Right Hemisphere Cognitive Functions: From Clinical and Anatomic Bases to Brain Mapping During Awake Craniotomy Part I: Clinical and Functional Anatomy

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Key words
- Awake surgery
- Nondominant hemisphere
- Social cognition
- Unilateral neglect
- Visuospatial cognition

Abbreviations and Acronyms
AG: Angular gyrus
DAN: Dorsal attentional network
fMRI: Functional magnetic resonance imaging
FN: Face network
IFG: Inferior frontal gyrus
IFOF: Inferior fronto-occipital fasciculus
ILF: Inferior longitudinal fasciculus
IPL: Inferior parietal lobule
mvPFC: Medial ventral prefrontal cortex
MFG: Middle frontal gyrus
MTG: Middle temporal gyrus
SLF: Superior longitudinal fasciculus
SMG: Supramarginal gyrus
STG: Superior temporal gyrus
STS: Superior temporal sulcus
TOM: Theory of mind
TPJ: Temporoparietal junction
UN: Unilateral neglect
VAN: Ventral attentional network
VFC: Ventral frontal cortex

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The nondominant hemisphere (usually the right) is responsible for primary cognitive functions such as visuospatial and social cognition. Awake surgery using direct electric stimulation for right cerebral tumor removal remains challenging because of the complexity of the functional anatomy and difficulties in adapting standard bedside tasks to awake surgery conditions. An understanding of semiology and anatomic bases, along with an analysis of the available cognitive tasks for visuospatial and social cognition per operative mapping allow neurosurgeons to better appreciate the functional anatomy of the right hemisphere and its relevance to tumor surgery. In this article, the first of a 2-part review, we discuss the anatomic and functional basis of right hemisphere function. Whereas part II of the review focuses primarily on semiology and surgical management of right-sided tumors under awake conditions, this article provides a comprehensive review of knowledge underpinning awake surgery on the right hemisphere.

INTRODUCTION

In terms of function, the dominant (usually the left) cerebral hemisphere is traditionally regarded as the more important side of the brain. Neurosurgical decisions regarding surgical approaches in clinical practice are influenced by this paradigm. Nevertheless, the notion of a minor right hemisphere is now being challenged.[1] Neurosurgeons are focusing more and more on elaborate right-lateralized cerebral functions, rather than on the patient as a whole. As they did few decades ago with the executive and left lateralized functions, they are trying to bring new insights to right hemisphere mapping.

The nondominant hemisphere (usually the right) is responsible for primary cognitive functions such as visuospatial and social cognition. Visuospatial cognition supports spatial awareness, perception, and representation of space. It allows sensory events and spatial relationships to be perceived and reported. Lesions on the network underpinning visuospatial cognition are associated with different symptoms, the most significant of these being unilateral neglect (UN). Social cognition is the other main function of the right hemisphere. Social cognition includes all cognitive processes involved in social interaction using nonverbal language (such as facial emotion recognition and emotional prosody), empathy, and theory of mind (TOM).

Compared with language mapping in the left hemisphere, few accounts of right hemisphere per operative mapping have been published.[2-17] This lack of interest could be explained by underestimation of the cognitive role of the right hemisphere but could also be caused by the complexity of the functional anatomy and the difficulties inherent in adapting standard bedside tasks to awake surgery conditions. It is possible to suggest a new model of visuospatial and social cognition based on parallel and interactive large-scale distributed networks, similar to that previously developed for language. Just as in the language model, these functions cannot be reliably localized on anatomic criteria alone, mostly because of variation between individuals. For this reason, individual brain mapping using direct electric stimulation during awake craniotomy is essential when looking to preserve these functions.

An understanding of semiology and anatomic bases, along with an analysis of the available cognitive tasks for visuospatial and social cognition per operative mapping, allow neurosurgeons to better appreciate the functional anatomy of the right hemisphere and its relevance to tumor surgery. In the first part of this 2-part review, we discuss the anatomic and functional basis of right hemisphere function.

THE COGNITIVE RIGHT HEMISPHERE: A MIRROR SYSTEM?

In the right hemisphere, the cortical areas and white matter fascicles involved in

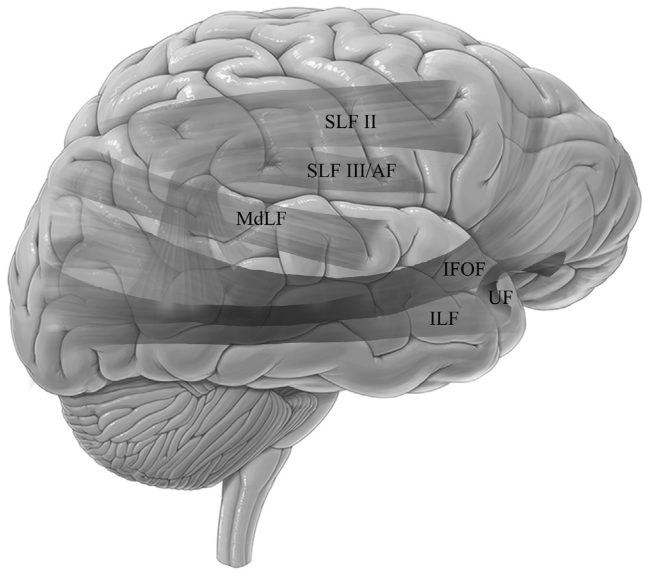

Figure 1. White matter fiber tract involved in right hemisphere cognitive functions. In the perisylvian area, the main long association fiber pathway is the superior longitudinal fasciculus (SLF), which has 3 parts: SLF I (dorsal), II (middle), and III (ventral). The SLF I (dorsal pathway) is positioned within the superior frontal gyrus, the SLF II (middle pathway) within the middle frontal gyrus, and the SLF III (ventral pathway) within the inferior frontal gyrus. Starting at the lateral surface and moving medially, the components of the SLF are encountered in reverse order: SLF III, SLF II, and then SLF I. The SLF III (so-called arcuate fasciculus [AF]) is the most superficial. The SLF III generally extends from the supramarginal gyrus to the pars opercularis. The inferior occipitofrontal fasciculus (IFOF) forms part of the extreme and external capsule and travels under the ventral insular cortex from the posterotemporal to the prefrontal regions. The middle longitudinal fasciculus (MdLF) travels from the upper portions of the occipital lobe to the superior temporal gyrus.[22] MdLF covers the IFOF, which is situated deeper and slightly inferiorly. Whereas MdLF fibers continue at a relatively superficial level to reach anterior portions of the temporal lobe, the IFOF penetrates the deep temporal white matter to reach the insular lobe. The uncinate fasciculus (UF) connects the anterotemporal lobe with the orbitofrontal area. The inferior-longitudinal fasciculus (ILF) connects the occipital lobe and anterior temporal lobe, running along the lateral walls of the temporal horn of the lateral ventricle.

visuospatial and social cognition are almost symmetric to those involved in language with a perisylvian network.[18] Is this apparent symmetry total or partial? This question has been a topic of debate and has also raised some interesting questions regarding determinism and brain anatomy. Several diffusion tensor imaging studies[19,20] have reported a heightened prevalence of leftward asymmetry of perisylvian white matter volumes. On the other hand, some investigators have reported the presence of the right arcuate fasciculus in only 40% of their patients, whereas others have reported it in all patients.[21] Anatomically, the white matter structure can be considered mostly symmetric. The same white matter fascicles as found in the left hemisphere have been identified (Figure 1). Most postmortem fiber dissection studies have not reported a significant difference between the left and right white matter fascicles, either in terms of the cortical connections[23] or in terms of fascicles volumes.[23-25]

Most of our knowledge about the neuroanatomy of visuospatial and social cognition has come from imaging studies of patients with UN or from functional magnetic resonance imaging (fMRI) studies. As for language in the dominant side, the right temporoparietal junction (TPJ) and ventral frontal cortex (VFC) both seem to play a significant role in all these studies (Figure 2A). This anatomically ambiguous terminology reminds us of pioneering work in language anatomy using the Broca-Wernicke-Lichtheim-Geschwind model.[29-31] The medial ventral prefrontal cortex (mvPFC) is involved too. No standardized anatomic definitions exist for the localization of TPJ, VFC, and mvPFC.[24] Before describing the anatomic substrate of the cognitive right hemisphere, we propose to replace these terms with more precise anatomic definitions, based on standardized terminologia anatomica nomenclature (Table 1).[32]

The VFC is involved in visuospatial cognition (see section on Neuroanatomy). According to Vossel (Figure 2), the VFC corresponds anatomically to the middle frontal gyrus (MFG) and inferior frontal gyrus (IFG), which is composed of the precentral gyrus, pars opercularis, triangularis, and orbitalis. The mvPFC is involved in social cognition (facial emotion recognition, empathy, and TOM; see sections on Facial Emotion Recognition, Emotional Prosody, and Empathy and Theory of Mind). The mvPFC is an anteromedial and inferior part of the frontal lobe (Figure 3). Although there is no universal agreement on how it should be demarcated, it is equivalent to the anterior cingulate gyrus, the gyrus rectus, and the medial aspect of the superior frontal gyrus in most sources.[33-35]

Providing an anatomic definition of the TPJ is more challenging, because it is not a single unitary structure; rather, it consists of multiple subregions with different connectivity patterns.[25,29] One of these subregions is the inferior parietal lobule (IPL), which consists of 2 major gyri: the supramarginal gyrus (SMG) and the angular gyrus (AG) (Figure 4A). The sulcal patterns in the IPL vary greatly between individuals, with the superior temporal sulcus (STS) extending its caudal branches into the IPL, and the SMG and AG usually separated by the intermediate parietal sulcus of Jensen.[30,31] The TPJ is a variably defined region located approximately where the IPL meets the superior temporal gyrus (STG) and is not associated with any objective landmarks. The term TPJ has been used for activations observed in the IPL as well as

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