Enhancing brain activity by controlling virtual objects with the eye

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ABSTRACT

Stimulation of the damaged neural networks is a key factor for the reorganization of neural functions in the treatment of motor deficits. This work explores, using functional MRI, a system to activate motor regions that does not require voluntary limb movements. Healthy participants, in a virtual environment, controlled a virtual paddle using only their eye movements, which was related with an increase of the activity in frontoparietal motor regions. This may be a promising way to enhance motor activity without resorting to limb movements that are not always possible in patients with motor deficits.

1. INTRODUCTION

Physical therapy is a common treatment for motor deficits but it is not always possible because of limitations in the affected limbs. Thus, alternative approaches have been used to support the recovery of motor functions by generating an activation of the sensorimotor system without resorting to overt voluntary movements (Szameitat, Shen, Conforto and Sterr, 2012). One approach is based on passive movements caused by an external agent. Another approach is based on motor imagery, i.e. the mental rehearsal of motor acts in the absence of actual movement production (Zimmermann-Schlatter, Schuster, Puhan, Siekierka and Steurer, 2008). There is a third approach (action observation therapy), based solely on the visual presentation of actions, which may facilitate the reorganization of the affected motor areas, and has demonstrated good therapeutic results (Carvalho et al, 2013).

Several basic imaging studies, outside the field of the neurorehabilitation, comparing different kinds of limb and eye movements have supported the idea that the cortical representations for diverse movements, specifically frontal and parietal circuits for limb and eye movements, are highly distributed and overlapping in the human brain (Filimon, 2010). This overlap, which may seem surprising at first, is not so surprising if one takes into account that limb and eye movements are naturally coupled in daily life (Levy, Schluppeck, Heeger and Glimcher, 2007). Thus, it would not be unreasonable to think that eye movements could be used in some way to generate brain activity related with limb movements.

Considering the results of such basic studies, this work explores a new system to activate sensorimotor regions in healthy participants that does not need voluntary limb movements. The idea is to use the eye (instead of the limb) to control objects in a virtual environment. Here, the object is a virtual paddle that is controlled by the participants in the context of a digital game. Participants in a functional MRI experiment move the virtual paddle to hit a ball using their eyes (with an eye tracking system) or just observe the game (baseline). An increase of frontoparietal activation might be expected when participants are using the eye as effector because of the overlapping of brain circuits for limb and eye movements. If this expectation is confirmed, it could have a potential application in the field of the virtual reality neurorehabilitation.

2. MATERIALS AND METHODS

2.1 *Participants*

15 right-handed neurologically healthy subjects (10 female, 5 male) between 19 and 21 years of age (mean=20.8; SD=0.6). They had normal or corrected-to-normal vision. The study was approved by the local Ethics Committee (University of La Laguna) and was conducted in accordance with the Declaration of Helsinki.

2.2 *Virtual environment*

A virtual 3D environment, using Visual C# and DirectX, was developed where the subjects play a paddle and ball game from an egocentric perspective. Participants had to prevent the ball entering the space behind them by trying to hit the approaching ball back towards the opponent (the computer), who controlled its own paddle (Figure 1). The paddle had one degree of freedom (left-right) and was cuboid in shape.

Participants used their gaze to control the virtual paddle. This was done by using an MRI-compatible eye tracking system (MReyetracking, Resonance Technology Company, Northridge, CA), which obtains the participant's gaze point in real-time. This system includes a Software Developer's Kit (SDK) that allows programs like the virtual game to interface with the eyetracker. The gaze point horizontal coordinates were transformed into positions of the virtual paddle using this SDK, which allowed the participant to control it in real-time.

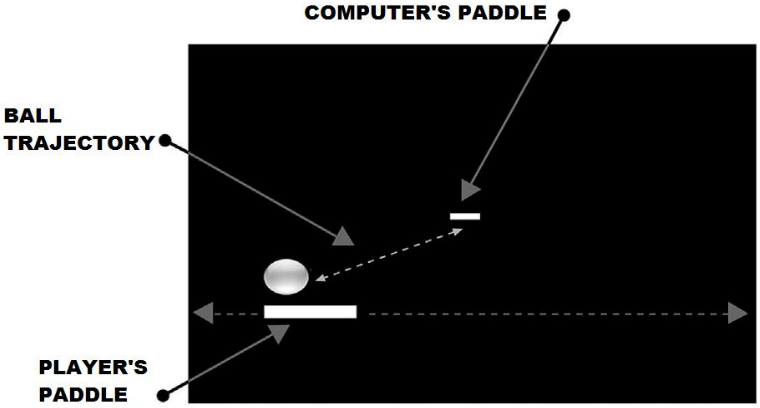

Figure 1. *The virtual game. Participants used their eyes to control a paddle to hit an approaching ball. The paddle had one degree of freedom (left-right). The display had a 3D feel, so the more distant computer's paddle was smaller and further away.*

2.3 *Data acquisition*

The fMRI run consisted of three conditions: *play*, *observation* and *fixation*. The *play* condition consisted of six 20 s blocks where the participant was playing against the computer using the gaze. During the *observation* condition, the participants just watched another six games. These observed games were similar to the executed games, but in this case the two paddles were controlled by the computer. The *play* and *observation* blocks were presented in random order and were preceded by a *fixation* task where the player stared at a grey cross in the middle of a black screen. The participants were instructed to focus on the game during the *observation* periods. Visual stimuli were given via MRI compatible eyeglasses (Visuastim, Resonance Technology, Northridge, CA).

Axially oriented functional images were obtained by a 3T Signa HD MR scanner (GE Healthcare, Milwaukee, WI) using an echo-planar-imaging gradient-echo sequence and an 8 channel head coil (TR = 2000 msec, TE = 22 msec, FA = 75º, matrix size = 64 x 64 pixels, 36 slices, 4 x 4 mm in plane resolution, spacing = 4 mm, ST = 3.3 mm, interleaved acquisition). The slices were aligned to the anterior commissure - posterior commissure line and covered the whole brain. High resolution sagittally oriented anatomical images were also collected for anatomical reference. A 3D fast spoiled-gradient-recalled pulse sequence was obtained (TR = 6 msec, TE = 1 msec, FA = 12º, matrix size= 256 x 256 pixels, .98 x .98 mm in plane resolution, spacing = 1 mm, ST = 1 mm).

2.4 *Data analysis*

Data were preprocessed and analyzed using the software SPM8 (www.fil.ion.ucl.ac.uk/spm/). The images were spatially realigned, unwarped, normalized and smoothed using standard SPM8 procedures. The three conditions were modelled in the design matrix for each participant. Activation maps for the contrast *play > observation* were generated for each subject by applying t statistics. These first level contrast images were used in a random effects group analysis. Statistical maps were set at a voxel-level threshold of $p<0.05$, FDR corrected for multiple comparisons, and a minimum cluster size of 25 voxels.

3. RESULTS

Figure 2 shows the brain regions that were more activated when participants played the game using their gaze than when they were just observers. Many of the activations appear located in areas related with motor aspects (Kandel, 2013). It is worth mentioning here the extended, bilateral activity that was found in a region centred in the Brodmann area 6 (premotor cortex and supplementary motor area). Bilateral activity was also found in several regions of the inferior and superior parietal lobules (such as the supramarginal gyrus, the angular gyrus and the precuneus). The occipital lobe and the cerebellum were also bilaterally activated, and, to a lesser extent, some temporal areas.

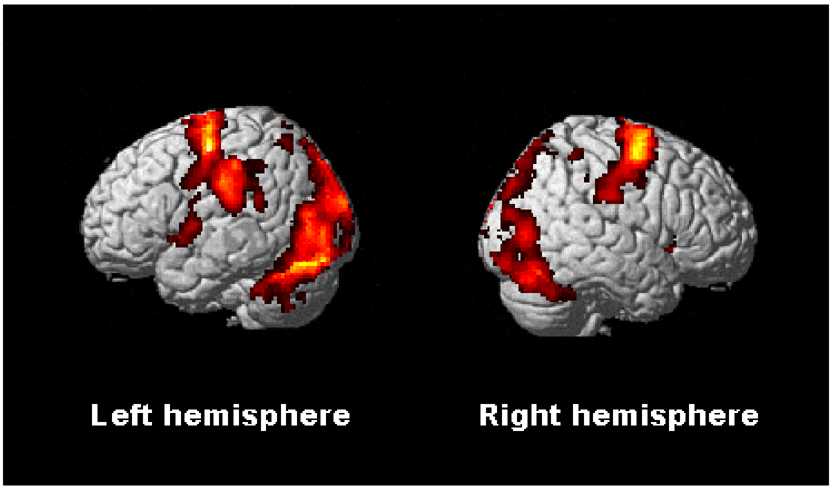

Figure 2. *Results of the play > observation contrast. When compared with an observation task (with a similar visual input), controlling the virtual paddle using eye movements was associated with an increase of the activity in frontoparietal motor regions (group analysis, N=15, threshold: p<0.05 at the voxel level, false discovery rate [FDR] corrected for multiple comparisons; minimum cluster size=25 voxels).*

4. CONCLUSIONS

In line with our expectations, when compared with an observation task with a similar visual input, using the gaze to control a virtual object is associated with an increase of the activity in frontoparietal motor regions. A key factor influencing reorganization of function in damaged neural networks is stimulation (Johnson-Frey, 2004), and the method presented here may be a promising approach to enhance motor activity without resorting to voluntary limb movements. Another advantage of this approach is that the control of a virtual object with the gaze may be more entertaining for the patients than other kinds of tasks used in rehabilitation, which therefore may help the patient to adhere to the therapy. In the future, attractive neurorehabilitation gaze-based systems could be developed for the users, which may be especially useful in the case of children and adolescents. Therefore, the results presented here can be of interest for researchers, developers and medical professionals working in the field of the neurorehabilitation.

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