Assessing the Use of Cognitive Resources in Virtual Reality

William E. Marsh[1], Jonathan W. Kelly[1,2], Veronica J. Dark[1,2], and James H. Oliver[1]

[1] Human Computer Interaction Graduate Program, Iowa State University, 1620 Howe Hall, Ames, Iowa, USA
[2] Department of Psychology, Iowa State University, W112 Lagomarcino Hall, Ames, Iowa, USA
{marsh,jonkelly,vjdark,oliver}@iastate.edu

Abstract. Due to system limitations, interactions in virtual environments are often unnatural and this may impact performance. During learning, unnatural interactions draw from a finite pool of cognitive resources, meaning that those resources cannot be used for a concurrent, possibly more important task. Because users typically have primary objectives to accomplish in the virtual world, we argue that interaction techniques and other system design choices should account for task compatibility. We use a dual-task paradigm to study resource usage during locomotion tasks varying in their similarity to real-world locomotion. In one experiment, unnatural locomotion interfaces required additional spatial resources compared to natural movements. Some participants used unique strategies unlikely in traditional dual-task studies, possibly due to the high level of immersion.

Keywords: Virtual reality, dual-task paradigm, working memory, locomotion, cognitive resources, user interfaces.

1 Introduction

Due to system limitations, interactions in virtual reality (VR) often require responses that are unlike those in the natural world and that are based on limited sensory feedback. These *unnatural* responses may affect a user's performance at interface manipulations and attempts to interact with the system are likely to interfere with performance on other tasks as well. During the interface-learning phase, unnatural interactions draw from a pool of cognitive resources [1], meaning that those resources cannot be used for a concurrent, possibly important task. Users often have primary objectives to accomplish in the virtual world, aside from interface manipulation, and understanding how interface-learning affects performance on these objectives may enable better interface design.

1.1 Limitations of Virtual Reality

Hardware limitations in VR often lead to unnatural input techniques to perform actions in the virtual world. Locomotion is one noteworthy example because a

C. Stephanidis (Ed.): Posters, Part II, HCII 2011, CCIS 174, pp. 120–124, 2011.

majority of virtual environments require that the user have the ability to move about while accomplishing tasks [2]. VR systems cannot support completely natural locomotion through an infinite virtual world due to boundaries such as tracking ranges or walls. Many techniques have been proposed to address these problems and to make aspects of locomotion more natural. Examples include treadmills [3], giant "hamster balls" [4], and methods of tricking the user with modified sensory feedback [5]. System limitations affect not only the input techniques, but also the feedback provided to the user by the system. Systems often have low-resolution graphics and a reduced field-of-view, for example. We are interested in understanding what the actual impact of using these systems is on concurrent tasks performed in the environment.

1.2 Dual-Task Paradigm

Psychology researchers have distinguished between different pools of cognitive resources [6]. Most multi-component models of memory distinguish between verbal and visuo-spatial resources, and some research supports further partitioning the visuo-spatial pool into separate visual and spatial components. Verbal resources are needed by tasks requiring storage or manipulation of verbal items, while visuo-spatial resources are used for tasks involving storage or manipulation of visual or spatial information. Baddeley's [7] often cited model of working memory makes the distinction between verbal and visuo-spatial resources and further describes a "central executive" that serves to direct attention, mediating access to the other two components.

A dual-task selective-interference paradigm is used to determine which set of resources a given task requires. In this paradigm, a task of interest is administered concurrently with other simultaneous tasks of known resource demands. If there is selective interference, above a general dual-task deficit, between the task of interest and a simultaneous task, it can be concluded that the task of interest requires some of the same resources as the simultaneous task. A commonly used simultaneous cognitive task is the span task in which participants are asked to remember a span of items. The nature of the items, either verbal (numbers, letters, or words) or spatial (locations), determines the type of resource that is used. For example, if a concurrent spatial span task disrupts performance at a task with unknown cognitive requirements more than a verbal span task does, then the unknown task is presumed to require spatial resources [7].

2 Using the Dual-Task Paradigm in Virtual Reality

Due to the limitations of VR, interactions are likely to compete for resources from the pools described above. The dual-task paradigm has not been widely used in VR, but it can be applied to examine the cognitive resources required for different types of VR interfaces. Cognitive resource usage in VR is interesting for several reasons:

- When interacting with a VR system, a user typically has other more important, resource-demanding tasks to complete in the environment than just using the interface. VR is often used in domains with high cognitive demands, such as tele-operation of unmanned vehicles [8].

- Locomotion through virtual environments provides a particular challenge beyond what might normally be encountered in desktop computer applications. These environments are often large or even infinite and it is impossible to provide a fully natural interface within the physical bounds of the VR hardware.
- The immersive nature of VR means that system designers have a high degree of control over all aspects of a user's experience, including cognitive task demands.

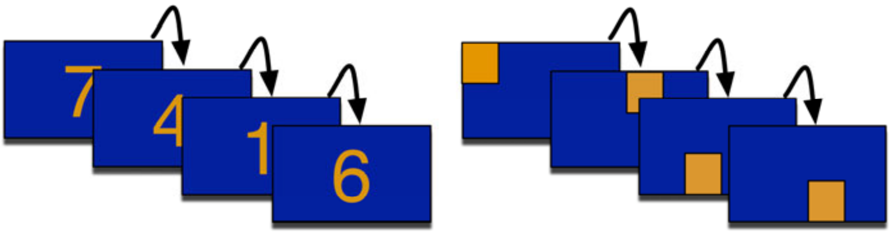

Fig. 1. Examples of verbal and spatial memory task flow

We conducted a study applying the dual-task selective-interference paradigm to investigate cognitive resource usage during virtual locomotion tasks using interfaces varying in naturalness. Each participant was assigned one of three interfaces (between subject): gamepad, body-based, and real walking (in increasing order of assumed naturalness). Each participant completed basic movement tasks (sidestep, walk forward, rotate, duck) concurrently with different working memory conditions (within subject): spatial span, verbal span, and no task. In these scenarios, a user was presented with memory items (see Fig. 1), asked to complete movements, and then tested on the memory items. The verbal span task required a participant to remember a sequence of numbers and the spatial span task required memory of a sequence of boxes presented in different spatial locations within a grid. We predicted that the spatial task would interfere with locomotion the most and that the verbal task would interfere very little in comparison to the no-task condition. We customized the span task difficulty to each participant's individual ability level by assigning sequences of five items if the participant could successfully complete two practice tasks at the five-item level. Otherwise the difficulty was set to four items.

Although performance is often slower in a dual-task situation (a general dual-task deficit), results on many measures showed faster performance when participants had a concurrent task than when they did not. Many participants indicated during the post-experiment interview that they found it difficult to perform the movement tasks while simultaneously remembering a verbal or spatial sequence. We believe that users hurried to complete the movements in order to get back to devoting all of their resources to the working memory tasks. Unfortunately, because of the nature of the movements used, we had no measure of movement accuracy to assess the possibility of a speed-accuracy tradeoff. Memory task results showed marginal significance of interface group and of the interaction between group and memory task. As predicted, the locomotion tasks interfered more with the spatial span tasks than the verbal tasks. Spatial memory items were forgotten more than verbal items and stopping performance in the body-based group was worse when combined with a spatial task than a verbal task.

The post-experiment interviews also revealed other relevant aspects of interacting with the VR interface. Users reported memory problems caused by being startled by the ducking task, in which an I-beam came floating overhead. A few users in the body-based and gamepad groups believed that rotation tasks might have interfered with the memory tasks. Finally, there is the possibility that participants may have adopted strategies to remember the spatial span task that were specific to full-scale VR. For example, one user reported that in order to accomplish the spatial span task, she imagined placing her hands and feet on the squares, as in the game Twister. We note that the imagined motor actions may have interfered with the locomotion movements.

3 Conclusions and Future Work

The experiment described above illustrates the kind of information that can be obtained using the dual-task selective interference paradigm to assess cognitive issues relating to VR. While this study focused on an input technique, the limited perceptual fidelity provided by VR systems may also lead to cognitively demanding strategies. We plan next to investigate the cognitive implications of restricting a user's field-of-view. The design will be similar to the one described above except that the between-subjects variable will be field-of-view (wide, narrow) instead of locomotion interface. If we understand the types of task conflicts that may exist in a given domain, we can strategically make system design choices and possibly even create systems that adapt according to the user's current task load.

The unexpected result that participants performed some locomotion tasks better when there was a memory task than with no task should be further explored. While we were able to measure accuracy in the span tasks, the locomotion tasks that we used involved only small, fast, direct movements that did not allow us to get a good measure of accuracy. In future research we need tasks that also allow us to measure accuracy, so that we can determine if there might be a speed/accuracy tradeoff, whereby improved performance on the memory task comes at a cost to the locomotion task. We also would like to ensure that users understand that completing movements faster will not get them to the memory recall faster. Finally, several users believed that they were capable of more difficult memory tasks and generally performance was high, so in future studies we may increase the task difficulty to more fully tax users.

Acknowledgments. This research was funded by a grant from the Air Force Research Laboratory.

References

1. Anderson, J.R.: Acquisition of cognitive skill. Psychological Review 89(4), 369–406 (1982)
2. Bowman, D.A., Kruijff, E., LaViola, J.J., Poupyrev, I.: 3D User Interfaces: Theory and Practice. Addison-Wesley Professional, Boston (2005)

3. Darken, R.P., Cockayne, W.R., Carmein, D.: The Omni-Directional Treadmill: A Locomotion Device for Virtual Worlds. In: 10th Annual ACM Symposium on User Software and Technology, pp. 213–221. ACM, New York (1997)
4. Medina, E., Fruland, R., Weghorst, S.: Virtusphere: Walking in a human size VR ”hamster ball”. In: Human Factors and Ergonomics Society 52nd Annual Meeting, pp. 2102–2106. Human Factors and Ergonomics Society, Santa Monica, CA (2008)
5. Razzaque, S., Kohn, Z., Whitton, M.C.: Redirected walking. In: Eurographics, pp. 289–294. European Association for Computer Graphics, Geneve, Switzerland (2001)
6. Navon, D.: Resources - A theoretical soup stone? Psychological Review 91(2), 216–234 (1984)
7. Baddeley, A.: Is working memory working? The fifteenth Bartlett lecture. The Quarterly Journal of Experimental Psychology: Section A 44(1), 1–31 (1992)
8. Foo, J.L., Knutzon, J., Kalivarapu, V., Oliver, J.H., Winer, E.: Three-Dimensional Path Planning of UAVs in a Virtual Battlespace using B-Splines and Particle Swarm Optimization. Journal of Aerospace Computing, Information, and Communication 6, 271–290 (2009)