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Interindividual differences in musical and rhythm imagery

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ABSTRACT

The study explores interindividual differences in rhythm imagery skills. In particular, we considered the effect of musical training, sensitivity to musical rhythm and auditory imagination abilities. Thirty-seven participants with limited musical training were asked to imagine the continuation of a rhythm and determine if a subsequent beep was on or off the beat. Their performance was correlated with scores from three questionnaires: the Goldsmiths Musical Sophistication Index (GOLD-MSI), assessing perceptual abilities and musical training; the Barcelona Auditory Imagery Scale (BAIS), measuring the ability of auditory imagination vividness and control; and the eBMRQ, evaluating music reward sensitivity. Results indicated that higher scores in reward sensitivity, musical training, perceptual abilities, and vivid auditory imagery were associated with better performance in the rhythm imagery task. Participants with greater sensitivity to music rewards also showed enhanced accuracy. However, the ability to control auditory imagery did not significantly affect task performance. These findings suggest that musical expertise, vivid auditory imagination, and reward sensitivity may enhance rhythm imagery, while control over imagery may be less critical.

CHAPTER ONE

1. MUSICAL IMAGERY

Imagery can be defined with several aspects. An experience that imitates actual experience is called imagery. Without experiencing the object, we can be conscious of "seeing" an image, "feeling" movements as an image, “tasting," tasting, or hearing a sound. In contrast to dreams, it occurs while we are awake and aware (White & Hardy, 1998). Another way to define imaging is as the mental or imaginative practice of a physical skill without using explicit muscle movement. The underlying premise is that one should produce or recreate an experience that is analogous to a specific physical event using the senses, which for a musician are primarily auditory, visual, and kinesthetic (Connolly & Williamon 2004). The capacity to envision sounds in situations where there are no audible sounds is known as musical imagery, or the use of imaginations by musicians. The process of imaging has given rise to several words. Terms like inner hearing, mental practice, aural or mental rehearsal, internal representations, visualization, and finger practice are frequently utilized. This variety of terms has caused some confusion in the meaning and understanding the imagery term. A lack of consistency exists in the elements of the imaging process, according to Morris, Spittle, and Watt (2005). Put differently, it appears that the emphasis of each term shifts according on the context in which the description of the picture is employed. The application of images to improve musicians' performances was the subject of early studies on the subject. According to Wright, D. M. (2009), the use of imagery in performance and practice, pre-experiencing performance scenarios, learning and memorizing music, developing, and improving expressivity during practice and performance, and aiding in the prevention and treatment of playing-related injuries are all being studied in current research.

According to the literature on auditory imagery, researchers have long evaluated subjects' skills to visualize sounds and patterns using tonal and musical stimuli. The larger picture has thus been illustrated by this work, which shows that individuals can distinguish between single-tone pitches, remember the loudness of brief musical passages, and, when asked, experience auditory stimuli using musical imagery (Zatorre & Halpern, 2005)

These lab-based auditory imagery investigations frequently use single tones, chords, musical scales, or unusual musical passages as stimuli; in real life, musical imagery rarely looks like these things. People might regularly repost musical images that they have heard recently or are familiar with. The use of musical imagery by musicians is said to support intricate creative objectives such mentally practicing repertory, foreseeing performance segments, and creating original compositions. Pervious research assessing musical imagery from an everyday point of view has highlighted specific varieties of experiences: involuntary musical imagery (INMI) or earworms has been investigated primary in the past years. INMI is a spontaneous and uncontrollable phenomenon, characterized by repetitiveness and Constance. A significant amount of work was done about INMI. Researchers usually ask subjects to report about their INMI of music that are in their heads and not coming out (Floridou & Müllensiefen, 2015; Halpern & Bartlett, 2011). The scale developed to assess individuals' INMI experience in daily life is "The Involuntary Musical Imagery Scale" (IMIS) (Floridou et al., 2015). IMIS is mainly focusing on the psychological investigation of everyday musical imagery with some expectations. INMI was investigated from different researchers; one of them was Bailes. In 2007 Balies conducted an experiment aiming to investigate the nature and traits of musical imagery, including instances that could be classified as involuntary musical imagery (INMI). With a sample of 11 music students at undergraduate and postgraduate levels. Participants were randomly contacted over the course of seven days to report their current experiences with musical images as part of the study's experience sampling procedure. This approach allowed for the capture of real-time data on the nature and characteristics of musical imagery as experienced in daily life. A significant portion of the reported episodes were classified as INMI, characterized predominantly by repeated fragments of tunes. This repetitive nature suggests that these musical fragments are particularly prone to recurring in the minds of individuals without conscious effort. One of the key findings was the high recognizability of the musical imagery, with 89 reported tunes being recognizable compared to only 18 unrecognizable ones. The high recognition rate highlights the close relationship between INMI and familiarity in long-term memory, suggesting that people who are familiar with music are more likely to hear it again unintentionally. 58% of participants reported that their INMI episodes were associated with music they had recently heard or performed. This suggests that recent exposure to music plays a crucial role in triggering INMI, reinforcing the idea that musical experiences linger in the cognitive processes and can spontaneously reemerge. In another study, Wammes and Barušs (2009) conducted an in-depth investigation with 67 volunteers to explore and classify the different dimensions of involuntary musical imagery (INMI) experiences, as well as the contexts in which these episodes occur. Using the Musical Imagery Questionnaire, the researchers gathered detailed information about participants' experiences with musical imagery, focusing particularly on the involuntary aspect. Through factor analysis of the questionnaire responses, they identified six distinct dimensions that characterize INMI experiences. Two notable dimensions emerged from their analysis: entertainment and completeness. The entertainment dimension suggested that INMI could play an effective role in daily life by providing mental engagement or amusement, particularly in conditions where external stimulus is minimal. This finding challenges the often-negative perception of INMI as merely an annoying or intrusive phenomenon, proposing instead that it can serve a positive function by keeping the mind entertained during mundane tasks. The completeness dimension indicated that INMI episodes might be linked to the individual's ongoing concerns or emotional states, reflecting current issues or preoccupations in their life. This dimension implies that the content of INMI is not random but can be personally relevant, offering insights into the individual's cognitive and emotional landscape, much like how dreams are analyzed in psychology. The study also aimed to understand the situational factors associated with the occurrence of INMI. By analyzing the contexts in which participants reported experiencing INMI, Wammes and Barušs were able to identify patterns and commonalities in these episodes. Their findings highlight the significant roles of memory and recent musical exposure in triggering INMI, with familiar and recently heard music being more likely to reemerge involuntarily.

The use of musical imagery as a compositional and performance tool is another facet of common musical imagery research. It includes the investigation of "hearing" musical representation in the inner ear, mentally performing music ad using musical imagery when composing music. This is entirely distinct from the experiences examined by INMI research since mental rehearsal and creation are guided by the active musical intentions of the performer.

A few studies have looked into topics related to everyday musical imagery. People were questioned by Williamson et al. (2012) about the origins of their earworms. The findings revealed the following four categories of themes: Affective States (when INMI is triggered by particular affective states), Memory Triggers (when INMI is triggered from memories, environmental stimuli, or anticipation of future events), and Low Attention States (the occurrence of INMI when there was low attentional demand). Previous research has concentrated on the format of INMI encounters; findings have indicated a range of pleasant, negative, and ambivalent feelings, as well as variations in the fidelity of the music in the INMI. However, these methods have concentrated on INMI rather than more on everyday musical imagery.

A dimensional approach can focus on theoretical similarities between different musical imagery experiences. It was proposed a five-dimension model to represent musical imagery: valence, repetitiveness, vividness, length, and mental control. In defining these dimensions, literature on everyday musical imagery has been investigated to see which aspects of musical imagery recurs (Floridou, Williamson, Stewart, & Müllensiefen, 2012)

Valence. It suggests the feeling of music playing in an individual's mind. In other words, it includes whether listening to music is enjoyable or desired as opposed to upsetting, uncomfortable, or undesired. This is a metacognitive component since it involves individuals assessing their mental conditions. Furthermore, valence which is defined as how pleasant, positive, loved, negative, and irritating musical imagery is has been quantified in numerous research on everyday musical imagery. These investigations have revealed a great deal of variety in valence: whereas some encounters with musical images are perceived favorably, neutral, or unpleasant experiences are also frequently seen. (Cotter et al., 2019)

Repetitiveness. It indicates if the music is played as an extended aural image or as a recurrent loop. According to Liikkanen (2011), there was a significant variation in the degree of repetitiveness. While half of the participants reported having non-repetitive INMI, the other half of the respondents said their INMI was repetitive. Furthermore, there is evidence from other studies that suggests musical imagery, both non-repetitive and repetitive, is common. Musical mind-pops are another phrase for non-repetitive experiences. Because they involve spontaneous, unbidden musical thoughts or tunes that pop into the mind without repetitive patterns. Unlike earworms, which typically involve a repetitive loop of the same musical fragment, musical mind-pops are characterized by their spontaneous and non-repetitive nature.

Vividness. it is a globally studied component of mental imagery. In the research on visual imagery, vividness has been examined using a variety of metrics, including the Vividness of Visual Imagery Questionnaires. The VVIQ is a self-report assessment tool used for evaluating an individual's level of vividness in their mental images. Additionally, it is frequently employed in psychological studies to evaluate individual variations in the capacity to create and modify visual representations. It can provide valuable insights into cognitive processes and is often used in studies related to creativity, memory, and visual thinking. Moreover, considerable study on vividness has been conducted in the more closely related field of auditory imagery research. The Bucknell Auditory Imaging Scale (BAIS) is a tool used to evaluate auditory imaging vividness. It uses prompts that center on vocal, musical, and ambient auditory scenarios. Additionally, BAIS is a self-report questionnaire that includes two subscales: BAIS-V for vividness and BAIS-C for control. BAIS-V, and performance on activities involving musical imagery are correlated. It has also been demonstrated that there is a substantial correlation between the BAIS-C and the results of a pitch discrimination task, in which participants had to choose which of two tones was higher in pitch.

Length. Two factors affect how long musical imagery lasts: the length of the entire musical imagery experience and the duration of the musical segment that is playing in the person's head. According to research, people's musical images might remain for a few seconds, four hours, days, or even forever. Length can also describe the duration of a musical segment that repeats. People report hearing parts of songs or songs in full, suggesting some diversity, although frequently they just encounter a small section or segment of the visual. The duration of musical sections is one of the items on the most recent Involuntary Musical Imagery Scale, and more recent studies indicate that section lengths have changed.

Mental Control. It is an important term in the emerging involuntary musical imagery research. It consists of two aspects: initiation and management. In much of the INMI research, it was stressed that musical imagery came to mind inadvertently and spontaneously. This sense of involuntary is known as initiation. However, the initiation of regular musical imagery experiences in non-musician samples has not been studied. Though the reasons for initiation may differ, it is likely that non-musicians initiate musical imagery. People have been instructed to consciously visualize a tone or musical phrase in certain neuroimaging studies. In other research, participants had to use musical imagery to accomplish a certain goal, which required them to initiate the experimental stimuli voluntarily. Few research has explicitly examined the management of commonplace musical imagery experiences; instead, management-related topics, such as the capacity to conduct intricate melodic transformations or alter the pitch of an imagined tone when directed, have been the focus of most investigations. Other studies in the lab have looked at the accuracy of the emotionality or loudness profiles of imagined music and discovered that when listening to the music, listeners are able to create and sustain musical pictures that reflect the profiles. When focusing on vividness, the BAIS which was previously mentioned includes a control subscale that evaluates people's capacity to modify created images (Cotter et al., 2019).

Another approach which claims to be the present research to assess musical imagery, in this study, the participants' musical imagery was studied using experience sampling methods (ESM), which means that the participants reported their internal experiences as they occurred. This approach avoids drawbacks of cross-sectional research designs that have participants respond to questionnaires concerning their usual frequencies of musical imagery, a procedure that tends to yield unreliable data because of the respondents' inability to recall momentary experiences. ESM snapshots the occurrence of such states, and yields more real-time and diverse information, while it reduces the impact of past or intense experiences which may affect their recall. Another field adopted ESM in musical imagery research showing that it is feasible. However, it has to be noted that in many of these studies (Beaman & Williams, 2013; Halpern & Bartlett, 2011; Hyman et al., 2015; Liikkanen, 2011) musical imagery was described as involuntary, or the sample size was considered small or consisted of specialized subjects. By using the ESM approach in this study, certain aims were hoped to be met; particularly, that recall bias would be minimized and a more extensive and diverse representation of musical imagery experiences would be captured. The authors (Beaman & Williams, 2013; Halpern & Bartlett, 2011; Hyman et al., 2015; Liikkanen, 2011) were focused on the within-person, episode-level variability not its between-person, variable mean level, therefore the best answer is ‘Event details. That is why although it was realized that some factors like individual differences related to music training, personality traits, and cognitive abilities were present between participants, the focus was made on within-person covariation to minimize their effect. Participants of the sample included professional players with different levels of musical training, such as music majors focusing on different areas such as performance, and education, as these people are most likely to employ musical imagery for specific purposes. Even though episodic musical imagery is rather a norm for most individuals, the study hypothesized that musicians’ objectives and training entail the diversification of the occurrence and kind of musical images. The study's main objectives were various. First, it looked at whether there were differences between the five aspects of musical imagery, especially in terms of start and management as aspects of mental control. Second, by digging deeper into the connections between various aspects of musical imagery, the research aims to increase our knowledge of the type and frequency of control that these experiences undergo (Cotter et al., 2019).

1.1RHYTHM IMAGERY

According to Cambridge dictionary, rhythm is defined as a strong pattern of sounds, words, or musical notes that is used in music, poetry, and dancing. Rhythm imagery is the tendency to imagine a rhythm when there are no rhythm or musical track presented. Examining the literature on the idea of auditory imagery instead concentrates on figuring out where it is likely to fit into the larger framework of human cognition because auditory imagery is a subset of mental imagery, it provides a perfect example of how complex the human mind is in its execution of function. Rhythm imagery is present in almost all domains of cognitive functioning ranging from memory especially reference and prospective memory through to volitional decision making, problem-solving, creativity, and even emotional regulation, interwoven into the fabric of our conscious experience. However, it is worth noting that auditory imagery remains a rather difficult subject even for imaginative analysis since it is mainly incorporated in surreptitious mode. Particularly, while visual imagery can be observed at the level of behavior or considering that a portion of it happens in mental images, auditory imagery makes sense given its function of existing strictly in the sphere of subjects' consciousness. This is due to the fact that aesthetics is a highly personal or subjective matter, making the effort to investigate it formally quite challenging: indeed, it is difficult to research on this topic using mainstream experimental methodologies. Thus, to test rhythm imagery some studies has employed. For this reason, there has been rising interest in decoding strategies and techniques that incorporated machine learning to determine patterns of auditory representation in the brain. These attempts have been fruitful and have provided substantial progress to the understanding of the neural aspects of auditory imagery. However, the definition of auditory imagery does not stop with mere activation in the areas of the brain involved in auditory processing but rather is a multifaceted construct associated with sensorimotor integration that forms the basis of our internal soundscape. This correlation between the auditory and the motor explains an aspect on how the sequence of events related to auditory imagery maybe controlled or influenced. Researchers have developed more complex methods to compare the brain activity patterns of mentally performed and listened to melodies in order to gain a deeper understanding of the intricate link between sound perception, imagery, and movement. Moreover, by incorporating rhythmic tapping with a visual metronome into the experimental setups, researchers will be able to gain a deeper comprehension of the intricate cognitive phenomenon by examining the impact of rhythmic motion on the nervous system's perception of auditory images.

Rhythm and reward topic was tackled in this research paper. Individuals are able to process rhythmic information from a variety of auditory inputs with differing degrees of rhythmicity with ease. The organization and patterns of sound and quiet durations and inter-onset intervals across time are referred to as rhythm (London, 2012; McAuley, 2010). It was referred throughout the paper that rhythm in music is rhythmic patterns that are built in a way that makes it possible to derive underlying temporal regularities like beat and meter. The connection between the rhythmic information acquired from the external musical signal and the listener's internal states facilitates the temporal synchronization of movements with external rhythmic events. Synchronization, or entrainment, is one of the primary ways that the ear engages with external rhythmic information. This process can be thought of as the link between the regularity detected in the external rhythm, such the beat or meter of a song, and internal oscillations or other sorts of innate timekeeper processes. Beat regularity has the ability to influence respiratory, cardiovascular, and even pupillary responses at varied tempi on a physiological level. Entrainment manifests itself at the behavioral level when listeners are able to sense a beat in music, take advantage of events happening on the beat (such as quicker processing), and move their bodies in rhythm with the beat. The phase of oscillatory brain activity adjusts at the neuronal level to the external rhythmic signal, perhaps instilling in the listener expectations about the timing of a specific occurrence.

Temporal expectancies are essential to entraining movement to rhythm because they activate the anticipation of when to begin a movement to be precisely coordinated with the music. They are a one of the main aspects of musical rhythm perception and have an impact on human perception and attention. The motor system and neural entrainment are closely related. Regular beats in rhythm stimulate motor pathways in the brain's sensory and motor regions, and motor activity is inherently connected to temporal expectations and entrainment. The different hierarchical degrees of entrainment that can be seen in both behavioral and neurological contexts are reflective of the hierarchical metric nature of musical rhythm (Zatorre & Salimpoor, 2013)

1.2 RHYTHM IMAGERY AND NEURAL CORRELATES

Several studies explore the construct of rhythm imagery while an individual is imagining a piece of music (Schulze & Koelsch, 2012; Jäncke & Shah, 2004; Bailes & Howe, 2016; Jones & Yee, 2015; Hannon & Trehub, 2005) Neuroscientists have searched functionalities in the human brain that can be responsible for the mentioned process. In the field of fMRI, EEG, and MEG, the researchers were able to get to the neural codes since there is a very close similarity between the samples of the activation maps of the real and imagined sounds. Such structures as the bilateral auditory cortex and the frontal/parietal cortical areas mean that auditory perception and imagery overlap at some neural levels (Hubbard & Cummings, 2019; Zatorre & Halpern, 2005) In other words, that sensation and basic perceptual processes are integrated with other complex cognitive processes. Research done by Okawa and collogues in 2018, investigates the neural mechanisms investigating the imagery of musical rhythms using EEG analysis. The purpose of the research is to determine whether brain entrainment to the visualization of rhythms can cause brain activity to synchronize with imagined rhythms in the absence of auditory stimulation. Nine participants were shown a visual stimulus that gave timing signals and instructed to visualize three different types of rhythm: unaccented beat, binary meter, and ternary meter. The study's findings revealed that participants' EEG signals exhibited distinct periodic responses that aligned with the imagined rhythms, despite the lack of any auditory input. This suggests that the brain can entrain to internally generated rhythmic patterns purely through mental imagery. Moreover, the study used Canonical Correlation Analysis (CCA) to classify and differentiate between various imagined rhythms based on their neural signatures and based on CCA- classification of the different rhythm types it was showed that it is possible to distinguish between various imagined rhythms based on their neural signatures. Different types of imagined rhythms produce distinct neural signatures, which can be detected and differentiated using EEG analysis. The amplitude spectra of the EEG data showed periodic responses corresponding to the rhythms being imagined, providing evidence of neural entrainment to rhythm imagery. This study provides a deeper understanding of how the brain processes rhythmic information through internal imagery and has potential applications in brain-machine interfaces (BMIs). By demonstrating that it is possible to decode imagined rhythms from neural activity, the research lays the groundwork for future developments in reconstructing perceived or imagined music from brain signals. Such advancements could have significant implications for neurofeedback, cognitive training, and rehabilitation, particularly for individuals with auditory impairments or motor disabilities (Okawa et al., 2017).

In another study done by Herholz and colleagues (2012). Participants were asked to mentally recreate recognizable tunes in their minds without actually hearing them. This task is often used to investigate the cognitive processes involved in musical imagery, which includes the ability to internally generate and manipulate musical representations. In the imaging assignment, subjects were told to close their eyes and see a well-known song being played. They were instructed to concentrate as intensely as they could on the melody, beat, and other elements of the song. The researchers used functional magnetic resonance imaging (fMRI) to track participants' brain activity while they completed the imagery task. They discovered that when people visualized music, the same brain regions were active as when they actually heard well-known songs. Particularly, during musical imagery, regions of the auditory brain that process auditory information were active. This suggests that the brain simulates the experience of hearing music even when it is only imagined. Additionally, regions associated with memory retrieval, such as the hippocampus, were also activated during musical imagery. This indicates that imagining familiar music involves accessing stored memory representations of the tunes. The findings suggest that musical imagery engages overlapping neural networks with actual perception of music, highlighting the cognitive processes involved in mentally recreating musical experiences. To sum up, it was found coherently activated brain areas throughout several studies. Auditory cortex activation is one of the most prominent activation: the brain simulates the experience of hearing music even in the absence of external auditory input. Different regions within the auditory cortex may be involved in processing different musical features, such as pitch, rhythm, and timbre, during the imagery process. Also, brain areas associated with memory retrieval were also activated during musical imagery. Specifically, the hippocampus, a brain structure crucial for the formation and retrieval of memories, showed increased activity when imagining a sound. This suggests that imagining familiar music involves accessing stored memory representations of the tunes, retrieving them from long-term memory and bringing them into conscious awareness. Musical imagery may also involve sensorimotor integration, as participants mentally simulate the act of playing or listening to music. In this process, even if there isn't any physical movement, the brain's motor planning and execution regions like the supplementary motor area are activated. Musical imagery also activates brain regions like the nucleus accumbens and amygdala that are linked to reward and emotional processing. This highlights the significant impact of music on the brain's reward system and implies that the emotional reactions, like pleasure or nostalgia, that are evoked by music can be felt even in the absence of actual auditory input. (Regev et al., 2021)

Furthermore, a study done by Lee and Seung-Schik in 2001 investigated the neural mechanisms underlying auditory imagery by employing event-related functional magnetic resonance imaging (fMRI). In order to shed light on the functional significance of these particular regions during auditory imagining tasks, this study set out to identify and map them. An adult population in good health was selected to participate in this study. In an fMRI machine, each participant completed a series of exercises involving auditory imagery. The experiment's architecture was painstakingly created to guarantee exact control and timing. With visual cues, participants were asked to visualize well-known songs and noises. These signals played a critical role in accurately mapping neural activation patterns by time-locking the commencement of the auditory imagery to the brain activity being recorded. As a baseline for comparison, the tasks were dotted with control circumstances in which individuals either rested or participated in mental activities unrelated to imaging. The event-related fMRI approach utilized in this work allowed for great temporal resolution, capturing the dynamic changes in brain activity associated with the beginning and maintenance of auditory imagery. The imaging data were examined using advanced statistical approaches to identify regions with substantial activity during the imaging tasks when compared to the control conditions.

The findings demonstrated significant activation in the primary and secondary auditory cortices during auditory imaging. When participants imagined sounds, these regions—which are often linked to the processing of real auditory stimuli showed significant activation. This discovery suggests that the regions of the brain responsible for auditory processing are engaged in both the generation of internal auditory experiences and the perception of external sound. The activation of these cortices provides a neurological basis for the vividness and realism of imagined sounds, indicating that auditory imagery depends on similar brain substrates to actual auditory perception. Moreover, the study also found greater activation in the parietal lobes and prefrontal cortex in addition to the auditory cortices. The auditory imagining tasks were connected with increased activity in the prefrontal cortex, which is recognized for its involvement in higher-order cognitive processes. This region's involvement in the executive features of mental imagery suggests that it is probably engaged in the planning, regulation, and manipulation of imagined sounds. The prefrontal cortex's involvement emphasizes how cognitively difficult auditory imagery is, requiring the coordination of memory, attention, and mental gymnastics. There was also noticeable activation in the parietal lobes, which are linked to attention and spatial processing. This activation implies that auditory imaging includes spatial and attentional elements required to construct a coherent and contextually appropriate auditory scene, in addition to the production of sound. When imagined sounds are positioned inside a spatial context, auditory imagery is multimodal and integrative, as evidenced by the activation of the parietal lobes. The study's conclusions have a significant impact on how we comprehend mental imagery and the brain processes that underlie it. Similar brain pathways are thought to be involved in both auditory perception and auditory imagining because of the overlap in activation patterns between the two processes. This overlap demonstrates the versatility and flexibility of neural networks involved in sensory processing and illustrates the brain's ability to produce detailed sensory experiences only from memory and imagination (Yoo et al., 2001).

Assaneo et al. (2019) found that those who entrained to normal speech with ease exhibited a distinct white matter architecture compared to those who did not entrain. Possible additional neural correlates related to sources of variation in rhythmic skills include neural responses at early stages of auditory processing (e.g., brainstem responses) and the degree of connectivity between higher-level auditory and motor cortical regions, as well as regions supporting higher-level cognitive and social processes (Chen et al., 2006, 2008; Heggli et al., 2021; Tierney et al., 2017).

CHAPTER TWO

INTERINDIVIDUAL DIFFERENCES IN RHYTHM IMAAGERY AND REWARDS

2.1 REWARD SENSITIVITY

Apart from their varying rhythmic skills, people also range in how sensitive they are to rewards in general and music rewards specifically. The population's sensitivity to rewards in music has been demonstrated to differ, as demonstrated by a subgroup of individuals with musical anhedonia, is at least partially autonomous from general reward circuitry (Belfi and Loui, 2020; Mas-Herrero et al., 2018). To take advantage of the potential benefits of the rhythm-reward link for memory and social interaction, it is probably necessary for an individual to have a sufficiently developed sensitivity to (musical) reward in addition to the ability for rhythmic activity. It is true that, in terms of social behavior and learning, not everyone benefits from musical rewards in the same manner. First, listening to music that makes you happy can help you remember things better, including irrelevant information and the music itself. However, this effect varies depending on how sensitive you are to rewards; the stronger your sensitivity, the better your memory (Ferreri and Rodriguez-Fornells, 2022). Second, people's enjoyment of the music that synchronizes conduct with rhythm determines how beneficial the behavior is to society (Stupacher et al., 2020). Thus, any benefits of rhythmic reward for memory and social bonding may depend on the variation of sensitivity to rhythmic reward from an individual differences point of view. These results may be the result of decreased sensitivity to reward, decreased rhythmic aptitude, or decreased enjoyment of a particular musical composition.

In this context, we aim to examine the literature on rhythm and reward. According to studies, music activates the brain's reward system and is generally seen as gratifying (Zatorre, 2015). According to Ferreri et al. (2019), Mas-Herrero et al. (2021), Salimpoor et al. (2011), 2013; Zatorre (2015), and others, the dopaminergic reward system in the brain is activated when listening to music, producing a joyful (hedonic) and motivated response. Despite the fact that musical reward is an essential component of musical emotion (Goupil and Aucouturier, 2019) and that musical emotion is closely linked to its rhythmic element. The investigation about the connection between music, rhythm and reward is a bit recent in the scientific research (Fiveash et al., 2023). The most recent assessment, by Zatorre (2015), concentrated on a few facets of this relationship (music and reward). The reasoning on the finding was based on that previous studies have examined the following relationships: a) rhythm and learning and memory (through temporal regularities) as well as rhythm and social connection (through interpersonal synchronization); b) reward and learning and memory as well as reward and social connection. The relationship between rhythm and reward, however, and how they might work together to enhance learning, memory, and social ties is the subject of some small-scale studies. The researchers' goal was to bring these several domains, which addresses how these discoveries might be used to 1) study individual variations, 2) apply clinical settings, 3) study development, and 4) make connections with animal studies.

Rhythm and reward topic was tackled in this research paper. Individuals are able to process rhythmic information from a variety of auditory inputs with differing degrees of rhythmicity with ease. The organization and patterns of sound and quiet durations and inter-onset intervals across time are referred to as rhythm (London, 2012; McAuley, 2010). It was referred throughout the paper that rhythm in music is rhythmic patterns that are built in a way that makes it possible to derive underlying temporal regularities like beat and meter. The progressive matching of with external rhythmic events and movements is promoted by the interaction between the rhythmic information retrieved from the external musical signal and the listener's interior states. One of the main ways that the listener interacts with external rhythmic information is through synchronization or entrainment. This process can be seen as the link between the periodicity experienced in the external rhythm, such the beat or meter of a song, and internal oscillations or other sorts of endogenous timekeeper processes. Beat regularity has the ability to influence respiratory, cardiovascular, and even pupillary responses at varied tempi on a physiological level. Entrainment manifests itself at the behavioral level when listeners are able to sense a beat in music, take advantage of events happening on the beat (such as quicker processing), and move their bodies in rhythm with the beat. The phase of oscillatory brain activity adjusts at the neuronal level to the external rhythmic signal, perhaps instilling in the listener expectations about the timing of a specific occurrence.

Various people's rhythmic ability may have various effects on the reward experience. First, variations in rhythmic aptitude may influence a person's capacity for interpersonal synchronization, which in turn may influence the reward that may arise from engaging in social conduct (Fiveash et al., 2023). Research on sensorimotor synchronization has revealed that differences between individuals in anticipation and temporal adaptation abilities are linked to unique neural signatures and various aspects of personality, including locus of control and empathic perspective taking (Fairhurst et al., 2014; Novembre et al., 2019; Nozaradan et al., 2016). These correlations may impact social interaction dynamics, such as leader-follower dynamics and the extent to which synchronizing with specific people is socially beneficial. Accordingly, relationships between temporal prediction skills and interpersonal synchronization proficiency (Pecenka and Keller, 2011) might affect how social connection via rhythm affects reward. First, people's level of enjoyment in response to music may vary according on their level of rhythmic ability (Fiveash et al., 2023). Second, the degree to which people enjoy music differently may be influenced by disparities in rhythmic ability. (Fiveash et al., 2023). The degree to which reward networks are triggered at the brain level during synchronization activity is contingent upon the participant's ability to maintain rhythm (Kokal et al., 2011). Additionally, research has demonstrated that listening to music that is culturally known to an individual may increase or decrease functional connection between auditory and regions responsible for reward in general (Guo et al., 2021). Remarkably, recent research revealed that groove scores are more closely linked to people's perceptions of beat synchronization than they are to measured synchrony and syncopation (Matthews et al., 2022). This research paints an even more nuanced picture, suggesting that individual differences in both perceived and actual rhythmic abilities may be the primary source of the joyful response to music.

Research on music-driven affect indicates that rhythm is significant because it stimulates arousal and fosters a sense of community, both of which are intimately tied to reward systems. It also may lead to rhythmic entrainment, depending on the rhythmic pattern (Zatorre, 2015). According to some literature (Juslin, 2013; Trost and Vuilleumier, 2013), the temporal patterns of music can modulate physiological entrainment processes linked to respiration rate and heart rate, hence causally causing musical emotion. Empirical assessments of valence, arousal, and enjoyment have demonstrated that rhythmic characteristics of the input, like the perceived intricacy or syncopation of the beat, can influence subjective emotional measurements. Importantly, rhythm in music has the ability to precisely modify reward responses in addition to impact responses like valence and arousal. On the other hand, research on emotional-affective reactions to rhythm has typically focused on perception (Gabrielsson and Lindstrom, 2010; Gundlach, 1935; Keller and Schubert, 2011). Reward reactions are tightly linked to movement through sensorimotor synchronization, physical entrainment, and groove. Therefore, research on the groove experience shows that rhythm, movement, enjoyment, and prediction are closely related (Janata et al., 2012; Matthews et al., 2020; Vuust and Witek, 2014). The finding that people find rhythms of intermediate complexity to be more enjoyable (Kraus and Hesselmann, 2021; Vuust and Witek, 2014) may be due to a domain-general characteristic of statistical inference learning, which finds optimal learning rates for stimulus complexity that is intermediate and hence more valuable (Erle et al., 2017). This shows that universal mechanisms relating reward and prediction may be the source of music's hedonic qualities.

The significant movement-inducing component of rhythm further confirms the relationship between reward and rhythm, which is further supported by psychometric tests designed to detect individual differences in reward sensitivity. The Barcelona Music Reward Questionnaire (BMRQ) (Mas-Herrero et al., 2013) is a useful tool for measuring musical reward with reliability. It has been linked to both neuronal and psychophysiological responses related to musical reward (Ferreri et al., 2019; Mas-Herrero et al., 2014). In order to assess a person's sensitivity to musical reward, or musical hedonia, the BMRQ considers several of musical experiences. The sensory-motor subscale has strong connections with other subscales related to musical enjoyment, including emotion evocation, mood management, musical desire, and social reward experience. It also significantly contributes to characterizing the complex reward experience during music listening. The sensory-motor subscale particularly reflects the capacity to voluntarily and instinctively coordinate simple or complicated bodily motions (e.g., from toe tapping to dancing) to a rhythmic beat. This demands the matching the somatosensory motor brain networks with auditory processing networks (Mas-Herrero et al., 2013).

It is also possible to test brain responses to music reward using BMRQ. A wide variety of brain regions, including the cerebellum, premotor cortex, supplementary motor area, and basal ganglia, have been linked to rhythm processing at the neurological level. Most importantly, these areas also exhibit robust connections to the reward system (for example, the striatal-beat model connects interval timing and the reward system). (Grahn, 2012, Schwartze et al., 2012). The cerebellum and the basal ganglia, in particular the putamen and the caudate nucleus, emerge as central locations and the primary neural correlates of beat perception and interval timing among these activations. (Grahn, 2009; Nozaradan et al., 2017; Teki et al., 2011; Thaut et al., 2008). The extensive neural network of subcortical and cortical regions that are activated by music reward responses includes the basal ganglia, specifically the ventral striatum, which contains the nucleus accumbens as well as its dorsal part, which consists of the putamen and the caudate nucleus (Zatorre, 2015), the insula, the superior and inferior temporal gyri, the anterior and ventromedial prefrontal cortices, and other brain regions (Mas-Herrero et al., 2021). More specifically, it has been shown that the caudate nucleus and putamen process musical structure, rhythm creation and perception, anticipation of musical pleasure, groove perception, and chill reactions when listening to music (Janacsek et al., 2022 Stockert et al., 2021) Trost and colleagues (2014) examined whether the pleasantness of music affects rhythmic entrainment and discovered that, when compared to less pleasant here implemented as dissonant music short clips of more pleasant music facilitated rhythmic processing and increased activity in the caudate nucleus. Also, according to Matthews et al. (2020), pleasant-medium complexity rhythms influenced both motor and reward brain networks, and the nucleus accumbens, caudate, and putamen were associated with feelings of pleasure and the desire to move (Stupacher et al., 2022). It should be noted that, outside of the literature on music cognition, connections between the cerebral cortex, cerebellum, and basal ganglia have been hypothesized to demonstrate a close relationship between cognitive, motor, and affective areas in the brain (Bostan and Strick, 2018).

In relation to rhythmic reward, it is clear that the framework mentioned above would also apply to study on individual differences as Ferreri, Fiveash, Mas Herrero, Zatorre et al. (2023) demonstrated that. Individual variances in reward sensitivity and rhythmic skills, as well as social behavior characteristics (e.g., empathy), may have a variety of effects on the interaction between rhythm, reward, memory, and social behavior. Everyone agrees that one of the most enjoyable stimuli is music, and that it plays a significant part in mood regulation and emotion evocation. That being said, music is abstract and does not immediately communicate any obvious natural advantage, in contrast to other aesthetic stimuli like sex or food. Empirical research utilizing behavioral measures has demonstrated that listening to music can elicit emotional reactions that are correlated with physiological modifications.

However, little is known about individual differences in how people experience reward in music- related activities. There could be a number of reasons for the unique variations in music reward that people feel. For instance, everyone agrees that music has the power to profoundly affect people's emotions (Mas-Herrero et al., 2012).

2.1.2 BMRQ

Providing a thorough and nuanced knowledge of the different elements that explain the individual variances in how people perceive rewards from music is the main objective of Mas-Herrero's and his colleagues' study. The Barcelona Music Reward Questionnaire (BMRQ), a novel psychometric instrument, is introduced by the study in order to accomplish this. The purpose of this questionnaire is to document the various dimensions of reward experiences associated to music and to provide an explanation for the observed interindividual variation in these experiences. The BMRQ was constructed in the first investigation by the researchers using a large pool of 112 items. These products were made to encompass a wide range of scenarios and actions related to music and rewarding experiences. The initial items of the questionnaire underwent exploratory factor analysis to verify its validity and reliability. This procedure assisted in the selection of 20 items free from acquiescence and social desirability biases. Next, using an online platform, a sizable sample of 804 Spanish individuals were given the finished BMRQ. Professional musicians and non-musicians were represented in this sample, guaranteeing a wide variety of answers. On the other hand, the goal of the second study was to further validate the BMRQ. A fresh sample of 605 Spanish university students was given the questionnaire. The researchers made sure this new group was more representative of the overall population in order to prevent any biases from the previous sample. Both exploratory and confirmatory factor analysis were used to assess the data. To guarantee that both halves of the sample were equally representative, the sample was divided using the DUPLEX method. This meticulous method validated the BMRQ's factor structure and dependability, enhancing its generalizability to a variety of demographics. Moreover, In the third trial, an online platform was utilized to administer the BMRQ to a global sample of 252 people after it was translated into English to assess the BMRQ's generalizability across linguistic and cultural contexts, this step was essential. The instructions did not specifically state that the study was about music to reduce potential biases. In order to generate a more unbiased sample, the majority of participants (73.8%) were not aware that the questions were explicitly related to music. The BMRQ's robustness in a variety of cultural contexts was demonstrated by the confirmatory factor analysis on the English version, which revealed that the factor structure was consistent with the Spanish version. The fourth study further refined the factor loadings and scores by combining information from the third and second studies. The factor structure of the BMRQ was confirmed to be valid and trustworthy across a sizable and varied sample through this thorough investigation, which involved 857 people in total. The reliability estimates for each of the BMRQ's five scales were calculated, and the scores earned by participants who spoke Spanish and English were compared. The results showed that the component structure remained the same in all populations, indicating that the BMRQ is a useful tool for assessing musical reward experiences.

Five major components of music reward are identified by the BMRQ: Musical Seeking (the desire to discover new music), Mood Regulation (the use of music to control emotions), Emotion Evocation (the capacity of music to evoke emotions), Sensory-Motor (the body's reaction to music), and Social Reward (the function of music in fostering social cohesiveness and bonding). These characteristics illustrate the richness of pleasure experiences associated to music and capture the different ways in which it can be gratifying to individuals (Mas-Herrero et al., 2012).

The study also looked at the connection between other reward-related domains, such physical and aesthetic pleasures, and music reward. In addition, the BIS/BAS scales which assess behavioral inhibition and activation, the Physical Anhedonia Scale (PAS), which assesses openness to experience were given to the participants to complete. The researchers were able to examine whether the ability to experience benefits in other areas is linked to a tendency to seek rewards in music thanks to their all-encompassing strategy.

The study offers insightful information about how people's experiences with music reward vary from person to person. The research provides a trustworthy instrument for gauging these variations by creating and validating the BMRQ. Given that individual heterogeneity in music reward experiences can be used to better adapt therapeutic techniques to fit unique needs, the findings have significant implications for individualized music therapy. Also, by illuminating the intricate interactions between personality, culture, and brain mechanisms that shape our musical experiences, the study advances our comprehension of the universal yet intensely personal attraction of music.

2.2 MUSICAL TRAINING

Basic synchronization and rhythm perception in humans seem to develop naturally without musical training. These abilities are improved by music theory (eg.learning how read musical notes) (Rammsayer et al., 2012), and there are significant individual variations in rhythm perception and production throughout development as well as among healthy adults. Dedicated test devices that often measure multiple components of rhythm processing can be used to evaluate these discrepancies. Different musical experiences and training may account for some of this individual variance, while genetic variables that affect the development of brain structures and functions that support rhythmic talents may account for another portion. The term "musical training" describes organized, formal music education or practice. It includes a broad range of exercises meant to enhance different musical abilities, comprehension, and knowledge.

Furthermore, comparing subgroups showed that individuals who started their musical training earlier had a larger region in this area. The authors (Gärtner, M., Schmidt-Wilcke, T., & Fiebelkorn, D., 2013) made the observation that the observed anatomical difference must be interpreted in light of the necessity for enhanced interhemispheric communication that underlies musicians' intricate bimanual motor sequences. The size of the right and left motor cortices in right-handed musicians and non-musicians was assessed by (Gärtner et al., 2013): both groups had a leftward imbalance as predicted, however musicians displayed a reduced degree of asymmetry due to their larger right motor cortex. The age at which a person started practicing music was also found to be negatively correlated with the size of the motor cortex in both hemispheres. According to Gärtner, M., Schmidt-Wilcke, T., & Fiebelkorn, D. study, early hand skill training that results in structural conformity is what causes the physical differences in the motor cortex. Furthermore, (Schlaug and Gaser,2003) utilized voxel-based morphometry analysis, a method that permits the identification of structural differences throughout the whole brain space, to discover that musicians' motor, auditory, and visuospatial cerebral regions had larger gray matter volumes. According to Rodrigues et al. (2007), the authors' argument that the data demonstrate structural alterations in response to long-term skill acquisition and repeated rehearsal of these skills is supported by their finding of a significant association between structural differences and practice intensity.

One of the main tests that can assess musical training is The Goldsmiths Musical Sophistication Index (Gold-MSI) (Müllensiefen et al., 2014).The Gold-MSI is a thorough and popular self-report questionnaire used to evaluate musical expertise in several ways. It was created as a component of the Goldsmiths Music Sophistication Index project at Goldsmiths, University of London. In order to capture the complex nature of musical sophistication, the Gold-MSI attempts to measure a wide range of musical behaviors, abilities, and experiences. The purpose of the Gold-MSI is to offer a valid and trustworthy way to measure individual differences in musical complexity. It acknowledges that musical talent encompasses a range of activities and abilities related to music rather than just professional training or performance. The Goldsmiths Musical Sophistication Index (Gold-MSI) consists of several subscales that target different aspects of musical sophistication, encompassing a total of 38 items in the full version and 15 items in the shorter version. The main dimensions assessed by the Gold-MSI include musical training, perceptual abilities, singing abilities, emotions, and general sophistication. The musical training dimension involves formal education and the extent and duration of practice on musical instruments or singing. Perceptual abilities assess listening skills, including the ability to recognize and differentiate between musical elements such as pitch, rhythm, and harmony, and ear training, which evaluates the ability to identify musical structures and features by ear. Singing abilities are measured through self-reported vocal skills, assessing the ability to sing in tune and maintain pitch. The emotions dimension measures emotional connection and sensitivity, evaluating how individuals use music to express and regulate emotions and how deeply they are affected by music emotionally. Finally, the general sophistication dimension evaluates overall musical engagement, including listening habits, concert attendance, and involvement in musical activities, as well as creativity in composing or improvising music. These dimensions collectively provide a comprehensive assessment of an individual's musical sophistication.

2.2.2 GOLD-MSI

The Goldsmiths Musical Sophistication Index (Gold-MSI) is a comprehensive tool developed to assess an individual's level of musical sophistication across various dimensions of musical experience and ability developed by Müllensiefen, Gingras, Musil, and Stewart in 2014 at Goldsmiths, University of London. It offers a multidimensional approach to measuring musical engagement, beyond the traditional focus on formal training. Along with several other factors, including perceptual abilities, emotional responses, and everyday musical activities. The Gold-MSI was designed to accommodate individuals with varying levels of musical experience, from professional musicians to those with no formal musical training. Its plasticity makes it particularly valuable for research, as it gives the space for researchers to assess professional musicians and individuals with no musical background with the same assessment tool. A 38 self-report items make up the Gold-MSI, which measures various facets of musicality across five subscales; Active engagement, perceptual abilities, singing abilities, musical training, and emotions. The subscale for musical training assesses the level of formal musical education, taking into account factors such the duration of time spent studying a musical instrument or singing, the frequency of practice sessions, and involvement in organized musical events. The second subscale is the perceptual abilities, and that subscale assesses a participant’s ability to perceive musical elements, such as melody, harmony, and rhythm. In other words, this subscale captures a person’s quickness in learning for identifying musical structures even without formal training. The Singing Abilities subscale is one of GOLD-MSI subcales which is a self-reported proficiency in singing, including pitch accuracy and performing vocally. Participants are asked to rate their vocal skills in both informal settings and more structured environments. Moving forward to another subscale which is the active engagement subscale; evaluates the extent to which individuals engage with music in their daily lives. To illustrate, activities such as attending live concerts, listening to music etc… Finally, the emotions subscale focuses on the emotional responses individuals have to music, as exploring the depth of emotional connection experienced while listening to music.

The Gold-MSI has been widely used in research to explore topics such as the relationship between musical training and beat perception. Urte Cinelyte's and his collegues in 2022 introduction of the Beat-Drop Alignment Test (BDAT) is a noteworthy development in this field of study. Researchers investigated relationships between participants' self-reported musical complexity and their performance on tasks requiring implicit beat detection by combining the Gold-MSI with the BDAT. Researchers can measure participants' emotional engagement with music, perceptual skills, and degree of musical training, among other things, using the Gold-MSI. Researchers can find complex relationships and possible predictors of beat perception abilities by looking at correlations between Gold-MSI subscales (like emotional engagement, perceptual abilities, and musical training) and BDAT performance metrics (like accuracy in beat alignment and response variability). In order to further our understanding of beat perception in music cognition research, the Goldsmiths Musical Sophistication Index and the Beat-Drop Alignment Test have been integrated (Cinelyte et al., 2022)

2.3 AUDITORY IMAGERY SKILLS

The complex relationship between individual differences in auditory imagery abilities and their related neurological and behavioral manifestations is examined in the work "Differences in Auditory Imagery Self-Report Predict Neural and Behavioral Outcomes" by Andrea R. Halpern 2015 The ability to mentally recreate sounds in the absence of outside auditory stimuli is known as auditory imagery. This ability can be used to imagine rhythms, melodies, or even ambient noises. This skill affects how people interpret and engage with music and other auditory events profoundly and varies greatly across individuals. Halpern's study's main goal was to ascertain the relationship between variances in brain activity and performance on tasks involving auditory imagery and self-reported disparities in auditory imagery ability. In order to do this, a wide range of subjects were enrolled in the study and their auditory imagery skills were evaluated using the Bucknell Auditory Imagery Scale (BAIS). Vivdness and control, two important aspects of auditory imagery, are measured by the extensive self-report questionnaire known as the BAIS. The participants scored how well they could manage their auditory images and imagine noises. Participants performed exercises intended to evoke auditory images while undergoing functional magnetic resonance imaging, or fMRI. One of the objectives was to imagine tunes and then mimic them by tapping out the rhythm or singing along. The fMRI data highlighted brain activation patterns related to the activities, offering insights into the neurological correlates of auditory imagery. The superior temporal gyrus and the auditory cortex, two brain areas involved in auditory processing and imagery, were shown to be more activated in people who self-reported having higher talents in auditory imagery. These areas are well-known for their functions in facilitating mental sound modeling and processing auditory information. The study looked at auditory imagery's behavioral effects in addition to brain measurements. Accuracy and speed were used to assess participant performance on tasks that involved manipulating and reproducing imagined sounds. The results showed that people with higher BAIS scores did better on these tasks. In particular, they responded faster to activities requiring rhythmic tapping and were more accurate in mimicking imagined tunes. This implies that increased brain activity and improved performance on auditory activities are both related to higher auditory imagining abilities. Significant individual differences in auditory imagining abilities and their effects on brain activity and behavioral performance are highlighted by the study. Higher BAIS scores are indicative of enhanced auditory imagining ability, which is associated with more effective brain processing in regions essential for auditory perception and memory. These results demonstrate the validity of self-reported auditory imagery measures in predicting neurological and behavioral outcomes, offering researchers a useful instrument to evaluate individual variations in this cognitive domain. Furthermore, the study's ramifications go beyond fundamental research to include possible uses. For example, therapies targeted at enhancing musical training and rehabilitation programs for people with auditory processing problems can benefit from an awareness of individual variability in auditory imagery. Teachers and therapists can modify their methods to improve auditory imagery abilities in different populations by determining the behavioral and neurological indicators linked to high auditory imagery capacity (Halpern, 2013)

CHAPTER THREE

3.EXPERIMENT

This experiment aims to investigate musical reward sensitivity and rhythm imagery abilities. By using the eBMRQ to assess participants' sensitivity to music reward, the study could explore whether individuals who derive greater emotional reward from music exhibit enhanced rhythm imagery abilities, reflected in their performance during rhythmic tasks. Moreover, it investigates the impact of musical expertise on rhythm imagery. Through the Gold-MIS, the study could aim to determine whether higher levels of musical training or expertise correlate with stronger rhythm imagery abilities, as demonstrated by the accuracy and speed in mentally recreating and categorizing rhythmic patterns. As well as to assess the role of auditory imagery in rhythm-based tasks as using the BAIS, helps the study to explore whether individuals with more vivid auditory imagery are better at mentally simulating and categorizing rhythmic patterns, linking auditory imagination to rhythm imagery abilities. Lastly and most importantly the study aims to explore individual differences in rhythm imagery processing: as we used different questionnaires assessing musical reward sensitivity, expertise, and auditory imagery.

3.1 PARTICIPANTS

37 neurologically healthy volunteers took part in the study (6 males, mean age = 23.73 ± 3.04 years). All participants were non-musicians, having received less than three years of formal or informal musical training. The experimental protocol was approved by the local ethical committee of the University of Pavia (Ethical Committee Prot. 132/23) and participants were treated in accordance with the Declaration of Helsinki. We removed the participant 29 because only the responses of only 33 trials over the total (180), were recorded. In addition, we removed the answer given 50ms after the beep presentation, due to impossibility of processing information in such a small window. Lastly, we removed the observation in which participants answer differently before and after the beep presentation. In total 213/6450 observations were excluded.

3.2 METHODS AND PROCEDURES

Prior to the procedure, participants filled in 3 questionnaires: the eBMRQ (Cardona et al., 2024) assessing measures individuals' sensitivity to music reward; the Gold-MSI (Müllensiefen et al., 2014) to evaluate musical expertise in several ways; the BAIS (Halpern, A. R.,2015) was used to assess the ability to mentally recreate sounds in the absence of outside auditory stimuli is known as auditory imagery. The task we used was adapted from the Beat Drop Alignment Test (BDAT) (Harrison & Müllensiefen, 2018) In this task, participants hear brief musical excerpts composed in the style of contemporary electronic dance music (EDM) using Ableton Live 10, with no vocals, diverse instrumentation, and a tempo of 125 bpm. Each excerpt consists of six bars of music. During the fourth bar, a beat-drop occurs (a brief absence of rhythmic musical cues), and a probe sound (a woodblock pitched at F2) is played. This probe sound can either be aligned with the underlying beat (ON condition) or misaligned (OFF condition). In the OFF condition, the displacement of the probe varies, with several possible shifts away from the beat, ranging from 15% to 45% of the beat period. Participants are tasked with identifying whether the probe is on or off the beat, with correct answers scoring 1 point. The goal is to assess participants' ability to detect whether a rhythmic event is aligned with the beat or displaced. In this paradigm, participants listen to 30 musical clips and respond whether the probe is on or off the beat.

Same as we used in our rhythm imagery task, only the first five seconds of each melody will be presented. Following this time, there will be a silent gap of ~4 s, during which participants will be instructed to imagine the continuation of the rhythm. After the silent gap a beep will be presented as a test stimulus. This is either on the beat or shifted (600 msec before or after the real beat). Participants will be required to respond as fast and as accurate as possible in a forced-choice task (response alternatives: on-beat or off-beat) The response keys were counterbalanced across participants. Six practice trials were included at the beginning of the task and feedback ("incorrect") was displayed only after wrong responses. Participants will not see the feedback after practice trials. Trial started with a fixation cross, after which the auditory stimulus was presented. Participants were asked to categorize the beep sound as 'on beat' or 'off beat' compared to the musical rhythm, quickly and accurately as possible by pressing the "A" or "L" keys on the keyboard. Short breaks were incorporated every 60 trials. The order of presentation of stimuli was randomized. Stimuli were binaurally delivered using headphones. The software Eprime was used for stimuli presentation and data collection. The entire experiment lasted approximately 1 hour, including instructions, short breaks, and questionnaires.

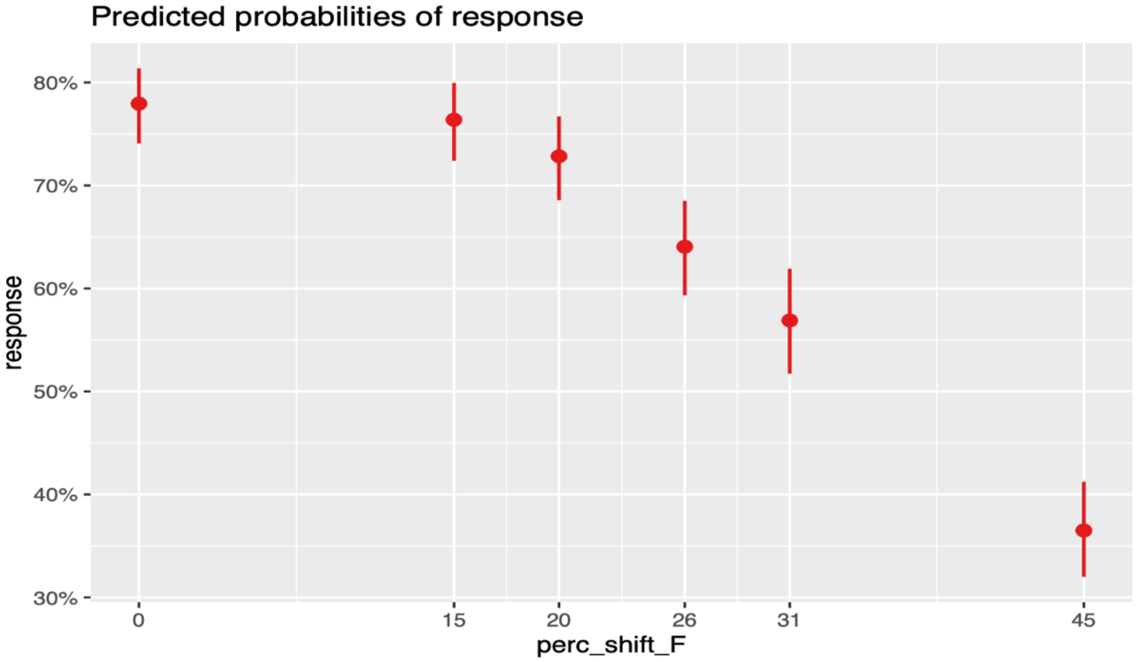
3.3 STATISTICAL ANALYSIS

The focus of statistical analyses was predicting the binary responses (0 = off-the-beat, 1 = on-the-beat), using different sets of independent variables. To account for binary dependent variable and the nested structure of the data (within participant and within trial), we fitted a multilevel logistic regression model (Gelman & Hill, 2006) predicting the percentage of on-beat responses by the degree of alignment of the beep. The same model was performed including as predictor also the interaction between the degree of alignment and each questionnaire scoring. To facilitate interpretation of main effects, questionnaire scorings were standardized with M = 0 and SD = 1, before entering the model. All models included random intercepts per participant and per trial, to account for both individual differences in response styles and stimulus characteristics. Models were fitted using package lme4 (Bates et al., 2015) in the R statistical language (R Core Team, 2023). R2 for multilevel models was estimated using package performance (Lüdecke et al., 2021; Nakagawa & Schielzeth, 2013). The main effect model revealed a significant effect of degree of alignment (chisq(5) = 506.50, p < .001; Marginal R2 = .103 .084, Conditional R2 = .155), indicating that the probability of responding that a stimulus was on-beat increases with the degree of alignment, as expected (see Figure 1). Post-hoc analysis using Holm correction are reported in the table no. (1).

Comparison	**Chisq**	**P value**
0-15	.74	.388
0-20	7.47	.018
0-26	48.65	p < .001
0-31	91.77	p < .001
0-45	340.43	p < .001

15-20	3.50	.122
15-26	37.68	p < .001
15-31	77.54	p < .001
15-45	315.11	p < .001
20-26	18.51	p < .001
20-31	50.51	p < .001
20-45	262.30	p < .001
26-31	9.68	p < .001
26-45	152.63	p < .001
31-45	74.47	p < .001

Table no. (1)



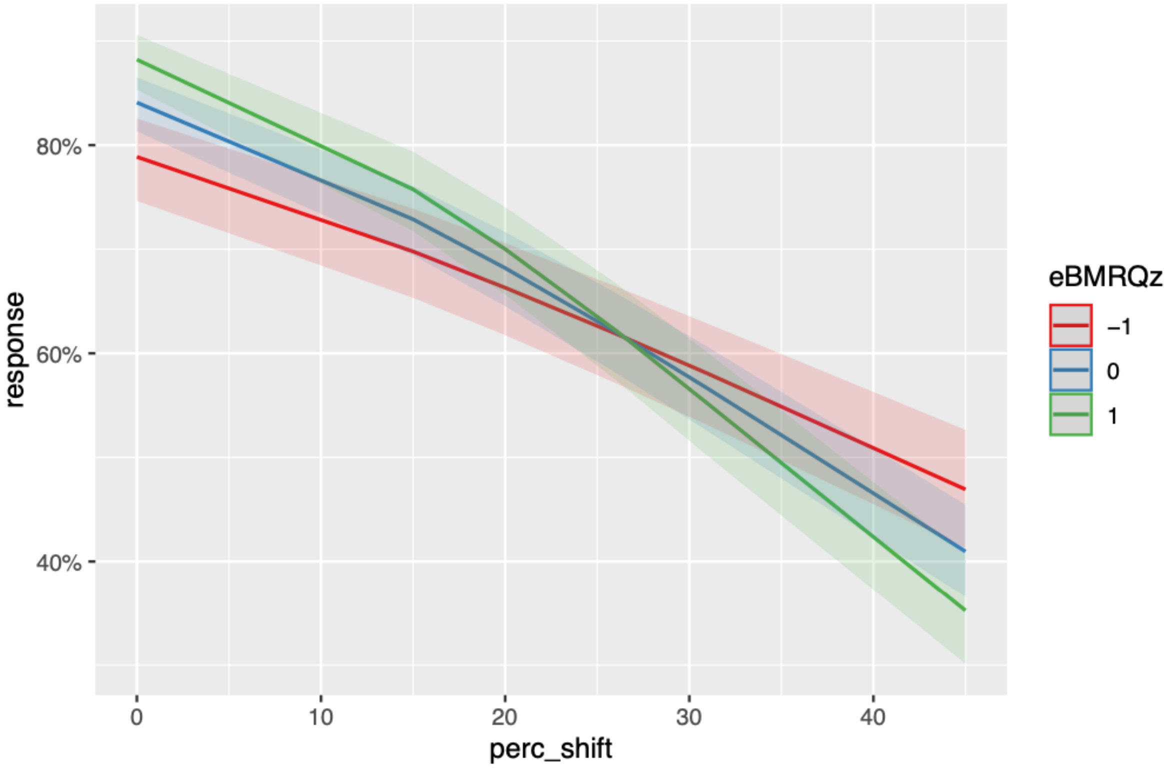
The predicted probabilities of response for the experiment.

Figure (1)

4. RESULTS

4.1 BMRQ

The model extended the main effect model by including as predictors of the binary response also the overall eBMRQ score as well as its interaction with the degree of alignment (Marginal R2 = .112, Conditional R2 = .163). We found a main effect of the percentage of shifting (b = -.05, z = -21.08, p <.001), as well as the eBMRQ (b = .035, z = 4.55, p <.001). In addition, the model indicated a significant interaction between eBMRQ and the percentage of alignment (b = -.01, z = -6.28, p <.001), as indicated in Figure 2.

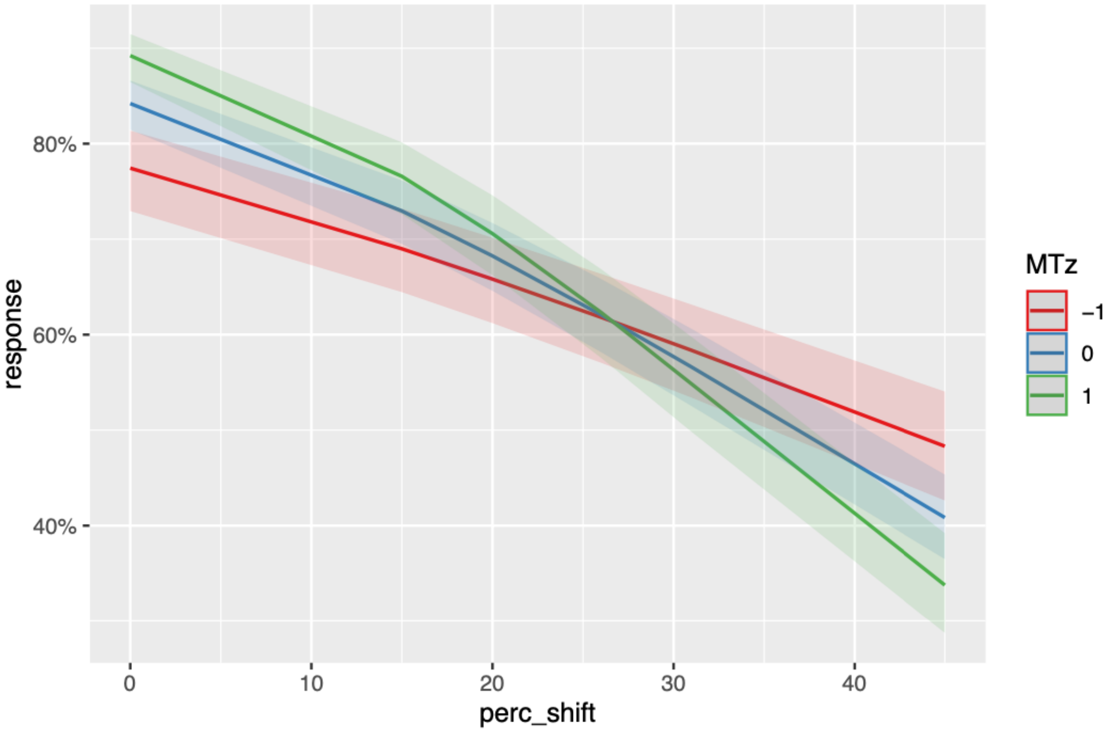


Number of on-beat responses in function of the percentage of shifting, divided by levels of eBMRQ.

Figure (2)

4.2 Musical Training (GOLD-MSI)

By using the overall GOLD-MSI (Musical Training) score and its interaction with the degree of alignment as predictors of the binary answer, the model expanded upon the main effect model (Marginal R2 =.119, Conditional R2 =.169). We found a main effect of the percentage of shifting (b = -.05, z = -21.11, p <.001), as well as the MT (b = .44, z = 5.42, p <.001). In addition, the model indicated a significant interaction between MT and the percentage of alignment (b = -.01, z = -7.30, p <.001), as indicated in Figure 3.

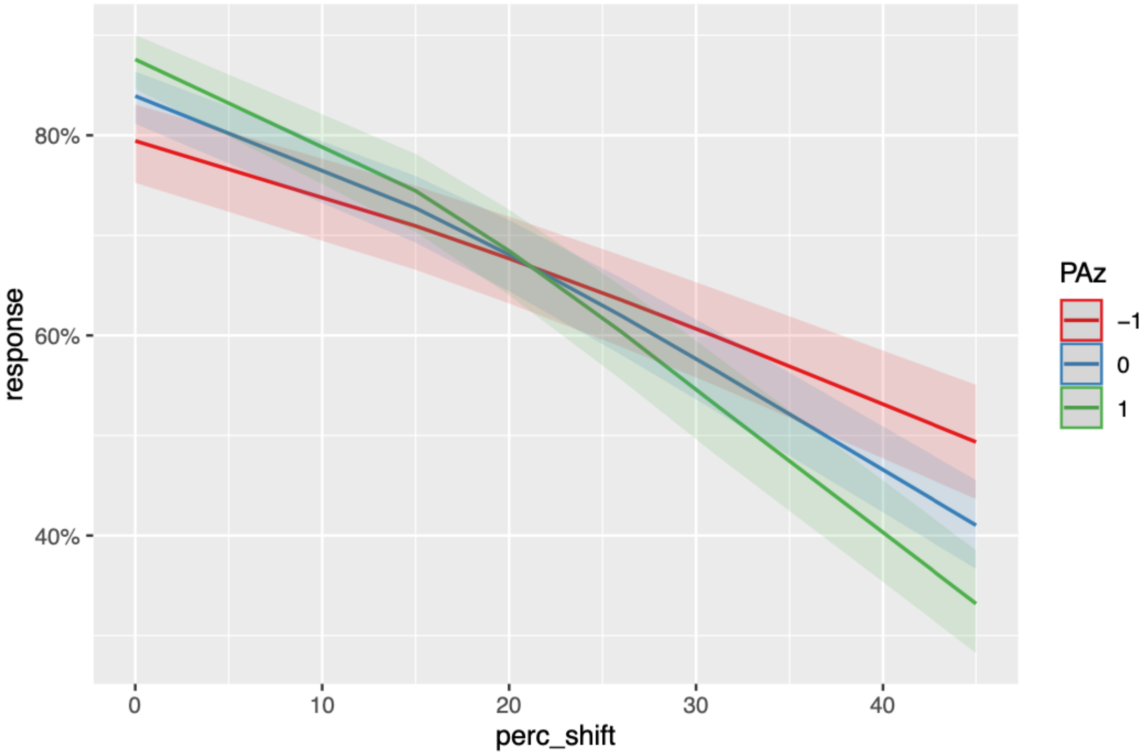


Number of on-beat responses in function of the percentage of shifting, divided by levels of GOLD-MSI (Musical Training)

Figure (3)

4.3 Perceptual Abilities (GOLD-MSI)

In addition to the overall GOLD-MSI (perceptual abilities) score and its interaction with the degree of alignment, the model expanded the main impact model by incorporating these factors as predictors of the binary answer (Marginal R2 =.112, Conditional R2 =.162). We found a main effect of the percentage of shifting (b = -.04, z = -20.95, p <.001), as well as the PAz (b = .30, z = 3.98, p <.001). In addition, the model indicated a significant interaction between PAz and the percentage of alignment (b = -.01, z = -6.80, p <.001), as indicated in Figure 4.

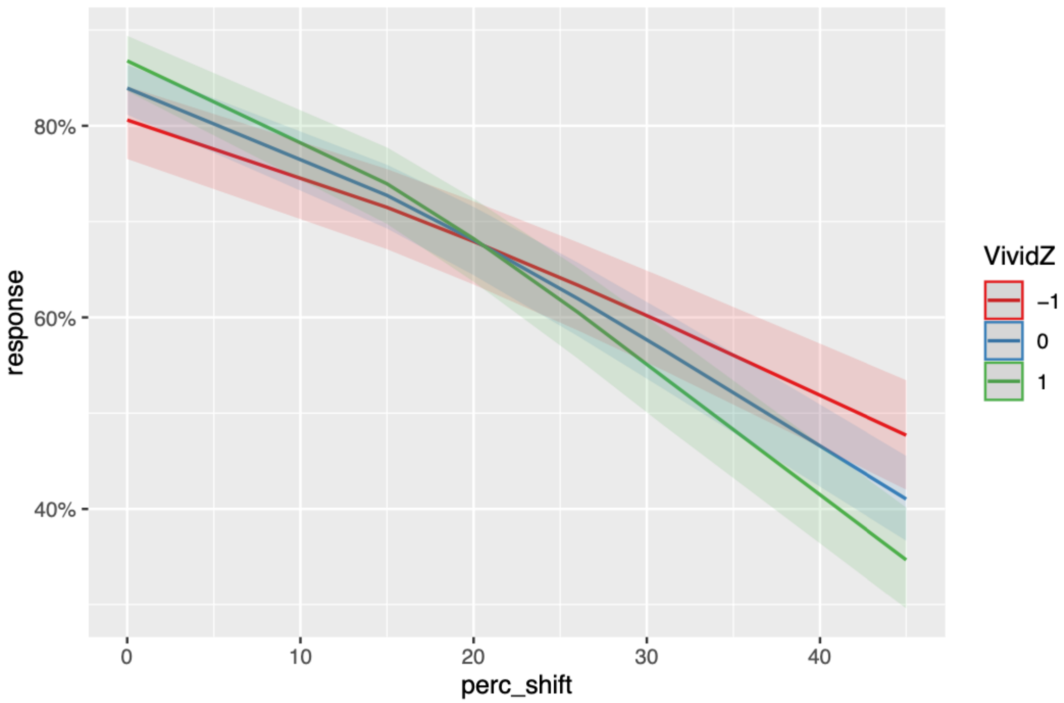


Number of on-beat responses in function of the percentage of shifting, divided by levels of GOLD-MSI (Perceptual Abilities)

Figure (4)

4.4 BAIS (Vividness)

By incorporating the overall BAIS (vividness) score and its interaction with the degree of alignment as predictors of the binary answer, the model expanded upon the main effect model (Marginal R2 =.108, Conditional R2 =.159). We found a main effect of the percentage of shifting (b = -.04, z = -21.01, p <.001), as well as the BAIS (VividZ) (b = .22 z = 2.91, pr=.003). In addition, the model indicated a significant interaction between BAIS (VividZ) and the percentage of alignment (b = -.01, z = -5.14 p <.001), as indicated in Figure 5.



Number of on-beat responses in function of the percentage of shifting, divided by levels of BAIS (Vividness)

Figure (5)

3.5 BAIS (Control)

The results of BAIS control using the same model as used in the previous tests with the degree of alignment as predictors of the binary answer (Marginal R2 =.102, Conditional R2 =.152). We found a main effect of the percentage of shifting (b = -.04, z = -20.99, p <.001), as well as the BAIS (Control) (b = -.08 z = -1.04, pr=.29). The model demonstrated that there is no significant interaction between BAIS (Control) and the percentage of alignment (b = .00, z = .39 pr= .69).

5.DISCUSSION

Digging deeper into analyzing our experiment results and relating them to the three questionnaires used in our experiment eBMRQ, GOLD-MSI and BAIS.

Our findings showed a significant relationship between participants' scores in the eBMRQ (Beat-based Musical Reward Questionnaire) and their ability to detect rhythmic misalignment in the experimental task. Participants with higher eBMRQ scores demonstrated greater sensitivity to identifying whether the beep was on or off the beat. This result aligns with previous research on the link between musical imagery and reward sensitivity. Studies, such as Salimpoor et al. (2013), have showed that musical pleasure is connected to rhythmic engagement. In other words, those who experience greater reward from music also have enhanced perceptual abilities in musical rhythm tasks.

The significant interaction between participants' scores on the GOLD-MSI (Goldsmiths Musical Sophistication Index) and their task performance highlights the strong relationship between musical training and rhythmic imagery abilities. The more musically trained participants were better able to perceive whether the beep was on or off the beat, reflecting their enhanced auditory imagery and rhythmic perceptual skills. These findings are consistent with the Research done by Urate Cinelyte and his collegues (2022) investigating the Beat-Drop Alignment Test

(BDAT) and its relationship with musical training and detecting musical misalignment Researchers found a relationship and possible predictors of beat perception abilities by looking at correlations between Gold-MSI subscales and BDAT. Moreover, as was mentioned in the literature review that GOLD-MSI can be used with professional musicians as well to explore their expertise. Since our experiment participants were non musicians individuals future research can be done as using the same assessment tool (GOLD-MSI) and same rhythmic task with professional musicians. Results are expected to be more likely aligning with our current experiment results.

Previous studies have shown that musical training not only sharpens perceptual skills but also improves one's ability to engage in musical imagery (Halpern, 2001). For instance, Zatorre et al. (2007) found that musicians are better at imagining musical sequences due to their extensive training in auditory perception. This is likely contributed to our finding that participants with higher musical training were more adept at detecting rhythmic irregularities through imagined sequences.

The BAIS (Bucknell Auditory Imagery Scale) results provided further insights into the role of auditory imagination in rhythmic imagery. As expected, participants with higher vividness scores demonstrated higher performance in identifying whether the beep was on or off the beat. This is consistent with studies showing that the vividness of auditory imagery can significantly impact one's ability to imagine and process rhythmic information (Hubbard, 2010). Furthermore, according to Halpern and Zatorre (1999), individuals who can vividly imagine music or rhythm are more likely to engage in complex auditory imagery tasks, such as imagining a beat in the absence of sound.

Interestingly, the BAIS Control scores did not show a significant relationship with task performance. This lack of significance might be explained by the fact that our task did not require participants to switch between imagined sounds or control their auditory imagery flexibly, which is the primary skill assessed by the Control subscale. As suggested by Bailes (2007), activities that demands switching or controlling the flow of auditory images usually need different cognitive resources to be engaged than those activities focused on sustained auditory imagery, which may explain why BAIS Control results were not relevant in our experiment.

Future research can investigate additional aspects of rhythm imagery and its neural correlates, particularly through the use of non-invasive brain stimulation techniques such as Transcranial Magnetic Stimulation (TMS). Studies using TMS could help clarify the causal relationship between specific brain regions involved in rhythm imagery (e.g. Premotor Cortex) and performance in rhythm imagery tasks. For example, stimulating TMS will be applied over the PMC and a control site, while participants listen to or imagine accents during the presentation of an auditory tone sequence that will create a march or a waltz metric structure. The same stimuli have been previously used and are expected to elicit auditory-motor response and beta-band oscillation in auditory and sensory-motor cortices. Moreover, future studies might investigate whether individuals with different levels of musical training or reward sensitivity benefit from rhythm-based interventions for social devotions. The results from such studies could have an impact for developing music-based therapeutic interventions to enhance social bonding.

6.CONCLUSION

In summary, our experiment highlights the fascinating ways in which our minds interact with music, even when the music isn't actually playing. We found that people who are more sensitive to the rewards of music, as measured by the eBMRQ questionnaire, were better at determining whether a beep was in sync with an imagined rhythm. This suggests that the joy and reward we get from music might enhance our ability to engage with it mentally. Similarly, participants with more musical training and better perceptual skills, according to the GOLD-MSI, were more accurate in the task. This makes sense—people who have spent time honing their musical abilities seem to have a sharper ear for rhythm, even in their imagination. When it comes to imagining music, those who could vividly picture sounds in their minds (as shown by their BAIS Vividness scores) also performed better in the experiment. However, the ability to control and switch between different imagined sounds (BAIS Control) didn’t seem to matter as much for this specific task, which might be because our task focused more on holding onto a rhythm rather than switching between different sounds. These findings open up some exciting possibilities for future research. For instance, how might we use rhythm and music to boost learning or build social connections? Understanding the interaction between our musical mind and our abilities could have real-world applications in education, therapy, and beyond. Ultimately, our study adds a small but important piece to the puzzle of how we experience and imagine music.

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