Tracing the Relationship Between Music and Memory

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Abstract

In everyday life, we are constantly bombarded with a substantial amount of information, and it is essential that we consolidate some of that knowledge into our long term memory. Here we present a literature search that will focus on explicit memories: our memory for facts and events. Specifically, we will investigate the role of music in the formation of explicit memories. Music is often present during the formation of long term memories; people often study with music or associate music with life changing events (ex: a song at a wedding). Here we aim to study whether music (and what kind) benefits the formation of memories and the role of specific brain regions in this process.

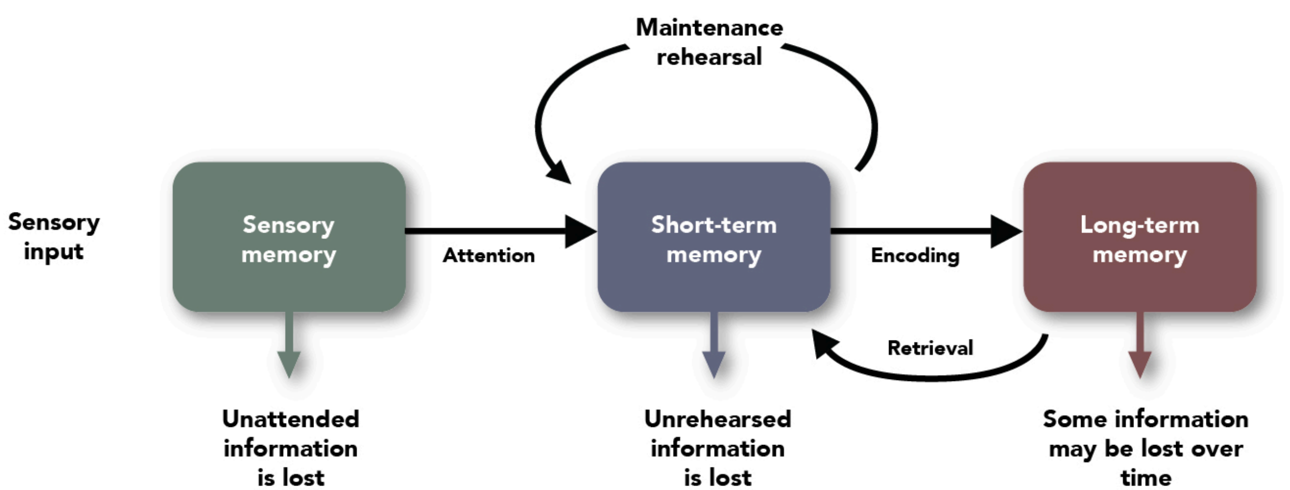
Introduction

Music is incorporated into all aspects of our lives: from listening to your favorite artist while studying to hearing an orchestra play at a wedding. In this digital era, it's common for students to listen to music while studying or doing chores. But does music really have an impact on whether people can learn more pieces of information or does it distract and actually hinder memory consolidation? While some people claim that music is beneficial for concentration, others believe that music is too distracting. These polarizing beliefs are also present among scientific studies, as there is no clear answer to whether music benefits memory consolidation. There are a variety of factors that may influence these results from the type of memory being tested, to the population of participants, or the level of music hedonia. This paper aims to answer these questions by defining the key parts of the brain and their function in terms of memory consolidation and how memory consolidation may go awry. It also explores how different areas of the brain are affected by music, and how music may change brain structures and function.

Section 1: What is memory consolidation? What are explicit memories and the regions of the brain involved?

We are constantly bombarded with novel information from our environments, which we perceive and only certain components wind up in our long-term memories. The formation of memories starts at encoding, or the formal process for how we take in this new information from our surrounding environment through one, or more, of four senses: visual, auditory, olfaction, or tactile. Then, this encoded information is stored into short-term memory (Fig. 1). Short-term memory can only hold up to five to nine items of information, lasting between 15-30 seconds. In order to keep information in short-term memory, the brain uses a process called rehearsal, which is the repetition of information. This is closely related to working memory which is how people store temporary information during tasks. For instance, this includes rehearsing a phone number as you are dialing or learning someone's name and remembering it throughout a conversation. This type of information is also quite susceptible to distraction (i.e., if you get distracted, you'll likely forget that phone number). However, for information that is deemed important for long-term memory (ex: if you want to remember that person's name or this interaction for when you see them next), the process in which short-term memory becomes long-term is called consolidation. Once information is stored into long-term memory, it can be stored indefinitely, and retrieved through association. It is no longer easily forgotten; susceptible to distraction. It is also worth flagging that each time a memory is retrieved, it is "reconsolidated" which may lead to modifications to the original memory as it was (see: "false memories; Section 4") For instance, if you have a conversation with a friend about a past event and your friend says "Sally was there", next time you talk about this event, you may say that Sally was there even though this was not the case, but you've reconsolidated your memory of the event based on the past conversation. What's particularly interesting is that reconsolidation doesn't just modify a single detail—it can affect how we recall the whole context or feel about an event. Each time we recall a memory, it becomes temporarily flexible, making it possible for new details to be added or for existing ones to fade.

Fig 1. Process of memory encoding and consolidation



Explicit memory, one of the two types of long-term memory, is made up of both **episodic**, previous experiences (ex: first day of school or a wedding), and **semantic** memories, memorized information such as facts (ex: Paris is the capital of France). Multiple cortical and subcortical regions are involved in these memory processes including the hippocampus, the amygdala, and many regions of the neocortex. The hippocampus, located inside the temporal lobe, is where episodic memories are formed and indexed. A classic example of this is the HM case study, which provided evidence that the hippocampus is necessary for explicit memories (Corkin *et al.*, 1997). Dr. Scoville, HM's doctor, believed that removing HM's hippocampus would cure his epileptic seizures. However, although the surgery was successful, HM began to suffer from anterograde amnesia, which prevents people from forming or keeping new memories (Dewar *et al.*, 2010). The hippocampus helps project information to cortical regions that help give memories meaning and connect them to other memories. Another crucial region is the amygdala; this region is also located in the temporal lobes above the ear, helps shift new learning into long-term memory and is especially responsible for connecting emotional significance to memories. The amygdala also plays an essential role in forming memories related to fear (Kim & Richardson, 2008; Ressler, 2011). This will be discussed further in Section 4.

The neocortex involves multiple cognitive processes including sensory perception, the generation of motor commands, and spatial reasoning and language. Therefore, unimodal sensory regions such as the visual cortex or auditory cortex are responsible for the original perception of the item that is being put into memory. Multimodal regions such as the prefrontal cortex, among other regions, is involved with short-term memory and working memory, keeping track of the novel information that is being encoded (Sridhar *et al.*, 2023). Some work suggests that there might be some degree of lateralization within the brain with the left side accounting for verbal working memory (language processing such as a student reading a paragraph aloud) while the right side accounts for spatial working memory (recalling locations, such as remembering the route to work; van Asselen *et al.*, 2006). Other cortical regions such as the angular gyrus and the posterior cingulate cortex have also been linked to memory formation and retrieval (van der Linden *et al.*, 2017); both of these regions have been linked to the default mode network of regions that is often associated with memory formation.

Section 2: How are different regions of the brain involved with music?

The temporal lobe is the brain's language center, and it's where music is processed (Soundstripe Team, 2018). Another key region of the temporal lobe is the auditory cortex. This unimodal sensory region, as noted in Section 1, takes into external input from the environment (sound) and helps transduce it for more complicated processing in the brain. Specifically, the auditory cortex helps people distinguish volume, pitch, speed, melody, and rhythm as they are listening to music. Other regions of the multimodal cortex such as those involved in memory (Section 1), permit the feeling of familiarity when listening to memory (for instance; 'recognizing' that you have heard a song before or bringing up a memory of the lyrics). It is also worth noting that while the above section highlighted explicit memory, the cerebellum is involved in **implicit** memories, including long-term motor memories. This allows musicians to play instruments correctly: from playing the right keys to hitting a drum with the correct force. The limbic system, including the aforementioned amygdala (Section 1), is thought to be the emotional switchboard that allows people to feel inspired after hearing uplifting music.

Section 3: The Role of Music in Forming Memory: What We Do and Do Not Know

The goal of this paper is to understand the role of music in the encoding and consolidation of memories. This is motivated by the fact that music is often associated with big events in our lives, ranging anywhere from weddings to graduation. Colloquially, people often say that listening to music while studying is beneficial.

However, as the literature currently stands, it is unclear whether music aids or is detrimental to memory consolidation. Musliu *et al.*, (2019) conducted three different tests aimed at assessing this question. In all tests, participants were asked to memorize 50 nonsense syllables (ex: BIK, GUX). The first group took the tests in silence, the second listened to lyrical music, and the third listened to relaxing music. Findings indicated that the no-music group was able to recall more nonsense syllables than the other two groups, suggesting that listening to music will weaken short-term memory. In another study, Judde & Rickard (2010) researchers found different results. Instead of short-term memory, this study focused on long-term memory. They exposed participants to emotionally arousing music while learning a neutral word list. Participants were either exposed to positive or negative arousing musical pieces following delays of 0, 20, or 45 minutes. A week later, participants were tested on their retention of the word list. This experiment found that retention was significantly enhanced regardless of positivity for the 20 minute delay, but not for the 0 minute or 45 minute delay. Therefore, this study highlights that the emotional content of music does not matter and rather that it enhances memory only at a specific time period.

In a third study, Rickard *et al.* (2012), researchers wanted to test whether emotional events would be retained more in comparison to everyday occurrences. This stands in contrast to the previous two studies where memory was tested for neutral pieces of information. In this experiment, participants viewed a slideshow with either emotional or neutral narration and with either relaxing music or no music playing. A week later, the participants' retention was tested using a forced choice recognition test. It was found that retention for the emotional narration was higher compared to the neutral narration. However, relaxing music significantly reduced the recall of the emotional story.

Crucially, there are major differences between these studies, both on the side of the memory itself and on the side of the music. There are differences in terms of which type of memory was tested for (short-term versus long-term memory), the degree to which the content was emotional, which type of music was used, and whether or not the music was emotionally arousing (or whether the authors even accounted for this). This highlights that there needs to be a lot more work in this space to really start to triangulate across these differences to understand the link between music and memory. However, in the next section, I focus on why emotion may play a critical role in these processes with the hope that it could account for at least some of the big variability seen across studies.

Table 1. Comparison of Musliu et al. and Judde & Rickard

The Impact of Music in Memory (Musliu *et al.*, 2019)	The effect of post-learning presentation of music on long-term word-list retention (Judde & Rickard, 2010)
● Tested short-term memory ● Used both lyrical / instrumental in experiment ● Aim: Investigate if music can help memorize different tests (nonsense syllables, numbers, rhyming poems) ● Results: Significant difference between no-music group and lyrical music	● Tested long-term memory ● Used positively arousing and negatively arousing music ● Aim: Examine the effects of time and positively/negatively emotionally arousing music on long-term word-list retention ● Results: Retention was significantly

group ○ No-music group recalled more items ● Conclusion: Presence of music did impact memory	enhanced regardless of whether music was positive/negative for 20 min group but not 0 min or 45 min group ● Conclusion: Valence of music (positive or negative) did not impact memory, but music in general enhanced memory

Section 4: Emotional memories & music

Emotional responses are defined as reactions to evocative stimuli (ex: music) which can be expressed as physiological arousal (escalations in blood pressure, higher rate of respiration), goal-directed behavior (going to a store to buy an instrument), expressive behavior (politician eating meal with supporters despite not being hungry), cognitive appraisal (sound of gunshot causing fear), and subjective experience (pain) (Deckert *et al.,* 2019). Arousal is probably the most key factor in the perception of emotional stimuli when it comes to its relationship to memory. Past work has indicated that emotional stimuli such as facial expressions or words can amplify arousal as opposed to neutral ones (Regenbogen *et al.*, 2012; Fiori *et al.*, 2023), and one would expect this to extend to emotional music as well. This will be discussed further below. Emotions, such as anger or envy, can also be universally recognized (Williams, 2017) and may not have an evolutionary basis, leading to generally consistent responses across people.

Experiencing an important event generally results in a vivid and detailed memory. A lot of prior work has investigated the links between this emotional arousal and the formation of memories in other, non-music, domains. Studies confirm that emotional arousal increases the chance of recalling items and suggest that the mechanism underlying this may be that the amygdala causes arousal-induced enhancement (Hamnn, 2001; Phelps, 2006; Phelps & LeDoux, 2005). However, this doesn't mean emotional arousal improves memory binding. Memory binding is the ability to recall the features of an object, person, or event as a coherent whole (i.e., if you are remembering a face, you don't remember the nose or mouth separately – you bind those features together). The two main theories regarding emotional arousal and binding are Mackay's "priority-binding theory" and Nadel & Jacobs' "arousal-impairs-binding theory." Mackay's theory predicts that memory binding prioritizes arousing stimuli over non-arousing stimuli when stimuli are initially perceived. Nadel & Jacobs' proposed that acute stress weakens the function of brain regions involved in binding, such as the hippocampus and prefrontal cortex, but improves amygdala performance. Nonetheless, there are some problems with both theories that are not addressed (Mather, 2007). Mackay's theory does not consider when neutral experiences are better for memory binding rather than positive experiences. Nadel & Jacobs' theory does not account for item-based effects as the temporary arousal caused by an item is not enough to impair the hippocampus or frontal cortex function for memory binding (Mather, 2007).

Regardless of how arousal impacts binding, it is hypothesized that simply perceiving an event as significant will stimulate the activation of neural and physiological systems (emotional arousal hypothesis; Judde & Rickard 2010). This will then induce the release of adrenal stress hormones such as epinephrine, norepinephrine, and cortisol into the bloodstream. Epinephrine and norepinephrine are similar neurotransmitters and hormones, as both are responsible for the human body's "fight-or-flight" reaction. However, epinephrine has more of an effect on the heart while norepinephrine affects the blood vessels more. Another word in the United States for epinephrine is "adrenaline" which is more frequently used in everyday life. Cortisol is a primary stress hormone that increases glucose in the bloodstream and regulates the body's stress response. The release of the mentioned hormones is closely linked to the modulation of recently acquired information (LaLumiere *et al.*, 2017), such that when more hormones are released, memory has been shown to be improved. More generally, the release of these adrenal hormones has been shown to impact attention, learning, and memory consolidation (Nielson & Powless, 2007).

How many of these cognitive processes are related? Does arousal lead to increased attention that, in turn, improves memory? Arousal caused by an object can lead to focused attention and in turn improve memory binding by making it easier to recall the object's features (ex. color, location), but it does not necessarily improve the binding of the object in context with other objects, and may even impair the binding. In the case of music, an example would be remembering an emotional song at an event, but not necessarily remembering the conversations that occurred around the same time. Focusing too intently on an object may weaken the maintenance of other bound representations.

Another relevant factor during emotional arousal that is also important for considering how attention is distributed in the formation of memories is reward. Ferreri *et al.,* (2021) investigated how memory recollection could be influenced by individual differences in sensitivity to music reward. To do so, they investigated another hormone similar to epinephrine and norepinephrine—dopamine. Dopamine is part of the same family of hormones (catecholamines) and is actually the precursor to the other two, but is much more implicated in the pleasure and reward systems of the brain. In order to test the relationship between dopamine-dependent musical reward and memory enhancements, 29 participants ingested a dopaminergic antagonist, dopaminergic precursor, or a placebo. Then, they were tasked with rating 24 unfamiliar classical instrumental music pieces based on level of pleasantness, arousal, emotional valence, familiarity, and to rank all of the musical excerpts. After 24 hours, participants were presented with 24 old and 24 new musical excerpts and asked to recall whether they had listened to the piece the previous day. The researchers found that a greater reward experience (as induced by more dopamine) while listening to music was associated with better memory recollection.

There is also a distinction between objective and subjective memory. First, there is the subjectivity of how much the music itself is enjoyed – i.e., the degree to which there even is an emotional experience. While this is incredibly idiosyncratic, most prior work has completely ignored this feature. In addition to modulating dopamine levels, Ferreri *et al.,* (2021) accounted for trait-level differences between participants; participants with high music hedonia—sensitivity to music reward—had greater pleasure while listening to music, which led to greater pleasure and ultimately caused better memory. When people listen to music they enjoy, this can lead to a phenomenon known as "chills." We know that this type of emotional experience can lead to biological changes. Listening to music can lead to the release of dopamine in the brain, which has an important role in creating a good mood or “the chill” (Zatorre & Salimpoor, 2011); incredibly, dopamine release is found to be 9% higher when volunteers listen to music that they enjoy. When participants felt a chill, there was increased endogenous dopamine transmission compared to when participants didn’t produce a chill, who released less dopamine. This would then lead to arousal and the memory mechanisms discussed above, yielding likely better memory for music that is subjectively enjoyed.

While the studies discussed above focus on the links between music and objective memory measures (i.e., raw performance), music may also impact subjective memory (i.e., how well you think you remember). For instance, the relationship between confidence and accuracy for arousing events is weaker than the memory for neutral events (Clifford & Hollin, 1981; Talarico & Rubin, 2003) because the strength of memories for emotionally arousing events compared to neutral events does not mean the emotional stimuli is accurately remembered (Sharot *et al.*, 2004). Vivid memories of emotional elements of an arousing event may cause people to feel confident about their recall, even if their memory is inaccurate. The emotionality of events in these subjective contexts can also severely go awry leading to clinical conditions.

Post-traumatic stress disorder (PTSD) is a mental health condition that is caused by a stressful event (ex. Combat exposure, childhood physical assault, sexual violence) and this can causes common symptoms such as intrusive memories (flashbacks, nightmares), severe anxiety, and uncontrollable thoughts about the event. The brain regions impacted by PTSD include the amygdala, hippocampus, and prefrontal cortex. When traumatic events occur, the brain will shut off areas of the brain in order to manage the processing of information. This causes the sympathetic nervous system to release stress hormones, which will put the body in a “fight-or-flight mode”. It is theorized that the body produces epinephrine (adrenaline) and stress hormones that will cause the memory to imprint onto the amygdala, which holds memories of the five senses (McGaugh & Roozendaal 2002). This causes, colloquially speaking,traumatic events to replay in the “emotional side” of the brain and disconnect from the “cognitive side”. This is supported by evidence of hyperactivity in the amygdala in patients with PTSD, which is likely because the brain fails to recognize that the threat is no longer present (Zotev *et al.*, 2018). Additionally, PTSD may even cause structural changes in the amygdala, as it reads ordinary situations as dangerous (Prajjwal *et al.*, 2022). The amygdala and the hippocampus work together to relay information back and forth. For instance, when a person hears fireworks, their hippocampus relays information to the amygdala that the fireworks are not dangerous. But someone with PTSD, whose cognitive side of the brain is disconnected, may have inaccurately relayed messages. Most of the time, the body will go back to normal, but if the brain is stuck in survival mode, the brain will be unable to resume function. We discuss PTSD in this paper to highlight how the emotional features of memories can make them particularly salient. Memories tend to be awry, fragmented or intrusive in individuals with PTSD. There is also considerable evidence that music can serve as a successful behavioral therapy for those with PTSD, though the mechanisms of this occurrence have yet to be uncovered.

Discussion

Originally, music was seen as a luxury—as a pastime for the rich and viewed as an extra discipline that was unnecessary (Pippen, 2024). But over time, music became democratized; it has transformed into a universal language, as there is a seemingly unlimited amount of genres and varied day-to-day use (spiritual ceremonies, teaching the alphabet to toddlers through rhyme and verse, listening to music while going to the gym, background music in grocery stores, etc.). Now, music has even deeply embedded itself into mainstream culture with shows like “American Idol” and “The Voice” that are entirely dedicated to singing, or musicians appearing as guests on non-musical shows like “The Colbert Report”.

This paper suggests that there is no straightforward answer to whether music benefits memory consolidation because there are too many interacting factors to consider. For instance, there is variability at the level of the (1) individual being tested (ex: age, music experience, arousal sensitivity), (2) the music being employed itself (ex: music genre, music loudness), and (3) the type of memory being consolidated (ex: long-term versus short-term memory). Earlier, we highlighted a couple of studies that show differing effects of music on memory; all of these studies varied across all of these factors, making it difficult to pinpoint where the effects were different due to how the experiment was set up. For instance, imagine two studies in which one found that **classical** music improved **working memory** while another found that **country** music did not impact **episodic memory**. Taking these two studies, it is impossible to know if it is just that classical music is good for all memory, if country music is bad for all memory, and/or, more likely, classical (or any) music may improve some types of memories, but not others. And, of course, the proclivity to different types of music would play a role here.

We did, however, find that there was meaningful evidence for how emotion-inducing music beneficially impacted memory consolidation. This has been considered in both a subjective (ex: how confident you are that your recollection is correct) and objective context (accuracy of memory). These studies begin to consider individual variability in terms of responses to music (i.e., is an individual more naturally aroused by one musical piece than another). This could, of course, be impacted by expertise with music.

The role of musical expertise in how music impacts memory is a great example of how these processes may result in either improved or disrupted memory. To put this colloquially, musician’s ears are more “fine-tuned” to hearing details in music, so if they are listening to music as they are forming memories, we would expect their memories to be slightly different than the average person’s. In fact, prior work has suggested that musicians have different neural responses; they exhibit more pronounced auditory and motor regions compared to non-musicians and show heightened activity while listening to music. Further, anatomically, musicians have been shown to possess a substantial corpus callosum, which allows the brain’s left and right hemispheres to communicate (Toader *et al.*, 2023). Consequently, music experience often results in improved auditory discernment, sound-associated emotional interpretation, and intricate motor control. Therefore, if the source of the memory is music, one would expect that musicians have higher accuracy. However, if the goal was to remember something else that was encoded with music, one could expect that musicians either have improved memory because they’re linking the other information to the music *or* have worsened memory because their attention is being held by the music itself and not what they’re supposed to remember.

Musical expertise (ex: comparing musicians to non-musicians) may mediate how much music impacts memory. To put this colloquially, musician's ears are more "fine-tuned" to hearing details in music, so if they are listening to music as they are forming memories, we would expect their memories to be slightly different than the average person's. In fact, prior work has suggested that musicians have different neural responses; they exhibit more pronounced auditory and motor regions compared to non-musicians and show heightened activity while listening to music. Further, anatomically, musicians have been shown to possess a substantial corpus callosum, which allows the brain's left and right hemispheres to communicate (Toader *et al.*, 2023). Consequently, music experience often results in improved auditory discernment, sound-associated emotional interpretation, and intricate motor control which would obviously impact how music is remembered if it is the source of the memory or would impact how other things are remembered given their relationship to the music itself.

The scope of this paper was to highlight how varied the findings are in this space. Below we propose a couple of experiments that aim to discern this variability. For instance, future work should investigate how different types of music can impact memory consolidation. Therefore, a potential future experiment would test groups of people on the same material that they learned while listening to different types of music. Additionally, it is worth looking into how lyrical versus non-lyrical music interacts with memory. To get a sense of the role of music in attention, future experiments should explore whether playing music impacts working memory capacity and how that translates into forming long-term memories. Furthermore, we mostly focused on declarative memories in this paper, but the role of music during non-declarative, implicit memories such as learning to play a sport or another type of motor activity has limited experimentation and documentation.

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