

BENEFITS OF MUSIC ON VERBAL LEARNING AND MEMORY: HOW AND WHEN DOES IT WORK?

LAURA FERRERI

Cognition and Brain Plasticity Unit, University of Barcelona, Barcelona, Spain

LAURA VERGA

Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

A LONG-STANDING DEBATE IN COGNITIVE NEUROSCIENCE concerns the effect of music on verbal learning and memory. Research in this field has largely provided conflicting results in both clinical as well as non-clinical populations. Although several studies have shown a positive effect of music on the encoding and retrieval of verbal stimuli, music has also been suggested to hinder mnemonic performance by dividing attention. In an attempt to explain this conflict, we review the most relevant literature on the effects of music on verbal learning and memory. Furthermore, we specify several mechanisms through which music may modulate these cognitive functions. We suggest that the extent to which music boosts these cognitive functions relies on experimental factors, such as the relative complexity of musical and verbal stimuli employed. These factors should be carefully considered in further studies, in order to reliably establish how and when music boosts verbal memory and learning. The answers to these questions are not only crucial for our knowledge of how music influences cognitive and brain functions, but may have important clinical implications. Considering the increasing number of approaches using music as a therapeutic tool, the importance of understanding exactly how music works can no longer be underestimated.

Received: March 9, 2015, accepted February 28, 2016.

Key words: music, memory, verbal learning, language, cognitive improvement

THE CLAIM THAT MUSIC ENHANCES COGNITIVE functions is widespread, especially the idea that music boosts memory and learning of verbal material (Schellenberg & Weiss, 2013). This belief is supported by evidence from patient populations. Music

has been shown to boost verbal memory not only in patients with memory deficits, such as those with Alzheimer's disease (AD; Simmons-Stern, Budson, & Ally, 2010; Thompson, Moulin, Hayre, & Jones, 2005), but also in conditions where memory is not primarily impaired, such as stroke (Sarkamo et al., 2008) and multiple sclerosis (Thaut et al., 2009). In addition, music has been increasingly adopted as a therapeutic tool for language training in aphasic patients (Altenmüller & Schlaug, 2013; de l'Etoile, 2010; Hillecke, Nickel, & Bolay, 2005; Hurkmans et al., 2011; Thaut, 2010). The use of music is justified not only because it is well-known to have a positive effect on mood and arousal (Koelsch, 2009; Sarkamo et al., 2008), but also because it may recruit spared language homologue areas in the right hemisphere following a left-hemispheric lesion (Altenmüller & Schlaug, 2013; Stahl, Henseler, Turner, Geyer, & Kotz, 2013; Zumbansen, Peretz, & Hébert, 2014).

Despite this evidence of the positive effect of music, several other authors have shown that music can negatively affect memory performance in both AD (Mousard, Bigand, Belleville, & Peretz, 2012) and aphasia (Racette & Peretz, 2007). A possible explanation for these conflicting results is that music might negatively affect memory by attracting patients' attention away from the relevant information (such as words to learn or remember), thereby generating a dual-task situation. The presence of both positive and negative effects of music on verbal memory is also found in healthy participants (for an overview, see Jäncke, 2008; Schulkind, 2009). As a consequence, the debate about whether music can boost non-musical cognitive abilities is still open (Schellenberg & Weiss, 2013). A delicate balance seems to exist between settings in which music facilitates recall from memory, and settings where music interferes with memory processes (Kang & Williamson, 2013).

These previously described inconsistencies may stem from the variety of different approaches and paradigms employed to evaluate the effect of music on learning and memory. Music is an intrinsically complex stimulus and is used in experiments that investigate several different facets of cognition. For this reason, finding exactly how and why music works across different studies may prove particularly difficult. Indeed, different aspects of music

may convey various types of information, thus hinging on different neural and psychological systems. For example, listening to a Bach piece is not the same as listening to a mechanically played and very simplified (e.g., MIDI) melody. While the former was created by the composer to communicate with the audience, the latter was most likely intended to experimentally test for a specific effect, which required a balancing of specific parameters. Do these differences contribute to verbal memory and learning? Or, do different types of music always elicit the same effect, independently of their composition and genre? The importance of finding an answer to these questions was clearly raised during recent international conferences and meetings on music and neuroscience,¹ where it became evident that it is necessary to unravel which types of material and experimental paradigms lead to improvements in memory. This is important for two reasons: First, from a theoretical perspective, this will deepen our knowledge about how music influences brain functions such as memory and learning. Second, from a rehabilitation perspective, understanding whether or not music can boost learning and memory performance is critical for developing specific paradigms for different patient populations.

The aim of this review is, therefore, to examine the most recent literature on music and verbal learning and memory in order to provide a critical overview of the existing literature and of the multitude of paradigms in use. We aim to identify a pattern of results that could explain how and when music improves verbal memory functions. With this in mind, we have classified the most relevant studies in these domains according to the auditory stimuli that have been employed, and the population in which they have been tested. Although music training modulates both brain plasticity and behavioral outcomes (Herholz & Zatorre, 2012), the present review does not take into account the effect of expertise or long-term exposure to music on verbal memory and learning. Instead, we focus on studies that employ verbal stimuli (words or sentences) encoded with different types of music and retrieved according to typical learning and memory tasks (e.g., recognition, recall). After considering studies that used sung versus spoken verbal material, we review the literature on the effects of listening to background music on verbal memory and

learning (see Table 1 for a summary of paradigms, stimuli, and tasks employed). We then propose and discuss different mechanisms that can explain why music can facilitate verbal memory and learning (e.g., temporal scaffolding-attentional, arousal, and emotional-reward processes). We pay particular attention to the type of musical stimuli and its complexity, ranging from low complexity (e.g., simple tones, rhythms or melodies) to high complexity (e.g., classical or jazz music). Finally, the last section considers the reviewed studies from a methodological perspective, with the goal of suggesting new directions for further research.

When Does Music Boost Verbal Memory and Learning?

SUNG VERSUS SPOKEN STIMULI

Whether sung stimuli may facilitate word and text learning is a highly debated question that has led to the development of several different theoretical approaches and paradigms. Sung stimuli have indeed been used both passively (i.e., listening to sung stimuli) and actively (i.e., where the learner themselves sings the to-be-learned stimuli). Studies have also used either texts or just simple words, which has led to an equivocal pattern of results. We next will introduce several studies and highlight the differences in the paradigms employed and in the results obtained.

Several experiments using sung versus spoken paradigms explore the segmentation of the continuous flow of speech into discrete words. While learning their first language, children use statistical properties in speech — both within words and at the word boundary — to extract single words (Saffran, Aslin, & Newport, 1996). Music can enhance this process by providing multiple cues that facilitate the identification of word boundaries (Saffran, 2003; Thiessen & Saffran, 2009; see also Besson & Schön, 2001). Do adults also benefit from music in this fashion? A series of studies by Schön and colleagues attempted to answer this question by investigating song learning in adults. In a first behavioral study, adult French speakers were exposed to a continuous stream of trisyllabic pseudo-words, either spoken or sung. In the latter case, linguistic and musical boundaries could either be matching or non-matching. Results showed that participants learned the words in the sung-matching boundaries condition, while they were at chance level in the spoken condition; intermediate results were obtained for the sung but not matching condition (Schön et al., 2008). In a follow-up study employing both behavioral and EEG measures (Francois & Schön, 2010), French participants were presented

¹ We are chiefly referring to “The neurosciences and music V” in Dijon (2014) and the EBRAMUS final conference in Pavia (2013). The interested reader will find more information on the official websites of the conferences: <http://www.fondazione-mariani.org/en/neuromusic/conferences/dijon-may-june-2014.html> and <http://www.fondazione-mariani.org/en/neuromusic/otherevents/ebramus-2013.html>

TABLE 1. Overview of the Cited Studies on Music and Verbal Learning and Memory, Classified According to the Experimental Paradigm Employed

Study	Year	Testing type	Population	Musical Expertise	Verbal Stimuli	Music stimuli	Music effect	Native Language
SUNG Vs. SPOKEN								
Wallace	1994	Recall, Delayed recall	Healthy	Musicians, non-musicians	Text	Ballads (The Frank C. Brown Collection of North Carolina Folklore)	M+ (if melody easily learned)	English
McElhinney & Annet	1996	Recall and Chunking	Healthy	n.r.	Words (lyrics)	"You're my home" (Billy Joel)	M+ (recall + chunking)	English
Rainey & Larsen	2002	Recall	Healthy	n.r.	Words	"Pop Goes the weasel", "Yankee Doodle"	M+ (long-term)	English
Peterson & Thaut	2007	Recall	Healthy	n.r.	AVLT (words)	Simple repetitive novel melody	M= (but > frontal EEG coherence)	English
Racette & Peretz	2007	Recall	Healthy	Musicians, non-musicians	Song lyrics	Songs from Claude Gauthier	M-	French
Schön et al.	2008	Recognition	Healthy	Non-musicians	Pseudo-words	One tone x syllable	M+	French
Thiessen & Saffran	2009	Headturn Preference Procedure	Infants (6;5 to 8 months)	n.a.	Strings of digit names	One tonal and one non-tonal melody; two tonal melodies in C major	M+	English
Francois & Schön	2010	Recognition (forced choice discrimination)	Healthy	Non-musicians	Pseudo-words	One tone x syllable	M+	French
Simmons-Stern et al.	2010	Recognition	Healthy older adults, AD	Non-musicians	Song lyrics (children songs)	Simple repetitive melodies and perfect tail rhyme scheme	M+ (AD only)	English
Stahl et al.	2011	Repeat (Articulatory quality)	Stroke (non-fluent Aphasics)	n.r.	Original, formulaic, non-formulaic lyrics	Nursery Rhyme ('Hänschen klein') and rhythm	M+ (rhythmic > sung/spoken)	German
Moussard et al.	2012	Recall	AD (single-case)	Non-musicians	Song lyrics	Songs from Claude Gauthier	M- (initial learning), M+ (repeated learning)	French
Stahl et al.	2013	Repeat (Articulatory quality)	Stroke (non-fluent Aphasics)	n.r.	Original, non-formulaic lyrics	Nursery Rhyme ('Haenschen klein') and rhythm	M+ (formulaic phrases), M- (non formulaic)	German
Ludke et al.	2014	Production, Recall, Recognition, Vocabulary tests	Healthy	n.r.	Paired-associate phrases (L1-L2)	Novel melodies (based on Hungarian folk songs)	M+ (sung > rhythmic > spoken)	L1 English L2 Hungarian
Thaut et al.	2014	Recall, Delayed recall	MS	Musicians, non-musicians	RAVLT	Originally composed song	M+ (word memory, word order memory, frontal alpha LRS)	English

(continued)

Table 1. (continued)

Study	Year	Testing type	Population	Musical Expertise	Verbal Stimuli	Music stimuli	Music effect	Native Language
BACKGROUND MUSIC								
Smith	1985	Delayed recall	Healthy	n.r.	words	Mozart piano concert (n.24 in c minor); jazz ("People make the world go around" - Milt Jackson)	M+ (music-dependent memory)	English
Balch et al.	1992	Recall, delayed recall	Healthy	n.r.	Words	slow ("How long has this been going on?" - Fox & Worth) and fast jazz ("sing sing sing" - Cowan); slow (Clarinet quintet in A major - Mozart) and fast classical (Devil's trill - Tartini). "Haegum Shinawa" (violins) as distractor.	M+ (music-dependent memory)	English
Balch & Lewis	1996	Recall	Healthy	n.r.	words	Piano sonata C major Rondo (Mozart); "Jazz Holiday," (Nevin) (with tempo changes)	M+ (music-dependent memory and mood)	English
Thompson et al.	2005	Verbal fluency	Healthy older adults, AD	n.r.	Fluency categories (vehicles, fruits, colors, and furniture)	Four Seasons: winter (Vivaldi)	M+	English
de Groot	2006	Translation, learning?	Healthy	n.r.	Translation pairs (word + nonword)	Brandeburg Concerto (J.S.Bach)	M+ (> learning)	Dutch
Jäncke & Sandmann	2010	Recognition	Healthy	Non-musicians	Neologisms	computerized piano sounds, C major (in-tune fast, in-tune slow, out-of-tune fast, out-of-tune slow)	M= (but different cortical activation for different background)	German
Kang & Williamson	2013	Recall, Translation	Healthy	Musicians, non-musicians	Words, Phrases	Instrumental, medium tempo, low dynamics	M+ (for Mandarin)	L1 English L2 Mandarin/Arabic
Ferri et al.	2013	Recognition (item-source memory)	Healthy	Non-musicians	Words	jazz instrumental ("if you see my mother - Bechet)	M+ (item memory)	French
Jäncke et al.	2014	Recall	Healthy	Musicians, non-musicians	Neologisms	Vocal + instrumental, high + low intensity (modern music)	M=	German
Ferri et al.	2014	Recognition (item-source memory)	Healthy older adults	Non-musicians	Words	jazz instrumental ("if you see my mother - Bechet)	M+ (source memory)	French
Ferri, Bigand, & Bugajska	2015	Recognition (item-source memory)	Healthy	Non-Musicians	Words	Blues-Rock instrumental (Down Down Down - Joe Satriani)	M+ (source memory)	French

Note: For each study we report year of publication, experimental task (testing type), tested population, participants' musical expertise, type of verbal and music stimuli, presence of a music effect, and participants' native language. Abbreviations, in alphabetical order: AD = Alzheimer's disease; AVLT = Auditory-Verbal Learning Test; BDAE = Boston Diagnostic Aphasia Test; CVLT-II = California Verbal Learning Test; F = Familiar; HKLIT = Hong Kong List Learning Test; L1 = First Language; L2 = Second Language; LH = Left Hemisphere; MCA = Middle Cerebral Artery; MIT = Melodic Intonation Therapy; M+ = effect of the music condition; M- = effect of the non-music condition; M= = same effect for the music and non-music conditions; MS = multiple Sclerosis, n.a. = not applicable; NF = Non Familiar; n.r. = not reported; RAVLT = Rey Auditory Verbal Learning Test; RBMT = Rivermed Behavioural Memory Test; RH = Right Hemisphere; RVDLT = Rey Visual Design Learning Test.

with a stream of tone-melodies, each associated with a particular pseudo-word. Again, both melodies and syllables could be grouped into specific pseudo-words that participants had to identify in the test phase. While performance in the behavioral test was not significantly different from chance at the group level, ERP data revealed a significant learning effect, emerging as a familiarity effect for words expressed by a larger negativity in the N400 range at fronto-central electrode sites for part-words (i.e., letter strings not corresponding to a pseudo-word) and tone-melodies (perceived as unfamiliar) compared to words. These results suggest that the superimposition of two matching linguistic and musical structures in song facilitates segmentation of linguistic information. Furthermore, these results indicate an improved sensitivity of electrophysiological—as compared to behavioral measures (François & Schön, 2013).

The comparison between sung and spoken stimuli has been adopted not only in speech segmentation, but also to investigate explicit learning. In this case, lists of words are often employed to evaluate the impact of music on learning and memory. For example, Peterson and Thaut (2007) found no behavioral advantage for sung as compared to spoken word lists in an explicit learning task (Rey's Auditory Verbal Learning test). This was possibly due to the different modalities of recall compared to learning (sung learning compared to spoken recall). However, they found learning-related changes in frontal EEG coherence in the sung condition, reflecting strengthened synchronous cortical oscillations in the prefrontal regions, which have been reported to support learning. The authors suggested that these changes are caused by a temporally structured learning template provided by music. These results were replicated in a series of studies by Thaut, Peterson, and McIntosh (2005). These experiments suggest that significantly higher coherence in alpha and gamma bands is observed for sung stimuli, despite the lack of behavioral differences between sung and spoken conditions. However, a behavioral advantage for sung stimuli emerged in studies on patients with multiple sclerosis when they were instructed to sing during the recall phase, suggesting that particular care should be taken when considering the testing modality (Thaut et al., 2009; Thaut, Peterson, McIntosh, & Hoemberg, 2014). These studies explored the possibility that music may act as a mnemonic or learning device, providing a structured temporal scaffolding framework that facilitates word learning. Furthermore, results suggest that while behavioral learning performance may not be significantly different for sung and spoken stimuli, significant

learning-related changes may be identified by using more sensitive techniques (e.g., EEG/ERP). However, the absence of behavioral results in the presence of electrophysiological differences does not allow a clear conclusion to be made. More conclusive evidence has been provided by Rainey and Larsen (2002). They showed a behavioral effect of music on delayed recall of learned items. They presented English speakers with sung or spoken word lists. Participants did not learn word lists faster in either condition. However, recall one week later was superior among those who learned the sung word list. Hence, the authors concluded that the advantage of sung over spoken words for verbal memory could be a long-term effect.

Significant effects of music in verbal long-term memory are also evident in AD patients. Despite the overall mnemonic deficits typical of this disease, music processing is often spared by the neurodegenerative progression of the pathology. For this reason, paradigms using sung versus spoken words or lyrics have been employed to test this patient population. In one of the most well-known studies (Simmons-Stern et al., 2010), healthy older adults and AD patients were asked to encode lyrics of unfamiliar children's songs presented bimodally: Visual stimuli were accompanied by either a sung or a spoken recording. While older adult controls showed no significant difference between the two conditions, probably due to ceiling effects, AD patients demonstrated better recognition accuracy for the sung lyrics over the spoken lyrics. Another single-case study on an AD patient showed that the sung version interfered with the initial learning (i.e., lower performance for sung versus spoken), but when a familiar melody was used, the sung condition led to better word retrieval but only after repeated learning (Moussard et al., 2012). These findings seem to suggest that beyond delayed recall, item repetition may be crucial for positive behavioral results. In agreement, McElhinney and Annet (1996) showed that the total number of recalled words, as well as the extent of chunking of recalled material, was better in a sung condition compared to a spoken condition after several unfamiliar word repetitions.

These studies on AD patients (McElhinney & Annett, 1996; Moussard et al., 2012; Simmons-Stern et al., 2010) differed from those that only tested healthy participants. The material to be memorized was not based on single words but more complex stimuli: texts. The question is whether similar effects can be observed in healthy participants and – in general – how can music influence learning and memory of complex verbal stimuli? The answer lies in studies that investigate how spoken or sung text is learned, and it seems to be related to the

complexity of the melodies as well as to experimental factors (including the number of repetitions, recall delay, and the consistency between learning and testing phase).

A first proposition in this direction was made by Wallace (1994). In a series of experiments, Wallace reported that songs can facilitate the learning and recall of a text compared to a spoken version of the same text, suggesting that a musical context can assist in learning and retrieving words. However, for this effect to emerge, the melody needs to be simple and easy to learn. Melodies with simple, symmetrical melodic contours showed better facilitation of text recall compared to a spoken version. Another important limitation investigated by Kilgour and colleagues (2000) concerns the relative duration of spoken and sung material. Indeed, sung stimuli usually have slower presentation rates. This can facilitate the learner's understanding and, hence, ability to memorize the words. In a series of three experiments, the authors demonstrated that an advantage of recall for sung lyrics vanished when presentation rate of sung and spoken material was equated (Kilgour et al., 2000).

The fact that the impact of music in learning and memory may be confounded by experimental factors (for example, the stimulus presentation rate) calls for the use of more experimental control. To this end, in a pivotal series of studies, Racette and Peretz (2007; see also Racette, Bard, & Peretz, 2006) presented French-speaking university students with novel (French) songs to be learned. Three modalities of learning-recall were assessed: sung learning and sung recall, sung learning and spoken recall, divided learning (melody with spoken lyrics), and spoken recall. Further, in a subsequent experiment, singing was assessed with and without words in order to investigate whether music creates a dual-task (divided attention) condition. If there is an attentional cost to musical production that harms memory, producing the melody with the text should require more resources than producing either the text or the melody alone. The authors found no advantage of sung over spoken stimuli for any of these conditions (Racette & Peretz, 2007). More recently, Ludke, Ferreira, and Overy (2014) reached a different conclusion in a study that investigated singing in foreign language learning. They explored several variables deemed crucial in previous studies (e.g., modality of learning vs. modality of recall, complexity of melody, presentation rate). Participants learned paired associates in their native language (English) and in a new language (Hungarian) in one of three conditions: speaking, rhythmic speaking, and singing. The authors found singing to be a more effective

condition for learning than either speaking or rhythmic speaking, and concluded that the melodic component may be the most important aspect for learning and memory (see Stahl, 2014; Stahl et al., 2013; Stahl, Kotz, Hensele, Turner, & Geyer, 2011, for a different point of view on the role of rhythm).

BACKGROUND MUSIC

In the previous section, we discussed the role played by singing (either perceived or produced) on verbal memory. Singing represents a particular type of stimulus because it involves oral language. In singing, music and language are intertwined, and they represent the same acoustical signal. The question arises as to what effect music might have when presented in a more "pure" and less synchronized form, such as instrumental background music during verbal encoding. Evidence of the influence of background music on memory is debated and, again, depends on several factors (Schellenberg & Weiss, 2013; see also Kämpfe et al., 2011, for a meta-analysis on the effects of background music on cognitive functions). A systematic review of this specific research domain is complicated by the fact that studies on background music often fail to report exact stimuli details (e.g., which music was used, which features, at which intensity level, etc.).

Background music can be defined as the act of music being played when the music itself is not the main focus of attention (Hallam, 2012). In this scenario, music could provide a particularly helpful encoding context likely to improve subsequent memory performance. Indeed, it has been extensively demonstrated that a rich context enhances the encoding of contextual information associated with novel items that need to be encoded (Hamann, 2001; Lövdén, Rönnlund, & Nilsson, 2002). The same context subsequently can be used as a mnemonic cue during retrieval, facilitating access to a target item. Examples of enriched (non-musical) contexts are represented by enacted encoding (i.e., using real objects corresponding to nouns, Lövdén et al., 2002) or by emotional stimuli (Hamann, 2001). In both cases, the context at encoding enhances memory retrieval. In this sense, background music that evolves over time and has a strong emotional impact (Salimpoor et al., 2013) may represent a perfect example of an enriched context that facilitates memory encoding and retrieval.

This hypothesis has been pursued in several studies. Smith (1985) was the first to successfully demonstrate that the presence of background music (Mozart's Concerto No. 24 in C Minor for Piano and Orchestra and "People Make the World Go Around," a Milt Jackson's jazz piece) during word encoding and retrieval facilitates

memory. These results were not found for a white-noise control condition, thus supporting the existence of music-dependent verbal memory (Balch & Lewis, 1996; Balch, Bowman, & Mohler, 1992). However, several studies failed to replicate this positive result, and have instead reported a disruptive effect of background music on serial recall (Nittono, 1997), phonological short-term memory (Salamé & Baddeley, 1989), and on the processing of verbal and spatial memories (Iwanaga & Ito, 2002).

A positive influence of music has also been shown in several studies on second language (L2) learning. For example, de Groot (2006) used a “paired associated learning” protocol to present participants with pairs of stimuli (word in the first language—Dutch—paired with L2 translations—pseudo words), while listening to the Brandenburg Concerto by J. S. Bach as background music or with a silent background. de Groot found that learning with a musical background, compared to a silent background, significantly improved L2 word learning. However, this effect emerged slowly and only in a subgroup of participants. de Groot discusses the possibility that this result relates to personal characteristics of the participants, namely their personality traits: While extroverts achieve optimal performance at high levels of stimulation (i.e., heightened arousal), introverts tend to work optimally at low stimulation levels. Accordingly, extroverts are likely to benefit more from the musical background as compared to introverts. This interpretation is in line with the “arousal and mood hypothesis” (Schellenberg & Peretz, 2007; Thompson, Schellenberg, & Husain, 2001) and with studies on extroverts/introverts cognitive performance in music conditions (Cassidy & MacDonald, 2007; Furnham & Bradley, 1997; Furnham & Strbac, 2002). In the realm of language learning, a recent study by Kang and Williamson (2013) suggests that the impact of music on learning may depend on the characteristics of the language to be learned (in this specific case: tonal versus non-tonal). English speakers significantly benefited from the presence of background music while learning Chinese Mandarin—a tonal language. Contrarily, no such effect was found for a non-tonal language such as Arabic. However, in this study, the learning material was represented by commercially available language learning CDs. The course had a duration of two weeks, during which participants learned both single words as well as sentences, but no distinction between these aspects was specified. Hence, it is unclear which aspect of learning was facilitated during the experiment (e.g., semantics or grammar; Kang & Williamson, 2013). A crucial difference between the type of background music used in these

studies (de Groot, 2006; Kang & Williamson, 2013) must be pointed out: While de Groot used a Bach piece, newly composed tunes were employed in the study by Kang and Williamson. More specifically, these tunes were described as medium tempo melodies with low dynamics, minimal instrumentation, and few changes to tempo, rhythm, and amplitude. The question thus arises, whether the type of background music a learner may be exposed to influences the results more than the type of language. However, this would still not explain why in the Kang and Williamson’s study, where the same background music was used for both languages, a facilitatory effect was only found for participants learning Chinese Mandarin. The authors’ suggestion that this difference may relate to the specific characteristics of the language (tonal or non-tonal) has not been directly explored. Hence, further investigation is required.

A series of behavioral and electrophysiological studies by Jäncke and colleagues devoted particular attention to the type of background music participants used (Jäncke, Brügger, Brummer, Scherrer, & Alahmadi, 2014; Jäncke & Sandmann, 2010). In a first study, the authors investigated the effect of background music on German native speakers learning pseudo-word lists. When using novel music that had been carefully controlled for emotion, complexity, tempo, and associated semantic knowledge, no behavioral effects were found. However, an increase in desynchronization was found in an attentional fronto-parietal network around 400–800 ms after word presentation for in-tune and fast music (Jäncke & Sandmann, 2010; see also François & Schön, 2014, for a review).

According to the authors, when fast music is played in the background, the fronto-parietal network may employ greater cortical resources to learn verbal material. However, this activation increase may have been too small to be measured at the behavioral level. As an alternative explanation, the in-tune fast music possibly represented the most distracting condition for the participants, attracting attention away from the relevant information to remember. In turn, this would reduce the available attentional resources for verbal material. However, if so, a negative—rather than null—effect should have been found in the music condition. Once again, these results underline the difficulty in interpreting music-related functional results when not supported by behavioral effects. To clarify whether the lack of a beneficial effect was due to the type of background music, in a follow-up study, modern music pieces were selected from radio hits. These were of four different types: vocal music experienced with high intensity, vocal

music with low intensity, instrumental music with low intensity, and instrumental music with high intensity. There was also a silent control condition. This background music was played while participants performed the same verbal learning task as in the previous study (i.e., learning word lists). However, once again the authors failed to identify any effect of music as compared to the control condition on both immediate and delayed recall tests (Jäncke et al., 2014).

In a recent series of fNIRS (functional near-infrared spectroscopy) studies, a different conclusion has been reached, supporting the idea that music creates a facilitatory context. These studies have shown that background music—compared to a silent background—played during the encoding phase significantly improves behavioral performance in item and source memory, respectively, in healthy young (Ferreri, Aucoeur, Muthalib, Bigand, & Bugajska, 2013) and older adults (Ferreri et al., 2014), while decreasing prefrontal cortex (PFC) activation. In these studies, the acoustic jazz piece *If You See My Mother* by Sidney Bechet was chosen for its positive valence and medium arousal quality. However, an explanation of the results based on attention or arousal may be excluded based on the observed activation pattern. While the authors observed reduced PFC activation during the task, several other fNIRS studies have shown that alertness or attentional states significantly increase PFC activation (Ehli, Bähne, Jacob, Herrmann, & Fallgatter, 2008). A plausible explanation for this pattern of PFC activations is that the musical context modulates encoding in a state-dependent manner, enabling the creation of inter-item and item-source binding, an efficient mnemonic strategy (Ferreri, Bigand, & Bugajska, 2015). As such, less PFC activity is required to form these efficient associations. It is therefore possible that the presence of background music facilitates association of items, consequently boosting verbal encoding and subsequent retrieval. This interpretation is in agreement with studies showing that music is able to increase chunking during word retrieval (Ferreri, Bigand, Bard, & Bugajska, 2015; McElhinney & Annett, 1996).

While focusing on the effects of background music during encoding of verbal material has led to conflicting results, it has been shown that music presented during the consolidation phase of newly acquired items is associated with significant improvement in recognition (e.g., Judde & Rickard, 2010). Judde and Rickard presented participants with background music (either Beethoven's Symphony No. 6 or Modest Mussorgsky's *A Night on the Bare Mountain*) in a temporal window either immediately after stimulus presentation, 20 min post-stimulus presentation, or 45 min post-stimulus presentation.

They found that music enhanced long-term (1 week) recognition of word lists previously presented only when presented 20 minutes after the learning session. According to the authors, this suggests that memory modulation is time-dependent, with facilitatory emotional arousal effects having a maximal impact around 25 min post-learning (see also Balch et al., 1992).

How Does Music Boost Verbal Learning and Memory?

A contemporary memory theory suggests that several factors are crucial for successful encoding and subsequent retrieval of information. These factors can be internal, such as motivation, strategies, or prior knowledge, or external, such as the material to be learned, the encoding context, or the experimental instructions (see Brown & Craik, 2000, for a review). As an example of an internal factor, it is well-known that a level of processing manipulation leads to differences in memory performance (Craik & Tulving, 1975). In this paradigm, a deep level of processing during the encoding of verbal information, such as semantic processing (e.g., “judge if the presented words are animals”) leads to better memory performance than more shallow processing such as orthographic or phonological processing (e.g., “judge if the presented words contain the ‘e’ vowel”). For the external factors, the nature of to-be-learned material is examined (e.g., verbal materials: digits, letters, words, sentences, etc., or non-verbal materials: pictures, faces, sounds, odors, etc.). Also, the modality of presentation (e.g., visual, auditory) has been shown to strongly influence subsequent memory performance (e.g., Engelkamp & Zimmer, 1984).

Music can be thought of as a stimulus that can influence both internal and external factors; it has often been employed in memory research as a form of cognitive stimulation to boost memory and learning or to alter mood. For example, studies on proactive interference showed how musical stimuli can be employed to manipulate a participant's mood during encoding and retrieval. This type of manipulation is used to elicit depressive states or increase arousal level, which may affect subsequent memory performance (Eich, 1995; see also Brown & Craik, 2000). Such studies that treat music as a factor in memory research can therefore inform our thinking about the processes involved in musical facilitation of memory. The main goals of this section are to: 1) summarize the mechanisms proposed in the most relevant studies on music and verbal learning and memory, and 2) propose how these mechanisms may be involved differently in the paradigms previously described.

WHICH MECHANISMS?

The literature reviewed above provides evidence for several mechanisms involved in verbal learning and memory in music conditions. First, music can provide a temporal scaffolding framework that supports sequence learning. In this view, melodic and rhythmic properties of music may provide a template that drives the formation of an internal rhythm in cortical networks involved in learning and memory (Thaut et al., 2005). More specifically, it is hypothesized that sounds may create a cognitive structure able to support learning by facilitating the processing and interpretation of sequential and multi-modal information in the environment (Conway, Pisoni, & Kronenberger, 2009; Tillmann, 2012). This explanation is in line with a general theoretical framework, the Dynamic Attending Theory (Jones, 1976; Jones & Boltz, 1989). According to this framework, the temporal structure of an event—such as temporal accents in music—entrains oscillations in attention over time. These oscillations support structural and temporal integration of information. Events presenting regularly accented structures should yield better performance in both perceptual and memory tasks because they direct attention towards relevant points in time (Boltz & Jones, 1986; Jones, Summerell, & Marshburn, 1987). Interestingly, several studies have shown the crucial role that timing of metric stress and temporal regularities plays in language segmentation and syntactic processing (Cutler, 1994; Hoch, Tyler, & Tillmann, 2013; Schmidt-Kassow & Kotz, 2008, 2009), suggesting that Jones' theory of dynamic attending can also be applied in the language domain. It is therefore possible that a music-related temporal scaffolding can be superimposed and integrated with verbal material. In particular, temporal regularities may drive participants' attention to the verbal information to encode, thus facilitating learning and memory tasks.

Other mechanisms have been proposed to play a crucial role in music-driven facilitation. For example, the arousal and mood hypothesis (Thompson et al., 2001) states that the positive effect of music on cognitive abilities can be attributed to changes in listeners' arousal or mood (also see Schellenberg & Peretz, 2007). Indeed, several studies have confirmed how the modulations of participants' arousal (i.e., via variations of musical tempo) and mood (i.e., with mode-major, minor-variations) can strongly influence participants' cognitive performance during spatial tasks or on IQ subtests (Schellenberg, 2005, 2006, 2012).

The highlighted link between music and mood leads to another crucial point, namely the role played by music-related emotional responses. Emotion and

learning share a strong and well-established relationship (see Christianson, 2014, for a comprehensive overview). As reviewed by Hamann (2001), findings from neuroimaging, neuropsychological, drug, and neural stimulation studies have underlined that stimuli with emotional valence—such as music—can enhance memory of verbal and visual stimuli by engaging specific cognitive and neural mechanisms during both memory encoding and consolidation processes. Indeed, several functional neuroimaging studies have shown that music modulates activity in brain structures crucially involved in emotions, such as the amygdala, the nucleus accumbens, hypothalamus, hippocampus, insula, cingulate cortex, and orbitofrontal cortex (see Koelsch, 2014, for a review). Therefore, it is reasonable to believe that music-related emotional responses could play a crucial role in enhancing memory and learning processes.

Finally, music is likely to activate the reward system by virtue of its powerful emotional properties (Blood & Zatorre, 2001), in turn facilitating a variety of verbal mnemonic tasks because of the role played by reward circuits during learning. Indeed, a pleasant music experience is often accompanied by activity in the mesolimbic reward system (Blood & Zatorre, 2001; Salimpoor et al., 2013). Activation in this system is thought to precede memory formation during reward-motivated learning (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006). Of course, depending on musical preferences, individual differences may explain the huge variability in behavioral results (see e.g., de Groot, 2006). For example, recent findings have pointed out that not only do different pleasurable responses to music exist among the general population, but also that—as in the case of musical anhedonics—there are listeners who do not experience any pleasure in response to music stimulation (Mas-Herrero, Marco-Pallares, Lorenzo-Seva, Zatorre, & Rodriguez-Fornells, 2013; Mas-Herrero, Zatorre, Rodriguez-Fornells, & Marco-Pallarés, 2014). Therefore, if the reward system activation explains memory and learning improvement through music, inter-individual differences in music-related reward responses can, at least in part, explain the learning outcome differences observed across participants. However, to the best of our knowledge, none of the studies reviewed so far have explored this aspect, and further investigation is needed to understand to which extent music-related reward system activations are involved in memory and learning processes.

HOW COULD THESE MECHANISMS INTERACT?

The above-mentioned mechanisms represent viable candidates to describe the positive effect that music has

on verbal learning and memory. It is therefore crucial to gain a deeper understanding of how these mechanisms act to induce music-related improvements. This would be particularly important for music-based rehabilitation programs, specifically for patients suffering from verbal memory and learning deficits. However, to the best of our knowledge, no model currently exists that aims to combine these mechanisms and unravel their involvement in the equivocal results in the music and memory literature. Considering music as a highly complex stimulus that engages the whole brain through a diverse set of perceptive and cognitive functions (Altenmüller, 2001), we propose that the explained mechanisms are not mutually exclusive, but rather coexist during music-related memory and learning processes. However, we suggest that the extent to which a given mechanism is recruited critically depends upon the complexity of musical stimuli, and involves aspects such as tempo, mode, arousal, and length.

The reviewed studies seem to suggest that the huge variability of results may arise from different experimental settings. For example, the less musical stimuli are controlled (i.e., the more musical parameters such as tempo and mode are modulated), the larger the effect of music is. Positive effects are found using complex music: Bach (de Groot, 2006), Beethoven (Judde & Rickard, 2010), Bechet (Ferreri et al., 2013; Ferreri et al., 2014). In contrast, negative effects are found using experimentally balanced music stimuli (Jäncke & Sandmann, 2010; Kang & Williamson, 2013; Verga, Bigand, & Kotz, 2015; for an exception see Jäncke et al., 2014). Indeed, more complex and ecologically valid music stimuli might have greater impact than more controlled ad hoc stimuli created to support the experimental requirements. For example, Tillmann and colleagues (2013) elegantly demonstrated this evidence by testing recognition memory for details of musical phrases. The authors found that recognition memory was significantly better for expressive pieces as compared to “mechanical” MIDI stimuli. Because “artificial” music stimuli are usually controlled for variables such as tempo and mode, they often tend to be more uniform and plain, with less variety, as compared to more expressive musical pieces. This may explain why experiments in which musical stimuli are usually complex and less controlled, provide consistent evidence of positive effects on verbal memory (e.g., Jäncke et al., 2014).

We propose that different types of musical stimuli may improve verbal memory and learning performance by acting directly on the verbal material to encode, as well as by activating more general-purpose mechanisms (Figure 1). First, temporal mechanisms (i.e., temporal

scaffolding) may assist verbal encoding by attracting and driving participants’ attention to the relevant information to be remembered when the stimuli are simple enough to allow identification of clear temporal patterns aligned in music and language (e.g., statistical learning). In this case, temporal scaffolding mechanisms allow direct anchoring between words and musical stimulus, in line with the Dynamic Attending Theory (Jones, 1976), thus focusing the participant’s attention. In this case, it is likely that the simpler the musical stimuli, the easier it is to align them with the linguistic stimuli. This would be the case for paradigms using sung versus spoken verbal material, where stimuli such as simple tones, rhythms, and melodies temporally align with the verbal stimuli. In support, in the majority of such tasks, music has been shown to improve memory and learning performance (see Table 1 for a summary). Instead, in more complex paradigms, the presence of two non-matching temporal structures may create a dual-task, divided attention situation that interferes with attentional processes (Jäncke, 2008; Jäncke et al., 2014). In other words, when more complex musical stimuli (e.g., classical or jazz pieces) are employed, a one-to-one correspondence between the temporal structure of musical and verbal material is less likely to occur. This mismatch does not allow attention to be directed to a particular point in time, resulting in poorer memory performance. This is the case, for example, in paradigms employing music as a background stimulus, where an account based on temporal regularities may instead predict that background music can draw a participant’s attention away from the relevant information to be remembered. However, it does not explain why several studies report an enhancement of memory when exposed to background music.

It is likely that other mechanisms are recruited when handling more complex music stimuli. In particular, a Beethoven or Bach piece has a greater impact on the arousal and/or emotional system compared to simple tones or melodies created in a laboratory. Therefore, it is likely that more ecological excerpts lead to thoughts and feelings that can be then associated with the verbal material. As such, the music-related effect on verbal material would derive from associative strategies that trigger semantic binding, likely to help subsequent retrieval (Daltrozzo & Schön, 2009a, 2009b; Ferreri et al., 2013, 2014). Similarly, expressive-ecological stimuli other than laboratory-mechanical controlled pieces may stimulate encoding and subsequent retrieval of verbal information mainly by relying on general-purpose mechanisms, such as the arousal level, or by modulating systems involved in emotions, mood, and possibly reward.

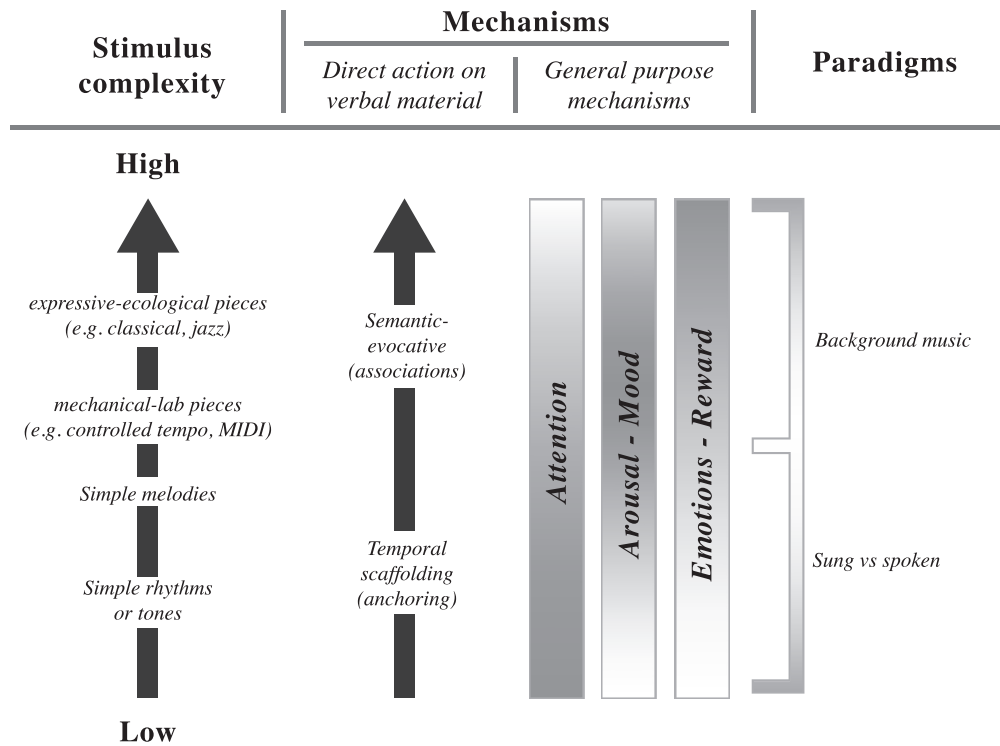


FIGURE 1. Proposition of a model explaining the effect of music on verbal learning and memory. The model postulates the implication of several cognitive mechanisms exerting either a direct action on verbal material (i.e., from semantic-evocative associations to temporal scaffolding), or an indirect action via general-purpose processes (i.e., attention, arousal-mood, emotions-reward; center of the figure). The impact of these mechanisms on verbal material (expressed by the direction of the arrows and by color gradient, with higher intensity representing greater impact) varies according to stimulus complexity (left side: from low to high complexity stimuli) and experimental paradigm (right side: sung versus spoken and background music).

It is worth noting that this proposition does not account for music familiarity, which can modulate music effects on memory and learning performance. It would, therefore, be interesting to test the extent to which the interpretation model proposed here is able to predict different results according to the familiarity of the stimulus. For example, it is possible that a simple non-familiar stimulus employed in sung versus spoken paradigms would require greater attentional demand and interfere with anchoring processing, thus hindering memory performance. This would, for example, explain results showing that AD patients are better at memorizing a sung text if the melody is familiar (Moussard et al., 2012). On the contrary, according to the model, a complex non-familiar stimulus used in background music paradigms would not influence the activation of emotional, reward, and arousal mechanisms. It may, therefore, help to create new associative memories, thereby improving subsequent item retrieval (e.g., De Groot, 2006; Ferreri et al., 2013; Ferreri et al., 2014).

Finally, it is also important to note that the model in Figure 1 aims to interpret the different and contrasting

results according to stimulus complexity and related involved mechanisms. However, further investigation is needed to test such explanation, as also discussed in the next section.

From Observations to Further Research

We have reviewed studies that employed music in the form of sung stimuli, usually contrasted with spoken stimuli, as well as studies that employed different kinds of background music. The evidence collected by these studies raises some important points, which may be summarized as follows: (1) Although behavioral paradigms can fail to demonstrate a reliable effect of music on memory and learning performance, music encoding is nonetheless reliably associated with specific neurophysiological responses, which emerge when neuroimaging techniques are employed. (2) Similarly, it is possible to fail to find a short-term behavioral benefit of music, but to show long-term effects of music after a retention interval, thus supporting the idea that music produces a long-term effect on memory traces. (3)

Inconsistencies in the use of stimuli in the learning phase and testing phase (e.g., sung-spoken) may hide positive effects due to music. (4) Clinical populations show more consistent effects than healthy populations. The reason behind this observation is so far unclear. It is possible that music capitalizes on functions spared by certain diseases (for example, in aphasia or AD). (5) Differences in results may stem from inter-individual differences, related for example to personality traits (e.g., introversion vs. extroversion), as well as from stimuli characteristics (e.g., familiarity or complexity).

Taken together, these observations provide a complex picture, in which methodological aspects play a crucial role, and suggest several considerations for future lines of research. In general, the interpretation of existing findings would benefit from more precise information concerning the characteristics of the employed musical stimuli (genre, emotional valence, arousal scores, pleasantness, and familiarity) and of the participants (musical expertise, personality traits such as extroversion, musical hedonia, and abilities in music perception/production). This would not only allow the replication of existing studies, but also identify similarities and differences across studies investigating the same phenomena. Specific attention to the musical stimuli may also help to investigate and disentangle which subcomponent of music specifically impacts learning (e.g., melody, rhythm). A first step would be to directly compare elements suggested to play a role, such as melody and rhythm, in the same experiment under controlled conditions. The null findings on behavioral measures, especially when compared to imaging and electrophysiological indexes, suggests that behavioral measures may be—in some instances—not powerful enough to detect music-related memory and learning effects (Francois & Schön, 2010; Jäncke & Sandmann, 2010; Peterson & Thaut, 2007).

This suggests that using measures of brain function may be critical in research into the effect of music on memory. However, the presence of behavioral outcomes is critical for the employment of music in the clinical domain. Moreover, brain responses not related to behavioral outcomes could be due to the presence of music per se rather than to music-guided memory and learning processes. In our opinion, this underlines the need of more precise control conditions (e.g., with passive exposure to background music without memory tasks) as well as a greater variety of tests for memory and learning performance. That is, the employment of several behavioral measures (e.g., episodic testing—through source or remember/know paradigms—or chunking, see Brown & Craik, 2000), rather than only

one form of test (such as free recall or recognition), may help to obtain a reliable and specific behavioral effect. This will also help to understand which memory processes (e.g., familiarity or recollection) are specifically modulated by music.

Considering the observed differences according to the duration of the retention time, experimental paradigms would benefit from different testing phases that investigate long-term memory performance several days after the encoding phase. Another crucial parameter to investigate would be the consistency between the learning and the testing phase. For example, in sung vs. spoken paradigms, it would be important to create an experimental design in which all possible combinations of the learning and testing modality can be compared directly (e.g., music-music, music-spoken, spoken-music, spoken-spoken). If consistency between the learning and testing modality is a relevant factor for music-related mnemonic processes, we would expect participants to learn and remember more items when they are being tested in the same modality used for learning. This would explain why several studies that employ different learning and testing modalities fail to identify a positive effect of music.

Earlier we suggested that by working directly on verbal material as well as via more general-purpose mechanisms, each process may intervene differently according to the stimulus complexity and paradigm employed. However, further studies are undoubtedly needed to investigate this explanation in depth. A possible way to test the effect of stimulus complexity on verbal learning and memory would be to employ the same learning/memory paradigm (same verbal material, same type of learning phase, retrieval, etc.) with musical stimuli of different complexity. For example, the range of stimuli could extend from simple, regular tone sequences to laboratory-mechanical music to complex stimuli, such as a Bach piece. In relation to the type of verbal material employed, we would expect different outcomes for each music condition, based on our model. Simple verbal stimuli, possibly aligned with the temporal structure of the underlying sound, would gain maximum benefit from simple tone sequences or mechanical stimuli, in which the temporal structure can be aligned to the words. More complex stimuli, such as text, would benefit more from complex, naturalistic music stimuli, in virtue of their ability to stimulate emotions, reward, and mood and their evocative power. Furthermore, by systematically manipulating factors known to recruit such mechanisms, a more in-depth understanding of how the aforementioned general-purpose mechanisms operate in music experiments may be achieved.

One possibility is to consider testing special populations such as musical anhedonic subjects (Mas-Herrero et al., 2013, 2014). Testing such people or employing musical stimuli that elicit different reward responses in memory and learning tasks would help us to understand the extent to which the reward system is responsible for music-related memory and learning facilitation. A possible way to test the relation between reward responses, semantic-associative mechanisms, and complex material would be to use simple and complex background music and subsequently test memory performance (e.g., chunking mechanisms) in both musical hedonics and anhedonics. According to our proposed model, an improvement in memory, and particularly increased associative mechanisms, is to be expected for a more complex musical background. This pattern would not be found in the musical anhedonic population: who would lack the required emotional or rewarding response to music to generate such a beneficial effect on memory function. If such experiments were carried out in alongside imaging techniques, we could verify that the type of music used invoked the proposed neural mechanisms related to reward, emotion and arousal (e.g., reward/emotions for background music, areas related to temporal processing, such as the superior temporal gyrus; for simple temporal stimuli and reward areas that belong to the mesolimbic pathway for more complex music stimuli).

Concluding Remarks

In the current review, we summarized the most influential literature on the effects of music on verbal learning and memory. The variety of paradigms and stimuli employed in the studies analyzed makes it difficult to identify which subcomponent in music affects specific forms of learning or memory. However, several key points are highlighted. First, because of the complexity of music as a stimulus, it is possible that several mechanisms (both general-purpose and domain-specific) work simultaneously. More specifically, we propose that music may function as: 1) a temporal scaffolding in which stimulus regularities may selectively attract attention and reinforce and facilitate verbal learning and memory, 2) an enhancer of arousal and mood, and 3) an enhancer of emotional responses that influence the reward system. While these effects may be

concurrently present in several tasks, a predominance of one or the other may be dependent on the specifics of the stimuli employed, such as the predominance of predictable temporal regularities or the modulation of music parameters (e.g., tempo, mode, arousal, etc.). Second, depending on the type of experiment, behavioral measures may not be powerful enough to capture music-related effects. For this reason, a more comprehensive approach should also include more sensitive measures, such as those provided by imaging methods such as EEG, fNIRS, and functional magnetic resonance imaging (fMRI). A combination of behavioral and imaging methods would inform us not only of the effects of music, but also the mechanisms through which such effects are produced. Finally, the studies reviewed here show considerable variability in results. It is of great importance for music research to report the type of stimuli employed with accuracy. This would help improve existing knowledge of music-related benefits for verbal learning and memory, thus leading to more specific and efficacious music-based neuro-rehabilitative interventions.

Author Note

The authors contributed to this work equally.

LF and LV were supported by the European Community's Seventh Framework Program under the EBRA-MUS project (grant agreement no. 238157). LF was supported by the Morelli-Rotary Foundation fellowship. The authors would like to thank Emmanuel Bigand, Sonja Kotz, and Barbara Tillmann for their valuable feedback and insightful comments in every step of the manuscript preparation. Their constant support greatly contributed to the final version. The authors are also grateful to Irene Alonso-Fernandez, Tatiana Selchenkova, Shameem Wagner, and Chris Moulin for helpful comments and edits on previous versions of this manuscript. The authors additionally thank Grazia Fino for her help with the model figure.

Correspondence concerning this article should be addressed to Laura Ferreri, Cognition & Brain Plasticity Unit, C/ Feixa Llarga, s/n - Pavelló de Govern - Edifici Modular 08907 L'Hospitalet de Llobregat, Barcelona, Spain. E-mail laura.ferreri@ub.edu or Laura Verga, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, 04103, Leipzig, Germany. E-mail verga@cbs.mpg.de

References

- ADCOCK, R. A., THANGAVEL, A., WHITFIELD-GABRIELI, S., KNUTSON, B., & GABRIELI, J. D. (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. *Neuron*, *50*(3), 507-517.
- ALTENMÜLLER, E. (2001). How many music centers are in the brain? *Annals of the New York Academy of Sciences*, *930*(1), 273-280.
- ALTENMÜLLER, E., & SCHLAUG, G. (2013). Neurobiological aspects of neurologic music therapy. *Music and Medicine*, *5*(4), 210-216.
- BALCH, W. R., BOWMAN, K., & MOHLER, L. A. (1992). Music-dependent memory in immediate and delayed word recall. *Memory and Cognition*, *20*(1), 21-28.
- BALCH, W. R., & LEWIS, B. S. (1996). Music-dependent memory: The roles of tempo change and mood mediation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(6), 1354-1363.
- BESSON, M., & SCHÖN, D. (2001). Comparison between language and music. *Annals of the New York Academy of Sciences*, *930*(1), 232-258.
- BLOOD, A. J., & ZATORRE, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences USA*, *98*, 11818-11823.
- BOLTZ, M., & JONES, M. R. (1986). Does rule recursion make melodies easier to reproduce? If not, what does? *Cognitive Psychology*, *18*(4), 389-431.
- BROWN, S. C., & CRAIK, F. I. (2000). Encoding and retrieval of information. In E. Tulving & F. Craik (Eds.), *The Oxford handbook of memory* (pp. 93-107). New York: Oxford University Press.
- CASSIDY, G., & MACDONALD, R. A. R. (2007). The effect of background music and background noise on the task performance of introverts and extraverts. *Psychology of Music*, *35*(3), 517-537. DOI: 10.1177/0305735607076444
- CHRISTIANSON, S.-A. (2014). *The handbook of emotion and memory: Research and theory*. New York: Psychology Press.
- CONWAY, C. M., PISONI, D. B., & KRONENBERGER, W. G. (2009). The importance of sound for cognitive sequencing abilities: the auditory scaffolding hypothesis. *Current Directions in Psychological Science*, *18*(5), 275-279.
- CRAIK, F. I. M., & TULVING, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, *104*(3), 268-294.
- CUTLER, A. (1994). Segmentation problems, rhythmic solutions. *Lingua*, *92*, 81-104.
- DALTROZZO, J., & SCHÖN, D. (2009a). Conceptual processing in music as revealed by N400 effects on words and musical targets. *Journal of Cognitive Neuroscience*, *21*(10), 1882-1892.
- DALTROZZO, J., & SCHÖN, D. (2009b). Is conceptual processing in music automatic? An electrophysiological approach. *Brain Research*, *1270*, 88-94.
- DE GROOT, A. (2006). Effects of stimulus characteristics and background music on foreign language vocabulary learning and forgetting. *Language Learning*, *56*(3), 463-506.
- DE L'ETOILE, S. K. (2010). Neurologic music therapy. *Music and Medicine*, *2*(2), 78-84.
- ENGELKAMP, J., & ZIMMER, H. D. (1984). Motor programme information as a separable memory unit. *Psychological Research*, *46*, 283-299. DOI: 10.1007/BF00308889
- EHLIS, A.-C., BÄHNE, C. G., JACOB, C. P., HERRMANN, M. J., & FALLGATTER, A. J. (2008). Reduced lateral prefrontal activation in adult patients with attention-deficit/hyperactivity disorder (ADHD) during a working memory task: A functional near-infrared spectroscopy (fNIRS) study. *Journal of Psychiatric Research*, *42*(13), 1060-1067.
- EICH, E. (1995). Mood as a mediator of place dependent memory. *Journal of Experimental Psychology: General*, *124*(3), 293-308.
- FERRERI, L., AUCOUTURIER, J.-J., MUTHALIB, M., BIGAND, E., & BUGAJSKA, A. (2013). Music improves verbal memory encoding while decreasing prefrontal cortex activity: An fNIRS study. *Frontiers in Human Neuroscience*, *7*.
- FERRERI, L., BIGAND, E., BARD, P., & BUGAJSKA, A. (2015). The influence of music on prefrontal cortex during episodic encoding and retrieval of verbal information: A multi-channel fNIRS study. *Behavioural Neurology*, *501*, article ID 707625.
- FERRERI, L., BIGAND, E., & BUGAJSKA, A. (2015). The positive effect of music on source memory. *Musicae Scientiae*, *19*(4), 402-411.
- FERRERI, L., BIGAND, E., PERREY, S., MUTHALIB, M., BARD, P., & BUGAJSKA, A. (2014). Less effort, better results: How does music act on prefrontal cortex in older adults during verbal encoding? An fNIRS study. *Frontiers in Human Neuroscience*, *8*.
- FRANÇOIS, C., & SCHÖN, D. (2010). Learning of musical and linguistic structures: Comparing event-related potentials and behaviour. *NeuroReport*, *21*(14), 928-932. DOI: 10.1097/WNR.0b013e32833ddd5e
- FRANÇOIS, C., & SCHÖN, D. (2013). Neural sensitivity to statistical regularities as a fundamental biological process that underlies auditory learning: the role of musical practice. *Hearing Research*, *308*, 122-128.
- FRANÇOIS, C., & SCHÖN, D. (2014). Neural sensitivity to statistical regularities as a fundamental biological process that underlies auditory learning: The role of musical practice. *Hearing Research*, *308*, 122-128.

- FURNHAM, A., & BRADLEY, A. (1997). Music while you work: The differential distraction of background music on the cognitive test performance of introverts and extraverts. *Applied Cognitive Psychology*, 11(5), 445-455.
- FURNHAM, A., & STRBAC, L. (2002). Music is as distracting as noise: The differential distraction of background music and noise on the cognitive test performance of introverts and extraverts. *Ergonomics*, 45(3), 203-217.
- HALLAM, S. (2012). The effects of background music on health and wellbeing. In R. Macdonald, G. Kreutz & L. Mitchell (Eds.), *Music, health and wellbeing* (pp. 491-501). Oxford: Oxford University Press.
- HAMANN, S. (2001). Cognitive and neural mechanisms of emotional memory. *Trends in Cognitive Sciences*, 5(9), 394-400.
- HERHOLZ, S. C., & ZATORRE, R. J. (2012). Musical training as a framework for brain plasticity: Behavior, function, and structure. *Neuron*, 76(3), 486-502.
- HILLECKE, T., NICKEL, A., & BOLAY, H. V. (2005). Scientific perspectives on music therapy. *Annals of the New York Academy of Sciences*, 1060(1), 271-282.
- HOCH, L., TYLER, M. D., & TILLMANN, B. (2013). Regularity of unit length boosts statistical learning in verbal and nonverbal artificial languages. *Psychonomic Bulletin and Review*, 20(1), 142-147.
- HURKMANS, J., DE BRUIJN, M., BOONSTRA, A. M., JONKERS, R., BASTIAANSE, R., ARENDZEN, H., & REINDERS-MESSELINK, H. A. (2011). Music in the treatment of neurological language and speech disorders: A systematic review. *Aphasiology*, 1-19. DOI: 10.1080/02687038.2011.602514
- IWANAGA, M., & ITO, T. (2002). Disturbance effect of music on processing of verbal and spatial memories. *Perceptual and Motor Skills*, 94(3c), 1251-1258.
- JÄNCKE, L. (2008). Music, memory and emotion. *Journal of Biology*, 7(21). DOI: 10.1186/jbiol82
- JÄNCKE, L., BRÜGGER, E., BRUMMER, M., SCHERRER, S., & ALAHMADI, N. (2014). Verbal learning in the context of background music: No influence of vocals and instrumentals on verbal learning. *Behavioural and Brain Functions*, 10(1): 1-7.
- JÄNCKE, L., & SANDMANN, P. (2010). Music listening while you learn: No influence of background music on verbal learning. *Behavioural and Brain Functions*, 6(1): 1-14. DOI: 10.1186/1744-9081-6-3
- JONES, M. R. (1976). Time, our lost dimension: Toward a new theory of perception, attention, and memory. *Psychological Review*, 83(5), 323-355.
- JONES, M. R., & BOLTZ, M. (1989). Dynamic attending and responses to time. *Psychological Review*, 96(3), 459-491.
- JONES, M. R., SUMMERELL, L., & MARSHBURN, E. (1987). Recognizing melodies: A dynamic interpretation. *Quarterly Journal of Experimental Psychology*, 39(1), 89-121.
- JUDDE, S., & RICKARD, N. (2010). The effect of post-learning presentation of music on long-term word-list retention. *Neurobiology of Learning and Memory*, 94(1), 13-20. DOI: 10.1016/j.nlm.2010.03.002
- KÄMPFE, J., SEDLMEIER, P., & RENKEWITZ, F. (2011). The impact of background music on adult listeners: A meta-analysis. *Psychology of Music*, 39(4), 424-448.
- KANG, H. J., & WILLIAMSON, V. J. (2013). Background music can aid second language learning. *Psychology of Music*, 42, 728-747. DOI: 10.1177/0305735613485152
- KILGOUR, A. R., JAKOBSON, L. S., & CUDDY, L. L. (2000). Music training and rate of presentation as mediators of text and song recall. *Memory and Cognition*, 28(5), 700-710.
- KOELSCH, S. (2009). A neuroscientific perspective on music therapy. *The Neurosciences and Music III: Disorders and Plasticity*, 1169, 374-384.
- KOELSCH, S. (2014). Brain correlates of music-evoked emotions. *Nature Reviews Neuroscience*, 15(3), 170-180.
- LÖVDÉN, M., RÖNNLUND, M., & NILSSON, L.-G. (2002). Remembering and knowing in adulthood: effects of enacted encoding and relations to processing speed. *Aging, Neuropsychology, and Cognition*, 9(3), 184-200.
- LUDKE, K. M., FERREIRA, F., & OVERY, K. (2014). Singing can facilitate foreign language learning. *Memory and Cognition*, 42(1), 41-52.
- MAS-HERRERO, E., MARCO-PALLARES, J., LORENZO-SEVA, U., ZATORRE, R. J., & RODRIGUEZ-FORNELLS, A. (2013). Individual differences in music reward experiences. *Music Perception*, 31, 118-138.
- MAS-HERRERO, E., ZATORRE, R. J., RODRIGUEZ-FORNELLS, A., & MARCO-PALLARÉS, J. (2014). Dissociation between musical and monetary reward responses in specific musical anhedonia. *Current Biology*, 24(6), 699-704.
- MC ELHINNEY, M., & ANNETT, J. M. (1996). Pattern of efficacy of a musical mnemonic on recall of familiar words over several presentations. *Perceptual and Motor Skills*, 82(2), 395-400.
- MOUSSARD, A., BIGAND, E., BELLEVILLE, S., & PERETZ, I. (2012). Music as an aid to learn new verbal information in Alzheimer's disease. *Music Perception*, 29, 521-531. DOI: 10.1525/mp.2012.29.5.521
- NITTONO, H. (1997). Background instrumental music and serial recall. *Perceptual and Motor Skills*, 84(3 Pt 2), 1307-1313. DOI: 10.2466/pms.1997.84.3c.1307
- PETERSON, D. A., & THAUT, M. H. (2007). Music increases frontal EEG coherence during verbal learning. *Neuroscience Letters*, 412(3), 217-221.
- RACETTE, A., BARD, C., & PERETZ, I. (2006). Making non-fluent aphasics speak: sing along! *Brain*, 129(10), 2571-2584.
- RACETTE, A., & PERETZ, I. (2007). Learning lyrics: To sing or not to sing? *Memory and Cognition*, 35(2), 242-253.

- RAINEY, D. W., & LARSEN, J. D. (2002). The effect of familiar melodies on initial learning and long-term memory for unconnected text. *Music Perception*, 20, 173-186.
- SAFFRAN, J. R. (2003). Musical learning and language development. *Annals of the New York Academy of Sciences*, 999(1), 397-401. DOI: 10.1196/annals.1284.050
- SAFFRAN, J. R., ASLIN, R. N., & NEWPORT, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, 274, 1926-1928.
- SALAMÉ, P., & BADDELEY, A. (1989). Effects of background music on phonological short-term memory. *Quarterly Journal of Experimental Psychology*, 41(1), 107-122.
- SALIMPOOR, V. N., VAN DEN BOSCH, I., KOVACEVIC, N., MCINTOSH, A. R., DAGHER, A., & ZATORRE, R. J. (2013). Interactions between the nucleus accumbens and auditory cortices predict music reward value. *Science*, 340, 216-219.
- SARKAMO, T., TERVANIEMI, M., LAITINEN, S., FORSBLOM, A., SOINILA, S., MIKKONEN, M., ET AL. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain*, 131(3), 866-876.
- SCHELLENBERG, E. G. (2005). Music and cognitive abilities. *Current Directions in Psychological Science*, 14(6), 317-320.
- SCHELLENBERG, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, 98(2), 457-468.
- SCHELLENBERG, E. G. (2012). Cognitive performance after listening to music: A review of the Mozart effect. *Music, Health, and Wellbeing*, 324-338.
- SCHELLENBERG, E. G., & PERETZ, I. (2007). Music, language and cognition: unresolved issues. *Trends in Cognitive Sciences*, 35(1), 5-19.
- SCHELLENBERG, E. G., & WEISS, M. W. (2013). Music and cognitive abilities. In D. Deutsch (Ed.), *The psychology of music* (3rd ed., pp. 499-550). Amsterdam: Elsevier.
- SCHMIDT-KASSOW, M., & KOTZ, S. A. (2008). Entrainment of syntactic processing? ERP-responses to predictable time intervals during syntactic reanalysis. *Brain Research*, 1226, 144-155.
- SCHMIDT-KASSOW, M., & KOTZ, S. A. (2009). Event-related brain potentials suggest a late interaction of meter and syntax in the P600. *Journal of Cognitive Neuroscience*, 21(9), 1693-1708.
- SCHÖN, D., BOYER, M., MORENO, S., BESSON, M., PERETZ, I., & KOLINSKY, R. (2008). Songs as an aid for language acquisition. *Cognition*, 106(2), 975-983.
- SCHULKIND, M. D. (2009). Is memory for music special? *Annals of the New York Academy of Sciences*, 1169(1), 216-224.
- SIMMONS-STERN, N. R., BUDSON, A. E., & ALLY, B. A. (2010). Music as a memory enhancer in patients with Alzheimer's disease. *Neuropsychologia*, 48(10), 3164-3167.
- SMITH, S. M. (1985). Background music and context-dependent memory. *American Journal of Psychology*, 98(4), 591-603. DOI: 10.2307/1422512
- STAHL, B. (2014). Efficacy of melody-based aphasia therapy may strongly depend on rhythm and conversational speech formulas. *Frontiers in Psychology. Conference Abstract: Academy of Aphasia — 52nd Annual Meeting*. DOI: 10.3389/conf.fpsyg.2014.64.00021
- STAHL, B., HENSELER, I., TURNER, R., GEYER, S., & KOTZ, S. A. (2013). How to engage the right brain hemisphere in aphasics without even singing: Evidence for two paths of speech recovery. *Frontiers in Human Neuroscience*, 7.
- STAHL, B., KOTZ, S. A., HENSELER, I., TURNER, R., & GEYER, S. (2011). Rhythm in disguise: Why singing may not hold the key to recovery from aphasia. *Brain*, 134(10), 3083-3093.
- THAUT, M. H. (2010). Neurologic music therapy in cognitive rehabilitation. *Music Perception*, 27, 281-285. DOI: 10.1525/mp.2010.27.4.281
- THAUT, M. H., GARDINER, J. C., HOLMBERG, D., HORWITZ, J., KENT, L., ANDREWS, G., ET AL. (2009). Neurologic music therapy improves executive function and emotional adjustment in traumatic brain injury rehabilitation. *Annals of the New York Academy of Sciences*, 1169(1), 406-416.
- THAUT, M. H., PETERSON, D. A., & MCINTOSH, G. C. (2005). Temporal entrainment of cognitive functions. *Annals of the New York Academy of Sciences*, 1060, 243-254.
- THAUT, M. H., PETERSON, D., MCINTOSH, G. C., & HOEMBERG, V. (2014). Musical mnemonics aid verbal memory and induce learning related brain plasticity in multiple sclerosis. *Frontiers in Human Neuroscience*, 8. DOI: 10.3389/fnhum.2014.00395
- THIESSEN, E. D., & SAFFRAN, J. R. (2009). How the melody facilitates the message and vice versa in infant learning and memory. *Annals of the New York Academy of Sciences*, 1169(1), 225-233.
- THOMPSON, R., MOULIN, C., HAYRE, S., & JONES, R. (2005). Music enhances category fluency in healthy older adults and Alzheimer's disease patients. *Experimental Aging Research*, 31(1), 91-99.
- THOMPSON, W. F., SCHELLENBERG, E. G., & HUSAIN, G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science*, 12(3), 248-251.
- TILLMANN, B. (2012). Music and language perception: Expectations, structural integration, and cognitive sequencing. *Topics in Cognitive Science*, 4(4), 568-584.
- TILLMANN, B., DOWLING, W. J., LALITTE, P., MOLIN, P., SCHULZE, K., POULIN-CHARRONNAT, B., ET AL. (2013). Influence of expressive versus mechanical musical performance on short-term memory for musical excerpts. *Music Perception*, 30, 419-425.
- VERGA, L., BIGAND, E., & KOTZ, S. A. (2015). Play along: Effects of music and social interaction on word learning. *Frontiers in Psychology*, 6. DOI: 10.3389/fpsyg.2015.01316
- WALLACE, W. T. (1994). Memory for music: Effect of melody on recall of text. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20(6), 1471-1485.
- ZUMBANSEN, A., PERETZ, I., & HÉBERT, S. (2014). Melodic intonation therapy: Back to basics for future research. *Frontiers in Neurology*, 5(7). DOI: 10.3389/fneur.2014.00007