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Musical, visual and cognitive deficits after middle cerebral artery infarction

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ABSTRACT

The perception of music can be impaired after a stroke. This dysfunction is called amusia and amusia patients often also show deficits in visual abilities, language, memory, learning, and attention. The current study investigated whether deficits in music perception are selective for musical input or generalize to other perceptual abilities. Additionally, we tested the hypothesis that deficits in working memory or attention account for impairments in music perception. Twenty stroke patients with small infarctions in the supply area of the middle cerebral artery were investigated with tests for music and visual perception, categorization, neglect, working memory and attention. Two amusia patients with selective deficits in music perception and pronounced lesions were identified. Working memory and attention deficits were highly correlated across the patient group but no correlation with musical abilities was obtained. Lesion analysis revealed that lesions in small areas of the putamen and globus pallidus were connected to a rhythm perception deficit. We conclude that neither a general perceptual deficit nor a minor domain general deficit can account for impairments in the music perception task. But we find support for the modular organization of the music perception network with brain areas specialized for musical functions as musical deficits were not correlated to any other impairment.

1. Introduction

The perception, recognition, and joyful sensation of music can be affected by a stroke – a condition called acquired amusia. Impairments of music perception are widely reported in the literature [2,30,32,41,55], and can occur after lesions to temporal, frontal, and parietal areas [4,10,11,18,25,35,39,40,44–47,50], but also after subcortical lesions [19].

These patient studies showed a double dissociation between melody [18,36,47,59] and rhythm perception [10,36,47,56]. Melody perception refers to the perception of pitch height, intervals and the contour of a melody (e.g. whether the melody is ascending or descending in pitch). Rhythm perception involves the temporal organization of the melody including the length of different tones also with respect to the underlying beat of that sequence. Patients with deficits in melody perception cannot perceive sequences of single tones as a melody but are able to recognize the rhythmic structure. Patients with deficits in rhythm perception on the other hand can perceive melodic parts of a musical sequence (like single pitch height) and the ongoing melodic structure (like the contour of a melody), but have problems identifying the rhythm of that sequence. In both types of amusia the comparison of musical sequences with either differing melody or differing rhythm cannot be differentiated.

This double dissociation was supported by recent models for music perception suggesting a highly complex and distributed network of temporal, frontal, and parietal areas, additional to subcortical and limbic structures [7,16,27,38,51]. Melodic information is supposed to be mainly processed in superior temporal and frontal areas; the cerebellum and basal ganglia are thought to be involved in processing rhythmic material. Other studies strengthen the role of premotor and supplementary motor areas in beat perception [14,17,58]. Furthermore, functions of pitch and contour processing as well as rhythm perception are attributed to the parietal lobe [15,29,49,52].

Hemispheric lateralization has also been addressed by these models: it was suggested that the right hemisphere processes melodic information and that rhythm is processed in both hemispheres [1,7,16,51]. Johnsrude, Penhune, & Zatorre [26] found that patients with right (but not left) temporal lobe removal overlapping with the Heschl's gyrus showed significantly higher thresholds in judging direction of pitch changes but not in pitch discrimination. In the context of lateralization,

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the relationship of music and language perception comes into mind. Although the feature extraction for language perception seems to be similar to that for music, speech perception also needs segmentation of phonetic information [27]. Long time it was thought that language is processed in the left hemisphere while music is solely processed in the right hemisphere. However, a number of functional magnetic resonance imaging studies showed that music and speech perception share similar processes and brain structures [12,13,27]. A positron emission tomography study demonstrated that primary motor cortex, supplementary motor area, Broca's area, anterior insula, primary and secondary auditory cortices, the temporal pole, basal ganglia, ventral thalamus and posterior cerebellum were all activated while generating melodic and linguistic phrases [6]. Behavioral and electroencephalography studies determined the beneficial relationship between music and language functions (for a review see [23,31,34]). Additionally, music and language impairments seem to be correlated [11,24,35]. This knowledge about neuroanatomical correlates of music processing is further complicated by individual differences in the representation of music perception [47,53].

In addition, the music perception network widely overlaps with areas usually responsible for domain-general attention and working memory [22]. This knowledge is expanded by findings that amusia patients often show deficits in visual-spatial abilities, executive functions, memory, learning, and attention [10,18,44,45]. Furthermore music perception problems seem to be highly correlated with aphasia [44,45,47–51] and to visuo-spatial neglect [44,45]. Conclusively, a direct link between music perception and other cognitive functions, as well as even visual abilities, has been suggested.

Särkämö and colleagues [44,45] measured a large group of amusia patients after stroke who presented several cognitive deficits, primarily in attention, working memory (WM), and executive functions. Their work underlined the close relationship between amusia and other cognitive deficits. However, the question whether these connected deficits arise because music perception and the other cognitive functions are accomplished by shared neural processes or whether they involve functionally different but anatomically close areas could not be answered. Lesions in the amusic group were significantly larger than in the non-amusic group and therefore might have mediated the results. Additionally, deficits in attention and WM may have accounted for the poor performance in the music perception task of the amusic patients. The Montreal Battery of Evaluation of Amusia [37] was used in this study and the selected tasks require relatively good WM, attention, and executive abilities [44,45].

In the current study we wanted to investigate whether symptoms of amusia are specific for musical material or whether a general perceptual deficit can explain the symptoms. Furthermore we were interested in the question whether or not impairments in general domain specific functions like WM or attention could account for poor performances in the MBEA. For this aim we specifically measured stroke patients with small cerebral artery infarctions in order to control for lesions possibly damaging a large array of areas and functions. We applied a large battery of neuropsychological and psychophysical tests including the Montreal Battery of Evaluation of Amusia and tests for visual perception, categorization, neglect, and cognitive functions of attention and WM. Our sample of patients suffering subacute stroke in supply areas of the middle cerebral artery showed a variety of initial symptoms including aphasia, paresis, sensory deficits, and also visual symptoms. Performances in different tests were compared via correlation analysis. Results of healthy control subjects served as cut-off values to determine impaired performances across patient groups. Furthermore, a lesion analysis based on MRI images obtained in the stroke unit was conducted.

2. Material and methods

2.1. Ethical approval

This study was approved by the local ethics committee of the University of Bremen. Subjects were informed about the aim and procedure of the experiment and had to sign a written consent form according to the Declaration of Helsinki. They were free to withdraw from the study at any time.

2.2. Subjects

Patients ($n = 20$) were ten female and ten male volunteers suffering a subacute stroke in supply areas of the medial cerebral artery. Patients were tested one to six days after the stroke onset in the stroke-unit of the central hospital in Bremen. The mean age was 52 years (± 9.8) and all of them were right-handed.

Data from age-matched healthy control subjects ($n = 20$) with a mean age of 58 (± 7.7) years were acquired in this study as well. Age differences between both groups were not significant (determined by two-tailed two-sample *t*-test).

Exclusion criteria were previous neurological, psychiatric or ophthalmological disorders and auditory defects. Further exclusion criteria for the stroke patients were bleedings, bilateral and previous lesions.

2.3. Clinical investigations

All patients underwent a series of neuropsychological tests, including assessment of visual neglect and extinction, visual fields, stereoscopic vision, colour vision, and hearing.

The visual neglect tests included: a line bisection test [57], the apple test [3], the clock task [20], and a copying task (target: flower). For assessment of visual field defects static perimetry of 30° of the visual field was conducted with the contralesional eye. The Lang Test [28] and the Ishihara Colour Vision test [21] served as measures for stereoscopic and colour vision. An audiometry with 8 frequencies for each ear was applied for assessment of hearing.

Furthermore, patients were asked for impairments in the following domains: memory deficits, anomia, reading deficits, visual field defects, spatial orienting disorder and auditory impairments in relation to loudness, sound, voice, and music perception.

All following computer-based tests were performed at 60 cm distance from the screen and subjects wore headphones when required (Sennheiser HD 201). Spatial resolution of the monitor (Samsung Sync Master 1100 MB) was 1600 × 1200 pixels (2041 × 1617 arcmin) and the temporal resolution was 75 Hz. The fixation dot in each test had a size of 5 arcmin. Response time was 'infinite', i.e. the next trial started only after a response was given (enforced response).

2.4. Attention test

The D2 Concentration Endurance Test [5] is a test for assessing sustained attention and visual scanning ability. It is a paper and pencil task, where subjects are required to cross out targets and leave non-targets untagged with a time constraint of 20 s for each row (14 rows and 47 characters per row). To measure the quality of performance (correctly processed characters) for each subject the overall number of processed characters, omissions, and errors were evaluated.

2.5. Montreal battery of evaluation of amusia

2.5.1. Stimuli

In order to compute a computer-based version of the Montreal Battery of Evaluation of Amusia ([37]; MBEA) stimuli were taken from the original version. The subtests 'scale' and 'rhythm' with thirty trials each were used for this experiment. Each trial consisted of a target melody and a comparison melody and both subtests included 15 same and 15 different trials. In 'different' trials, one tone was in a different scale or the rhythm of two subsequent tones was changed (for further information see [37]). Särkämö and colleagues [44,45] showed that the subtests 'scale' assessing melody perception and 'rhythm' assessing rhythmic perception are sufficient to adequately assess music perception skills.