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Coping with spatial attention in real space: A low-cost portable testing system for the investigation of visuo-spatial processing in the human brain

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ABSTRACT

While two-dimensional stimuli may be easily presented with any computer, an apparatus which allows a range of stimuli to be presented in three dimensions is not easily or cheaply available to researchers or clinicians. To fill this gap, we have developed the Realspace Testing System (RTS) which addresses the need for a flexible and multimodal stimulus presentation system capable of displaying stimuli in a three-dimensional space with a high degree of temporal accuracy. The RTS is able to control 26 channels of visual or audio stimuli, to send trigger pulses during each trial to external devices, such as a transcranial magnetic stimulator, and to record subject responses during the testing sessions. The RTS is flexible, portable and can be used in laboratory or clinical settings as required while being built at a low cost using off the shelf components. We have tested the RTS by performing an exploratory experiment on the role of right posterior parietal cortex in visuo-spatial processing in conjunction with online transcranial magnetic stimulation (TMS) and verified that the system can accurately present stimuli as needed while triggering a TMS pulse during each trial at the required time. The RTS could be appealing and useful to a range of researchers or clinicians who may choose to use it much as we have designed it, or use it in its current state as a starting point to customize their stimulus control systems in real space.

1. Introduction

Spatial processing has been a focus of a considerable amount of research using a variety of experimental paradigms in a range of animal species, in intact human participants and patient populations. One of the most popular ways to perform experiments on visual cognition has been through the use of computer-controlled displays and commercially available or custom-made stimulus presentation software such as Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) which allows a researcher to easily control the display of visual stimuli in two dimensions on a flat computer screen. In response to a growing interest in studying visuo-spatial processing in a more naturalistic manner, we developed the Realspace Testing System (RTS). The RTS is designed to present visual or audio stimuli within a three-dimensional, egocentric frame of reference with high temporal accuracy. Given the range of cortical areas involved in spatial processing (Shaw and Shaw, 1977; Hughes and Zimba, 1985; Shulman et al., 1985 among others) and our own interest in transcranial magnetic stimulation (TMS), we designed the RTS to be able to interact with TMS devices, so that we could perform studies identifying causal relations between visually guided spatial processing as well as specific cortical sites and networks and examining the chronometry of such brain events.

Visual processing in general and visuo-spatial processing in particular have also been extensively studied in animal models and in patients who have developed hemispatial neglect or other spatial processing deficits (e.g., He et al., 2007) derived from focal brain lesions after parietal or occipital strokes. Therefore, an additional goal of ours in designing the RTS was to provide an alternative assessment technique for use with patients with such impairments. Assessing such patients with the RTS would allow for their spatial processing abilities to be evaluated while permitting a detailed analysis of their performance in spatial processing tasks as well as providing reaction times for their responses to individual targets, differences in which may indicate changes in their condition or incipient or incomplete signs of recovery. In parallel, we have performed research on animal models of hemispatial neglect using the predecessor to the RTS, which is a manually controlled real

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space stimulus presentation system designed for use with feline subjects (Valero-Cabre et al., 2005, 2006; Schweid et al., 2008). The design of the RTS took its initial inspiration from this manual system, although we have made many changes and improvements in the course of designing the RTS. Central among these was the use of computer hardware and software to control stimulus presentation, which also allowed us to make the RTS capable of accurately triggering external devices; a feature which we used in an experiment of the chronometry of visuo-spatial processing using online transcranial magnetic stimulation within each trial.

The Realspace Testing System we have developed represents a useful and accessible addition to the range of devices and procedures currently in use to evaluate spatial processing. It allows an experimenter to present a large number of stimuli anywhere in the visual field, rather than within the comparatively limited field of view afforded by a desktop display, while maintaining outstanding temporal control over stimulus presentation. We designed the RTS to use low-cost, off the shelf components; all of the parts required to build the system can be obtained from any well-stocked electronics supplier for two or three hundred dollars and the system can be built in a day or two by a researcher with modest soldering skills. As the barrier to entry is extremely low for such a research device, we believe that the RTS represents an affordable, easy to build and easy to use addition to the toolkit of any researcher. While we created the RTS in response to our own research needs, it was our goal to develop a system with broad utility and appeal to a range of researchers. With this in mind, in this paper, we provide the research community with a description of the RTS, the results of our tests of its capabilities and the results of a preliminary experiment we performed using the RTS which demonstrate its usefulness and reliability. We encourage other researchers to use our open designs for the RTS (provided in the Supplemental Materials) and to modify them as needed to suit their own experimental requirements.

2. Materials and methods

2.1. Overview

The design of the Realspace Testing System (RTS) grew out of a need for a flexible system to present multiple visual and auditory stimuli at different locations, including sites in the far periphery of the visual field. We required the presentation of these stimuli to be extremely accurate, and also needed the device to have the ability to record user input via a three-button response box and to trigger external devices. Finally, as the system was to be used in studies involving both neurologically intact subjects and neurologically compromised patients, it needed to be designed so that it could be brought to the patient. Such a requirement necessitated a design that was sufficiently durable to withstand the journey, physically compact yet easy and fast to set up, while remaining sufficiently flexible to accommodate a wide range of changes in the testing environment. The resulting design for the Realspace Testing System (RTS) is inexpensive and easy to build, versatile, flexible, portable and solidly constructed. The entire RTS can be packed inside a medium sized suitcase for transit and is durable enough to be quickly deployed and taken down. Using the RTS, stimuli can be presented at any desired elevation, azimuth or depth, constrained by the available cable length between the stimulus boxes and the RTS router.

A laptop computer controls the RTS, and through the RTS software (source code and executable provided in the Supplemental Materials) on the computer, the user is able to set all stimulus characteristics, including stimulus timing, sequencing and triggering. The computer is connected to the RTS router, which uses inexpensive integrated circuits to route signals from the computer to command up to 13 individual stimulus boxes. The system is built to accommodate 2 sets of 13 channels per stimulus modality, which in our design translate to 13 discrete visual stimuli, and 13 auditory stimuli. The ease of construction allows for the designer to control and build 26 discrete stimulus channels of virtually any modality (e.g., tactile stimulators, thermogenic stimulators, buzzers, etc.), limited only by the requirement that the stimulus of choice needs to run on a 3.5 V input. The router also provides two output trigger channels to integrate external devices (e.g., a transcranial magnetic stimulator) within the experimental design; in addition, the RTS router receives and logs input from a handheld subject-controlled response box.

2.2. Building the Realspace Testing System

The RTS is composed of four major components; the router, which is connected to a computer running the control software, the stimulus boxes and the response box (see Fig. 1A for an overall view of the RTS). The connections between the RTS router, the stimulus boxes and the response box are made using 50 Ω Bayonet Neill-Concelman connectors (BNC connectors) for ease of construction and long-term durability, and the router is connected to the computer via a parallel cable. While other connections are now more commonly used for peripheral devices, the DB-25 parallel port was chosen due to its low cost, minimal programming overhead and its presence on the great bulk of Windows-compatible computers. Other interfaces, such as the Universal Serial Bus (USB), require considerably more in the way of dedicated hardware and would complicate the design of the RTS router. While the parallel port is being phased out, it is likely that older systems with onboard parallel ports will be available for some time to come at minimal cost. All of the components used in the system can be easily soldered by hand. All components of the RTS are readily available from any large electronic parts vendor with the exception of the main circuit board for the router. The latter is a custom-designed printed circuit board (a fabrication-ready design is provided in the Supplemental Materials) that may be cheaply and quickly fabricated by a board production company at a low cost. Having a custom board fabricated for the router, rather than building a point-to-point board by hand allows us to have a minimum of wiring within the router while ensuring good connections between the router's integrated circuit components.

The router circuitry begins with the parallel connection from the computer; this provides us with eight addressable lines on the connector, which are used by the software to control the router's two independent stimulus circuits. The visual circuitry consists of a 4:16 demultiplexer; which receives a binary control signal from four pins in the parallel connector. Based on the control signal it receives, it will push one of its sixteen output lines to a ground (0 V) state. As this will not illuminate a visual stimulus, each of these outputs are then passed through a secondary multiplexer which is wired to pass voltage (3.5 V) out to one of the visual output lines. The audio circuitry is considerably less complicated; we used a dedicated 4:16 audio demultiplexer which receives the same four-channel control signal as the visual circuitry, as well as an audio input and a control line (which is used to keep the visual and audio circuits from being used simultaneously) and using these inputs, it routes an audio signal along one of its sixteen outputs to one of the audio output lines on the router.

2.3. Building the RTS router

The router was constructed using a medium sized metal project enclosure. Thirty-one holes were drilled in the enclosure for BNC connectors and a space was cut for a parallel port connector (see Fig. 1B). Twenty-six of the BNC holes are allocated for the stimulus