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THE MIRROR NEURON SYSTEM AND MOTOR DEXTERITY: WHAT HAPPENS?

J. PLATA BELLO, [a,b]* C. MODROÑO, [a] F. MARCANO [a] AND J. L. GONZÁLEZ–MORA [a]

[a] *Department of Physiology, Faculty of Medicine, University of La Laguna, Spain*

[b] *Hospital Universitario de Canarias (Department of Neurosurgery), S/C de Tenerife, Spain*

Abstract—The mirror neuron system (MNS) is currently one of the most prominent areas of research in neuroscience. Some of the work has focused on the identification of factors that modulate its activity, but until now, no one has tried to identify the effect of motor ability on the MNS regions. The aim of the present work is to study a possible modulation of hand dexterity on the MNS activity.

A blocked fMRI experiment has been designed, consisting of an execution condition, where participants must repeatedly perform a precision grasping pantomime, and an observation condition, where the same motor action is passively observed. A conjunction analysis was performed in order to confirm the existence of mirror activity. Moreover, participants were classified depending on their hand dexterity (measured with the Purdue Pegboard Test) as ''High dexterity'' or ''Low dexterity'' and a regression analysis was performed to investigate a possible linear relationship between the degree of dexterity and brain activity in the MNS.

The conjunction analysis revealed, as expected, activity in the inferior parietal lobule, a region that constitutes one of the nuclei of the putative MNS and which is consistently activated by intransitive actions. The degree of dexterity only seems to modulate MNS regions during action execution. However, under the observation condition, no linear relationship of hand dexterity in MNS regions was registered in either the comparison between groups, or in the regression analysis.

Therefore, the MNS network does not seem to be linearly modulated by the degree of motor dexterity, as occurs with other action-related factors like familiarity.

Key words: mirror neurons, motor dexterity, action observation, precision grasping.

*Correspondence to: J. P. Bello, Hospital Universitario de Canarias (Neuroscience department), Calle Ofra s/n La Cuesta, CP 38320 La Laguna, S/C de Tenerife, Spain. Tel: +34-922-255-544/+34-646-625-973.
E-mail address: jplata5@hotmail.com (J. Plata Bello).
Abbreviations: FWHM, full width at half maximum; FDR, False Discovery Rate; HD, High dexterity; IPG, inferior frontal gyrus; IPL, inferior parietal lobule; LD, Low dexterity; MNI, Montreal Neurological Institute; MNS, mirror neuron system; SMC, sensorimotor cortex; VOIs, volumes of interest.

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INTRODUCTION

Mirror neurons are currently one the most prominent research topics. Since their discovery in macaques (di Pellegrino et al., 1992; Gallese et al., 1996), a large number of publications have elucidated many aspects about their features in non-human primates, as well as their presence and organization in humans. Although the presence of single mirror neurons has already been demonstrated in humans (Mukamel et al., 2010), it is more appropriate to talk about the fronto-parietal mirror neuron system (MNS), which is considered as being an action recognition network and, as occurs with mirror neurons, it is activated when an action is executed or observed (Cattaneo and Rizzolatti, 2009; Rizzolatti and Sinigaglia, 2010).

The human MNS presents activity during the observation or execution of transitive and intransitive actions (Iacoboni et al., 1999, 2001; Koski et al., 2003; Jonas et al., 2007; Lui et al., 2008). Nevertheless, there are differences in terms of MNS activation secondary to the transitivity of an action. Generally speaking, the brain activity on the MNS seems to be lower and more restricted to posterior parietal regions for intransitive actions (Rizzolatti and Craighero, 2004).

Apart from the activation of the MNS with transitive or intransitive actions, it is worth noting that one important factor that modulates brain activity within this network is the degree of motor familiarity with the executed or observed action. In this sense, a higher degree of motor familiarity is related to greater activity in MNS regions, independently of whether the action is transitive (Calvo-Merino et al., 2005, 2006; Cross et al., 2006) or intransitive (Plata Bello et al., 2013).

However, a frequent error is to consider motor familiarity as motor dexterity (which is the same as motor ability), because familiarity in motor actions is determined by how often they are performed or observed (Calvo-Merino et al., 2006) but this does not mean that subjects with the same degree of familiarity with a certain action (e.g. football players of different divisions) have the same degree of motor ability for this action performance (normally higher division means higher ability). Dexterity for a certain action means performing a movement skillfully, with velocity and precision, and achieving an efficient manner to perform that action. This aptitude depends on a continuous bidirectional flow of information from the cerebral cortex to the movement effectors and vice versa, via the spinal cord (Kühn et al., 2012).

To the best of our knowledge, no report has tried to identify a possible relationship between motor dexterity (measured by objective and validated tests) with the activity in MNS regions.

Bearing this in mind, the aim of the present work is to identify a possible modulation of hand dexterity in the MNS during the observation and execution of a simple and intransitive finger to thumb opposition task.

EXPERIMENTAL PROCEDURES

Subjects

Thirty-one healthy, right-handed (Edinburgh Handedness Inventory (Oldfield, 1971) < 25) and untrained participants were selected (17 women), with an average age of 26.1 (SD = 4.5). Written informed consent was explained and signed. The study was approved by the University of La Laguna Ethics Committee, according to the Declaration of Helsinki.

All participants performed two tests (the ''Letter Cancelation Task'' and the ''Digit Cancelation Task'') (Peña-Casanova et al., 2004) to identify any impairment in their attention capabilities and all of them were appropriate candidates for the study.

Manual dexterity measure

Participants were asked to perform the Purdue Pegboard Test to assess hand dexterity (Tiffin and Asher, 1948). This test consists of a board with two parallel rows with 25 holes per row into which cylindrical pins are placed by the participant. After explanation as well as demonstration of the task and three practice trials, participants were asked to place as many pins into the holes of the perforated board as possible within 30 s of each trial. Three trials per condition were administered with both, the dominant (right) hand and the non-dominant hand; bimanual performance was not allowed. Ability scores were obtained by averaging the number of pins placed correctly during the trials per condition, one for the right hand and another one for the left hand. These scores were used to identify a relationship between the degree of motor dexterity and brain activity associated with the execution or the observation of a finger–thumb opposition task in a further regression analysis which is explained below.

Data acquisition and processing

Data for the experiment were collected at the Magnetic Resonance for Biomedical Research Service of the University of La Laguna. Functional images were obtained on a 3-T General Electric (Milwaukee, WI, USA) scanner using an echo-planar imaging gradient-echo sequence and an 8-channel head coil (TR = 3000 ms, TE = 21 ms, flip angle = 90°, matrix size = 64×64 pixels, 57 slices/volume, spacing between slices = 1 mm, slice thickness = 3 mm). The slices were aligned to the anterior commissure–posterior commissure line and covered the whole cranium. Functional scanning was preceded by 18 s of dummy scans to ensure tissue steady-state magnetization.

A whole-brain three-dimensional structural image was acquired for anatomical reference. A 3D fast spoiled gradient-recalled pulse sequence was obtained with the following acquisition parameters: TR = 10.4 ms, TE = 4.2 ms, flip angle = 20, matrix size = 512×512 pixels, $.5 \times .5$ mm in plane resolution, spacing between slices = 1 mm, slice thickness = 2 mm.

After checking the images for artifacts, data were preprocessed and analyzed using Statistical Parametric Mapping software SPM8 (Wellcome Trust Centre for Neuroimaging; http://www.fil.ion.ucl.ac.uk/spm/) and displayed using xjView 8.1 (http://www.alivelearn.net/xjview8/). The images were spatially realigned, unwarped, and normalized to the Montreal Neurological Institute (MNI) space using standard SPM8 procedures. The normalized images of $2 \times 2 \times 2$ mm were smoothed by a full width at half maximum (FWHM) $8 \times 8 \times 8$ Gaussian kernel.

Study design

Two fMRI runs were performed, one for each condition (execution or observation). The order of the studies was

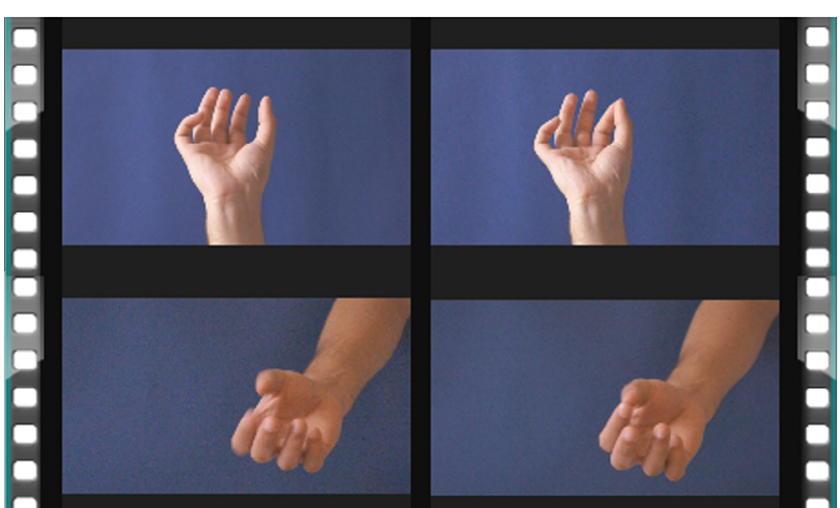

Fig. 1. Two frames of the observation condition showing the two visual perspectives: first (up) and third (down) person perspectives.