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General review

A surgical approach to the anatomo-functional structure of language

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ABSTRACT

Introduction. – Language is the most widely mapped cognitive function during brain surgery. Intraoperative language functional mapping using direct electrical stimulation under awake conditions is currently the gold standard technique for establishing the causal link between an area and a deficit that would be caused by its resection. It is also a powerful tool to investigate the anatomical correlates of current neuropsychological models of language.

Material and methods. – The aim of this article is to reexamine the anatomo-functional structure of language that could be inferred from data obtained in direct electrical stimulation studies during awake surgery.

Results. – Concomitantly with the development of new neuropsychological models of language, major advances have been made in our understanding of error patterns elicited by language network stimulation, both cortically and axonally. Following the recognition of visual information, the language network of picture naming is organized in parallel into two main dorsal phonological and ventral semantic subsystems that are sustained anatomically by two systems (arcuate fasciculus and inferior fronto-occipital/inferior longitudinal/uncinate fasciculus respectively). Networks of articulatory and motor aspects of speech are now better depicted (aslant tract, third branch of longitudinal fasciculus). Finally, the links between the core language networks and the cognitive control networks are also emerging.

Conclusion. – Mastering the language map and its dynamical properties should be a basic prerequisite for any neurosurgeon who wishes to operate on the brain with the aim of optimizing the extent of resection while preserving language abilities.

1. Introduction

Language is a complex human cognitive function. It is believed to be at the core of what makes the distinction between humans and other species. Consequently, and not surprisingly, language is the most widely mapped function for brain surgery. As widely reported, preoperative methods of language mapping are not reliable enough for ensuring a sensitive and specific identification of language networks. In particular, task-based fMRI mapping is in essence inadequate for distinguishing participating areas from essential ones. In fact, only methods interfering with neuronal networks can make this distinction, explaining why intraoperative electrical stimulation is currently the gold standard for establishing a causal link between an area and a deficit that would be caused by its resection.

Since the very first reports by Penfield, technology has not really changed that much: eloquent sites are identified by applying a 60 Hz electrical stimulation for a period of 3–4 seconds that will transiently disturb an on-going language task. However, since these pioneer studies, major advances have been made in our understanding of error patterns elicited by language network stimulation, both cortically and axonally [1]. These advances were concomitant with the development of new neuropsychological models of language (identifying phonological and semantic as the two main subsystems [2], and hypothesizing that they are sustained anatomically by two parallel pathways, the dorsal and ventral streams respectively [3]) and with the (re)-discovery of white matter anatomy by diffusion tensor imaging and cadaveric fiber dissections. For example, the inferior fronto-occipital fasciculus [4,5] has been rediscovered by diffusion tensor imaging (DTI) [6] and further detailed by fiber dissections [7,8], and new pathways (aslant [9–11], middle longitudinal fasciculus [12–14])

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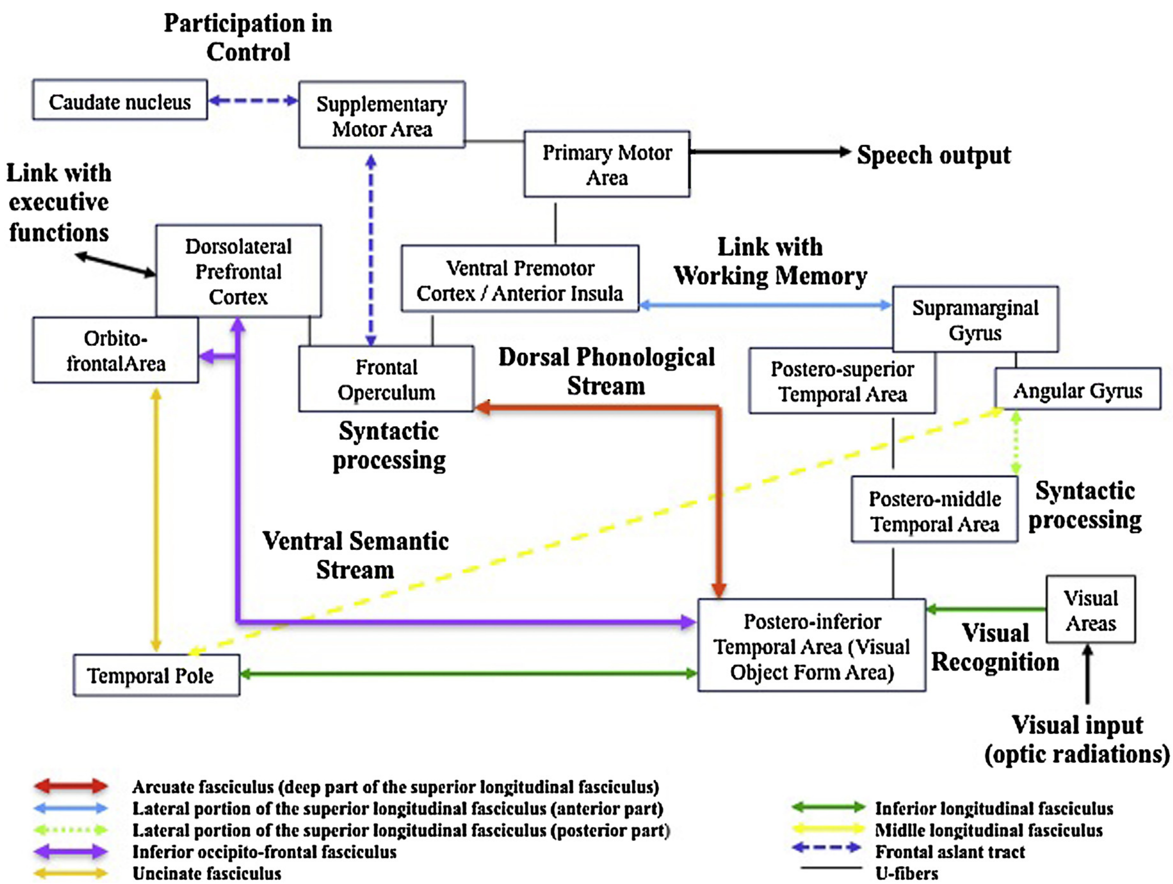

Fig. 1. Current neuropsychological model of language, with underlying cortical and axonal anatomy. Figure reproduced with permission from [17].

were discovered by virtual dissections, and then confirmed by fiber dissections [11,10,15]. Hence, we suppose the reader to be familiar with this white matter pathway anatomy.

In this paper, we will show how, from observations of errors patterns generated by electrical stimulation during picture naming, has emerged a plausible anatomical structure of neuropsychological models [16,17], as represented in Fig. 1.

2. The anatomo-functional structure of picture naming

Naming a picture follows a temporal series of neural computations, that can be somehow arbitrarily be subdivided into three main stages:

- a preprocessing of visual information;
- a core processing achieving the conversion of this preprocessed visual information towards two other modes of information (a lexico-semantic mode and a phonological mode, with a bilateral interaction between these two representations);
- an output system, converting phonological codes to the motor programs enabling the fine and complex coordination of the lips, jaws, tongue, laryngeal (and respiratory) muscles.

In fact, there is a fourth stage, usually overlooked by many models: before performing the task of picture naming, as the subject has been asked to do so, the processing of this order certainly has in fact prepared the brain networks in a specific state, for goal maintenance of naming the picture. In other words, a context-dependent implementation of action selection (i.e. permitting to name the picture and not its color) is an essential preliminary stage.

3. The input

After reaching the primary occipital areas, visual information will follow a ventral stream, up to an area supporting the visual concept [18], i.e. a visual information that has been filtered and transformed to become a unified version of each separated subparts, with properties of invariance (for e.g., the shape of a boat, independent of its size, color, context, etc.). These areas are located in the posterior fusiform gyrus, with specific spots dedicated to faces (right side), houses or tools (bilateral), or words (left side).

It has been shown that this posterior to anterior gradient of higher abstract content is likely to be supported by a series of U-fibers of the posterior part of the inferior longitudinal system, and by the fibers of splenium of the corpus callosum, allowing to maintain the same level of abstraction along the gradient between visual representations of the picture in the left and right hemispheres. Indeed, stimulation of these fibers generates visual paraphasia, that is an error visually close to the target word [19,20]. However, one should not forget that this stream of visual recognition is also supported by top-down influences, which can arise both from the same U-fibers system in the reverse direction or from more distant feedback through, for example, branches of the inferior fronto-occipital fasciculus.

4. The core processing

The core processing will map the abstract visual form of the picture towards its phonological form. Two types of errors can be encountered in this system: either a lexico-semantic error, (for e.g. "tiger" instead of "lion", see [21,22]), or a phonological error (for e.g. "goat" instead of "boat"). Finally, the impossibility to find the