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Verbal and musical short-term memory: Variety of auditory disorders after stroke

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ABSTRACT

Auditory cognitive deficits after stroke may concern language and/or music processing, resulting in aphasia and/or amusia. The aim of the present study was to assess the potential deficits of auditory short-term memory for verbal and musical material after stroke and their underlying cerebral correlates with a Voxel-based Lesion Symptom Mapping approach (VLSM). Patients with an ischemic stroke in the right (N = 10) or left (N = 10) middle cerebral artery territory and matched control participants (N = 14) were tested with a detailed neuropsychological assessment including global cognitive functions, music perception and language tasks. All participants then performed verbal and musical auditory short-term memory (STM) tasks that were implemented in the same way for both materials. Participants had to indicate whether series of four words or four tones presented in pairs, were the same or different. To detect domain-general STM deficits, they also had to perform a visual STM task. Behavioral results showed that patients had lower performance for the STM tasks in comparison with control participants, regardless of the material (words, tones, visual) and the lesion side. The individual patient data showed a double dissociation between some patients exhibiting verbal deficits without musical deficits or the reverse. Exploratory VLSM analyses suggested that dorsal pathways are involved in verbal (phonetic), musical (melodic), and visual STM, while the ventral auditory pathway is involved in musical STM.

1. Introduction

1.1. Auditory deficits after stroke

Music and language are present in all human societies. Even though music is not essential for the survival or the reproduction of the human race, it provides benefits for our physical and moral well-being (MacDonald, Kreutz, & Mitchell, 2012). Auditory cognitive deficits after stroke may affect language and/or music processing (Nicholson et al., 2003; Särkämö et al., 2009), and can also impact the processing of environmental sounds (Vignolo, 2003). Aphasia is more frequent after lesions in the left hemisphere, whereas acquired amusia can appear after lesions in both left or right hemispheres (Särkämö et al., 2009). Amusia is a music agnosia characterized by the inability to recognize music in the absence of sensory, intellectual, verbal and mnesic impairments. Amusia is rarely documented after stroke and remains largely underestimated. In Särkämö et al. (2009), 60% of patients had acquired amusia one week after stroke in the territory of the middle cerebral artery, and 42% remained amusic three months after stroke. In Schuppert, Münte, Wieringa, and Altenmüller (2000), 69% of the stroke patients (tested ten days after stroke) had deficits in perceptual musical functions, whatever the lateralization of the lesions in frontal, temporal and parietal areas. Acquired amusia

Abbreviations: fMRI, functional MRI; MBEA, Montreal Battery of Evaluation of Amusia; MEG, magneto-encephalography; MMSE, Mini Mental State Examination; PDT, pitch discrimination threshold; STM, short-term memory; VLSM, Voxel-based Lesion Symptom Mapping.

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may be also associated with musical anhedonia (Hirel et al., 2014), a loss of pleasure in listening to music, which can also arise without any perceptual deficits (Griffiths, Warren, Dean, & Howard, 2004; Satoh, Nakase, Nagata, & Tomimoto, 2011). These studies of musical anhedonia are case reports with diverse lesion locations and the association between amusia and musical anhedonia has not been studied so far in brain-damaged patients at the group level.

After brain damage, music and language deficits do not always co-occur, as evidenced by reported cases of amusia without aphasia (or the reverse) (Griffiths, Flees, & Green, 1999; Griffiths et al., 1997; Peretz, Belleville, & Fontaine, 1997; Peretz et al., 1994). These reported double dissociations suggest that music and language are processed by (at least partly) separate cerebral networks. However, the diagnosis of amusia or aphasia relies on qualitatively different neuropsychological testing: Diagnosing aphasia typically involves tests of language comprehension and production, whereas diagnosing amusia relies on testing the perception of various musical dimensions (e.g., pitch, rhythm) or musical emotions. To allow for a better understanding of auditory deficits after brain damage, music and language disorders needs to be assessed with the same methodological approach. For this aim, our present study tested patients' short-term memory (STM) for auditory material (either verbal or musical) in comparison to visual material with the same experimental paradigm. STM is a basic cognitive ability involved in a wide range of tasks and contexts, and deficits in STM could be associated to or cause various patterns of deficits (see for example Tillmann, Lévêque, Fornoni, Albouy, & Caclin, 2015, for a discussion of how deficits in pitch STM might be central in congenital amusia).

1.2. Auditory short-term memory: behavior and cerebral correlates

Auditory verbal STM refers to a temporary memory store of verbal information for a short period of time (on the order of seconds). Baddeley's model (Baddeley, 2003) posits that auditory verbal working memory has two components: a phonological store, for very brief storage of verbal information, and an articulatory rehearsal component (phonological loop), for refreshing the information and keeping it active. Previous research investigating brain-damaged patients suggests that the left inferior parietal lobe is critical for the phonological store and the left inferior frontal lobe for the articulatory rehearsal component (Baldo & Dronkers, 2006; Leff et al., 2009; Warrington, Logue, & Pratt, 1971).

A Voxel-based Lesion Symptom Mapping (VLSM) study on stroke patients showed that auditory verbal STM is linked to the left middle temporal gyrus, left superior temporal gyrus (including Heschl's gyrus) and left inferior parietal areas (angular gyrus and supramarginal gyrus) (Baldo, Katseff, & Dronkers, 2012). An analysis of the lesions of patients with conduction aphasia highlights the importance of a region in the posterior portion of the left planum temporale, area Spt (Sylvian-parietal-temporal) for phonological STM (Buchsbaum et al., 2011). More generally, the area Spt is a sensory-motor integration area for vocal tract actions (Hickok, Okada, & Serences, 2009).

Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) studies with healthy participants showed that the left supramarginal gyrus is involved in short-term storage of phonological information (Henson, Burgess, & Frith, 2000; Paulesu, Frith, & Frackowiak, 1993; Salmon et al., 1996). They further suggest that a larger network of cortical areas is operating in verbal STM, including the auditory cortex (notably left superior temporal areas), the (left) premotor cortex, and Broca's area, which supports the articulatory processes.

Taken together, the studies with brain-damaged patients and the neuroimaging studies in healthy participants converge on the implication of temporal posterior, parietal inferior, and frontal inferior regions in auditory verbal STM, with a predominant role for left-hemisphere structures.

In comparison to verbal material, the cerebral correlates of STM processing for tonal (musical) material have been less investigated by neuropsychological and neuroimaging studies. A study on brain-damaged patients (lobectomy for intractable epilepsy) showed that patients with right fronto-temporal lesions had a deficit in the retention of pitch in STM (Zatorre & Samson, 1991). To our knowledge, no research has investigated the anatomical locus of auditory musical STM in stroke patients.

A PET study in healthy participants (Griffiths, Johnsrude, Dean, & Green, 1999) showed that blood flow increased in the posterior superior temporal lobe, inferior frontal regions and the cerebellum when participants compared pitch sequences of six tones (requiring a same/different judgment), a classical STM paradigm. The network was bilateral, but predominant in the right hemisphere. Using fMRI when participants performed a STM task with single tones, Stevens (2004) showed bilateral activation in the supramarginal gyrus, the posterior insula and the posterior inferior temporal gyrus as well as activation in the right IFG. Grimault et al. (2014) showed in a MEG study the implication of superior parietal lobe and pre-central gyrus bilaterally in STM for tones. Other functional imaging studies showed the implication of bilateral parieto-fronto-temporal areas in pitch STM tasks (Gaab, Gaser, Zaehle, Jancke, & Schlaug, 2003; Platel et al., 1997; Stevens, 2004; Zatorre, Evans, & Meyer, 1994), while a tDCS study suggested a causal involvement of the left SMG in non-musicians (Schaal, Williamson, et al., 2015).

Some data sets suggest (at least partly) separate cognitive and neural resources for verbal and musical STM. In control participants, auditory STM seems to be different for words, tones and timbre. In congenital amusia, a selective disorder of auditory STM for tones and timbre has been demonstrated, while verbal STM is intact (Tillmann, Schulze, & Foxton, 2009; Tillmann et al., 2015). The disorder of auditory STM for tones has been confirmed with tonal and atonal sequences, contrasting with normal performance for the verbal digit span (Albouy, Schulze, Caclin, & Tillmann, 2013). For a musical STM task, functional anomalies in a bilateral fronto-temporal network have been reported with MEG data for congenital amusia (Albouy, Mattout, et al., 2013), supporting the view that this fronto-temporal network is involved in non-verbal auditory memory.

The work on congenital amusia thus suggests that the processing and storage of musical stimuli might recruit, at least partly, a different sub-system of STM than speech. However, neuroimaging studies on control participants have uncovered a cortical network for tonal STM that was surprisingly similar to the network for verbal STM (Koelsch et al., 2009; Schulze & Koelsch, 2012). The present study with stroke patients might thus further shed light on whether common or separated neural resources are involved in verbal and musical STM. Furthermore, whereas in congenital amusia compensatory plastic changes over the course of development in infancy might account for normal performance in verbal STM, such plastic changes should be largely reduced in the adult patient population tested here.

1.3. Objectives of the present study

Our present study investigated memory deficits after stroke, in particular verbal and musical auditory STM (in comparison to visual STM), and the cerebral underpinnings of these deficits using an exploratory voxel-based lesion symptom mapping approach. We included patients with focal cortical lesions in regions of interest for auditory STM, i.e., temporo-parieto-frontal areas in the territory of the middle cerebral artery.