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Research report

Lateralization of brain activity during motor planning of proximal and distal gestures

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HIGHLIGHTS

- We studied planning of tool-use pantomimes involving distal or proximal limb control.
- Distal gesture planning condition is more left lateralized than proximal condition.
- There is a quote of variability in the lateralization pattern across subjects.
- Functional connectivity between motor areas is distinctly modulated across gestures.

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ABSTRACT

Praxis functions are predominantly processed by the left hemisphere. However, limb apraxia is found in less than 50% of patients with left hemisphere damage, and also, although infrequently, in patients with right hemisphere damage. We studied brain representation of preparation/planning of tool-use pantomime separating the gestures involving mostly distal limb control (e.g., using scissors) from those involving proximal limb control (e.g., hammering). During the fMRI scan transitive pantomimes were performed with the dominant and the non-dominant hand by right-handed healthy subjects. Random and voxel-based analysis through laterality index (LI) calculation, demonstrated that for both limbs, distal gesture planning was in general left lateralized, while for the proximal condition the representation was found to be more bilateral particularly in the inferior frontal gyrus. LI distributions across subjects indicated that while the majority of subjects are left-hemispheric dominant for praxis, there are a minority with the opposite lateralization. Functional connectivity analysis showed that while the correlation between homolog areas involved in gesture production was high irrespective of gesture type, their correlation to the supplementary motor area was high in proximal but not distal conditions. Therefore, transitive gestures, when pantomimed to verbal commands, are differentially represented inter and intra hemispherically depending on whether the gesture is performed with the right or left arm or whether it involves predominantly distal or proximal limb movements. Furthermore, the representation of the different types of gestures may be related to a modulation of the connectivity between areas involved in motor planning.

1. Introduction

Apraxia, as clinically defined by Liepmann [1], is the most dramatic disorder of learned skilled purposeful movements or gestures. Apraxia comprises a wide spectrum of cognitive-motor disorders owing to acquired brain disease, affecting the performance of skilled learned purposeful movements with or without preservation of the ability to perform the same movements outside the clinical setting in the appropriate situation or environment, which cannot be accounted for by elementary motor or sensory deficit [2,3]. Since Liepmann [77] postulated that the left hemisphere of right-handed subjects contains the "movement formulae"

Abbreviations: LHD, left hemispheric damage; RHD, right hemispheric damage; IMA, ideomotor apraxia; LI, laterality index; PM, premotor cortex; IPL, inferior parietal lobule; SPL, superior parietal lobule; IFG, inferior frontal gyrus; SMA, supplementary motor area; FC, functional connectivity.

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that controls purposeful skilled movements of the limb of both sides of the body, every subsequent study on limb apraxia suggested left hemisphere dominance for praxis (see [4] for review) regardless of one's hand dominance [5]. However, limb apraxia has been found in around half of the patients with left hemisphere damage (LHD) and in a minority of patients with right hemisphere damage (RHD), which may indicate, as suggested by De Renzi [6], that in some patients praxis functions have bilateral representations or alternatively that left hemisphere lesions may not necessary damage regions underlying praxis functions.

Liepmann himself was cautious enough to point out that the right hemisphere may also possess some praxis skills, especially for the left half of the body [1]. Since then, the possibility that the right hemisphere may contain some capacity to control skilled purposeful movements in right handers has also been postulated by several authors, as a possible explanation for the sparing of certain left-hand praxis functions in patients with LHD or with surgically or naturally occurring callosal lesions [5,7–10,65]. Patients with ideomotor apraxia (IMA) may commit errors when performing transitive and intransitive gestures. Whereas transitive gesture imply the use of a tool and/or object (i.e., hammering), intransitive gestures are those representational ones which do not involve the use of a tool/object (i.e., hitch-hike) [11]. Most of the spatial and temporal errors exhibited by patients with IMA may also be seen in RHD patients when they pantomime intransitive gestures, imitate transitive movement and perform transitive movements using tool/objects, but are observed predominantly in LHD patients when they pantomime transitive gestures on verbal command, because in this condition the gesture is carried on outside the natural context [10,12,13,65]. Rusworth and colleagues have further proposed that the left hemisphere is also dominant for the selection of object oriented movements as well as for motor attention, it means, the process of directing attention while preparing for a particular limb movement [14,15]. Thus, it seems quite likely that the interhemispheric differences in the control of praxis skills depend on the context in which the movement is performed and the cognitive requirement of the task [16]. Moreover, it is a common clinical observation that apraxic patients perform some but not all movements in a particularly abnormal fashion and/or that individual differences appear in some but not all components of a given movement, further suggesting that action representation varies also as a function of the complexity and characteristics of the movement as well as the context and means.

Functional imaging studies in normal right-handed subjects have demonstrated that performing simple upper limb movements with the non-dominant hand produce more bilateral activation than that obtained when moving the dominant hand [17–19]. Moreover, activity in sensorimotor cortex was found to be more bilateral while moving the dominant limb in proximal tasks, such as shoulder movement, than in distal tasks, like finger tapping, where ipsilateral sensorimotor cortex was less activated [20]. Hemispheric distribution of brain activity was found to depend not only on the hand dominance [21] and whether it involved a proximal or distal limb movement, but also on the complexity of the task [17,22–25].

Many researchers have described activation of the left parietal region and bilateral in the premotor cortex during planning and executing praxis movements focusing on tool-use pantomime [26–28]. Moreover, recent studies have demonstrated a more pronounced lateralization in premotor cortex during planning [29] and recognition [30] of intransitive than transitive gestures. However, although these findings contribute to shed light to praxis dominance, the reason why some apraxic patients present deficits in the pantomime of some tool-use gestures and not in others remains unclear. Many studies in patients with disconnection syndrome and hemispheric lesions suggest and provided support for the common clinical observation that distal and proximal movement components in apraxia are differentially affected [31]. Right handed patients with disconnection syndrome due to callosal damage frequently performed verbal commands incorrectly with the left upper limb predominantly with the hand [7,32,33]. In turn, Sirigu et al. [34] reported a patient with bilateral posterior parietal cortex lesions; her main impairment in manual grasping involving actual use of objects. Furthermore, Buxbaum et al. [35,36] investigated patients with IMA due to left inferior parietal damage and found, a specific impairment in hand-object interactions. Distal-proximal differences in limb apraxia has been described also by Soliveri et al. [37] in patients with corticobasal degeneration but not progressive supranuclear palsy. Imitation of gestures seems to be also body-part specific. Left-brain damage patients have more difficulties imitating hand than finger postures, whereas right-brain damaged patients commit more errors with finger postures [38,39].

Clinical findings have been also supported by three-dimensional computergraphic analysis; Poizner et al. [40] demonstrated that IMA affects distal hand and finger simple movements more than proximal movements. Based on previous clinical and computergraphic analysis findings as well as in functional imaging studies of simple joint movements a most likely explanation would be that proximal and distal types of gestures are differentially represented inter as well as intrahemispherically [20,23,25,41] and therefore the connectivity underlying them and its relation to the pattern obtained for neural activity is different as well. As a matter of fact, modulation in the connectivity depending on task conditions has been observed in other neural networks [42–44].

Therefore, the aim of the present study was to determine, by using fMRI, the representation of different praxis skills in healthy subjects assessed while planning to pantomime distal, involving mainly finger and hand movement, and proximal, involving predominantly shoulder and arm movement, tool-use gestures with the dominant as well as the non dominant hand. We hypothesized that activity during planning of proximal gestures would be more bilaterally represented than during planning of distal gestures and that hemispheric representation would be more bilateral in general when planning proximal gestures with the non-dominant hand than with the dominant hand [17,20,22,23,25]. Moreover, we predict a general left lateralization for gesture representation with some quote of variability in a minority of subjects which potentially could develop apraxia in case of RHD [45–49]. In addition, we expected a modulation in the connectivity between homolog areas reflecting the different types of gestures.

2. Experimental procedure

2.1. Subjects

Twenty healthy subjects aged 30 ± 10 year old, participated in this study. The Edinburgh Handedness Inventory was used to assess handedness [50]. All the subjects were right-handed. The participants gave written informed consent. The study protocol was approved by the Institutional Review Board of the Institute of Neurological Research-FLENI.

2.2. Functional MRI

The fMRI measurements were carried out on a 3T Signa HDxt GE scanner using an 8 channel head coil. Change in blood-oxygenation-level-dependent (BOLD) T2* signal was measured using a gradient-echo EPI sequence. Thirty contiguous slices were obtained in the AC-PC plane with the following parameters: 2 s repetition time (TR), flip angle: 90°, 24 cm field of view, 64×64 pixel matrix, and $3.75 \times 3.75 \times 4.0$ mm voxel dimensions.