

Preservation of musical memory in an amnesic professional cellist

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Learning and memory of music involves a multitude of perceptual, motor, affective, and autobiographical memory processes [1]. Patient and imaging studies suggest that musical memory may involve distinct neural substrates [2,3]. However, the degree of independence of such a system from other memory domains is controversial [4]. We have investigated a 68-year-old professional cellist, patient PM, who developed severe amnesia following encephalitis. This case provided a unique opportunity to study musical memory in a patient with a precisely defined premorbid musical knowledge and well-demarcated focal lesions of the brain. Despite severe memory impairments, he performed like healthy musicians in various tests of recognition memory for music. These findings suggest that learning and retention of musical information depends on brain networks distinct from those involved in other types of episodic and semantic memory.

Throughout his career, PM had performed in major German orchestras and had gained a wide repertoire that ranges from early to contemporary music. In 2005, PM was affected by herpes encephalitis, causing lesions of the right medial temporal lobe, large portions of the left temporal lobe and parts of left frontal and insular cortex (see Figure S1 and Table S1 in the Supplemental Information available on-line with this issue). PM was left with a severe and persistent ante- and retrograde amnesia. Neuropsychological testing revealed an exceedingly poor performance in most subtests of the Wechsler Memory Scale, with relative sparing of short-term memory tasks (Table S2). Moreover, in a systematic interview, PM showed profound deficits in semantic and episodic memory. For example, he could not remember the name of any German river or chancellor. He was neither able to report biographical details from

childhood, youth or adulthood, nor other personal or professional events. PM had no memory of relatives and friends, except for his brother and his full-time caregiver. He was unable to recall or recognize lyrics of well-known folk and childrens songs. PM could not recall any famous cellist and remembered the name of only one composer (Beethoven). However, PM was still able to sight-read and to play the cello.

To test PM's musical abilities in more detail, we employed an established battery of tests for evaluation of amusia (Table S3). PM performed normally in all subtests assessing music perception. Surprisingly, he also showed normal performance in a subsequent incidental memory test for single-phrase melodies presented in the battery. To systematically investigate whether musical memory was truly intact in PM, we devised three tasks that took

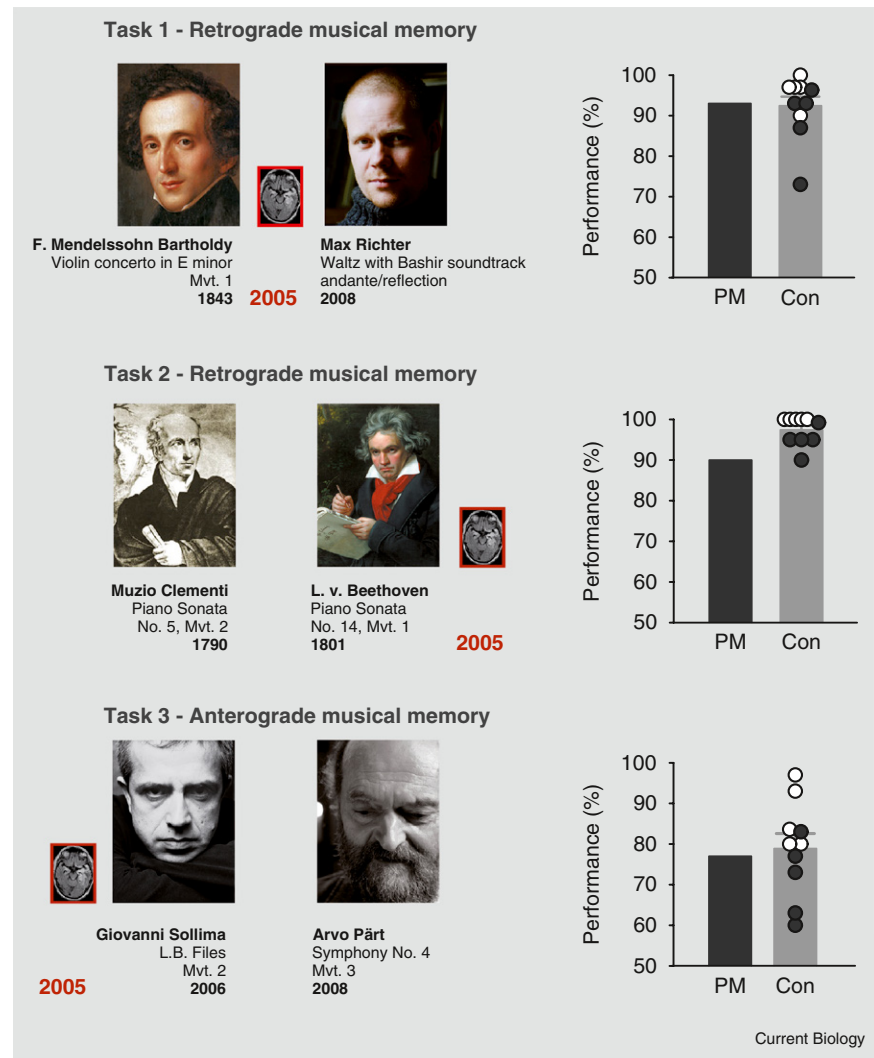


Figure 1. Schematics of the three musical memory tasks and corresponding performance of PM and control subjects.

Subjects listened to matched pairs of instrumental classical music and had to decide which excerpt sounded more familiar. Pieces were closely matched for musical character and instrumental line-up. White dots, Berlin Philharmonic string players; grey dots, active amateur musicians; error bars indicate s.e.m. Top row: retrograde musical memory. Subjects were presented classical music composed before 2005 (before the onset of PM's amnesia) paired with classical music composed after 2005 (after the onset of PM's amnesia). Middle row: retrograde musical memory. Subjects were presented famous and non-famous classical music composed before 2005 and in the same musical period. Bottom row: anterograde musical memory. First, subjects were asked to evaluate the emotional character of musical excerpts composed after 2005. In an incidental memory task 90 minutes later, subjects had to discriminate the previously rated excerpts from matched new excerpts.

the onset of his amnesia into account (Figure 1). Five age-matched string-players from the Berlin Philharmonic Orchestra and five age-matched active amateur musicians served as controls. First, we presented excerpts of well-known instrumental music composed before 2005 — so before the onset of PM's amnesia — paired with excerpts of instrumental music composed after 2005. These foils were matched with respect to musical character and instrumental line-up. PM discriminated targets from foils at the same level as the control group (93% *versus* 92 ± 2.5% (mean ± s.e.m.), $p = 0.94$).

To rule out that recognition of these excerpts was mediated by subtle differences in compositional style rather than by musical memory, we devised a second task, in which well-known instrumental classical pieces were matched to unfamiliar instrumental pieces of the same musical period (i.e. targets and foils composed before 2005). Although PM's continuous involvement with music had ceased since his encephalitis, he still discriminated famous from non-famous pieces at a level similar to controls (90% *versus* 97 ± 1.1%, $p = 0.07$). In a third task, we assessed PM's ability to learn new complex musical material. In an incidental memory task, where all targets and foils were composed after 2005, subjects were asked to discriminate instrumental pieces from closely matched pieces they had heard 90 minutes before. Again, PM performed at the same level as controls (77% *versus* 79 ± 3.7%, $p = 0.88$).

PM's performance in these musical memory tests was at the same level as a control group composed of amateur and professional musicians (see Supplemental Information for subgroup comparisons). To investigate whether his intact performance was part of a preserved supra-modal semantic memory for non-verbal material or modality-specific, PM was tested in anterograde recognition memory tasks for faces and objects. In both tasks, PM performed significantly worse than controls (faces, 55% *versus* 91 ± 1.9%, $p < 0.001$; objects, 50% *versus* 99 ± 1.2%, $p < 0.0001$). Further analysis confirmed a significant dissociation between musical and non-musical memory domains (music *versus* faces, $p = 0.0005$; music *versus* objects, $p = 0.00004$).

In patient PM, learning and memory of complex musical information

constitute an island of intact cognition within a severe amnesic syndrome. Representation of PM's exceptional premonitory musical knowledge and the ability to acquire new musical information survived damage to brain regions implicated in other types of memory surprisingly well. Both the degree of the dissociation between musical and non-musical memory domains and the preservation of explicit musical memory set PM apart from previous studies in amnesic patients with less focal disorders that mostly reported selective preservation of implicit musical memory [4].

Functional imaging studies support the hypothesis that semantic memory of music recruits a distinct and extensive bilateral network in temporal neocortex and prefrontal cortex [2], regions that were partly spared in PM. However, whether this system can be functionally separated from other semantic memory networks is controversial [5]. In particular, investigations of musical memory in patients with Alzheimer's disease (AD) and other dementias have yielded conflicting results. While some studies in AD patients showed that recognition of excerpts of familiar music and recognition of recently learned melodies was impaired together with other semantic and episodic memory domains [4], relative preservation of musical knowledge has been reported in other patients with AD and semantic dementia [6]. Extending these observations, the findings in PM show with particular clarity that the representation of music in the human brain is distinct and largely independent from other explicit memory modalities.

A reverse behavioral pattern to PM has been observed in non-musician patients with bilateral damage to the auditory association cortex [3]. Direct electrical stimulation of this region predominately in the right hemisphere has been shown to elicit musical hallucinations that relate to a subjects' previous musical experience, even after removal of the ipsilateral hippocampus [7]. Comparison of PM's lesion with these data and recent imaging studies [8] suggests that rostral temporal lobe structures in the right hemisphere, rather than the medial temporal lobe, mediate musical memory.

Although it is possible that lifelong musical training has contributed to the preservation of PM's musical

memory, the functional and structural dissociation reported here has theoretical and practical implications. It may be speculated that the particular relevance of music for the development of language and its important social functions may have driven the formation of a dedicated musical memory system in the human brain [9]. Preservation of musical knowledge and learning abilities may not only enhance quality of life in patients with otherwise compromised memory functions, but may also help to meet non-musical everyday challenges [10].

Supplemental Information

Supplemental Information includes one Figure, three Tables and Supplemental Experimental Procedures and can be found with this article online at doi: 10.1016/j.cub.2012.05.041.

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