Right Hemisphere Cognitive Functions: From Clinical and Anatomical Bases to Brain Mapping During Awake Craniotomy. Part II: Neuropsychological Tasks and Brain Mapping

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

Abbreviations and Acronyms
DES: Direct electric stimulation
fMRI: Functional magnetic resonance imaging
IFOF: Inferior fronto-occipital fasciculus
MTG: Middle temporal gyrus
SLF: Superior longitudinal fasciculus
SMG: Supramarginal gyrus
STG: Superior temporal gyrus
TOM: Theory of mind
TPJ: Temporoparietal junction
UN: Unilateral neglect

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The nondominant hemisphere (usually right) is determinant for main cognitive functions such as visuospatial and social cognitions. Awake surgery using direct electrical stimulation for right cerebral tumor removal remains challenging due to the complexity of the functional anatomy and the difficulties in adapting the classical bedside tasks for awake surgery conditions. An understanding of semiology, anatomical bases, and an analysis of the available cognitive tasks for visuospatial and social cognition per operative mapping will allow neurosurgeons to better appreciate the functional anatomy of the right hemisphere and its application to tumor surgery. In this second review of 2 parts, we discuss the pertinence of the neuropsychological tests available for the study of nondominant hemisphere functions for the surgery on right-sided tumors in awake surgery conditions. In conjunction with part I of the review, which focuses primarily on the anatomical, functional, and semiological basis of the right hemisphere function, this article provides a comprehensive review of current knowledge supporting the awake surgery in the right hemisphere.

INTRODUCTION

Traditionally, the dominant (usually left) cerebral hemisphere is regarded as the most important side in terms of functionality. Current neurosurgical decisions regarding the surgical approach in clinical practice are influenced by this paradigm. Nevertheless, the view of a "minor" right hemisphere is now being challenged by postoperative neuropsychological evaluations revealing very often cognitive and behavioral deficits after right hemisphere surgery.[1-3] Neurosurgeons are more sensitized to these defects and the better understanding of anatomical basis of the brain connectome and focus on elaborate right-lateralized cerebral functions replacing 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 the right hemisphere mapping with the aim of preserving cognitive function to achieve an optimal postoperative quality of life.

The nondominant hemisphere (usually right) is determinant for main cognitive functions such as visuospatial and social cognitions. The visuospatial cognition supports spatial awareness, perception, and representation of space. It allows perceiving, reporting, and orienting to sensory events towards one side of space to take place. Lesions of the network supporting the visuospatial cognition are associated with different symptoms; the most important one is the unilateral neglect (UN). The social cognition is the other main function of this hemisphere. It includes all cognitive processes involved in social interaction such as nonverbal language (like facial emotion recognition and emotional prosody), empathy, and theory of mind (TOM).

An understanding of semiology, anatomical bases, and an analysis of the available cognitive tasks for visuospatial and social cognition per operative mapping will allow neurosurgeons to better appreciate the functional anatomy of the right hemisphere and its application to tumor surgery, which was the subject of the first part of this review.[4]

Compared with language mapping in the left hemisphere, very few procedures of the right hemisphere per operative mapping have been published.[5-20] This disinterest could be explained not only by the underestimation of the cognitive role of the right hemisphere but also by the complexity of the functional anatomy as much as the difficulties to adapt the classical bedside tasks to awake surgery conditions. As for language, these functions cannot be reliably localized on anatomical criteria alone, mostly due to the interindividual variation.

The neuroplasticity is present before the surgery in a slow-developing lesion such as low-grade gliomas, during the surgery, and continues in the postoperative period.[21-23] Neural plasticity is itself a source of interindividual variability, with different cortical mapping of brain function identified in the same patient over

time and must be taken into account the neuroplasticity and the capacity to recover after surgical damage to maintain these cognitive functions.[24,25] The knowledge of the patient's neuroplasticity allows an optimal resection of a tumor even in traditionally "inoperable" localization, based on functional boundaries identified through direct electric cortical stimulation in awake surgery conditions while minimizing the risk of postoperative deficit.[26] In surgical series of low-grade gliomas, more than 95% of patients recovered a normal neurological examination and almost all patients returned to a normal socioprofessional life.[26-28]

In the second part of this review on the nondominant hemisphere, we propose a comprehensive review regarding previous experiences in cortical mapping for awake surgery focusing on the visuospatial and social cognitions, with reflections on the available neuropsychological tasks and their validity for awake surgery. Other right hemisphere functions such as calculation, nonverbal semantic cognition, and the motor control network will not be detailed in this review.[20,29-33]

THE VISUOSPATIAL COGNITIONS

Semiology

The most important visuospatial impairment is UN, which is highly heterogeneous in its severity and its manifestations.[34] Severity can vary from a minor increase in the reaction time of stimuli detection in the neglected space to the total disappearance of this hemispace. UN represents a gradient across space, and severe neglect may be difficult to differentiate from hemianopia.

UN can also involve all sensorial modalities, a remembered scene or mental image ranging to the non-use of the contralesional limb, called motor neglect. Anosognosia is the unawareness of a specific deficit. Besides UN, lesions of the nondominant hemisphere can also induce several other neuropsychological disorders such as somatoparaphrenia (a monothematic delusion where one denies ownership of a limb or an entire side of their body), allochiria (responding to a stimulus to one side of the body as if it had been to the other side), and constructional apraxia (inability to draw or copy complex diagrams). Another specific trait in lesions of the nondominant hemisphere is anosognosia, which is often associated and directed towards UN.

The degree of UN can fluctuate depending on the complexity of the task, the presence of distractor in the ipsilateral space (which corresponds to the extinction phenomenon), the emotional charge, and the patient's motivation. UN could also involve independently the far personal, peripersonal, and personal spaces. UN may also vary depending on the referential space such as egocentric and allocentric spatial referentials, where objects are located relative to their spatial configuration within a scene or to one another.

In summary, UN is polymorphic and does not constitute a unitary syndrome, but rather a complex set of signs and symptoms that is better represented on a continuous scale. Nevertheless, a common core set of symptoms, including biased gaze orientation and search, combined with an anosognosia regarding these symptoms, could be defined for clinical and functional magnetic resonance imaging (fMRI) studies of patients suffering from a lesion of the nondominant hemisphere.

Tasks and Per Operative Mapping

UN does not constitute a unitary syndrome and is highly polymorphic, and the use of single tests can fail to diagnose UN and differentiate it from general cognitive impairment or constructional apraxia. To detect UN at the bedside, clinicians use different pen-and-paper tests.[13] Test objects considered to be sensitive to detecting UN are a clock face, the human form, and a butterfly drawing (**Figure 1A**). Unfortunately, these tests do not seem suitable for the perioperative detection of induced UN with direct electric stimulation (DES) because of the time needed to complete the task. Formal evaluation test batteries are better suited to identify UN, but it is evident that these batteries are not compatible with brain mapping.

Two neuropsychological tests currently used to detect UN are more suitable for perioperative use. The line bisection task requires people to estimate and indicate the midpoint of a horizontal line presented on a piece of paper placed in front of them with respect to the patient's midline and aligned with the subject's horizontal line of vision (**Figure 1B** and **C**). Care should be taken to maintain each visual field within the corresponding half of the line to avoid visual field crossover that may result in inaccurate results. An ipsilateral deviation to the brain lesion is usually regarded as being indicative of neglect, although the magnitude can vary. There are many pen-and-paper or computerized versions of the line bisection task. Procedures are rarely standardized, except when used in a standardized test battery. For use as a bedside task, the line bisection task in spatial awareness seems to have a very good feasibility, a specificity of 90%, and a lower sensitivity of 60%.[17] It is interesting to note for surgery that rightward deviations seem to be less pronounced when patients are lying down than standing.[35] The line bisection test was used in all the published series of patients operated in awake surgery, not only because of its simplicity, but also for the speed of the test and its reproducibility.[9,15,18,19]

Interestingly, the line bisection task can dissociate visuospatial deficit from the core neglect disorder and fail to identify UN. For example, Ferber and Karnath (2001)[36] observed that 40% of patients with core symptoms of spatial neglect were unimpaired in the line bisection task. Moreover, lesion mapping demonstrates that patients with line bisection deficits have more posterior injury than those with only spatial neglect.[14,37-39] Indeed, this anatomical dissociation was observed in publications that did not explicitly attempt to differentiate these symptoms.[40] Therefore, although the line bisection task does appear to identify a profound perceptual disorder, it appears to be anatomically and behaviorally independent from the core symptoms of neglect. One possible explanation for this dissociation is that the line bisection task draws on allocentric representation whereas the core deficit in spatial neglect is egocentric.[14,41]

The perioperative observations described in the literature are in accordance with the previous studies on a visuospatial cognition anatomical substrate as described in part I of this review.[4] An important precursor work on 2 patients showed a rightward deviation on the line