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Short Communication

White matter in aphasia: A historical review of the Dejerines' studies ☆

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ABSTRACT

The Objective was to describe the contributions of Joseph Jules Dejerine and his wife Augusta Dejerine-Klumpke to our understanding of cerebral association fiber tracts and language processing.

The Dejerines (and not Constantin von Monakow) were the first to describe the superior longitudinal fasciculus/arcuate fasciculus (SLF/AF) as an association fiber tract uniting Broca's area, Wernicke's area, and a visual image center in the angular gyrus of a left hemispheric language zone. They were also the first to attribute language-related functions to the fasciculi occipito-frontalis (FOF) and the inferior longitudinal fasciculus (ILF) after describing aphasia patients with degeneration of the SLF/AF, ILF, uncinate fasciculus (UF), and FOF. These fasciculi belong to a functional network known as the Dejerines' language zone, which exceeds the borders of the classically defined cortical language centers.

The Dejerines provided the first descriptions of the anatomical pillars of present-day language models (such as the SLF/AF). Their anatomical descriptions of fasciculi in aphasia patients provided a foundation for our modern concept of the dorsal and ventral streams in language processing.

1. Introduction

Joseph Jules Dejerine (1849–1917) and his wife, Augusta Dejerine-Klumpke (1859–1927), were both involved in aphasia research. He is primarily remembered for his description of alexia without agraphia (Catani & ffytche, 2005; Dejerine, 1892), while Augusta Dejerine-Klumpke is most famous for her discussion about the quadrilateral zone of Pierre Marie at the "hot summer of aphasiology" congress in Paris in 1908 (Klippel, 1908a; Lecours & Caplan, 1984; Lecours, Chain, Poncet, Nespoulous, & Joanette, 1992) Their knowledge of brain anatomy was very precise and led them to postulate a neuroanatomically founded concept of a language zone (Dejerine & Dejerine-Klumpke, 1901, pp. 247–252; Miraillé, 1896, pp. 106–119). Their concept also integrated clinical information, which led to the introduction of an aphasia classification (Miraillé, 1896, p. 102ff). Biographical data about Dejerine-Klumpke and Dejerine can be found elsewhere (Bogousslavsky, 2005; Bogousslavsky, 2011; Creese, 2004; Ellis, 2010; Lecours & Caplan, 1984; Lecours et al., 1992; Sartran, 1974; Shoja & Tubbs, 2007; Sorrel-Dejerine, 1959; Ulgen, Brumblay, Yang, Doyle, & Chung, 2008; Yildirim & Sarikcioglu, 2008; Broussolle, Poirier, Clarac, & Barbara, 2012; Anonymous, 1969; Bassetti & Jagella, 2006; Gauckler, 1922; Henderson, 1984; Heuyer, 1963; Paciaroni & Bogousslavsky, 2011).

In the outgoing 19th century, a variety of these models existed, which were categorized as either localizationistic or associationistic, based on whether they focused on language processing as being locally specialized or highly distributed, respectively. The Paris congress in 1908 marked a climax in this controversy regarding aphasiology. At that time, several questions could not be explained with the then existing models, including that of the Dejerines. For example, the existing models could not explain why injury to anatomically distinct language regions could give rise to unpredictable and overlapping symptoms. Because of these issues, the existing models were progressively replaced by a more non-localizationistic or holistic view (Freud, 1891; Goldstein, 1910; Head, 1926; Marie, 1906; von Monakow, 1905). The deployment of individual models was of course not strictly sequential, but partially overlapping and coincidental. Holistic models were marked by their refusal to allocate language functions to distinct brain regions. However, the localizationistic models experienced a renaissance

Abbreviations: SLF/AF, superior longitudinal fasciculus/arcuate fasciculus; ILF, inferior longitudinal fasciulus; UF, uncinate fasciculus; FOF, fronto-occipital fasciculus.

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with Norman Geschwind (1926–1984; 1965) and his work on disconnection syndromes and the neo-associationist school he founded.

Historical overviews of the research on white matter anatomy and the association fiber tracts involved in language processing have been published previously (Catani, 2010; Catani & Mesulam, 2008; Catani & Thiebaut de Schotten, 2008). The Dejerines categorized association fibers as either short or long. Neighboring convolutions were interconnected by the short intracortical association fibers, tangential fibers, and U-fibers (Klippel, 1908, p. 1002; Miraillé, 1896, p. 112), while long association fibers connected more remote convolutions. Long association fibers belonging to the Dejerines' language zone were listed, described, and discussed in the Neuroanatomy Atlas "Anatomie des Centres Nerveux" (Dejerine & Dejerine-Klumpke, 1895, p. 749ff) and in the doctorate thesis of Miraillé (1896, p. 112ff).

Lesion studies including serial sectioning in autopsy patients, as they were performed by the Dejerines and others, are nowadays rare. Diffusion tensor imaging (DTI) plus tractography, a 3D modeling technique used to visually represent fiber tracts, enable us by their non-invasiveness to perform neuroanatomical studies at larger patient numbers. Functional magnetic resonance imaging (fMRI) can localize the activity of brain areas during certain tasks. DTI/tractography together with fMRI can thus replace the former lesion studies. Current limitations in DTI resolution particularly arise with signal interpretation at fiber endings (where fibers enter grey matter), and at loci where fiber tracts overlap (Mori & Zhang, 2006). Here, technical development will probably contribute to the improvement of resolution comparable to the level of lesion studies. An extra motivation for DTI/tractography will be, to set the new data into historical perspective. Examination of earlier findings obtained with invasive techniques including the anatomical overlap of fiber endings from the superior longitudinal fasciculus/arcuate fasciculus (SLF/AF), inferior longitudinal fasciculus (ILF), and uncinate fasciculus (UF) in the anterior temporal lobe; the course of language related fibers through the external capsule; and the composition of the SLF/AF may yield interesting comparisons (Supplemental text).

Although the influence of anatomical data is well documented in the Dejerines' literature, it remains unknown how their language processing theory was influenced by the combination of neuroanatomy and functional data from aphasia patients. In the present manuscript, we review primary and secondary sources in order to elucidate the relationship between the Dejerines' neuroanatomical knowledge, language, and aphasia.

2. Methods

Systematic review of primary and secondary literature. The search strategy was to screen literature from and about the Dejerines for their content of language-related white matter anatomy, patients with aphasia, and the concept of a language zone. Their most important books were found online and were freely accessible at the Bibliothèque nationale de France and Open Library (initiative of the Internet Archive). Primary and secondary literature was ordered via the University Bern library service or photocopied from library books in France (e.g. Klippel protocols by JMA). PubMed was searched with the terms "superior longitudinal fasciculus", "arcuate fasciculus", "inferior longitudinal fasciculus", "uncinate fasciculus", and "fronto-occipital fasciculus" for more recent publications, in order to put the Dejerines' knowledge of white matter anatomy into context with today's views. Who was first in describing association fiber tracts in relation to language and aphasia was verified by tracing citations in secondary literature back to their first publication. In analogy to the strategy how to study the history of white matter anatomy, we collected previously published data from primary and secondary literature about the Dejerines' language zone and contemporary models. All French or German literature, required for the preparation of this manuscript, was translated into English by HK.

3. Results

3.1. The superior longitudinal or arcuate fasciculus

The most well studied and canonical dorsal language pathway is the SLF/AF (Fig. 1). The SLF/AF consists of association fibers passing from the frontal lobe through the white matter of the frontal operculum to the posterior end of the Sylvian fissure. There, the fibers radiate into the parietal and occipital lobes and other fibers turn downward and anterior to radiate to anterior portions of the temporal lobe. In humans, the SLF is composed of four components, the SLF I–III and AF, which are bundled together, even though they are functionally separate (Makris et al., 2005). Of these, the AF was described first by Johann Christian Reil (1759–1813) (Catani & Mesulam, 2008). Recent work suggests that the AF may connect posterior receptive areas with premotor/motor areas, but not directly with Broca's area (Bernal & Ardila, 2009). By contrast, the Dejerines suggested that the SLF and the AF were the same tract rather than separate entities. They attributed its first anatomical description to Friedrich Burdach (1776–1847) and not to Reil (Dejerine & Dejerine-Klumpke, 1895, pp. 756, 758).

The first publication mentioning the SLF/AF as the tract connecting Broca's and Wernicke's areas has been ascribed to von Monakow (Catani & Mesulam, 2008), by referring to Geschwind's commented translation (1967, p. 454) of "Der aphasische Symptomenkomplex" by Carl Wernicke (1848–1905) (see also second paragraph of the present manuscript's discussion). Geschwind describes among other things Wernicke's realization that there must be a "psychic reflex arc" connecting motor articulation and sound areas. Wernicke assumed that the anatomical substrate for this arc was the *fibrae propriae*, association fibers running through the insular cortex, and not the AF (Wernicke, 1874, p. 19). Later, Wernicke (1908) modified his view to accept von Monakow's assertion that the path did indeed run in the AF.

Von Monakow's first monographs about aphasia (1897b) and association fibers (1900) did not contain any description of the

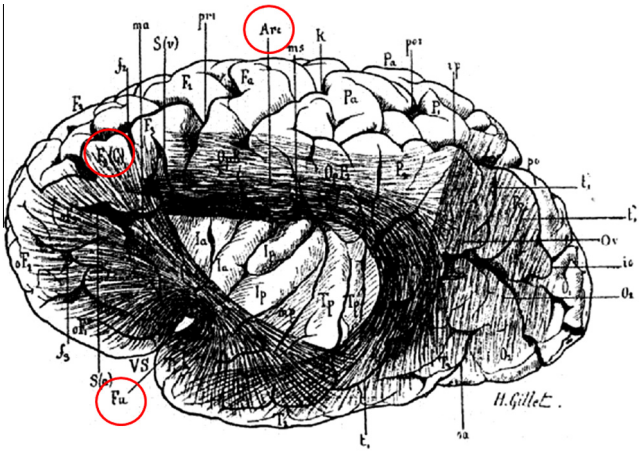

Fig. 1. Drawing by H. Gillet that shows the insula and the retro-insular region of the left hemisphere, after the borders of the sylvian fissure had been removed. Abbreviations of selected structures are explained: Arc (red circle: SLF/AF), Fu (red circle: UF), F_3(C) (red circle: pars triangularis of F3) and Fa (anterior central gyrus) (Dejerine & Dejerine-Klumpke, 1895, p. 757). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)