics.

Although there was a relation between route learning and practice, a primacy effect was observed as participants performed more poorly when going from the first zone to the last; and the impact of threat level on learning was most notable for its impact on Time in Zones. These findings are consistent with findings that emphasize that stress related responses to threat are important because associations have been found among increased stress, cortisol, and poor learning/memory in both rodents [17] and humans [18] can be well expressed in a virtual environment with varying levels of threat. Given the fact that when a user is immersed in a virtual environment, they can be systematically exposed to specific feared stimuli within a contextually relevant setting [19], [20].

In sum, results followed expectation: 1) learning occurred in the virtual reality based mental rotation test. Although there was a relation between route learning and practice, a primacy effect was observed as participants performed more poorly when going from the first zone to the last.

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