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CHANGING YOUR LOVE OF MUSIC BY STIMULATING THE BRAIN

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YOUNG REVIEWERS:

ARAN
AGE: 13

CARINA
AGE: 13

ERICA
AGE: 12

KALLIE
AGE: 13

For many of us, listening to our favorite songs makes us feel happy, energetic, and inspired. One goal of brain research is to understand the role of the brain as we listen to music. For years, researchers have hypothesized that the brain areas involved in processing the music we hear are involved in musical pleasure—but they had no hard proof. By stimulating people's brains using strong magnets, along with a brain-imaging technique that could see which areas of the brain were active, scientists have unraveled why we feel so awesome when we listen to our favorite jams. Now there is good evidence to show that our favorite tunes involve connections between specific brain areas, including the brain's "reward center"—an area that makes us feel good when we do something that we like. These brain circuits

MARY

AGE: 13

NORAH

AGE: 11

provide a solid piece to this complex puzzle of why music makes us feel so good.

MUSIC CAN MAKE US FEEL EMOTIONS

Many of us love listening to music. Sometimes we listen to feel better when we are sad. Other times, we listen to music to celebrate special occasions like birthdays, weddings, and holidays. It seems like listening to music is a common activity shared across people and cultures around the entire world. Scientists do not yet know exactly what happens in the brain to cause these feelings of happiness, energy, and inspiration, but they are making lots of progress.

In the last 20 years, researchers have discovered that listening to music uses many areas of the brain. For example, rhythm is processed by the motor cortex and cerebellum. Pitch and tone use the auditory cortex, cerebellum, and prefrontal cortex. Anticipation of your favorite parts of a song engages the prefrontal cortex (Figure 1A).

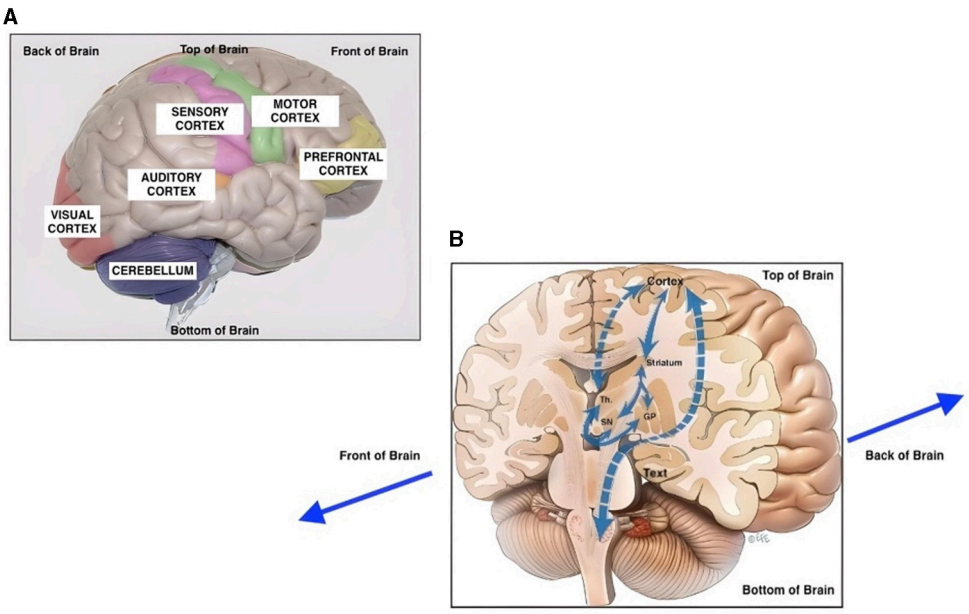

Figure 1

Figure 1

(A) Brain areas involved when listening to music. Auditory cortex is involved in perceiving the acoustic features of music. Prefrontal cortex is involved in focusing and keeping track of music. The motor cortex, sensory cortex, and cerebellum are involved in playing, singing, and moving to the beat of music. The visual cortex is involved in reading music and watching music performed (adapted from [1] and see The Kennedy Center). **(B)** A cortico-striatal circuit in the human brain. The image shows a brain that has been cut halfway between the face and the back of the head. The arrows show connections that are known (solid) and believed (dotted) to transmit messages between brain regions. Th, Thalamus; SN, Substantia nigra; GP, Globus pallidus. Adapted from Mas-Herrero et al. [2].

CORTICO-STRIATAL CIRCUITS

The connections, interactions, or communication highways between the cortex (outer layer of the brain) and striatum (located deep within the brain).

What about emotions triggered by music? Previous brain-imaging studies [1] have shown that, when people get pleasure from music, connections within the brain called **cortico-striatal circuits** are active. The name "cortico-striatal" means these connections involve both surface and deep brain areas (Figure 1B) [3]. When people listen to music that they like, these circuits, which are important for perception and for pleasurable sensations, become active [1]. However, these studies are **correlational**, meaning that they only show which brain regions are active—they cannot tell us which of those brain regions are actually *causing* the pleasurable feelings people experience with

music. To address this question, a new study used a method of stimulating the brain with magnets, to discover if activating or blocking those cortico-striatal circuits can change the amount of pleasure people experience from music [4].

CORRELATION

Relationship between two things that happen (ice cream sales and hot weather increase in summer) but do not necessarily cause each other (eating ice cream does not cause hot weather).

TRANSCRANIAL MAGNETIC STIMULATION (TMS)

A magnet that activates or blocks brain areas, causing them to wake up or calm down, respectively.

FUNCTIONAL MAGNETIC RESONANCE IMAGING (FMRI)

A way to "take picture" of the brain to show which parts of the brain that are active when a person is thinking, feeling, or doing something.

TESTING THE ROLE OF THE BRAIN IN ENJOYING MUSIC

The researchers hypothesized that if the brain's cortico-striatal circuits were involved in generating the pleasure we feel when we listen to music, then stimulating or blocking those connections should increase or decrease people's pleasure, respectively. To stimulate or block the circuits, the scientists used a technique called **transcranial magnetic stimulation** (TMS), in which a magnet activates or blocks brain areas, causing them to wake up or calm down, respectively.

To see exactly which brain regions within the cortico-striatal circuit were responsible for the effects of music, the scientists also used a method called **functional magnetic resonance imaging** (fMRI). fMRI is used to take pictures of the brain's activity patterns while a person does certain jobs or tasks (for more information of fMRI, see this Frontiers for Young Minds article).

EXACTLY WHAT DID THE RESEARCHERS DO?

Eighteen participants (11 females, seven males, mean age 24.3 years) with no formal music training took part in the experiment. One participant did not complete one of the sessions and was excluded from the study. Participants had no history of brain diseases or hearing impairments. Each participant was asked to provide five song excerpts (45 s each) that made them feel intensely pleasant emotions. Based on these excerpts, the researchers selected 10 similar songs using a music app called Spotify. The songs they selected were meant to be familiar (so that they would cause similar pleasant reactions in the listeners) but not easily recognizable.

Participants listened to each researcher-selected song and rated how much they liked it according to these choices: no pleasure, low pleasure, high pleasure, or chill. While they were listening, researchers used TMS over the left top prefrontal cortex to alter the brain circuits involved in reward by either activating them or blocking them. This site was chosen based on previous experiments by the same researchers [2]. As a **control**, the experiment also included a "fake" TMS session. This control was used as a baseline, so that the researchers could know whether activating or blocking the circuit actually caused differences in how each participant felt about the music.

CONTROL

The part of an experiment where conditions are kept constant to provide a baseline for comparison.

After TMS, individuals had their brains imaged in an fMRI scanner. While inside the scanner, each person listened to their own favorite and

experimenter-selected musical clips and rated how much pleasure they experienced from the music. fMRI imaging was performed without any brain stimulation (fake TMS control) or after the circuits were activated or blocked using TMS. fMRI was used to create images of various regions of the brain whose activity was changed by TMS.

RESULTS

When the results were collected, the scientists made several important discoveries. The first was that, consistent with their hypothesis, activating the cortico-striatal circuits using TMS led to more pleasure when listening to music, while blocking these same brain circuits led to a less pleasurable experience (Figure 2). Second, using fMRI, the researchers identified a small portion of the **striatum**, called the **nucleus accumbens**, caudate, and putamen, as the key brain regions driving musical pleasure (Figure 3A). The nucleus accumbens is considered the brain's reward center. It is responsible for the joy we experience with many activities, like eating our favorite foods or when we have fun playing or exercising (Figure 3B).

STRIATUM

Helps control movements and is involved in planning actions, making decisions, and feeling motivated.

NUCLEUS ACCUMBENS

The brain's pleasure center, which helps regulate feelings of pleasure and reward.

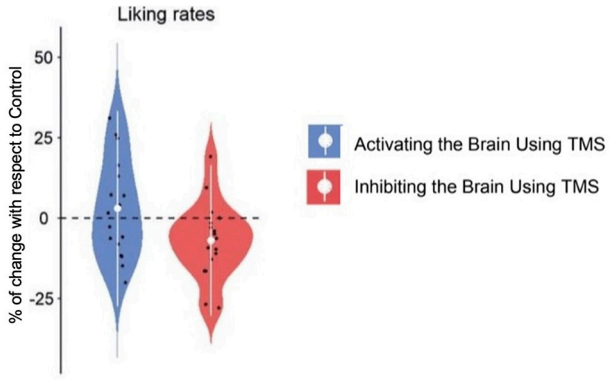

Figure 2

When participants' brains were activated with TMS, their brains showed that they liked the music more (white dot in blue shape) than when their brains were inhibited by TMS (white dot in red shape). "Liking rates" were measured by pressing a corresponding button to no pleasure, low pleasure, high pleasure. Figure adapted from Mas-Herrero et al. [4].

The individuals who reported the greatest difference in enjoyment between the activating and blocking TMS sessions were the same individuals who showed the greatest changes in the strength of the connections between the left dorsolateral prefrontal cortex (where TMS was administered) and the reward circuitry, specifically the left nucleus accumbens and caudate. In addition, researchers found that communication between the nucleus accumbens and cortical auditory (sound-processing) regions was also essential for the experience of musical pleasure. Brain regions work together—if the communication between the nucleus accumbens and other brain regions involved in hearing music is disrupted, individuals are less likely to experience pleasure from the music. If this communication is increased, people enjoy music more.

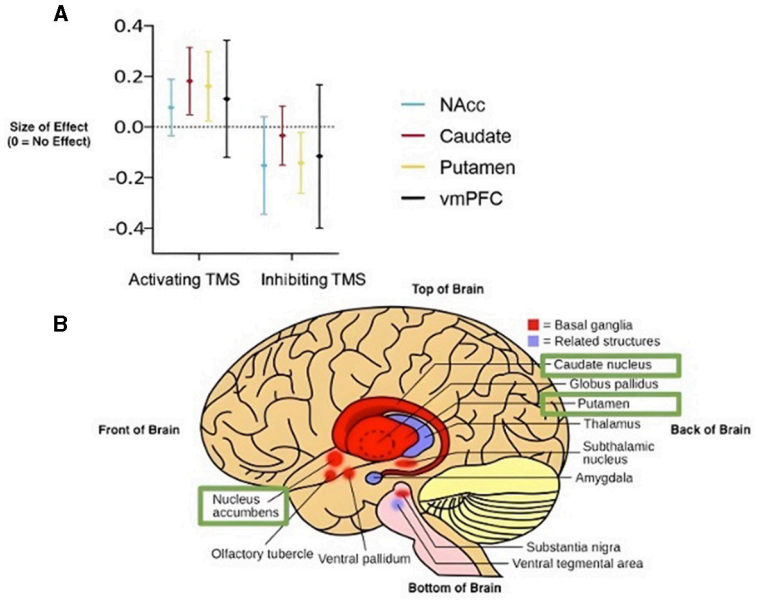

Figure 3

(A) During musical pleasure, results showed activation (i.e. Activating TMS) or inhibition (Inhibiting TMS) of the nucleus accumbens, caudate, and putamen. The *y*-axis shows the amount of the activation (positive number) and inhibition (negative number; adapted from Mas-Herrero et al. [4]). N Acc, nucleus accumbens; vmPFC, ventromedial prefrontal cortex. **(B)** Side view of the brain showing locations of the nucleus accumbens, caudate, and putamen—areas involved in reward and pleasure.

CHANGING BRAIN ACTIVITY CHANGES HOW WE FEEL ABOUT MUSIC!

These findings are extremely important because the cause of music's effects on the brain has finally been revealed—not only through correlations. This study demonstrated which brain regions are causing the feelings of pleasure people experience with music, not just showing which brain regions are active. In other words, this is the first study to show that, if you change these brain circuits, a person's emotional response to music will change, even if they really like music!

However, the study did have a few limitations. For example, 17 individuals is not a huge number, and there were a lot of differences between individuals in their responses to TMS. Further studies will be done to make sure these results are correct. Based on the results from the experiments we discussed, the researchers concluded that cortico-striatal pathways are needed to experience pleasure from music, because the researchers could disrupt the enjoyment of music by using TMS to turn that brain connection up or down. If they turned it up, people experienced more pleasure. If they turned it down, people experienced less pleasure. In conclusion, using technologies like TMS and fMRI can help researchers understand more about why people everywhere enjoy music.

ORIGINAL SOURCE ARTICLE

Mas-Herrero, E., Dagher, A., Farrés-Franch, M., and Zatorre, R. J. 2021. Unraveling the temporal dynamics of reward signals

in music-induced pleasure with TMS. *J. Neurosci*. 41:3889–99. doi: 10.1523/JNEUROSCI.0727-20.2020

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ARAN, AGE: 13
My name is Aran and I am 13 years old. I like to play soccer on my team and just with friends. I enjoy playing games, one of my favorite games is Zelda:Breath of the Wild. I am currently reading The Odyssey and I really enjoy it. I hope to one day become an

architect or a lawyer, I like STEM fields and debating. I find AI especially interesting and I think it will hugely impact many fields of research.

CARINA, AGE: 13

My name is Carina and I am 13 years old. I have many interests including soccer, music, reading, math, and science. I find science very fascinating, especially biology. My dream is to work in medicine. I am very interested in how our bodies work well and malfunction; I want to help people in the future achieve their best health. I am quite intrigued about how technology will improve our abilities to detect illness earlier and track how well therapies are working.

ERICA, AGE: 12

My name is Erica and I am 12 years old. I love video games, science and judo. My favorite game is Zelda, and I want to become a game director someday. In science, I like questioning new information and trying to figure out things I do not know based on what I do know. I also play judo, and I am currently an orange belt.

KALLIE, AGE: 13

My name is Kallie and I am 13 years old. I enjoy playing lacrosse on my team! I enjoy learning about neuroscience and I am interested in iPS cells. I participate in debate workshops. Some of my other hobbies are painting, reading, using Pinterest, and creating digital art! I am fascinated by butterflies, and all cats big and small. I am a member of my school's student council and school council. I love writing poetry and even won an award for one of my poems.

MARY, AGE: 13

My name is Mary and I am 13 years old. I do many sports including competitive Irish dance, softball, running, and sailing. I love doing anything with my friends and family. I am interested in human biology and physics. I hope to become a physical therapist someday. I also like learning about how animals communicate and interact with each other.

NORAH, AGE: 11

My name is Norah. I am 11 years old. I play the violin and really want to learn how to play the guitar. I like listening to Mitski and playing rhythmic games such as Colorful Stage. I enjoy drawing (especially manga), taking pictures of flowers and plants.

AUTHORS

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Patricia is a neuroscientist who works to help people with multiple sclerosis, Parkinsons' disease, and Alzheimer's disease. She also plays classical piano and studies how music can help the brain, especially in older adults and those with brain diseases. Her research has been published in important science journals. Patricia is also part of two non-profit organizations that support people with neurological disorders. She is passionate about making a difference in the lives of people with brain diseases around the world. *patinc91@gmail.com

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Alexandra (Alex) holds a Ph.D. in neuroscience and environmental toxicology from Michigan State University (Michigan, United States). She leads a scientist training program at a biotechnology company in San Francisco and is passionate about making science accessible to everyone. Her passion for neuroscience education, research, and mentoring has guided her professional journey and she has been actively engaged with mentoring the next generation of diverse scholars. When she has not working, Alex likes reading books and spending time outside with her family, exploring nature together.

ERNEST MAS-HERRERO

Ernest Mas Herrero is a neuroscientist at the Institute of Neuroscience at the University of Barcelona. He focuses on understanding how our brain translates music into pleasure. By studying how the brain processes music, Ernest aims to discover therapeutic uses for music and improve our understanding of the brain's functions. His research bridges neuroscience, psychology, and music, providing valuable insights into how music impacts our emotions and brain health.

ROBERT J. ZATTORE

Robert Zatorre comes from Buenos Aires, Argentina. As an adolescent he learned to play the organ, and then decided to study both music and psychology for his university studies. He is now the head of a laboratory at the Montreal Neurological Institute of McGill University, where he and his team study the how the brain allows us to perceive, produce, and enjoy music. In 2023 his book, "From Perception to Pleasure. The Neuroscience of Music and Why We Love It" was published by Oxford University Press.