Music in Dementia: From Impairment in Musical Recognition to Musical Interventions

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6.1 Introduction

Dementia, defined as a significant decline in cognitive functions interfering with independence in daily activities [1], is one of the most common causes of disability and dependency in the elderly. According to the World Alzheimer Report published in 2021 [2], over 55 million people worldwide currently suffer from dementia. Because of the ever-increasing life expectancy in most countries, this number is expected to double every 20 years, reaching around 139 million by 2050 (World Health Organization 2020).

Accounting for roughly 60–80% of all cases [3], Alzheimer's disease (AD) is the most common type of dementia in older subjects, causing a progressive decline in

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memory and eventually leading to loss of functional independence. The clinical syndromes caused by frontotemporal lobar degeneration (FTLD) are the most frequent causes of young-onset neurodegenerative dementia, with a relatively high prevalence in several countries [4]. These syndromes are divided into behavioral (bvFTD) and linguistic variants (or primary progressive aphasias, PPA), depending on their most prominent manifestations. BvFTD is characterized by abrupt behavioral and personality changes [5], while FTLD-related PPA can be further distinguished in semantic variant (svPPA), presenting progressive loss of world and semantic knowledge, and non-fluent variant (nfvPPA), defined by effortful and agrammatic speech production [6]. Although their clinical manifestations and neuropathological features are extremely heterogeneous, all these forms of dementia are due to an abnormal accumulation of proteins, both intra- and extra-cellularly, which causes failures in neuronal communication and subsequent cell death in vulnerable brain areas [7].

To date, there is no cure for dementia, and treatments can only reduce symptom progression for a limited amount of time. Only recently, Aducanumab, the first disease-modifying drug targeting neuropathology and protein build-up, has been approved by the US Food and Drug Administration for treating AD, although its efficacy is still controversial. Along with palliative pharmacological treatments, nonpharmacological approaches such as regular physical activity and cognitive stimulation have been widely employed for managing symptoms and improving patients' quality of life.

In this chapter, after a brief description of the neural substrate of music processing, we move on to discuss the most recent evidence regarding preserved and impaired musical functions in patients with dementia. We then conclude by providing an overview of the existing literature on musical interventions and their outcomes in this clinical population.

6.2 Neural Correlates of Music Processing

Processing music is an extremely complex activity, which engages a widespread circuit of cortical and subcortical brain areas.

When we listen to our favorite song, the acoustic signal coming from the inner ear is sent through the acoustic nerve to the thalamus and the brainstem. Here, anatomical connections departing to the cortex and to the limbic system give rise to the perception of musical stimuli and all their different attributes. Indeed, after receiving the auditory input from the aforementioned connections, the primary auditory cortex decodes physical information of sounds such as frequency, pitch, loudness, and individual notes. Then, the input is transferred to the surrounding auditory association areas, which elaborate more complex information like spatial location and recognition of the timbre of a voice or a musical instrument [8]. Thanks to the activity of the hippocampus, a crucial brain structure that stores our memories, we can recognize a song as familiar, or we can even start remembering an episode of our life that is particularly linked to that melody [9]. At the same time, the consonance or the dissonance of notes, the tonality, and the tempo of a melody engage our limbic system,

comprising the amygdala, the orbitofrontal, and the cingulate cortices, which are responsible for the emotions we experience when listening to music [10].

Songs have an intrinsic capacity for alternating tension build-up and resolution. This creates a psychological reaction of expectancy as the melody unfolds, which is followed by a reward-like feeling when the tension is released [10]. Indeed, the dopaminergic (or reward) network is implicated in experiencing music-evoked emotions. In particular, the nucleus accumbens, a structure of this network sensitive to primary and secondary rewards [11], is considered responsible for the feeling of "chills" when the music is perceived as pleasant [10]. As the music plays, perhaps without even realizing it, we might find ourselves singing along a catchy tune or tapping the foot to the beat of the rhythm, thus activating also our sensory-motor systems, basal ganglia, and cerebellum [9],

Interestingly, elaborating perceptual, mnestic, and emotional attributes of music are partially independent abilities, as demonstrated by patients with focal brain lesions or neurodegenerative conditions who present selective impairment in one of the aforementioned processes and preservation of the others (Fig. 6.1). Several studies showed that music can elicit positive responses even in people with advanced

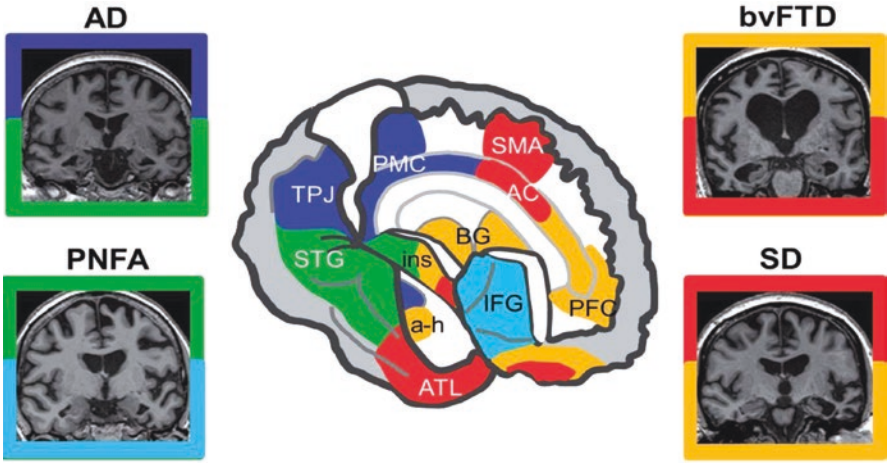

Fig. 6.1 Effects of dementia in musical cognition. Brain regions implicated in music processing are depicted and color-coded as follows: blue, tracking of musical episodic memory; green, elementary musical property (e.g., tempo) processing; cyan, scale and key processing; red, recognition of familiar musical motifs (musical semantic memory); gold, musical emotion. Coronal MRI brain sections (side panels; right hemisphere shown on the left in each section) represent patterns of atrophy typical of neurodegenerative syndromes associated with alterations in music networks. *AC* anterior cingulate; *a–h* amygdala–hippocampus; *ATL* anterior temporal lobe; *BG* basal ganglia; *IFG* inferior frontal gyrus/frontal operculum; *ins* insula; *PFC* prefrontal cortex; *PMC* posterior medial cortex (posterior cingulate, precuneus); *SMA* supplementary motor area; *STG* superior temporal gyrus; *TPJ* temporo-parietal junction. Adapted from Camilla N. Clark, Jason D. Warren, Music, memory and mechanisms in Alzheimer's disease, Brain, Volume 138, Issue 8, August 2015, Pages 2122–2125, https://doi.org/10.1093/brain/awv148; an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited

cognitive decline [12]. Therefore, it can constitute a means of communication with patients affected by different types of dementia and a valuable tool for stimulating spared cognitive functions.

6.2.1 Dementia and Musical Perception

> *There is certainly a universal and unconscious propensity to impose a rhythm even when one hears a series of identical sounds at constant intervals … We tend to hear the sound of a digital clock, for example, as "tick-tock, tick-tock" - even though it is actually "tick tick, tick tick.*
>
> *Oliver W. Sacks, Musicophilia: Tales of Music and the Brain*

Perceptual integrity has rarely been the focus of research on music processing in dementia, as the majority of studies in this field investigated musical memory. Some of these studies, however, used perceptual tasks as a control condition to rule out lower-level impairments potentially hampering mnestic or affective musical processing, and they have thus contributed to our understanding of the topic.

Findings regarding pitch detection ability in AD are quite mixed. When asked to state whether two melodies that differ by one single pitch are the same or not, AD patients perform as good as healthy controls [13, 14]. These results are in contrast with other studies describing a lower performance of AD patients compared to controls in different tasks of pitch and timbre discrimination [15, 16], or in the extraction of an auditory stream from a noisy background [17]. Notably, in all of these latter studies [15–17], the perceptual auditory deficits were not "pure" but rather secondary to impairments in non-verbal working memory. This is not surprising considering the crucial role played by working memory in music processing, which by nature requires maintaining in memory an auditory information that unfolds over time.

Fewer studies investigated less frequent forms of dementia, but it appears that bvFTD and svPPA patients perform similar to both AD patients and healthy controls in a pitch discrimination task [14], while nfvPPA patients show deficits in the identification of timbre and pitch direction compared to controls [16]. Although svPPA patients were able to discriminate changes of a single pitch in unfamiliar melodies, they were impaired in detecting pitch changes in familiar songs compared to controls and AD and bvFTD patients [14]. In these patients, this finding was significantly correlated with atrophy of the right inferior and superior temporal gyrus and temporal pole, areas that are markedly vulnerable in svPPA syndrome [14].

In a more complex task requiring to state whether melodies were harmonically resolved ("finished") or not ("unfinished"), bvFTD and AD patients showed a comparably lower performance relative to controls [18]. This deficit was associated with their executive capacity or behavioral alterations [18], such as impaired ability to anticipate future events in AD [19], and impaired detection of violations in social contexts (or faux pas) in bvFTD [20]. The link between music processing and social

cognition abilities was further highlighted by a recent meta-analysis, which reported compelling evidence of a neural overlap between social cognition and music perception in frontotemporal dementia [21].

Albeit mixed, these findings suggest that music perception impairments in dementia vary across the different clinical syndromes, and they might at least partially depend on the deterioration of other cognitive functions.

6.2.2 Dementia and Music-Evoked Emotions

Music imprints itself in the brain deeper than any other human experience. Music evokes emotion and emotion can bring memory. Music brings back the feeling of life when nothing else can

Oliver Sacks

Emotions are an integral and fundamental part of musical experience. Since the beginning of times, music had the ability to bring people together, promoting sociality in all cultures, and its power in relieving tension or resonating with one's feelings, be they positive or negative, is universally recognized.

Overall, the complete [22, 23] or partial [24] sparing of emotion recognition from music excerpts in AD is reported both in group and single case studies. On the contrary, svPPA is consistently associated with impairments in identifying emotions from musical stimuli. Omar et al. [25] described the case of a 56-year-old trumpet player with svPPA who did not show any problems in musical symbol knowledge or musical memory but was unable to discriminate the correct emotions conveyed by musical excerpts, especially negative ones. Another case study shed light on the neuroanatomical correlates of such deficit, comparing two svPPA patients with either bilateral or left-predominant anterior temporal atrophy [26]. Interestingly, the emotion recognition impairment was only found in the patient with bilateral atrophy, suggesting the presence of a potential right hemispheric specialization for such tasks [26]. These findings were also replicated in group studies, which found worse emotion recognition performance in svPPA patients compared to controls [27] and AD patients [28]. Besides, svPPA patients considered melodies less pleasing than both AD patients and healthy controls [18], demonstrating a reduced music-evoked reward feeling.

Emotion recognition deficits in bvFTD are extensively described in literature. Several studies suggest that these affective impairments also occur during emotion recognition from music [18, 27, 29]. Nonetheless, a case of a musician with bvFTD who maintained good affective ability has also been described, suggesting the existence of significant inter-individual variability [30].

Overall, we can conclude that emotion recognition from music can be relatively spared in AD. On the other hand, dementias belonging to the FTLD spectrum show affective problems that are not limited to concrete visual stimuli but also embrace more abstract emotional stimuli conveyed by music. The affective dysfunctions highlighted by musical emotion recognition tasks are in keeping with the typical behavioral disturbances seen in these patients, such as apathy and lack of empathy.

6.2.3 Dementia and Musical Memory

We see a frail and elderly woman in a chair, her eyes downcast. She motions for the music to be turned up, a swelling melody from Tchaikovsky's Swan Lake, and with a little encouragement her hands begin to flutter. […]. She leans forward, wrists crossed in classic swan pose; her chin lifts as if she's commanding the stage once more, her face lost in reverie.

Windship L. 2020, November 13.

Viral video of ballerina with Alzheimer's shows vital role of music in memory. The Guardian

The scene depicted above describes Marta Gonzalez, a former ballet dancer with advanced AD who started reproducing movements learned many years before as soon as the music of the Swan Lake played. Cases like this are not new in the literature focusing on dementia and musical memory. In fact, even though AD is by definition a progressive disturbance of memory, not all memory components are equally affected. While episodic (or explicit) memories are the first ones to be compromised, procedural (or implicit) memory, the one allowing us to remember how to ride a bike forever, remains relatively preserved even in more advanced AD stages [31]. This notion is particularly evident when considering music production abilities, as reported in case studies of advanced AD patients perfectly capable of playing musical instruments [32, 33].

The integrity of explicit forms of musical memory in AD, entailing recognition of familiar music, is a more controversial issue. While some studies describe good performances in tasks of familiar and unfamiliar music recognition even in more severe AD cases [34, 35], others do not support this finding [36]. Literature is even more inconsistent when considering music recognition in non-AD dementias, as the little evidence available is mainly anecdotical and focused on expert musicians. These studies suggest that musical recognition might be preserved both in svPPA [25] and bvFTD [30].

Music has also been appreciated for its ability to evoke autobiographical memories in people with dementia. AD patients are shown to retrieve as many autobiographical memories as healthy controls in response to music [35], even more than the memories they retrieved after seeing photographs [37]. Such music-evoked autobiographical memories are not found in bvFTD patients [38], arguably due to the degeneration of medial frontal regions that are implicated in autobiographical memory. Notably, these areas are affected in bvFTD but relatively spared in AD.

It appears that dementia does not prevent patients from learning new musical information, even in the presence of severe episodic memory impairment. Cowles et al. [33] described a violinist with AD who was able to learn new songs in spite of her extremely pervasive deficit in anterograde memory. Similar results were also found in a 91-year-old non-musician woman with severe AD who successfully learned a new song [39]. Furthermore, several studies reported the emergence of musical skills in bvFTD patients who were not musically trained before disease onset [40, 41]. Such musicophilia, or an increased interest and music-seeking behavior, was found to be even more prominent in svPPA compared to bvFTD [42].

Overall, these findings indicate that memory abilities, especially implicit ones, are relatively preserved in different forms of dementia, and music can facilitate the emergence of autobiographical memories and new musical skills.

6.3 Musical Interventions in Dementia

The expression "musical interventions" broadly refers to the study and the use of music to obtain beneficial effects for individuals. When applied to clinical settings, the use of music-based protocols to accomplish therapeutic goals is more specifically known as "music therapy." Overall, this type of intervention may range from informal to more structured protocols, consisting of receptive (e.g., music listening) or active exercises (e.g., music playing, singing, dancing).

The therapeutic effects of music in dementia can be attributable to a variety of reasons. First, as discussed in the previous sections, some musical functions remain preserved in patients with dementia despite their progressive cognitive decline. Indeed, the neurodegenerative process typically affects some brain regions while others remain relatively intact for longer periods, allowing therapists to act upon the residual cognitive abilities and strengthen them. Second, other benefits may arise from the nature of music per se, given its ability to affect cognition and mood in several ways. As exemplified in a recent model [43], music is engaging in the way that both active and passive activities involve numerous functions and brain regions simultaneously, therefore promoting neural plasticity. Furthermore, the emotional connotation of music plays a huge part in the efficacy of music therapies since certain melodies can elicit positive moods and provide the key to accessing significant autobiographical memories. Indeed, music has a strong personal meaning, and it can help patients retrieve a sense of self [43]. Group sessions can also be employed to boost social support and prevent isolation.

The implementation of therapeutic protocols taking into account all these potentialities showed encouraging results on global cognition, attention, and verbal fluency [43]. For example, weekly sessions of music listening or singing over a time period of 10 weeks in patients with early dementia (diagnoses were not specified) were associated with stable or improved performances in global cognition, attention, and executive functions compared to standard care [44]. However, such positive consequences on cognition were not found in more advanced stages of dementia [45].

Although heterogeneity exists across studies [12], memory and language functions appear to benefit from musical interventions. For example, mild AD patients recalled better verbal material learned through sung lyrics after 4 weeks compared to material learned in a speaking mode [46]. Similarly, there is evidence of nfvPPA patients who are incapable of conducting a conversation but are perfectly able to sing [47, 48].

Positive outcomes of music therapy have also been described for mood and behavioral symptoms such as agitation, depression, and anxiety [49], though the advantage of using music over other recreational activities is still debated [45].

Finally, improvements in quality of life are reported as a result of music-based interventions, both in patients and caregivers [44].

Notably, music can also serve as a risk prevention aid. Several lines of evidence suggest that lifetime musical activities, such as playing a musical instrument or dancing, are associated with a reduced risk of developing dementia [50]. Thus, music can also participate in enhancing cognitive reserve and delaying symptoms onset.

A severe limitation of the existing literature on music therapy is the paucity of details in the characterization of the sample (many articles refer broadly to dementia patients without specifying the exact diagnosis) and in the description of the protocols, which hinders reproducibility and confrontation across different studies. This shortcoming presumably accounts for many inconsistencies, and, due to these mixed results, there is still no agreement about several issues. For instance, there is no clear indication regarding optimal treatment duration, both with respect to the single session and to the total number of weeks needed for successful outcomes. According to a recent meta-analysis, treatments lasting less than 20 weeks provided better outcomes than longer ones [12]. Future studies are needed to assess whether the improvements found after treatment's end can last long-term.

6.4 Conclusions

In this chapter, we reviewed the existing literature related to music processing in the most common types of dementia. Overall, it appears that neurodegeneration leads to different selective impairment of musical skills depending on the clinical syndrome. Nonetheless, both anectodical and group studies consistently demonstrated that, even in the presence of cognitive and music processing deficits, some musical functions can still be preserved also in more advanced stages of the disease. Furthermore, music can be beneficial in managing psychological, cognitive, and behavioral symptoms in patients with dementia. Finally, the implementation of music-based interventions can be considered a promising tool for delaying symptoms of cognitive decline and for improving patients' quality of life in a relatively easy and cost-effective manner.

These findings, however, need to be expanded by more systematic studies. Literature in this field is often inconsistent, and it is particularly scant when considering less frequent forms of dementia. Contrasting results often originate between studies that employed different tasks and therapy protocols and that recruited subjects with heterogeneous musical backgrounds and disease duration. Thus, the lack of a consistent body of literature addressing all these variables prevents us from drawing solid conclusions. Future studies are also needed to develop specific batteries aimed at assessing spared musical functions in dementia, as well as questionnaires evaluating the individual history of music habits, in order to identify patients who will more likely benefit from a musical approach.

References

1. American Psychiatric Association D-TF. Diagnostic and statistical manual of mental disorders: DSM-5™. 5th ed. Charlottesville, VA: American Psychiatric Association; 2013.
2. Gauthier S, Rosa-Neto P, Morais JA, Webster C, editors. World alzheimer report 2021: journey through the diagnosis of dementia. London, England: Alzheimer's Disease International; 2021.
3. Erkkinen MG, Kim MO, Geschwind MD. Clinical neurology and epidemiology of the major neurodegenerative diseases. Cold Spring Harb Perspect Biol. 2018;10(4). 10.1101/cshperspect.a033118.
4. Rabinovici GD, Miller BL. Frontotemporal lobar degeneration: epidemiology, pathophysiology, diagnosis and management. CNS Drugs. 2010;24(5):375–98. https://doi.org/10.2165/11533100-000000000-00000.
5. Rascovsky K, Hodges JR, Knopman D, Mendez MF, Kramer JH, Neuhaus J, et al. Sensitivity of revised diagnostic criteria for the behavioural variant of frontotemporal dementia. Brain. 2011;134(Pt 9):2456–77. https://doi.org/10.1093/brain/awr179.
6. Gorno-Tempini ML, Hillis AE, Weintraub S, Kertesz A, Mendez M, Cappa SF, et al. Classification of primary progressive aphasia and its variants. Neurology. 2011;76(11):1006–14. https://doi.org/10.1212/WNL.0b013e31821103e6.
7. Elahi FM, Miller BL. A clinicopathological approach to the diagnosis of dementia. Nat Rev Neurol. 2017;13(8):457–76. https://doi.org/10.1038/nrneurol.2017.96.
8. Warren J. How does the brain process music? Clin Med (Lond). 2008;8(1):32–6. https://doi.org/10.7861/clinmedicine.8-1-32.
9. Särkämö T, Tervaniemi M, Huotilainen M. Music perception and cognition: development, neural basis, and rehabilitative use of music. Wiley Interdiscip Rev Cogn Sci. 2013;4(4):441–51. https://doi.org/10.1002/wcs.1237.
10. Koelsch S. Brain correlates of music-evoked emotions. Nat Rev Neurosci. 2014;15(3):170–80. https://doi.org/10.1038/nrn3666.
11. Sescousse G, Caldú X, Segura B, Dreher JC. Processing of primary and secondary rewards: a quantitative meta-analysis and review of human functional neuroimaging studies. Neurosci Biobehav Rev. 2013;37(4):681–96. https://doi.org/10.1016/j.neubiorev.2013.02.002.
12. Moreno-Morales C, Calero R, Moreno-Morales P, Pintado C. Music therapy in the treatment of dementia: a systematic review and meta-analysis. Front Med (Lausanne). 2020;7:160. https://doi.org/10.3389/fmed.2020.00160.
13. Hsieh S, Hornberger M, Piguet O, Hodges JR. Neural basis of music knowledge: evidence from the dementias. Brain. 2011;134(Pt 9):2523–34. https://doi.org/10.1093/brain/awr190.
14. Johnson JK, Chang CC, Brambati SM, Migliaccio R, Gorno-Tempini ML, Miller BL, et al. Music recognition in frontotemporal lobar degeneration and Alzheimer disease. Cogn Behav Neurol. 2011;24(2):74–84. https://doi.org/10.1097/WNN.0b013e31821de326.
15. Golden HL, Clark CN, Nicholas JM, Cohen MH, Slattery CF, Paterson RW, et al. Music perception in dementia. J Alzheimers Dis. 2017;55(3):933–49. https://doi.org/10.3233/jad-160359.
16. Goll JC, Kim LG, Hailstone JC, Lehmann M, Buckley A, Crutch SJ, et al. Auditory object cognition in dementia. Neuropsychologia. 2011;49(9):2755–65. https://doi.org/10.1016/j.neuropsychologia.2011.06.004.
17. Goll JC, Kim LG, Ridgway GR, Hailstone JC, Lehmann M, Buckley AH, et al. Impairments of auditory scene analysis in Alzheimer's disease. Brain. 2012;135(Pt 1):190–200. https://doi.org/10.1093/brain/awr260.
18. Clark CN, Golden HL, McCallion O, Nicholas JM, Cohen MH, Slattery CF, et al. Music models aberrant rule decoding and reward valuation in dementia. Soc Cogn Affect Neurosci. 2018;13(2):192–202. https://doi.org/10.1093/scan/nsx140.
19. Irish M, Piolino P. Impaired capacity for prospection in the dementias--theoretical and clinical implications. Br J Clin Psychol. 2016;55(1):49–68. https://doi.org/10.1111/bjc.12090.

20. Delbeuck X, Pollet M, Pasquier F, Bombois S, Moroni C. The clinical value of the faux pas test for diagnosing behavioral-variant frontotemporal dementia. J Geriatr Psychiatry Neurol. 2022;35(1):62–5. https://doi.org/10.1177/0891988720964253.
21. Van't Hooft JJ, Pijnenburg YAL, Sikkes SAM, Scheltens P, Spikman JM, Jaschke AC, et al. Frontotemporal dementia, music perception and social cognition share neurobiological circuits: a meta-analysis. Brain Cogn. 2021;148:105660. https://doi.org/10.1016/j.bandc.2020.105660.
22. Drapeau J, Gosselin N, Gagnon L, Peretz I, Lorrain D. Emotional recognition from face, voice, and music in dementia of the Alzheimer type. Ann N Y Acad Sci. 2009;1169:342–5. https://doi.org/10.1111/j.1749-6632.2009.04768.x.
23. Gagnon L, Peretz I, Fülöp T. Musical structural determinants of emotional judgments in dementia of the Alzheimer type. Neuropsychology. 2009;23(1):90–7. https://doi.org/10.1037/a0013790.
24. Arroyo-Anlló EM, Dauphin S, Fargeau MN, Ingrand P, Gil R. Music and emotion in Alzheimer's disease. Alzheimers Res Ther. 2019;11(1):69. https://doi.org/10.1186/s13195-019-0523-y.
25. Omar R, Hailstone JC, Warren JE, Crutch SJ, Warren JD. The cognitive organization of music knowledge: a clinical analysis. Brain. 2010;133(Pt 4):1200–13. https://doi.org/10.1093/brain/awp345.
26. Macoir J, Berubé-Lalancette S, Wilson MA, Laforce R, Hudon C, Gravel P, et al. When the wedding march becomes sad: semantic memory impairment for music in the semantic variant of primary progressive aphasia. Neurocase. 2016;22(6):486–95. https://doi.org/10.1080/13554794.2016.1257025.
27. Omar R, Henley SM, Bartlett JW, Hailstone JC, Gordon E, Sauter DA, et al. The structural neuroanatomy of music emotion recognition: evidence from frontotemporal lobar degeneration. NeuroImage. 2011;56(3):1814–21. https://doi.org/10.1016/j.neuroimage.2011.03.002.
28. Hsieh S, Hornberger M, Piguet O, Hodges JR. Brain correlates of musical and facial emotion recognition: evidence from the dementias. Neuropsychologia. 2012;50(8):1814–22. https://doi.org/10.1016/j.neuropsychologia.2012.04.006.
29. Downey LE, Blezat A, Nicholas J, Omar R, Golden HL, Mahoney CJ, et al. Mentalising music in frontotemporal dementia. Cortex. 2013;49(7):1844–55. https://doi.org/10.1016/j.cortex.2012.09.011.
30. Barquero S, Gomez-Tortosa E, Baron M, Rabano A, Munoz DG, Jimenez-Escrig A. Amusia as an early manifestation of frontotemporal dementia caused by a novel progranulin mutation. J Neurol. 2010;257(3):475–7. https://doi.org/10.1007/s00415-009-5393-y.
31. Baird A, Samson S. Memory for music in Alzheimer's disease: unforgettable? Neuropsychol Rev. 2009;19(1):85–101. https://doi.org/10.1007/s11065-009-9085-2.
32. Beatty WW, Winn P, Adams RL, Allen EW, Wilson DA, Prince JR, et al. Preserved cognitive skills in dementia of the Alzheimer type. Arch Neurol. 1994;51(10):1040–6. https://doi.org/10.1001/archneur.1994.00540220088018.
33. Cowles A, Beatty WW, Nixon SJ, Lutz LJ, Paulk J, Paulk K, et al. Musical skill in dementia: a violinist presumed to have Alzheimer's disease learns to play a new song. Neurocase. 2003;9(6):493–503. https://doi.org/10.1076/neur.9.6.493.29378.
34. Cuddy LL, Duffin JM, Gill SS, Brown CL, Sikka R, Vanstone AD. Memory for melodies and lyrics in Alzheimer's disease. Music Percept. 2012;29(5):479–91.
35. Cuddy LL, Sikka R, Vanstone A. Preservation of musical memory and engagement in healthy aging and Alzheimer's disease. Ann N Y Acad Sci. 2015;1337:223–31. https://doi.org/10.1111/nyas.12617.
36. Ménard MC, Belleville S. Musical and verbal memory in Alzheimer's disease: a study of long-term and short-term memory. Brain Cogn. 2009;71(1):38–45. https://doi.org/10.1016/j.bandc.2009.03.008.
37. Baird A, Brancatisano O, Gelding R, Thompson WF. Characterization of music and photograph evoked autobiographical memories in people with Alzheimer's disease. J Alzheimers Dis. 2018;66(2):693–706. https://doi.org/10.3233/jad-180627.

38. Baird A, Brancatisano O, Gelding R, Thompson WF. Music evoked autobiographical memories in people with behavioural variant frontotemporal dementia. Memory. 2020;28(3):323–36. https://doi.org/10.1080/09658211.2020.1713379.
39. Baird A, Umbach H, Thompson WF. A nonmusician with severe Alzheimer's dementia learns a new song. Neurocase. 2017;23(1):36–40. https://doi.org/10.1080/13554794.2017.1287278.
40. Cho H, Chin J, Suh MK, Kim HJ, Kim YJ, Ye BS, et al. Postmorbid learning of saxophone playing in a patient with frontotemporal dementia. Neurocase. 2015;21(6):767–72. https://doi.org/10.1080/13554794.2014.992915.
41. Miller BL, Boone K, Cummings JL, Read SL, Mishkin F. Functional correlates of musical and visual ability in frontotemporal dementia. Br J Psychiatry. 2000;176:458–63. https://doi.org/10.1192/bjp.176.5.458.
42. Fletcher PD, Downey LE, Witoonpanich P, Warren JD. The brain basis of musicophilia: evidence from frontotemporal lobar degeneration. Front Psychol. 2013;4:347. https://doi.org/10.3389/fpsyg.2013.00347.
43. Brancatisano O, Baird A, Thompson WF. A 'music, mind and movement' program for people with dementia: initial evidence of improved cognition. Front Psychol. 2019;10:1435. https://doi.org/10.3389/fpsyg.2019.01435.
44. Särkämö T, Tervaniemi M, Laitinen S, Numminen A, Kurki M, Johnson JK, et al. Cognitive, emotional, and social benefits of regular musical activities in early dementia: randomized controlled study. Gerontologist. 2014;54(4):634–50. https://doi.org/10.1093/geront/gnt100.
45. Sánchez A, Maseda A, Marante-Moar MP, de Labra C, Lorenzo-López L, Millán-Calenti JC. Comparing the effects of multisensory stimulation and individualized music sessions on elderly people with severe dementia: a randomized controlled trial. J Alzheimers Dis. 2016;52(1):303–15. https://doi.org/10.3233/jad-151150.
46. Moussard A, Bigand E, Belleville S, Peretz I. Learning sung lyrics aids retention in normal ageing and Alzheimer's disease. Neuropsychol Rehabil. 2014;24(6):894–917. https://doi.org/10.1080/09602011.2014.917982.
47. Racette A, Bard C, Peretz I. Making non-fluent aphasics speak: sing along! Brain. 2006;129(Pt 10):2571–84. https://doi.org/10.1093/brain/awl250.
48. Warren JD, Warren JE, Fox NC, Warrington EK. Nothing to say, something to sing: primary progressive dynamic aphasia. Neurocase. 2003;9(2):140–55. https://doi.org/10.1076/neur.9.2.140.15068.
49. Lam HL, Li WTV, Laher I. Effects of music therapy on patients with dementia-a systematic review. Geriatrics (Basel). 2020;5(4) https://doi.org/10.3390/geriatrics5040062.
50. Verghese J, Lipton RB, Katz MJ, Hall CB, Derby CA, Kuslansky G, et al. Leisure activities and the risk of dementia in the elderly. N Engl J Med. 2003;348(25):2508–16. https://doi.org/10.1056/NEJMoa022252.