Effects of 3D Display Technologies on Spatial Memory

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Abstract

Spatial memory has been recognized as an important factor in efficient human-computer interaction. However, most previous studies are limited to very simple depth cues and 2D displays. We present a study investigating the effects of head-coupled perspective, stereoscopy and simple landmarks on spatial memory by measuring performance and accuracy in a memory game. Our results indicate that head-coupled perspective affects spatial memory positively and should be investigated further. The polarized stereoscopic display and the landmarks used in this study had a significant negative effect, suggesting that they should be used with care. Users' perceived efficiency of a 3D display technology turned out to be a bad indicator of its actual efficiency.

Keywords: Spatial memory, 3D display technology

1 Introduction

Several studies show that users' spatial cognition is an important indicator of their performance when operating a user interface (Vicente et al. 1987). So it comes as no surprise that researchers have tried again and again to harness the power of spatial memory in user interfaces (Jones & Dumais 1986, Robertson et al. 1998). It is not clear whether adding depth cues to a 2D user interface actually enhances spatial memory: while some studies demonstrated improvements, e.g. Robertson et al. (1998), these improvements could be attributed to factors other than the depth cues, e.g. (Cockburn & McKenzie 2001). Moreover, the range of 3D display technologies that has been investigated with regard to spatial memory is rather narrow, using mostly primitive depth cues such as 3D perspective projection, size gradient and shadows.

In this study, investigate the effects of stereoscopy and head-coupled perspective (HCP) on spatial memory in a memory game (Figure 1). We incorporate 3D objects representing the data elements and simple landmarks consisting of a 3D room with distinctive wall, ceiling and floor patterns.

Figure 1: Screenshot of the 3D memory game with all objects uncovered

2 Methodology

The memory game task involved finding matching pairs of objects. In each round of the memory game, 20 objects (i.e. 10 matching pairs) were shown uncovered for five seconds, and then they got covered with boxes. In each move a player could uncover two objects by clicking on them, and if the two objects formed a matching pair, they stayed uncovered. Otherwise, they were covered again and the move was counted as a mistake to measure recall accuracy. Performance was measured as task completion time.

We measured user performance (task duration) and user accuracy (no. of mistakes made) in display conditions formed from different combinations of 3D perspective projection (3D), stereoscopy (S) using a polarized screen and polarized glasses, HCP (H) using a webcam and tracking software, and landmarks (L) involving flower wallpaper, a floor and a ceiling (Figure 1). Using a within-subject design, each participant played the game under nine display conditions: 2D, 3D 3DH, 3DL, 3DHL, 3DS, 3DSH, 3DSL and 3DSHL. The order of test conditions was permuted between participants to distribute any order effects. Object positions were chosen randomly from a set of pre-defined arrangements (without recurrence). Participants would play the memory game for five rounds in each test condition, of which the first two were training and did not count towards the experimental results. Participants had the option to rest between rounds. At the end of the experiment, each participant was asked to fill out a questionnaire.

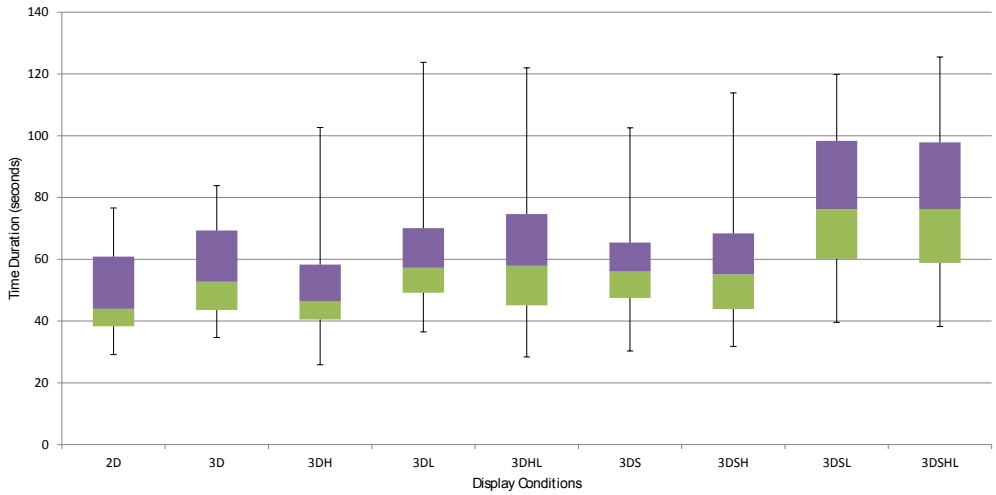

Figure 2: Task durations under different conditions (median and quartiles)

3 Results

We performed the experiment with 29 participants, which were chosen from different genders, age groups and occupations. Most of them were university students from various disciplines.

A boxplot of the task durations under the different conditions is shown in Figure 2. The results show a significant advantage of 2D and 3DH (3D projection with HCP) over all other display conditions, with no significant difference between the two. Landmarks and stereoscopy had significant negative effects, with 3DSL and 3DSHL performing worst.

There was not as much variation in the number of mistakes as there is for task duration. Noteworthy is only that simple 3D had significantly more mistakes than all other conditions except 3DSH and 3DSL. The only display technology that had a significant positive effect on the number of mistakes was HCP.

The questionnaire asked the participants to rank the display conditions with regard to their perceived efficiency and enjoyment. The results indicate that users' perceived efficiency was correlated with perceived enjoyment, but inversely correlated with the actual efficiency of display technologies as measured by task duration and number of mistakes.

Users were asked to think aloud during the task. Judging from that, the majority of participants believed that HCP was helpful because of adding more realism to the environment (i.e. the ability to see the environment from different view points) without imposing significant strain. The stereoscopic display used in our study caused fatigue and consequently deteriorated the performance. The landmarks added visual clutter and had therefore a negative effect on user performance. Other features such as the spatial arrangement of objects, their colors and a user's familiarity with them seemed to affect recall significantly.

4 Discussion

Unlike the 3D condition where the arrangements were random, the 2D condition always arranged all objects in a regular grid. Furthermore, the objects in the 2D condition were generally bigger than in the 3D conditions and had a clearer contrast to the background. Consequently, layout, object size and contrast were confounding variables that have likely made the 2D condition easier.

Technical problems in the head tracking system caused random jitter and occasional malfunction. Participants found this distracting, and it is a likely reason why participants mostly gave low rankings for HCP. This makes the positive effects of HCP the more surprising, and suggests HCP may perform even better if a more stable technology were used and the participants were more experienced in its use.

5 Conclusion

HCP seems to be a promising technology wrt. spatial memory and should be investigated further. Apparently stereoscopic displays can affect spatial memory negatively, likely because of fatigue. Landmarks need to be designed carefully, as they can have a significant negative effect on spatial memory by adding visual clutter to an environment. Finally, the perceived efficiency of a display technology is not necessarily an indicator of the actual efficiency, but may be more related to enjoyment. As future work, we will modify and replicate the study to remove confounding variables, especially in the 2D condition, and investigate the impact of other stereoscopic displays and types of landmarks.

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