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Brain lateralization of complex movement: Neuropsychological evidence from unilateral stroke

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ABSTRACT

Complex movement (CM) refers to the representation of a goal-oriented action and is classified as either transitive (use of tools) or intransitive (communication gestures). Both types of CM have three specific components: temporal, spatial, and content, which are subdivided into specific error types (SET). Since there is debate regarding the contribution of each brain hemisphere for the types of CM, our objective was to describe the brain lateralization of components and SET of transitive and intransitive CM. We studied 14 patients with a left hemisphere stroke (LH), 12 patients with a right hemisphere stroke (RH), and 16 control subjects. The Florida Apraxia Screening Test-Revised (FAST-R, Rothi et al., 1988) was used for the assessment of CM. Both clinical groups showed a worse performance than the control group on the total FAST-R and transitive movement scores ($p < 0.001$). Failures in Spatial and Temporal components were found in both clinical groups, but only LH patients showed significantly more Content errors ($p < 0.01$) than the control group. Also, only the LH group showed a higher number of errors for intransitive movements score ($p = 0.017$), due to lower scores in the content component, compared to the control group ($p = 0.04$). Transitive and intransitive CMs differ in their neurocognitive representation; transitive CM shows a bilateral distribution of its components when compared to intransitive CM, which shows a preferential left hemisphere representation. This could result from higher neurocognitive demands for movements that require use of tools, compared with more automatic communication gestures.

1. Introduction

Brain lateralization refers to the preferential way in which information is processed and represented in one of the two hemispheres, as well as the most efficient and flexible response generated by one of them (Gazzaniga, Ivry, & Ronald, 1998). It has been suggested that brain lateralization emerges to avoid a slowing down in the interhemispheric processing of information (Bizzasa, Rogers, & Vallortigara, 1998; Vallortigara, Rogers, & Bisazza, 1999). Additionally, it may allow for the delimitation of specific neuronal resources in such a way that circuits located in one hemisphere can process certain information of one task while the homologous area, located in the opposite hemisphere, can perform different or complementary processes of the same task (Hirnstein, Hausmann, & Güntürkün, 2008). This parallel processing is advantageous for highly complex brain functions (Belger & Banich, 1992).

The most solid findings on brain lateralization patterns in human beings have been reported in the areas of language and visuospatial functions (Whitehouse & Bishop, 2009). However, in the last years, several works have explored this process in other domains such as working memory (Wagner, Sziklas, Gaver, & Jones-Gotman, 2009), face and word recognition (Mercure et al., 2009), cognitive control (Goghari & MacDonald, 2009), and other executive functions (Horn, Berman, & Weinberger, 1996).

Another cognitive process of interest for the study of lateralization patterns is complex movement (CM), since handedness represents the most evident behavioral asymmetry in humans (Foundas, Leonard, & Hanna-Pladdy, 2002). CM is defined as the abstract representation of an intentional action that contains general information about the goal, the sequence of movements that need to be carried out, and the neuromuscular control that allows accomplishing the goal (Keele, 1968). Impairments in CM not caused by

Abbreviations: CM, complex movemen; TM, transitive movements; IM, intransitive movements; SET, specific error types; SEM, standard error of the mean; LH, patients with unilateral ischemic stroke on the left hemisphere; RH, patients with unilateral ischemic stroke on the right hemisphere.

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motor, sensory, or cognitive abnormalities are known as apraxias (Wheaton, Fridman, Bohlhalter, Vorbach, & Hallett, 2009).

CM is classified into two types: transitive movements (TM) and intransitive movements (IM). The former include actions related to the use of tools and a deficit corresponds to ideational apraxia, while the latter refer to communication gestures, impairment of which is related to ideomotor apraxia (Wheaton et al., 2009). It has been proposed that different hemispheric contributions exist for each type of CM, as TM require a greater neurocognitive demand due to the spatial representation of objects (Buxbaum, 2001; Buxbaum, Frey, & Bartlett-Williams, 2005; Buxbaum, Giovannetti, & Libon, 2000). In contrast, IM do not need this kind of configuration and their hemispheric representation can be influenced and facilitated by such factors as familiarity (Carmo & Rumiati, 2009). Rothi, Mack, Verfaellie, & Brown, (1988) and Rothi, Raymer, and Heilman (1991) propose a cognitive-neuropsychological model that allows for the study of CM (praxis) at distinct levels of motor function. The model divides TM and IM into three specific motor components: Content, Spatial, and Temporal (Grieve, 2000; Rothi, Raymer, & Heilman, 1991). These components are subdivided further into specific error types (SET) of the respective movement (Hanna-Pladdy et al., 2001; Rothi et al., 1988, 1991). This theoretical perspective allows for the exploration of the lateralization of CM at different levels of integration of cognitive function, which is addressed in the current study.

Even though it is well established that the left hemisphere is usually responsible for selection and planning of complex motor sequences and that its lesions may produce bilateral apraxia (Sabaté, González, & Rodríguez, 2004; Schluter, Krams, Rushworth, & Passingham, 2001), there is some evidence indicating that the motor planning and organization needed for TM and IM performance may be distributed between both hemispheres. Patients with crossed apraxia resulting in an impairment of CM due to right hemisphere injury show better performance of IM compared to TM, as well as good gesture comprehension compared to gesture production. Raymer et al. (1999) as well as Hanna-Pladdy et al. (2001) have confirmed the dominant role of the left hemisphere for praxis, but have also indicated the potential bilateral representation of it due to the significant number of time and External configuration errors shown by patients with right hemisphere injury. Additionally, it has been hypothesized that the right hemisphere plays a dominant role for imitation of unfamiliar or non-automatic gestures (Rumiati, 2000). These data are consistent with the proposal of a bilateral representation of CM (Rapcsak, Ochipa, Beeson, & Rubens, 1993).

Despite the extant findings on the contribution of each hemisphere for CM (Buxbaum et al., 2000; Carmo & Rumiati, 2009; Hanna-Pladdy et al., 2001; Raymer et al., 1999; Rumiati, 2000; Schluter et al., 2001), there are no specific descriptions of the interhemispheric differences in the processing of types, specific components, or SET of CM. The objective of the current study was to describe the brain lateralization for the types, components, and SET of CM. For this purpose, a clinical sample of patients with unilateral ischemic stroke was examined, as they provide a model of single-hemisphere damage that allows for the analysis of the distribution of neurocognitive complex functions (Gazzaniga et al., 1998).

2. Material and methods

2.1. Participants

A total of 48 participants were recruited from the Clinic of Vascular Disease at the Instituto Nacional de Neurología y Neurocirugía Manuel Velasco Suárez (INNNMVS) in Mexico. Of these, 17 patients had unilateral ischemic stroke in the left hemisphere (LH) and 15 patients had unilateral ischemic stroke in the right hemisphere (RH). The remaining 16 participants were healthy subjects comprising the control group. A neurologist diagnosed the patients based on clinical data and magnetic resonance imaging (MRI) findings. Patients showed a single ischemic stroke with an evolution time from two to six months. Healthy subjects did not have any neurological, psychiatric, or substance use disorders. All participants were right-handed.

Patients with global aphasia as determined by a score below 26 points on the Comprehension subtest of the Boston Test for the Diagnosis of Aphasia (Goodglass, Kaplan, & Barresi, 1996), visuospatial impairment as determined by a score below 25 points on the Motor Free Visual Perception Test (Calarusso & Hammill, 1972), or severe global cognitive deficit (Mini-mental State Examination score below 21 points (Folstein & Folstein, 1975) were excluded from the study. These screening measures were used in order to corroborate that deficits in complex movement were not due to motor, sensory, or cognitive abnormalities in a way that would meet established criteria to be considered an apraxia syndrome (Geschwind, 1975).

2.2. Instruments

The Florida Apraxia Screening Test-Revised (FAST-R) was used for the evaluation of CM (Rothi et al., 1988). It contains 30 items for the execution of gestures in response to a verbal command, 20 of which are transitive pantomimes (not actual object use) and 10 are intransitive pantomimes. The three components (Spatial, Temporal, and Content) were evaluated for each item according to the SET that constitute each one. For the Spatial component, SET were Amplitude, Internal configuration, External configuration, and Use of the body as object. SET for the Temporal component consisted of Sequence, Speed and Occurrence. Lastly, content Component SET were Related movements, Unrelated movements, and Perseverations. The FAST-R maximum score is 30 points, with 1 point for each correct movement. Apraxia is probable when the total score is <15 points. If an item is incorrect, the evaluator indicates the component corresponding error, as well as the associated SET. For a more detailed explanation of FAST-R scoring, see Rothi et al. (1988).

2.3. Procedure

The study was approved by the Research and Bioethics Committee of the INNNMVS and all procedures were in accordance with the Declaration of Helsinki (WMA, 2008). All the participants signed an informed consent. Once they agreed to participate, the evaluation was conducted in a single session that lasted approximately 30–40 min. The screening tests for aphasia, visuospatial impairment, and global cognitive decline were administered first. Subsequently, the FAST-R test was administered, which was performed by the patients using the upper limb ipsilateral to the damaged hemisphere due to contralateral hemiparesis suffered by some patients. Half of the control group performed the FAST-R with the left hand and the other half with the right hand. The administration of FAST-R was videotaped and subsequently scored by two neuropsychologists. In order to obtain an interrater reliability index, a Cohen-Kappa analysis was generated for each item. The result was a minimum concordance value of 0.682 and a maximum value of 1. The resulting significance for all items was $p < 0.001$.

2.4. Statistical analysis

Descriptive analyses were performed in terms of mean, standard deviation (SD), and percentages. Means were compared using Kruskall–Wallis or Mann–Whitney U tests as required for