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Music's Role in Enhancing Memory Retrieval and Encoding

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Abstract. Historically, it has been observed that music can help people better remember information in all kinds of situations, such as in clinical settings for speech recovery. It can also be frequently felt in daily life that a well-known song can trigger a memory more quickly than regular words. The reason for this is primarily because music affects many different areas of the brain simultaneously. This paper will examine how various parts of the brain such as the hippocampus, amygdala, and basal ganglia synchronize with music and work together to build an external temporal structure. This external structure may enhance neuroplasticity during memory encoding and can also help reconstruct memory in future retrieval processes by means of long-term potentiation and cue-dependent recall. Further possibilities of the clinical application of music will also be investigated, as music shows promise in becoming an engaging, personal, low-cost, and non-invasive treatment method during cognitive decline.

Keywords: memory encoding, memory retrieval, neuroplasticity, long-term potentiation

1. Introduction

Hearing a childhood song can immediately help many people remember a particular moment in their youth. Music is multi-sensory and stimulates all the senses of the brain. Different parts of the brain are involved in the processing of different aspects of music. The temporal lobe processes tone and melody while rhythm and movement are handled by the cerebellum. Music can also stimulate different areas in the limbic system, which are the emotional processing regions of the brain, such as the amygdala [1]. Because of diverse engagement, music cues can frequently provide a basis for context learning and give the brain many ways to access the same information.

It has been observed that music can help people better concentrate and remember. The cause of this phenomenon likely starts with music's promotion of neuroplasticity [2]. Neuroplasticity is the capacity of changes and remodeling in neural networks, particularly manifested through long-term potentiation (LTP). LTP increases the strength and stability of frequently used neural network pathways. When these pathways are activated later, it will be more convenient for important information to be recalled. This is the basis for memory recall. LTP is initiated at the first stage of memory formation, during the encoding process of information into a brain state.

Music can help to improve the encoding stage of verbal recall through scaffolding, division and grouping [3]. Ferreri et al. have shown that patients who listen to music during verbal encoding show reduced activity in the prefrontal cortex (PFC). The PFC is usually in charge of filtering the

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information that enters the memory encoding stage to keep only what is necessary and significant. Music has a rhythm and can help automate organization in that way [3]. This can help people with brain injuries learn new things and remember them better during rehabilitation with decreased cognitive stress.

Arousing music has also been found to increase the strength of free memory recall and memory consolidation by way of its connection with the limbic system in the brain [4]. Clark and Leal asked a more specific question: can music improve the quality of memory in addition to the quantity of recalled information? Based on their findings, it can be inferred that music may enhance memory (especially detailed memory) via mnemonic discrimination, the brain's ability to differentiate among many similar memories [5]. This can help to improve clarity and reduce confusion caused by memory loss.

The reasons behind these findings are as follows. Music is a kind of information organizer that can strengthen the neural connections for this information and serve as a memory retrieval cue. This paper examines the neural basis of memory encoding and retrieval, how music triggers brain activity, and finally, how these two processes connect.

2. How memory works

Generally, there are two types of memory: short-term and long-term, which are different in time and size. Short-term memory is a relatively easily accessible area of the brain for holding some information over a few seconds to minutes, such as remembering a new telephone number for a short time. Long-term memory is for more endured storage of information, which can last several days or even years. Although long-term memory is more stable, it is not eternal. As memory is more reconstructive than reproductive, these memories can still be changed in the process of retrieval and reconsolidation.

The transition from short-term to long-term memory is based on the hippocampus, which is particularly important for declarative and episodic memory. Declarative memory is what we are consciously aware of and can voluntarily access; non-declarative memory cannot be described or recalled intentionally, often describing habits. The two kinds of declarative memory are semantic memory and episodic memory. Semantic memory is the knowledge of facts, such as knowing that Paris is the capital of France, whereas episodic memory focuses on events, such as recalling a trip.

The hippocampus is located in the deep part of the medial temporal lobe, belongs to the limbic system, and is necessary for memory consolidation. It is responsible for the formation of episodic memory during learning, by combining various components of an experience such as sensory information, space, and context to create a single event [6]. Gradually, memories will no longer rely on the hippocampus and will be distributed in various parts of the cortex. Systems consolidation is the interaction formed during this time between the hippocampus and the neocortex. With time, the neocortex will form cross-connections among different cortical regions and build a stable memory network [7].

Long-term memories do not have a single location. Instead, they are distributed in the network of the neocortex, hippocampus, prefrontal cortex, and amygdala, and the retrieval of memories is a joint effort. Ecphory, or memory recall, is often triggered by external sensory input or internal stimuli. This process activates engrams, which are physical and chemical neural ensembles in the brain that store specific memories [8]. In general, the hippocampus is used to recall the detailed context of a memory and recreate the surrounding circumstances. In contrast, the amygdala governs the emotions in memory. Pavlovian fear conditioning is a typical case of this. During Pavlovian fear conditioning, a fear-inducing unconditioned stimulus (US) is given at the same time as a neutral

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stimulus. Thus, the neutral stimulus becomes a conditioned stimulus (CS) that can trigger the response associated with the US. This connection is mainly based on the synaptic plasticity of the lateral amygdala [9]. The PFC will then send a top-down signal to activate the neural pathways that have stored information acquired from all kinds of cues.

3. How music interacts with the brain

It has been found that music can help to improve some aspects of executive functions, such as attention span, stress regulation, and memory. This is because music engages various parts of the brain. When people listen to music, they are paying attention to several things at once: the tune, harmony, rhythm, and may also nod their heads or tap their feet.

The first part of the brain stimulated by music is the auditory cortex in the upper temporal gyrus of the temporal lobe. The auditory cortex processes sound and is divided into the primary and secondary auditory regions. The primary region organizes its neurons based on the frequency of sound, forming a tonotopic map [10]. Different pitches activate different regions of this map, and the lower the pitch, the further toward the front of the cortex it is processed; conversely, the higher the pitch, the further back it is processed. The secondary auditory cortex can differentiate between various types of music, such as tunes and harmonies.

Another trait of music is its ability to evoke emotion. Listeners may often feel longing, sadness, energy, and even chills from the same piece of music. Emotionally, it is thought that music may trigger changes in the brain's "emotional" areas in the limbic system. Music has been found to particularly stimulate the amygdala, and at the same time, the auditory cortex connected to it through feedforward and feedback neural pathways. Zaatar et al. have reported that, in some cases, listening to preferred music can increase the blood flow to the reward and emotion centers in the brain, such as the amygdala [2]. Because emotions can make certain experiences more easily remembered and thus influence memory encoding, this limbic response may help music enhance memory encoding.

One purpose of music's rhythm is for moving us physically, and this is controlled by the brain's motor area. The basal ganglia particularly help coordinate internal neural signals with external rhythm. The direct and indirect pathways of the basal ganglia regulate movement. The direct path is made up of D1-receptor neurons, and the indirect path uses D2-receptor neurons. When the brain receives a beat from outside rhythmically, it will release dopamine. Then, the D1-receptor neurons will be activated, and the D2-receptor neurons will be inhibited [11]. As a result, there is a "disinhibition" of the thalamus, and it is activated to send signals to the motor cortex for voluntary movement. This is the basis for tapping along to music.

4. Music for the aid of memory

Music can help people remember better during both learning and recalling. The first three methods by which music can help people remember are association, segmentation and grouping. Association is adding new information to knowledge that has been stored in memory to strengthen the memory trace. Music has many engagements, so it provides an outside support that can help the hippocampus link more pieces of information about an event into a whole memory.

Segmentation and grouping can also be carried out in memory encoding. Segmentation is dividing continuous information in the brain into several parts. Grouping refers to the combination of small units into a large one. The brain processes sensory information by means of neuronal oscillations, especially theta and beta oscillations. It is believed that these two kinds of oscillations

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function to connect the hippocampus and the cortex. Building on the process that music helps to enhance association, the strong rhythm and melody of music can also be used as a scaffold for synchronizing brain wave oscillations [12]. This synchronization is called neural entrainment, and it can help stabilize the neural oscillations at the level of encoding.

Neural entrainment is related to the process of long-term potentiation. LTP is an increase in the strength of synaptic connection after many times firing. At the time of neural entrainment, presynaptic neurons increase their firing rate. As a result, there is some depolarization in postsynaptic neurons, which then alters the structure of synapses and promotes the brain plasticity necessary for memory formation.

Music can help create a bigger memory by assisting in the organization of memories. At this time, music can help organize the data in the form of patterns and thereby reduce the amount of effort required from the prefrontal cortex [3]. Generally, the PFC will filter out some of the information it has received and send only the essential parts to the back sensory area through top-down signaling for storage. Music has been shown to promote top-down signaling; musicians can more cleanly distinguish two simultaneously played melodies than non-musicians [13]. It can thus be expected that music may increase the strength of top-down signals from the PFC, reduce stress on the PFC, and help it better organize and facilitate memory encoding.

Memory recall operates in a similar way, and music can help people remember things in two ways: cue-dependent recall and pattern recognition. At the time of memory storage, music can influence brain wave changes and activate parts of the brain, such as the limbic system. This is the bridge that connects external musical stimuli into internal emotions and thoughts. When the music is played once more, the first synchrony is resumed and responded to. Since the first synchrony has already strengthened the synaptic connection in that neural pathway, music can be used as a retrieval signal to increase the activation efficiency of the memory pathway. Another reason why music helps us remember things is that it has a pattern. The structure of music includes rhythm; it may also have many repeated patterns of motifs and themes. Just as the time organization of music can help automatize information filtering, rhythm in the brain can assist in predicting what is about to happen. If the information is first learned in the form of a musical pattern and later forgotten, hearing parts of the pattern again can help trigger the reconstruction of the missing parts of memory. This is probably why lyrics or facts in the context of a song are easier to remember than the same information without music.

5. Conclusion

Music is not only a pleasure and relaxation, but also an effective way to give form to memory. Through the activation of distributed neural networks, music has a different kind of all-encompassing effect on the brain. The auditory cortex is for hearing, the basal ganglia are organized by rhythm, the amygdala responds emotionally, and the hippocampus works with other areas to create memories. Together, these systems build a scaffold that can decrease the cognitive load of the prefrontal cortex, and promote changes in neural synchronization and plasticity that are needed for the consolidation of new memories. Later, in the process of memory recall, music can re-activate the same neural networks that were first formed and organized in the musical environment.

These neural mechanisms have some promising prospects for clinical application and may be used to help recall and cognitive functions in memory. People with neurodegenerative diseases, such as Alzheimer's disease and other kinds of dementia, may still remember some memories after hearing familiar music when they cannot react to other stimuli. A musical temporal scaffold may lower the risk of neurodegeneration by promoting the formation of synapses and memories. In the

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future, rhythm-entrainment, strong-beat music, and other means could be employed in the clinic to help patients better concentrate and regulate movement. However, the effect may differ from person to person due to different musical backgrounds, various stages of neurodegeneration, people's emotional links to the music, and other reasons. Therefore, it may be appropriate to use a more personalized way and play the music the patient enjoys to help them remember better.

Many of the current music-based interventions are small in scale, and there have been no prolonged clinical studies. Given that music can arouse many regions in the brain at once, it differs from the present drugs that target individual chemical messengers, and has the potential to be a good, low-cost remedy. Lastly, music can be added to memory treatment to transform traditional drug therapy into a personalized, interactive way of improving memory during cognitive decline.

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