An In-Depth Look at the Benefits of Immersion Cues on Spatial 3D Problem Solving

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ABSTRACT
We present a user study that takes an in-depth look at the effect of immersion cues on 3D spatial problem solving by combining traditional performance and experience measures with brain data.

INTRODUCTION
Interactive stereoscopic 3D displays offer the promise to enhance 3D spatial problems solving by leveraging three different immersion cues: binocular parallax, motion parallax, and haptic feedback. However, this potential has not yet been proven empirically. Our goal is to understand which immersion cues contribute to improve 3D spatial problem solving.

Our pilot studies utilized traditional performance and user experience measures including: time, task workload and spatial presence to explore the benefits of various immersion cues on 3D spatial problem solving. While we found no significant differences in terms of time-on-task and subjective workload, there were significant differences in the ways users perceived their presence in the virtual environment. Our preliminary findings also indicated that despite no apparent performance gains, users expressed preference for haptic feedback.

These intriguing results led us to extend prior explorations by looking at brain activity using functional near-infrared spectroscopy (fNIRS) as a supplemental measurement to more traditional performance metrics, along with tests to assess overall spatial reasoning skill of the participants. By looking at brain activity as well as overall spatial reasoning ability, we can examine whether there are immersive features that lead to lower mental load during spatial problem solving. Here, we present preliminary results.

USER STUDY
We have designed a 2x2 mixed factorial study. The between-subject factor is the *combination of immersive cues* used by the interaction device, which has four settings: non-stereo, stereo (i.e. binocular parallax and motion parallax), non-stereo with haptic feedback, and stereo with haptic feedback. The within-subject factor is *difficulty level* of the puzzle.

Procedure and Apparatus
Data was collected from 28 users, all right-handed females, randomly assigned one of four experimental conditions. Each participant completes 11 puzzles at 5 levels of difficulty. The dependent variables are *completion time, subjective workload rating* (NASA-TLX), *subjective presence rating* (MEC-Spatial Presence Questionnaire), and *fNIRS brain measurements.* All participants complete two pencil and paper tests to assess spatial reasoning ability and a demographic questionnaire.

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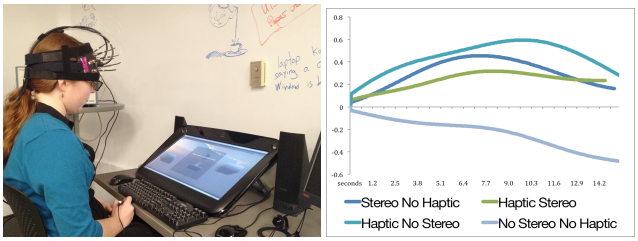

Figure 1. Left: zSpace 3D stereoscopic display and fNIRS brain sensors. Right: Average change in oxy-hemoglobin in Level 5.

We use zSpace, a passive polarized 3D system with circularly polarized glasses that provides head-tracking and stylus-tracking at 6-DOF (Figure 1). The fNIRS machine, an ISS, Inc. Imagent, is a non-invasive device that detects blood oxygen levels in the brain. The device has shown promise in the field of HCI [1, 2, 3].

Spatial Reasoning Task - zPuzzle
Our experimental task is based on the online game, Interlocked. We implemented a version for zSpace using Unity3D, which supports stereo, 6-DOF stylus and haptic feedback.

Preliminary Results
Preliminary results indicate significant effect of immersion cues on task workload (physical demand and frustration), on perceived spatial presence (attention allocation, spatial situation, spatial presence self location, and cognitive involvement) as well as in fNIRS brain data. In addition, we found a significant effect on time-on-task in difficulty levels three, four, and five. Participants working in condition 1 (no stereo, no haptic) tend to perform worse than participants in condition 2 (stereo, no haptic). Also, in some cases participants in condition 3 (no stereo, haptic) performed significantly worse than participants in condition 4 (stereo, haptic). Figure 1, right, shows that in the most challenging level, we observed significantly lower levels of oxy-hemoglobin in Condition 1 (no stereo, no haptic) than in other conditions.

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