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RHYTHM AND REWARD: WHEN THE MUSICAL PLEASURE IMPROVES RHYTHMIC ABILITIES

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1. ABSTRACT

Music is one of the most enjoyable activities of humans' life, just as the skills associated with it have been present in human life since time immemorial or almost forever. 121 young adults, aged 18 to 35, were asked to complete a questionnaire to assess their musical hedonia and rhythmic tasks to investigate their skills in rhythmic production, perception and memory. The purpose of the research was to assess whether higher hedonic values predicted better results in rhythmic abilities. The interaction between musical hedonia and rhythmic abilities showed that higher hedonic values predict better accuracy in rhythmic abilities, specifically higher musical hedonia predict better rhythmic production, better rhythmic perception, but it did not predict better rhythmic memory. Future studies could focus on evaluating the same hypotheses in different age groups, on analyzing if the interaction between musical hedonia and rhythmic abilities is gender-related or related to the ethnicity, using different type of music (eastern and western). It would be also important to study if the interaction show the same result with people with a Learning Disability as dyslexia.

Key words: music, pleasure, musical hedonia and rhythmic abilities.

2. INTRODUCTION

Music is thought to be just a hobby but it is important for accurate adaptive motive and enhancement in social functions. Music and all the abilities related to it (pitch perception, rhythm production etc.) are widely spread and appreciated all over the world, so much so that there is a specific type of pleasure related to music: music-specific hedonia. Since a wide number of studies focused on when the abilities born in humans and what are the brain circuits related to them, as well as with music-specific hedonia, it seemed innovative to study if there was some relationship between these features of human beings.

Music is that art which devise and produce sounds, more or less complex, high and intense. It is a form of expression different from one to another and it can be integrated with social activities and permits the transmission of knowledge. (Treccani vocabulary, 1). Music is considered the core of being human (Malloch & Trevarthen, 2018), since very early in the age of infants, to the extent that studies show that rhythmic abilities are present during the pregnancy (Visser et al., 1992), others that perception is acquired in the first year and that at 7 months infants can discriminate rhythm (Hannon & Trehub, 2005; Phillips-Silver & Trainor, 2005). Several areas are related to music and rhythmic abilities, starting with the auditory system. In particular, McDermott et al. (2008) write that musical features as time information and pitch frequency are present in the peripheral auditory system. In fact, in the cochlea there is a filter which provides a “tonotopic” map that divides the sound based on the frequency. Paquette et al. (2017) show in their article that also cerebellum is important for beat discrimination skills, as well as basal ganglia, which are central for beat perception and interval time (Grahn, 2009; Schwartze et al., 2012).

After discussing music, pleasure is the next topic to be analyzed. Pleasure is the satisfaction which results from the accomplishment of desires (Treccani vocabulary, 2). It is mediated by the mesocorticolimbic circuitry (Berridge & Kringelbach, 2015), basal ganglia and cerebellum (Pierce & Péron, 2020). Music is one of the most enjoyable activity in humans' life and it has a role in mood regulation and evocation of emotions (Dubé & Le Bel, 2003), and it elicit emotional response and physiological changes (Salimpoor et al., 2009). People present music-specific hedonia, which is the individual differences in how sensitive they are to musical pleasure (Mas-Herrero et al., 2013). Some people experience "chills" while listening to music, that is because a number of areas are relevant in evoking emotions (Blood & Zatorre, 2001). Other studies showed that process of dopamine in mesolimbic area is associated with musical pleasure. Amygdala and medial temporal lobe are involved in emotional response (Dellacherie et al., 2008), while other studies show that pleasure both from music and food engage similar regions as ventromedial prefrontal cortex, ventral striatum and insula (Mas-Herrero et al., 2021).

Even if it is thought that music does not have an evolutionary purpose, studies demonstrated the importance of musical hedonia in certain human abilities as long-term memory (Lisman et al., 2011) and episodic memory (Cardona et al., 2020; Ferreri & Rodriguez-Fornells, 2017). Reward responses link also to movement, in fact was demonstrated that there is a link between rhythm, movement and pleasure (Matthews et al., 2020). One of the subscales of

Barcelona Music Reward Questionnaire (BMRQ) (Mas-Herrero et al., 2013) reflects how synchronize body movements to a rhythmic beat is natural in humans and this require that somatosensory-motor network collaborates with the auditory processing networks (Mas-Herrero et al., 2013).

What lack in literature is to understand if there is an association between musical hedonia and rhythmic ability, specifically the hypothesis was if higher music hedonia predict better rhythmic abilities particularly better rhythmic production, rhythmic perception and rhythmic memory.

First, the elaborate will deal with the previous literature regarding music, its facets and rhythmic abilities, as well as pleasure and music-specific hedonia. After that the research hypotheses will be presented and subsequently it will be discussed the sample and how it was found. Then, the tools will be introduced for a better understanding of the procedure. The tools that will be described regarding this thesis are the Italian version of Musical Sophistication Index (MSI) (Müllensiefen et al., 2014; Santangelo et al., 2024), the Italian version of the extended Barcelona Music Questionnaire (eBMRQ) (Cardona et al., 2022; Carraturo et al., 2023), the Finger Tapping Test (FTT) (Horton & Hartlage, 1994), the Computerised Adaptive Beat Alignment Test (CA-BAT) (Harrison & Müllensiefen, 2018) and the Musical Ear Test (MET) (Swaminathan et al., 2021). The procedure of all the experiment will then be outlined. The analysis of data and the results will be presented after the procedure, to make one understand how the experimenter found the conclusions. Finally, a discussion of the data obtained, within the current literature, will be presented with the necessary conclusions.

Most interesting results show that music-specific hedonia predicts rhythmic abilities, in particular, higher values of musical hedonia predict better accuracy in rhythm production and better accuracy in rhythm perception, with a tendency towards better rhythmic memory, but without significant results.

3. THEORETICAL BACKGROUND

3.1 Music and Rhythm

3.1.1 Definition of music

Music is a major part of everyone life. In movies, concerts, festival, weddings, just as a hobby or as background, music has the ability to bring people together and elicit a large number of emotions during all these activities that depends also on how every individual perceive them. Why is it so important? Research focused on fields in which humans usually make music for adaptive motive as choosing mate, cohesion of groups and parental care (Savage et al., 2021) but also, it is probable that coevolution of musical features (beat perception, meter, harmony…) contribute to an enhancement of specific social functions, as group coordination or the improvement of bonds between people, as can be easily seen in world's musical culture (Savage et al., 2021). Music is, according to Treccani vocabulary (1) "*The art that consists in devising and producing structured sequences of simple or complex sounds, which can vary in height, intensity and timbre, through the human voice, instruments or the combination of both these sources*". According again to Treccani vocabulary, music is manifested as a form of expression, even though is different from one to the other that is integrated with social activities. This contributes to the cultural transmission and knowledge (Treccani vocabulary, 1).

Music is at the core of being human (Malloch & Trevarthen, 2018) since very early age and as time goes on, it becomes a more significant ability and a more structured one.

3.1.2 “Musiking” and benefits of music

“Musicking” (Small, 1999) is defined as the intentional attention to music during activities and it is a sign of healthy dyadic relationships. It is found in organized sounds but also between two people that are performing a dialogue (Small, 1999). Musicking represents the focusing on the energy that creates music, that moves people both emotionally and bodily, it is also, the expression of “communicative musicality”. It is the patterns that are used by children to explore the world, for instance, gurgles, repetition of syllables and laughter. They can be strengthened and encouraged teaching and during the relationship with the caregiver with vocalization and movements (Malloch & Trevarthen, 2018). It is demonstrated (Feldman et al., 2011) that mother-child dyad synchronizes their heart rhythm while episodes of affect, glances and vocal episodes. Malloch (Malloch & Trevarthen, 2018) theorizes that infants’ voices, bodies and communication with caregivers are parts of cultural aspects, such as music, art or dance (Porter et al., 1996). When children grow tend to take part in musical activity without a specific education (“The Muse within: Creativity and Communication, Song and Play from Childhood through Maturity,” 1993). As soon as children choose a formal education in music it is important to encourage them and teach them in a sensible way to let them grow the passion for music (Ingold, 2017).

Music abilities sustains well-being. This is supported by proof that musicality reinforces emotion and resilience to recover from mental illness or distress as wrote by Pavlicevic in her works (1997, 1999, 2000).

This definition of music is the first information that is needed to be analyzed to understand fully what will be written in the next pages.

3.1.3 Tempo and rhythm

Two fundamental aspects of music are tempo and rhythm. Tempo communicates the pace of a musical piece and can be paired with how many events occur in a regular interval, its function is to communicate emotions, fast music is perceived as happy, while slow tempo is perceived as sad (Dalla Bella et al., 2001) but it is also helpful to let the auditors to predict future events in music (McAuley, 2010). Rhythm is the ordered pattern of time intervals in a sequence (Fiveash et al., 2022). The two components of rhythm are beat and meter. Beat occurs at intervals that are periodic and it tends to be noted by the listeners, it can coincide with notes, as sounded event, or it can be in a silent moment. Hypothetically, the beat matches with the beat that the musician chooses, but this depends on different factors (McAuley, 2010), probably as genre of music or the meter division. Meter is the temporal organization of beats that can be perceived as more relevant that others in hierarchical "trees" (from the weakest beat perceived to the strongest one) (Fitch, 2013).

There are multiple cognitive processes that are employed in extracting a beat from a rhythm, including duration processing, working memory and attention. Rhythmic ability is an umbrella term in which some patterns of performance have been seen in studies. Rhythmic abilities are multiple, for example rhythm perception is the ability to make a judgment on a rhythm, while rhythm production is the capability to produce a rhythm. Rhythm is particularly important also in spoken language. Linguistic rhythm is hierarchical and the rhythmic hierarchy is similar to it. Langus et al. (2017) in their study discuss three levels of linguistic rhythm: segmental, metrical feet and phonological phrase level. It was studied that infants show a knowledge of linguistic rhythm at a very early age, and is acquired also the linguistic rhythm.

Before analyzing what are the characteristics in perceiving or producing a rhythm also at biological level, it is important focusing on when these abilities appear in human beings.

3.1.4 Birth of rhythmic abilities

Ability to sense elements of music are present in early stages of development and it is a topic widely discuss, for example by Phillips-Silver et al. (2005) in which they hypothesized that movements influence auditory encoding in patterns of rhythm. Trehub writes in her article (2003) that discrimination in pitch and other music features is similar in babies and in people that had years of musical exposure. Also, Patel (2008) writes that music and language are important parts of human and are present in every society, even if other cultural aspects are different. What it is not known is how infants perceive rhythms(Winkler et al., 2009). Sense a beat is an important ability that help the synchronization with others. Winkler and colleagues (2009) used auditory event related potential (ERP) to measure brain responses to auditory stimuli. In adults, when presenting a different sound in a regular pattern, the brain evokes a mismatch negativity (MMN) (Kujala et al., 2007). MMN is an early brain response to a violation to a rule at auditory level, such as changes in a sound pattern (Kujala et al., 2007). The same response was found in infants when sounds characteristics were changed, for example a variation in pitch or parameters in rhythmic stimuli.

Winkler, in his study showed that the expectation is higher for the first position in a musical unit, called downbeat, and if an omission is present in that position, an electrical brain response is present, while, if the omission is in a less salient position the response it is not elicited. It appears that ability in recognizing rhythmic sequences is present and functioning at birth, it is thought to be an innate capacity (Winkler et al., 2009). Some authors suggest that perception is acquired in the first year of life, and at 7 months infants can discriminate rhythms (Hannon & Trehub, 2005; Patel, 2008; Phillips-Silver & Trainor, 2005), others that the learning starts during pregnancy (Visser et al., 1992).

3.1.5 Brain areas and rhythmic abilities

Since it can be accepted that the ability to perceive music is innate, it is fundamental to know that the perception of it depends on cultural factors, yet bonded to the auditory system (McDermott & Oxenham, 2008). As Mc Dermott et al. write in their article (2008), pitch frequency and time information are both present in the peripheral auditory system. In the cochlea it is present a sort of filter that provides a "tonotopic" map that divides the sound based on their frequency. This map in the cochlea is present in the auditory system and in the primary auditory cortex, as indicated by Kaas et al.(1999). Thanks to another study (Paquette et al., 2017) it was discovered that other brain regions are associated with synchronization with beat and with perception of it. Thanks to Voxel-Based-Morphometry it was found that there was a significant co-variation between the performance in the used test (Harvard Beat Assessment Test (Fujii & Schlaug, 2013)) and grey matter variation in the cerebellum lobule IX in left hemisphere, in crus I bilaterally and crus I/II of left cerebellum. The results of the study show that cerebellum is important for beat discrimination skills and also suggest that cerebellar grey matter and the fact that the cerebellum is intact, without traumas, are important for the ability in discriminating a beat. Also, another study (Thaut et al., 2008) showed, with a fMRI method, that, during performing rhythmic movements, there was activation in supplementary motor area bilaterally, ipsilaterally in the supermarginal gyrus and caudate-putamen, while in the cerebellum there was a contralaterally activation. These activations suggest that there is a network for sensory-motor rhythmic integration, which could be specific for the elaboration of musical abilities.

In conclusion it can be said that rhythm processes are associated with all the areas underlined above and also basal ganglia (Schwartze et al., 2012), which are central for beat perception and for interval timing, as written by Grahn in her article (2009).

3.1.6 Deficits in rhythmic abilities

Since a number of studies have been presented in which specific brain areas appeared to be involved in the functioning of rhythmic abilities, it is also important to present those articles in which, precisely because of deficits in these areas, there are deficits in the abilities presented. In fact, it is showed (Bégel et al., 2017) that, even if motor synchronization to a beat is popular in human being, difficulties in synchronization to a beat and in beat perception are present. The condition "beat deafness" is linked to a deficit in perceiving the beat. The authors, with their article suggest that, based on the nature of the rhythmic task, in beat-deaf participants, there are different pathways involved in beat perception. "Beat deafness" is probably connected to a deficit in tracking the beat at perceptual level, and it is thought to be an anomaly without the presence of brain damage (Phillips-Silver et al., 2011). In theirs article the case of Mathieu was told. A sample without training was asked to perceive and produce a musical beat. All of the sample succeeded in the task, except for one: Mathieu. What was different in Mathieu was that he failed at locking his movement to musical beat and he did not detected asynchronies of dancers, while all the others participants detected when the dancer was not in time. This result suggests that time has a neurobiological origin, different from pitch origins. What was shown by Phillips-Silver et al. (2011) started from the congenital amusia, a disorder in musical pitch processing, reported for the first time by Peretz et al.(2002), in which case study, it is presented a volunteer (Monica), who showed this music-specific disorder. Since Mathieu was capable of perceiving pitch differences the term beat deafness was coined.

Given that congenital amusia is a neurodevelopmental disorder that affect music perception, and developmental dyslexia is a neurodevelopment disorder that affect reading perception, it was thought that could be some similarities and that a common factor, even if in different domains, could play a role. This was the idea of Couvignou and Kolinsky (2021), who analyzed 76 children (38 dyslexic) to understand if there is a comorbidity with congenital amusia. Assessing the Montreal Battery of Evaluation of Musical Abilities (Peretz et al., 2013), it was showed that 34% of the dyslexic children have congenital amusia, showing that there is a probable explanation at cognitive and neural level for the comorbidity between amusia and dyslexia (Couvignou & Kolinsky, 2021).

Other difficulties are showed in rhythm synchronization and it was studied from Sowiński & Dalla Bella (2013) that it can be a result from a not accurate map of the perceived beat to a movement. In fact, it was asked to participants to synchronize via hand tapping with musical and non-musical stimuli. Some participants were able to do it, while others showed poor synchronization and total incapacity of synchronizing. The results of the study lead to the idea that the key to this impairment in synchronizing with a beat is to be sought in an altered auditory-motor mapping.

3.2 Emotions and Pleasure

3.2.1 Definition of pleasure and related brain areas

Pleasure is defined as *"sense of lively satisfaction resulting from the fulfilment of desires, physical or spiritual, or aspirations of various kinds"* by Treccani vocabulary (2) In psychoanalysis the principle of pleasure, according again to Treccani (2) is *"one of the two fundamental principles of psychic functioning according to which man constantly tends to satisfy his own needs in order to reduce the tension that their occurrence had provoked; in the course of development, this occurs initially through direct satisfaction of the need, later also through imagination and sublimation, and normally through adaptation to the external world, in particular to persons and objects capable of providing drive gratification".*

Pleasure is mediated by the mesocorticolimbic circuitry and unfolds multiple adaptive function (Berridge & Kringelbach, 2015), for example wanting something for a reward is generated by a distributed brain system, while liking is generated by areas in limbic circuitry. These areas can be integrated in wider anatomical patterns for example in nucleus accumbens generators for desire and fear, as written by Berridge & Kringelbach in their article (2015).

Other areas that can activate pleasure response are basal ganglia and the cerebellum (Pierce & Péron, 2020). Pierce and Péron in their review show that these two subcortical areas, which were thought to be useful simply for the purpose of producing and modulating a motor output, are important in other domains as emotion recognition, feeling arousing and the evaluation of reward. The pathway from the thalamus that connects basal ganglia and cerebellum supplies a base for their influence on limbic function. These regions can model how people process their emotion regulating cortical oscillation to learn and reinforce the behaviours of reward or pattern of thought to reach a desired target (Pierce & Péron, 2020).

After introducing how pleasure is defined and what areas are deputed to let humans feel it, this thesis can move on to a specific type of pleasure, namely that related to music.

3.2.2 Specific-music hedonia and brain circuits

Music does not have a tangible advantage, but it is one of the most enjoyable activity in humans' everyday life and has a role in both mood regulation and evocation of emotions as written by Dubé & Le Bel (2003). In fact, it was demonstrated by Salimpoor, V. N. et al (2009) that music can elicit emotional responses and also physiological changes, such as changes in heart rate, body temperature and respiration.

What it is also intriguing about music is that people present what it is called music-specific hedonia, that is the individual differences in how sensitive they are to musical pleasure, as Mas-Herrero et al. measured in their article (2013). Quite a few neuroimaging studies focused also on what are the relevant brain areas when it comes to musical hedonia and emotions evoked by music. These studies showed a fair number of brain areas that are important for this purpose. For example, Blood & Zatorre (2001) showed that brain areas related with reward and emotions are activated while listening to music that can be described as enjoyable. Theirs was a Positron Emission Tomography (PET) study in which regional cerebral blood flow (rCBF) was measured to see changes in it while the participants listened to pleasant music. rCBF changes when participants, while listening to their selected music, experience “chills”. Chills are accompanied by alteration in heart rate, respiration depth and electromyogram. When the chills increased, the CBF oscillates and in particular it was observed in regions that are involved in emotions and reward, responsible for other pleasant stimuli that can produce euphoria (e.g., drug abuse, food…) among which amygdala, orbito-frontal cortex and ventral medial prefrontal cortex. This study let people understand that music is relevant at a biological level, and it is the first one of many others. Another study (Salimpoor et al., 2011) showed that the processing of dopamine in mesolimbic area is associated with musical pleasure, however until Ferreri et al. study (2019), there was no direct evidence of dopamine function. Again, Salimpoor et al. (2013) used fMRI (functional Magnetic Resonance Imaging) to understand in which areas is showed that the music acquires a reward value when heard for the first time during a false auction. Mesolimbic striatal regions, in particular the nucleus accumbens, were particularly active and it predicted quite well how much the participants were willing to spend. Other regions, as auditory cortices, ventromedial prefrontal regions and amygdala showed activation but they did not predict a reward value. Ferreri et al. (2019), to understand if there was a causality between dopamine function and the pleasure that people have listening to music, administered levodopa (a dopamine precursor), risperidone (dopamine antagonist) and a placebo to their participants three different times, to manipulate their dopaminergic system during listening to music. It was demonstrated that levodopa raises motivation and the pleasure of listening to music, while risperidone let decrease both. With this study it is demonstrated that the dopamine has a cause in musical pleasure increase.

3.2.3 Musical hedonia and human abilities

Even if music seems not to have an evolutionary purpose, there are studies that show how important is musical hedonia for certain human abilities. Lisman et al. (2011) in their work studied that, stimuli that trigger the release of dopamine could improve long-term memory, as supported by the neoHebbian framework for episodic memory, since dopamine can reinforce late synaptic potentiation that is produced by learning, and enhance consolidation processes. Reward related to music could help in establishing episodic memories in humans. Ferreri and Rodriguez-Fornells in their study (2017) tested if reward form music could modulate a performance in episodic memory. Participants evaluate unfamiliar musical pieces and, after 24 hours, their episodic memory was tested. What was found out is that pieces that were perceived as more rewarding were better recognized, also, BMRQ values predicted a better memory performance. This study showed that reward led by music responses are implicated in cognitive functions. Another important study that focuses on the episodic memory is the one written by Cardona et al. (2020). The authors investigated if musical hedonia improves verbal episodic memory and if the improvement occur if the pleasant stimulus is not presented in the encoding. Results of the study show that participants with higher scores on musical hedonia (i.e., eBMRQ values) present a better recollection, in particular for words that were presented in a pleasant musical context. These effects remain even when the stimuli are not present during the encoding phase (i.e., the moment in which the word is presented to the participants to let them memorize it). The outcome suggests that musical hedonia could improve memory thanks to reward mechanisms.

Other studies also focused on the involvement of the amygdala and also the medial temporal lobe in the emotional response. For example, Dellacherie et al. (2008) findings show that the amygdala is implicated in stimuli even if emotionally neutral. As Trost writes in his article (2017), rhythmic patterns create temporal expectation and they can elicit pleasurable responses. This was observed also in the musical domain (melody and harmony) as written by Cheung and colleagues (2019). Other studies, as the one written by Mas-Herrero (2021), show that pleasure, both from music (abstract reward) and food (concrete reward), engage similar brain regions, including ventromedial prefrontal cortex, ventral striatum and the insula.

Reward responses link strongly to movement. In fact, research demonstrated that there is a link between rhythm, movement and pleasure (Matthews et al., 2020). The sensation of “groove”, as called by Matthews, is the pleasurable desire to move to music, which is supported by both motor and reward networks, in particular, basal ganglia are important part of these networks and interact in the response to music. This groove sensation follows the inverted U shape relationship (Matthews et al., 2019). In the article, Matthews et al., (2019) asked participants to rate different stimuli, which was different both for rhythmic and harmonic complexity. The relationship between rhythmic complexity and pleasure and rhythmic complexity and wanting to move, showed an inverted U-shaped relation. This means that with a medium rhythm complexity both the pleasure and the will to move are higher than with a low rhythm complexity and with a high rhythm complexity. Matthews suggests that rhythmic complexity is the primary driver of pleasure, while harmony controls the attention and the processes in rhythm perception. The conclusion of the study is an aid to understand how prediction and the processes of entrainment involved in the perception of rhythm are in interaction with musical pleasure (Matthews et al., 2019). Since the intermediate complexity of rhythm is perceived as more pleasurable, it is probable that this could reflect the learning domain, in which intermediate rhythmic complexity are easier to learn and valued more pleasurable, suggesting also that hedonic nature of music could originate from the link between prediction and reward (Fiveash et al., 2023). As seen above, and will be analyzed in detail below, one way to measure musical reward is the Barcelona Music Reward Questionnaire (BMRQ) designed by Mas Herrero in 2013 (2013), and also the extended version of it (Cardona et al., 2022). BMRQ has different subscales, emotion evocation, mood regulation, musical seeking, social reward experience and sensory motor, which in particular correlates with the others subscales, helping the understanding of the reward experience. Sensory-motor subscale reflects the naturalness in synchronizing body movements to a rhythmic beat, requiring that somatosensory-motor network to collaborate with the auditory processing networks (Mas-Herrero et al., 2013).

In general, it can be said that the fact that the reward circuit and the amygdala have a strong role in evaluate music in humans, could be important in understanding why it is an activity that is present in all countries and cultures since time immemorial, but further studies are necessary to understand if higher musical hedonia is associated with higher pleasant responses driven by rhythm.

3.2.4 Musical anhedonia

Even if most people experience pleasure from music, and it was found that reward system is involved in the experience thanks to the use of BMRQ, a percentage of people who feel no pleasure or emotion while listening to music exists. These people have what is called musical anhedonia. Anhedonia is the inability to experience pleasure, and, in particular, musical anhedonia is a condition in which individuals draw no pleasure from music (Bernardini et al., 2020). It was found from Zatorre (2015) that 5% of the population have a low sensitivity to musical reward even in absence of anhedonia and depression, and it revealed that people respond in a normal way to rewards different than music, even if ability perception is intact.

What Bernardini et al. (2020) presented in their review about anhedonia is that people with musical anhedonia show a normal response to other type of reward (food, money, sex…), one may think that a deficit in musical pathways is present. Anhedonic people have normal capacities in perceiving it and also, they can recognize what emotion a musical excerpt is trying to evoke. Individual differences are associated with how auditory association areas in the superior temporal gyrus are connected to the anterior insula, and also white matter connectivity could be a sign for the differences in the perceiving pleasure from music. What is not clear is that, since the differences in the studies reviewed from Bernardini, is difficult to understand what are the causes of musical anhedonia.

There is a more recent study, written by Kathios et al. (2024) that uses sources of music that come from the real world (e.g., cheering, laughing…). In the study they presented musical anhedonic people matched with controls, with short sounds that could be pleasant or not, with a different variety of timbre. What was found is that anhedonic people evaluate as less pleasant the pleasing sounds, suggesting that musical anhedonia is not restricted to melodies, and that timbre is probably a musical component that has to be researched more since could be a source of pleasure in musical excerpt.

4. RESEARCH HYPOTHESIS

The study aims to collect behavioral and subjective data, to investigate, at an individual level, rhythmic abilities and reward response to music.

Given that rhythmic abilities are multifaceted, it seemed only right to attempt to analyze the associations between some of the various rhythmic abilities and musical hedonia.

In particular the hypothesis of this study that will be tested is:

- Higher musical hedonia predict higher rhythmic abilities. Specifically, a better rhythmic production, a better rhythmic perception and a better rhythmic memory.

5. METHODS

5.1 PARTICIPANTS

The initial sample size was formed by 129 subjects. The inclusion criteria of the experiment were that volunteers have to be Italian speakers, healthy male (M) and female (F) between 18 and 35 of age, they must not be professional musicians and they have to sign the Informed Consent, agreeing to participate and cooperate in every part of the study.

The recruitment was done by ads on the department's website or through institutional channels but also with social networks to have a sample that did not comprehend only University students. Participants that are students of the degree course in "Scienze e Tecniche Psicologiche" or "Psicologia" at University of Pavia had $\frac{1}{4}$ of CFU (Credito Formativo Universitario) to help them complete the Individual Training Activity requested from the University. Since in some cases there were poor internet connection, audio and video difficulties, the final sample is 121 participants (F=81; M=40) between the age of 18 and 35 (mean= 25.79; sd= 3.95). The number of participants allow to carry oud the analysis requested, in fact, the minimum number of subjects to obtain a correlation of r=.3, assuming α=.05, and power=.95, turns out to be N=115 (one-tail correlation (G*Power).

5.2 MUSIC SOPHISTICATION INDEX

Goldsmiths Music Sophistication Index (Gold-MSI) was implemented for the first time by Müllensiefen, et al. (2014). In their article was introduced the concept of "music sophistication" that describes the range of musical expertise. MSI is a self-report instrument to assess musical skills in multifaceted dimensions in the population. Participants of this study had to complete the validated Italian version of MSI (Santangelo et al., 2024). The questionnaire is formed by 39 sentences, but in this study only 16 of them were administered. For the first part of the questionnaire (11 statements) subjects have to express their level of agreement using a scale from 1 (completely disagree) to 7 (completely agree) about their musical skills (e.g., I usually know when I'm hearing a song for the first time). The other part (5 statements) required the participants to indicate how many years and hours they dedicated to musical studies and how many musical instruments they can play.

- I engaged in regular, daily practice of a musical instrument (including voice) for _____ years.
    - 0; 1; 2; 3; 4-5; 6-9; 10+
- At the peak of my interest, I practiced _____ hours per day on my primary instrument.
    - 0; 0.5; 1; 1.5; 2; 3-4 5+
- I have had formal training in music theory for _____ years.
    - 0: 0.5; 1; 2; 3; 4-6; 7+

- I have had ____ years of formal training on a musical instrument (including voice) during my lifetime.
    - 0; 0.5; 1; 2; 3-5; 6-9; 10+
- I can play ____ musical instruments.
    - 0; 1; 2; 3; 4; 5; 6+

The decision to let the participants fill out the questionnaire was made to be sure that no professional musician was in the study.

5.3 EXTENDED BARCELONA MUSIC REWARD QUESTIONNAIRE

The extended Barcelona Music Reward Questionnaire (eBMRQ) (Cardona et al., 2022) is the extended version of the BMRQ (Mas-Herrero et al., 2013). BMRQ is a self-report questionnaire used to deliver a description of the different factors of music experience that are observed in people and how these people feel reward associated with activities that are related to music. BMRQ is formed by 20 sentences, while Cardona et al. in their article (2022) using both the BMRQ and the Absorption in Musical Scale (AIMS) (Sandstrom & Russo, 2013) included 4 items, reaching a total of 24 items. The AIMS was used to increase the number of statements, since many of them were unique, thanks to the difference in the purpose of the two questionnaires. AIMS was first proposed in 2011 from Sandstorm and Russo to demonstrate that it potentially can predict which individuals will feel powerful emotions in response to music. Cardona's idea was to understand the relationship between the absorption state during listening to music and differences in the sensitivity to reward from music. Thanks to these results the complete five sub-scales which are used in the eBMRQ are presented: musical seeking, emotion evocation, mood regulation, sensory-motor and social reward. To understand better the sub-scales in the next lines there will be an explanation regarding the denomination of them and a statement for each subscale. *Musical seeking* relates to the tendence of a person to engage in music-related activities, for example going to a concert, or seek information related to the music that is listened "I inform myself about music I like". *Emotion evocation* is the capacity of music to induce an emotional response in someone "I get emotional listening to certain pieces of music". *Mood regulation* gives an assessment of how music is used to regulate mood “Music calms and relaxes me”. *Social reward* is the ability of music to boost and promote social interaction “Music makes me bond with other people”. *Sensory-Motor* scale assess the skill of music to induce someone’s body to produce movements that are synchronized to a beat “Music often makes me dance” (Cardona et al., 2022).

For each of the 24 sentences participants were asked to indicate their level of agreement using a five-point scale from 1 (completely disagree) to 5 (completely agree). The Italian version of the questionnaire was administered that was validated for age, gender and musicianship in the preprint article by Carraturo and colleagues (2023).

5.4 FINGER TAPPING TASK

The first rhythmic task that was presented to the subjects was Finger Tapping Task (FTT) (Horton & Hartlage, 1994). The purpose of this task was to understand how the participants are accurate in maintaining a rhythm without listening to the rhythmic cues for all the task. All participants had to wear headphones and had to be in a silent room. The task was divided in two phases. The first one is the *Synchronization phase* in which the beat is presented 10 times and the subject has to synchronize with it hitting the space bar (hence the request to have a keyboard). The second phase was the *Continuation phase*. In this phase the beat disappears after few cues and the subjects have to continue hitting the bar for 30 repetitions. The task lasts approximately 10 minutes. The FTT presents 12 items in which each InterOnset Interval (IOI)/Inter Stimulus Interval (ISI) is presented twice. The IOI is the time between one beat and the other. The IOI chosen were .4; .475; .55; .625; .7; .775 s. Considering the first IOI (.4 s) it means that between the first and the second beat there is an interval of 0.4 seconds.

5.5 COMPUTERISED ADAPTIVE BEAT ALIGNMENT TEST

The Computerised Adaptive Beat Alignment Test (CA-BAT) (Harrison & Müllensiefen, 2018) is the computerized version of the Beat Alignment Test (BAT) (Iversen & Patel, 2008). This test explores the perception ability of a listener using the beat alignment paradigm used by Iversen and Patel in 2008. In this task, participants wear headphones and have to listen to 32 musical pieces that last about 12 seconds each, with a succession of timed beats at the same distance as a metronome and have to respond if the beat was synchronous or asynchronous using the keyboard (A for asynchronous and L for synchronous). Each acoustic signal was temporally shifted at a proportion (P) of the music beat, forward or backward, with a P value that was $0 < \mathrm{P} \leq 0.5$, where 0.5 was the most asynchronous (Harrison & Müllensiefen, 2018). Before the actual task, two examples with feedback were provided to the sample to let them understand the assignment.

5.6 MUSICAL EAR TEST

Musical Ear Test (MET) is a listening test that has the goal to measure musical and rhythmic abilities without musical formal training (Correia et al., 2022). The original test has two subtest, Melody and Rhythm, in each of these participants have to determinate if two sequences are identical or not. In this experiment only the Rhythm subtest was used. The task lasts little more than 10 minutes. MET rhythmic test has 52 trials (half same, half different) and in each trial the subjects have to listened to two brief rhythmic excerpts (standard and the comparison) and press a button to indicate if the pieces were identical (key A) or not (key L of the keyboard). Participants are given a window after every trial (1659 to 3230 ms) to respond. The rhythmical sequences were presented at 100 beats per minute (bpm), that is 600 ms, at the same metrical structure (4/4). To understand the speed of the rhythm referred to, consider that a classic dance song has a tempo of 120 bpm, such as *I wanna dance with somebody* by Whitney Huston. Before the real task there were presented two practice trials (one same and one different) with feedback (Correia et al., 2022; Swaminathan et al., 2021).

6. PROCEDURE

The experiment was done remotely using *Zoom* platform, *Google form* for the questionnaire and *Pavlovia* for the rhythmic tasks. Pavlovia is a web site that provides a space for researchers to run, explore and share experiments online. After planning the appointment using e-mails or WhatsApp messages, participants receive an e-mail sent by the institutional mail (@universitadipavia.it) in which were written the information and instruction to follow to participate in the correct way. Each email, written in Italian, contained the participant ID number (from 1001 to 1129) to use during the experiment appointment in all the tasks, the link to the Zoom meeting's room, a reminder of the date of the appointment, the link to the questionnaires and the request to connect by computer (desktop or portable) or tablet with an external keyboard, and with headphones (Bluetooth or wired).

Participants had to complete three questionnaires by themselves before the date of the appointment. The questionnaires were administered with a Google form. They had to answer the Musical Sophistication Index (Müllensiefen et al., 2014), the extended Barcelona Music Reward Questionnaire (Cardona et al., 2022) and the Interpersonal Reactivity Index (Davis, 1983) (Albiero et al., 2006), all the instruction were written in the Google form for a correct completion. Completing the questionnaires took participants about 15 minutes. After they answered the questionnaires, they could connect by videocall. This hybrid testing (online with the experimenter in the videocall) allowed any questions to be answered immediately by the experimenter and also allowed to provide any solutions if the participant encountered any problems. During the videocall the subjects have to complete three rhythmic tasks: Finger Tapping Test (Horton & Hartlage, 1994), Computerised Adaptive Beat Alignment Test (Harrison & Müllensiefen, 2018) and Music Ear Test (Correia et al., 2022). For each rhythmic tasks instruction were given by voice and were written before the first trial of every task. Each rhythmic task lasted about 10 to 15 minutes. Once the subjects completed the rhythmic task, they were asked to watch and listen two clips in which there were two stories and at the end they had to answer general comprehension questions about them. This part of the videocall was registered, after the participants give consent, since this was a mimicry task in which the participants imitate the behaviours of the two people reading the stories. In the end they have to complete the DYSWYS in which the instructions were written before the first trial.

All of the procedure, questionnaires included, lasts on average 1 hour and 15 minutes.

These passages refer to all the procedure but for this research the focus will be only on the MSI, eBMRQ and the three rhythmic tasks.

The study was evaluated and approved by the Ethical Committee of the Department of Brain and Behavioural Science of University of Pavia. All personal data are treated in compliance with the provisions of current legislation on data protection, by EU Regulation 2016/679 (RGDP) and in accordance with the provisions of the Data Protection Authority's general authorization and in accordance with article 20, paragraph 4, of Legislative Decree 10 August 2018 of "Codice di deontologia e di buona Condotta per i trattamenti di dati personali per scopi statistici o di ricerca scientifica”. In accordance with aforementioned legislation, data treatment is respected by article 5 of RGDP and all sensible personal data are treated in accordance with Article 9, paragraph 2, lett. j) of RGDP. All data will be maintained for 5 years since the conclusion of the project.

7. ANALYSIS OF DATA

All the statistical analysis were carried out using *R*, an open-source programming language, used specifically for the analysis of data.

First of all, a descriptive analysis on all the measures was conducted. It was analyzed the distribution of results of eBMRQ to have a distribution of the hedonic values of the sample (N=121). This step was done to understand how this population feel and experience music.

The FTT (N=121) distribution was done to evaluate the accuracy of the participants in the task. The variable that is going to be analyzed is Delta. Delta is the accuracy of the participants in completing the task and it is the difference between RT and ISI (RT-ISI), where RT is the Reaction Time, so when a participant presses the space bar and ISI is the Inter Stimulus Interval, that is the time distance between one rhythmic stimulus and the subsequent. If Delta is 0 or similar to 0 it means that the task is been accurately completed.

Results of CA-BAT were evaluated to see the accuracy of the participants in choosing if the superimposed beat was synchronized or not with the musical excerpt. The variables analyzed were the proportion of asynchrony response and degree of synchrony in the task.

The last part of the descriptive analysis was about the MET results. The accuracy in completing the task was analyzed as variable.

After the descriptive analysis the focus was put on the interaction between the variables of each rhythmic tasks and the eBMRQ, with linear mixed-effects models and generalized linear mixed models. The choice of using linear models lies in having multiple dependent variables. Since the hypothesis that higher musical hedonia predicts higher rhythmic abilities, linear mixed-effects models were implemented to predict Delta response in FTT based on the time in the Continuation phase of the task and based on the sensitivity to music reward, hence eBMRQ values. The same type of analysis was conducted again to evaluate Delta responses based on all the six subscales of eBMRQ, to understand if there are facets of musical reward could predict the performance that has been assumed, hence a better one.

In CA-BAT it was analyzed firstly the slope of the participants, so their sensitivity to the task, secondly it was implemented a generalized linear-mixed models. Since it was hypothesized that higher musical hedonia predict higher accuracy in rhythmic perception, the slope of participant is put in interaction with musical hedonia values (eBMRQ). The same analysis was conducted with every subscale of eBMRQ to find out if there are aspects of musical hedonia that could predict the hypothesis assumed.

MET accuracy values were put in interaction with eBMRQ results to understand if higher musical hedonia could predict a higher accuracy in terms of memory perception. A generalized linear-mixed models was implemented also in this case, and the same analysis was conducted also with every subscale of eBMRQ to find out if there are aspects of musical hedonia that could predict the hypothesis assumed.

8. RESULTS

The initial analysis was done, thanks to the MSI, to understand if participants of the sample were professional musicians or not, to help delineate the actual sample.

The eBMRQ was submitted to evaluate levels of musical hedonia in the sample.

In Table 1 and in Figure 1 it is presented the distribution of the values of eBMRQ. A small part of the sample presented a low value of musical hedonia from 43 to 60 out of a total of 120 (N=6). Almost 50% (N=56) of the participants have a quite high value of musical hedonia and N=35 has the highest values of hedonia (from 101 to 120). The mean of the sample in the questionnaire is M=81 and the Standard Deviation (S.D.=16.076)

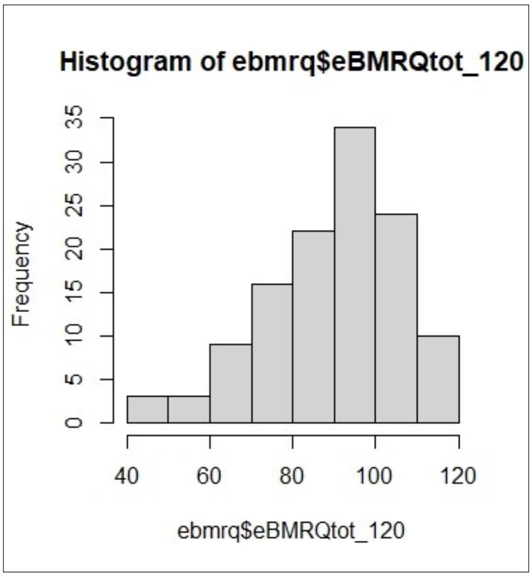
Table 1*:*

extended Barcelona Music Questionnaire (eBMRQ) distribution. In the left column are presented the intervals of values from 40 to 120 (the minimum and the maximum for eBMRQ) In the right column are presented the frequency with which the values occur.

eBMRQ VALUES	FREQUENCY
40-50	3
51-60	3
61-70	9
71-80	16
81-90	22
91-100	34
101-110	25
111-120	10

Figure 1:

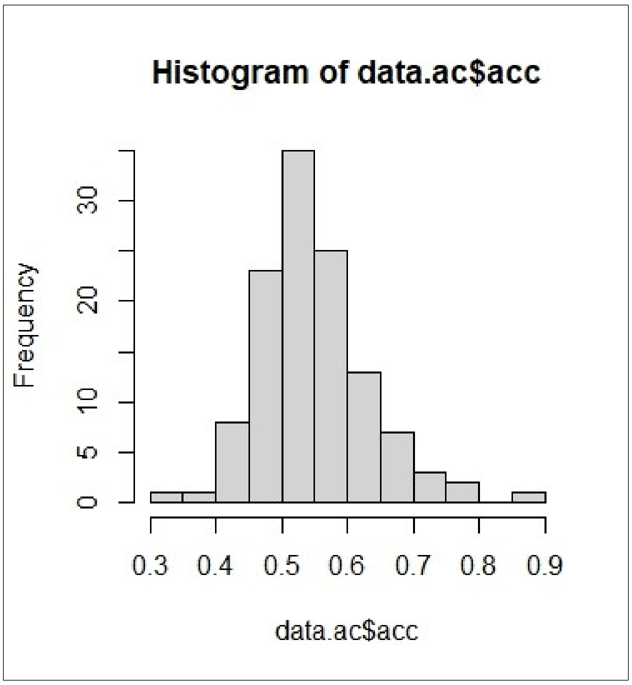
Histogram of eBMRQ. On the abscissa are the intervals of eBMRQ, from 40 to 120. On the ordinates there are the frequency, out of a total of 121, of the answers of the participants to the questionnaire (M=81; S.D.=16.076).



In Figure 2 is presented the distribution of CA-BAT. On the x axis it is presented the accuracy of the participants in choosing if the superimposed rhythmic beat was synchronous or not. It can be seen that the participants were not very accurate since the accuracy (in the x axis) is quite low, about 50% for the majority of the participants. Given the distribution, participants who had an accuracy higher than 90% were removed (N=1), also participants that have had problems with the task were removed (N=1), so for the CA-BAT distribution the sample is N=119.

Figure 2:

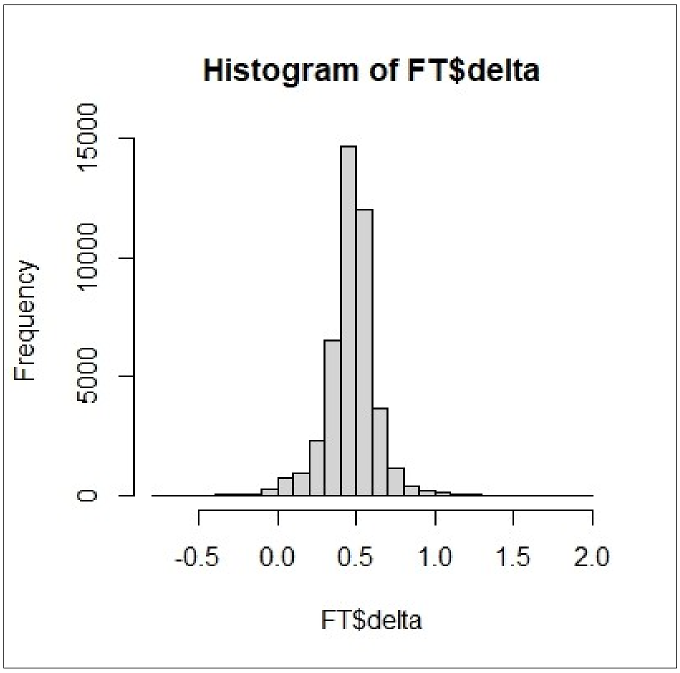
Histogram of the distribution of CA-BAT. On the abscissa there is the accuracy of the sample in responding to the task (from 0% to 100%) and in the ordinates there is the frequency of the accuracy value. About half of the sample (60 c.a.) has an accuracy between 50% and 60%.



The analysis on the FTT was done to evaluate the ability of the sample to recreate a rhythm after a few cues. In Figure 3 it is shown the distribution of FTT. On the abscissa there are Delta values. Delta is the accuracy of the participants in completing the task and it is the difference between RT and ISI (RT-ISI), where RT is the Reaction Time, so when a participant presses the space bar and ISI is the Inter Stimulus Interval, that is the time distance between one rhythmic stimulus and the subsequent. If Delta is 0 or similar to 0 it means that the task is been accurately completed. It can be seen from Figure 3 that the participants tend to respond with 0.5 second of delay from one ISI to the other, the sample is not very accurate.

Figure 3:

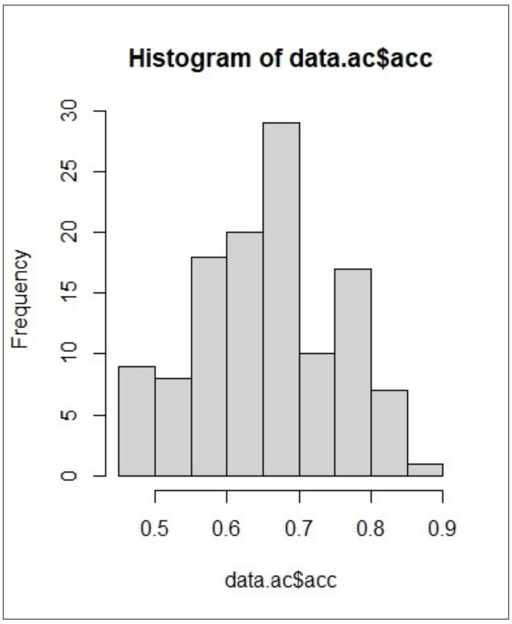
Histogram of Delta (RT-ISI). On the abscissa there are Delta values, while on the ordinate the frequency with which every Delta occur in the task.



In Figure 4 it can be seen the distribution of MET. It can be noticed that the participants were quite accurate in the task.

Figure 4:

MET distribution. On the abscissa there is the accuracy in responding to the task (from 0% to 100%). In the ordinate there is the frequency with which accuracy values occur.



The hypotheses that higher musical hedonia predicts higher rhythmic abilities and that higher musical hedonia predicts higher accuracy in rhythmic perception were tested by employing linear mixed regression models computing what it is presented in the next text lines. Figure 5 shows the interaction between the Finger Tapping Task and eBMRQ. In the abscissa there are the number of repetition (from 1 to 30) of tapping in the Continuation Phase. In the ordinate there are Delta values (the dependent variable). The right answer is Delta=0 s. It can be noticed in this Figure that all the participants tend to be less accurate with time. This model is interaction with eBMRQ: how the influence of musical hedonia has on the trend of response Delta over the Continuation Phase. A null hypothesis (H_0) is formulated. H_0 is that there are no differences in rhythmic abilities between the different ranges of values of eBMRQ, while H_1, the alternative hypothesis, is that there are differences between the groups. In Table 2, F is $F(1, 43366)=5.20847$, $p<.05$. This means that the null hypothesis has to be rejected and H_1 has to be accepted. So, there are differences in the rhythmic abilities between groups. In fact, results show that at the beginning of the continuation phase, all participants are inaccurate but moving forward in the task, participants with higher eBMRQ values are more accurate than those with lower eBMRQ.

Figure 5:

Interaction between eBMRQ and FTT. In the abscissa there is the number of beats of the Continuation phase of FTT and in the ordinate there are Delta values. For every interval of eBMRQ, is analyzed how the Delta value change (increase) as the task continues.

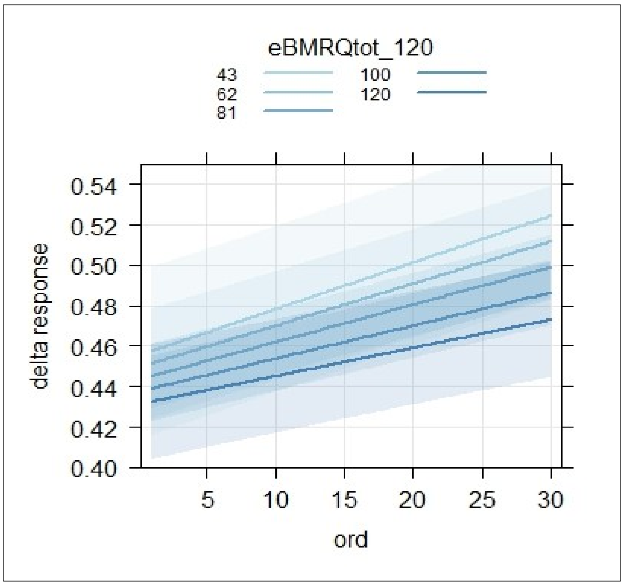


Table 2:

Results of linear mixed-effect model between total value of eBMRQ and FTT. $p<.05$ is significant.

	Sum Sq	Mean Sq	NumDF	DenDF	F	Pr(> F)
eBMRQtot_120	0.012	0.012	1	128	0.543	0.463
Ord	0.789	0.789	1	43366	35.392	<.001
eBMRQtot_120:ord	0.116	0.116	1	43366	5.208	0.022

To understand if there were differences between the different eBMRQ subscales (Musical seeking, Emotion evocation, Mood regulation, Social rewards and Sensory-motor), and rhythmic abilities of the sample, the same type of analysis was applied. For each subscale an H_0 was formulated. The hypothesis was that there were no differences between the different values of eBMRQ subscales and the accuracy in the FTT. Also, the alternative hypotheses were formulated.

It can be seen in Figure 6 and Figure 7 and relative tables (Table 3 and Table 4) that only in two of the subscales (emotion evocation and sensory motor) the interaction is significant. In the interaction between Emotion Evocation and FTT the value t was $t(43366)=-3.22$, $p<.001$ ($p<.05$ is significant), while the interaction between Sensory motor and FTT showed a t-value equal to $t(43366)=-3.53$, $p<.001$ ($p<.05$ is significant). The other tables (Table 5, Table 6 and Table 7) are presented to show the non-significant finds between FTT and eBMRQ subscales.

Figure 6:

Results of linear mixed-effect model between Emotion Evocation

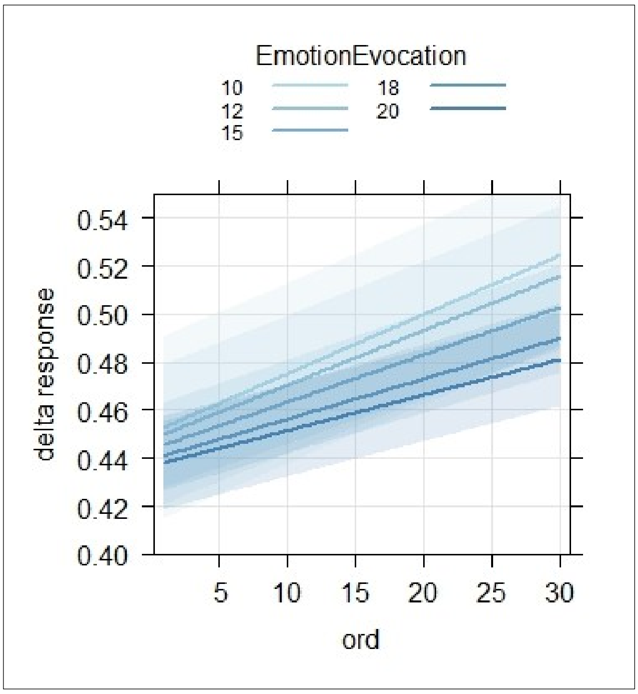


Table 3:

Results of linear mixed-effect model between Emotion Evocation subscale of eBMRQ and FTT. *p*<.05 is significant

FIXED EFFECTS					
	Est.	S.E.	t val.	d.f.	*p*
(Intercept)	0.46	0.04	10.62	128.60	<.001
EmotionEvocation	-0.00	0.00	-0.56	127.97	0.58
Ord	<.001	<.001	6.46	43366.00	<.001
EmotionEvocation:ord	-0.00	<.001	-3.22	43366.00	<.001

Figure 7:

Results of linear mixed-effect model between Sensory Motor subscale of eBMRQ and FTT.

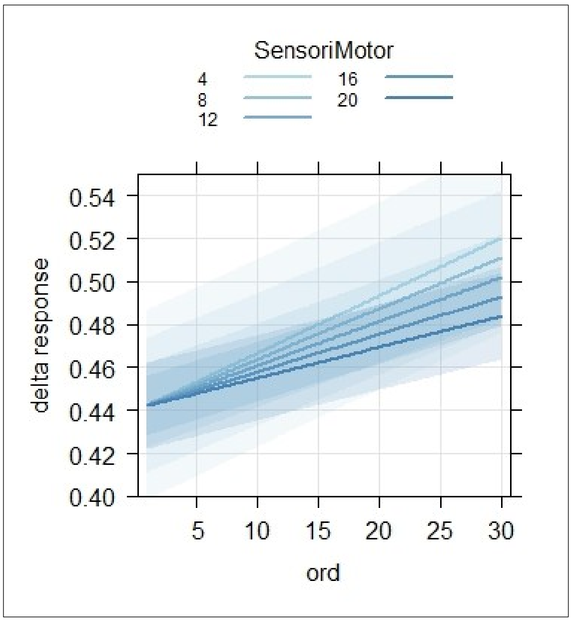


Table 4:

Results of linear mixed-effect model between Sensory Motor subscale of eBMRQ and FTT. *p*<.05 is significant

<u>FIXED EFFECTS:</u>					
	Est.	S.E.	t val.	d.f.	*p*
(Intercept)	0.44	0.03	14.86	129.22	<.001
SensoriMotor	<.001	<.001	0.02	127.90	0.98
Ord	<.001	<.001	8.33	43366.01	<.001
SensoriMotor:ord	-0.00	<.001	-3.53	43366.01	<.001

Table 5:

Results of linear mixed-effect model between Music Seeking subscale do eBMRQ and FTT. These results are not significant since *p*=.48 (*p*<.05 is significant)

FIXED EFFECTS:					
	Est.	S.E.	t val.	d.f.	*p*
(Intercept)	0.44	0.03	16.84	129.51	<.001
MusicSeeking	-0.00	<.001	-0.09	127.88	0.93
Ord	<.001	<.001	6.21	43366.00	<.001
MusicSeeking:ord	-0.00	<.001	-0.71	43366.01	0.48

Table 6:

Results of linear mixed-effect model between Mood Regulation subscale of eBMRQ and FTT. These results are not significant since *p*=.07. (*p*<.05 is significant).

FIXED EFFECTS:					
	Est.	S.E.	t val.	d.f.	*p*
(Intercept)	0.45	0.04	12.89	128.90	<.001
MoodRegulation	-0.00	<.001	-0.38	127.94	0.70
Ord	<.001	<.001	5.89	43366.03	<.001
MoodRegulatiom:ord	-0.00	<.001	-1.82	43366.03	0.07

Table 7:

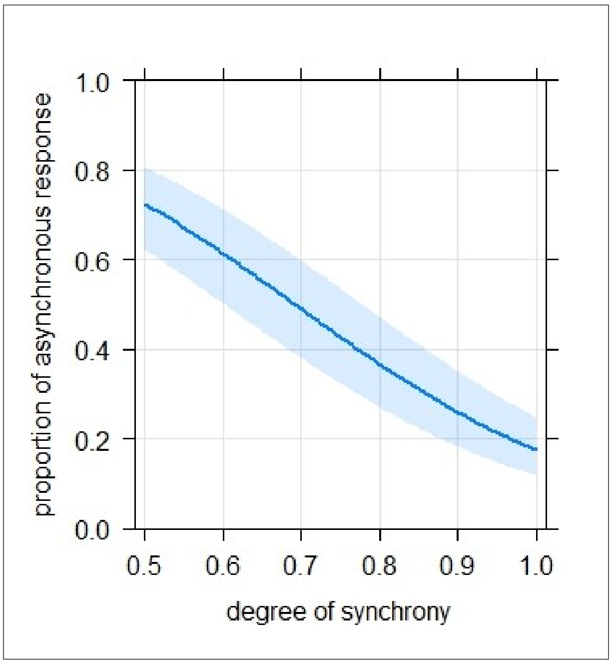
Results of linear mixed-effect model between Musical Absorption subscale of eBMRQ and FTT. These results are not significant since *p*=.10. (*p*<.05 is significant).

FIXED EFFECTS:					
	Est.	S.E.	t val.	d.f.	*p*
(Intercept)	0.48	0.02	19.71	130.07	<.001
MusicalAbosrption	-0.00	<.001	-1.68	128.19	0.10
Ord	<.001	<.001	7.45	43366.02	<.001
MusicalAbsorption:ord	-0.00	<.001	-1.64	43366.02	0.10

In Figure 8 it is presented on the abscissa the BAT values: 0.5, 0.6, 0.7, 0.8 and 0.9 that are the asynchronous values (0.5 is the most asynchronous) and 1.0 is synchronous. On the ordinate there is the Proportion of the asynchronous response, in which, higher the value, higher is the probability of responding that the superimposed sound is asynchronous. So, if the trace is closer to being synchronous (1.0), the probability of answering that the sound is asynchronous decreases. This means that the task actually works, in fact is easier to detect that the superimposed beat is asynchronous when the level of asynchrony is high (BAT=0.5), although is more difficult when the level of asynchrony is low (BAT=0.9). For this type of analysis, the reading will be in the negative

Figure 8:

CA-BAT slope of participants. Trend chart of the slope of participants between proportion of asynchrony response (ordinate) in which higher the value, higher is the possibility of responding that the beat is asynchronous, and degree of synchrony (abscissa) that varies from 0.5 (most asynchronous) to 1.0 (synchronous) in CA-BAT.



In Figure 9 on the abscissa there are the BAT values, while on the ordinate there is the Proportion of asynchronous response. The model is interaction with the eBMRQ and the influence of that musical hedonia has on the relationship between and proportion of asynchronous response can be seen. It can be seen from Table 8 that *z*=-2.87, *p*<.05, so there are differences between people with high hedonia and people with low hedonia. Results show that people that have higher values of eBMRQ are more sensitive to the task: as eBMRQ values increases, participants are more accurate in saying that the track is off-beat as asynchrony increases. As the on-beat condition is approached, the role of eBMRQ decreases.

Figure 9:

Generalized linear mixed model between eBMRQ total values and slope of participants of CA-BAT. For each interval of values (from 40 to 120) of eBMRQ is presented a different coloured slope.

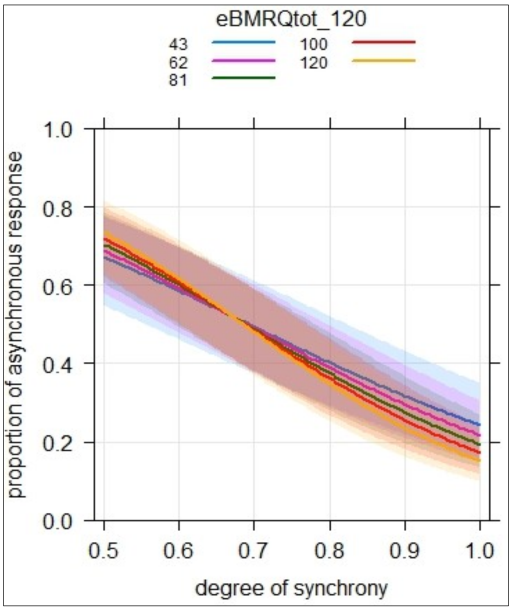


Table 8:

Generalized linear mixed model between eBMRQ total values and CA-BAT. *p*<.05 is significant

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(Intercept)	1.91	0.63	3.05	<.001
Stimuli	-2.72	0.73	-3.72	<.001
eBMRQtot_120	1.55	0.65	2.39	0.02
Stimuli: eBMRQtot_120	-2.30	0.80	-2.87	<.001

Figures 10 to 13 show that if it is put in interaction every subscale of the eBMRQ it can be noticed that all the subscales except for mood regulation are significant, starting with Music Seeking in Figure 9. In fact, in Table 9 *z*=-2.72, *p*<.01.

Figure 10:

Generalized linear mixed model between Music Seeking subscale in eBMRQ and CA-BAT. For each interval of values (from 5 to 20) of the subscale of eBMRQ is presented a different coloured slope.

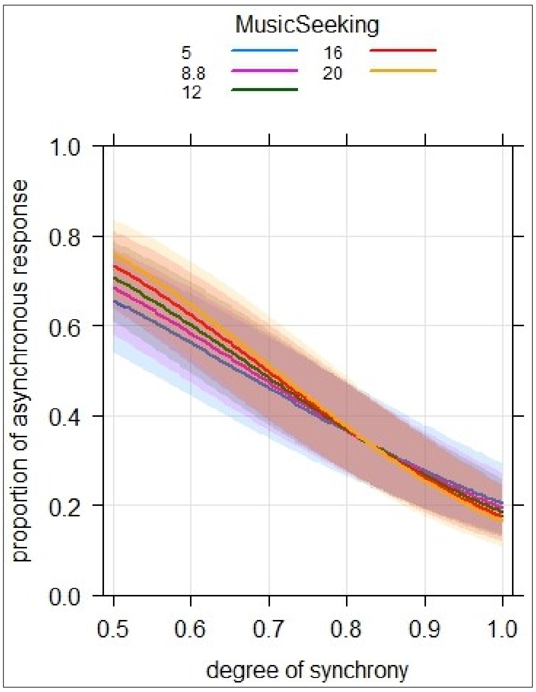


Table 9:

Generalized linear mixed model between Music Seeking subscale of eBMRQ and CA-BAT. (*p*<.05 is significant)

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	2.23	0.45	4.96	<.001
Stimoli	-3.50	0.49	-7.15	<.001
MusicSeeking	0.09	0.03	2.79	0.01
Stimoli: MusicSeeking	-0.10	0.04	-2.72	0.01

The second subscale that was analyzed and put in interaction with CA-BAT was Emotion Evocation, as shown in Figure 11. In table 10 it is shown that *z*=-2.41, *p*<.05, that means that there is a difference between values of Music Seeking subscale and how the participants complete the CA-BAT.

Figure 11:

Generalized linear mixed model between Emotion Evocation subscale of eBMRQ and CA-BAT. For each interval of values (from 10 to 20) ofte subscale of eBMRQ is presented a different coloured slope.

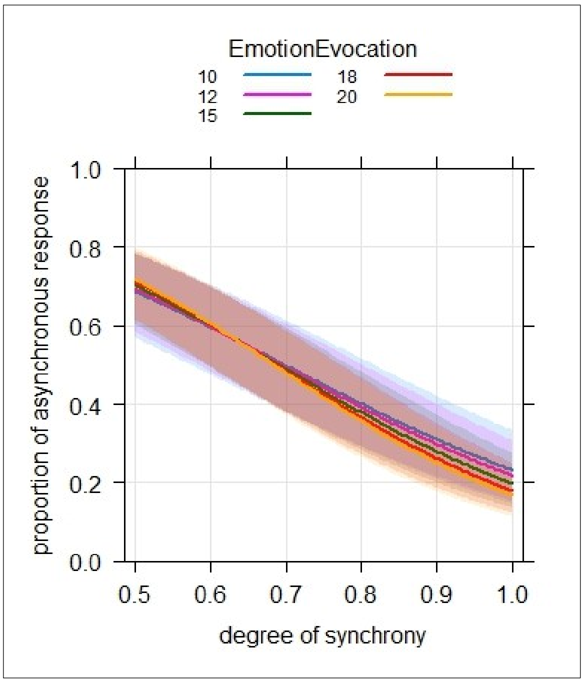


Table 10:

Generalized linear mixed model between Emotion Evocation subscale of eBMRQ and CA-BAT. (*p*<.05 is significant)

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	2.06	0.69	3.00	<.001
Stimoli	-2.85	0.81	-3.53	<.001
EmotionEvocation	0.07	0.04	1.90	0.06
Stimoli: EmotionEvocation	-0.11	0.05	-2.41	0.02

Sensory Motor was the third subscale analyzed and put in interaction with CA-BAT results (Figure 12), and it can be seen in Table 11 that *z*= -2.02, *p*<.05.

Figure 12:

Generalized linear mixed model between Sensory Motor subscale of eBMRQ and CA-BAT. For each interval of values (from 4 to 20) ofte subscale of eBMRQ is presented a different coloured slope.

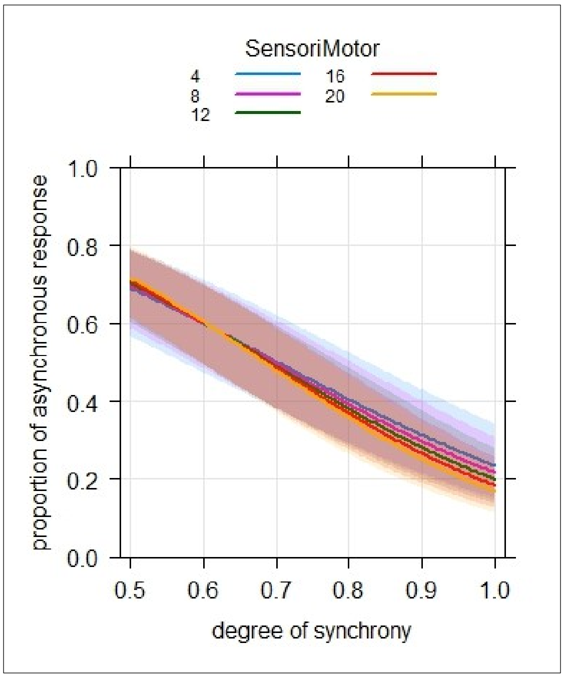


Table 11:

Generalized linear mixed model between Sensory Motor subscale of eBMRQ and CA-BAT. (*p*<.05 is significant)

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	2.63	0.49	5.36	<.001
Stimoli	-3.71	0.55	-6.79	<.001
SensoriMotor	0.04	0.03	1.55	0.12
Stimoli: SensoriMotor	-0.07	0.03	-2.02	0.04

The fourth subscale that showed a significant interaction with CA-BAT results was Social Reward (Figure 13). It is showed in Table 12 that *z*=-3.05, *p*<.05.

Figure 13:

Generalized linear mixed model between Social Reward subscale of eBMRQ and CA-BAT. For each interval of values (from 10 to 20) ofte subscale of eBMRQ is presented a different coloured slope.

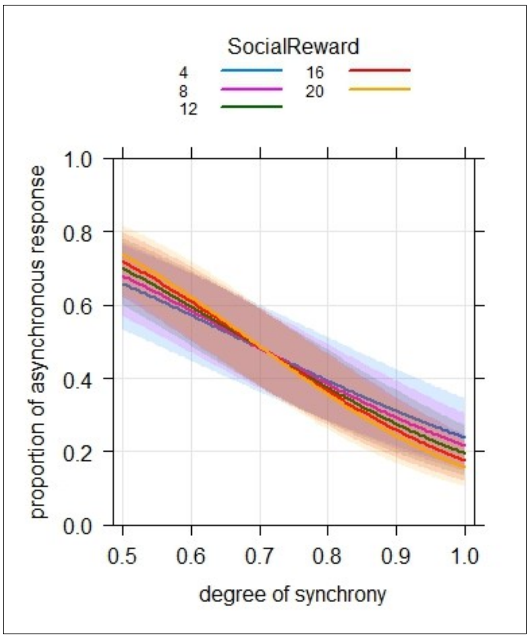


Table 12:

Generalized linear mixed model between Social Reward subscale of eBMRQ and CA-BAT. (*p*<.05 is significant)

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	2.16	0.48	4.48	<.001
Stimoli	-3.19	0.545	-5.96	<.001
SocialReward	0.08	0.03	2.71	0.01
Stimoli: SocialReward	-0.11	0.04	-3.05	<.001

The last subscale of eBMRQ analyzed that showed significant results in interaction with CA-BAT was Musical Absorption (Figure 14). In Table 13 it is showed that *z*=-2.11, *p*<.05.

Figure 14:

Generalized linear mixed model between Musical Absorption subscale of eBMRQ and CA-BAT. For each interval of values (from 4 to 20) ofte subscale of eBMRQ is presented a different coloured slope.

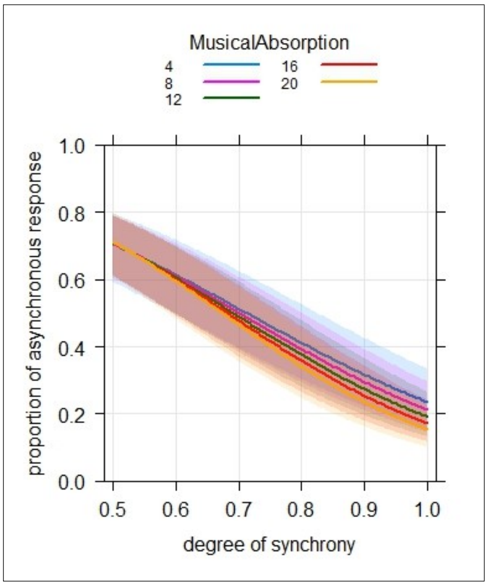


Table 13:

Generalized linear mixed model between Musical Absorption subscale of eBMRQ and CA-BAT. (*p*<.05 is significant)

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	2.79	0.46	6.50	<.001
Stimoli	-3.85	0.46	-8.31	<.001
MusicalAbsorption	0.04	0.03	1.40	0.16
Stimoli: MusicalAbsorption	-0.07	0.03	-2.11	0.03

It is also presented the Table of Mood Regulation and CA-BAT, that is not significant, since *p*>.05 (Table 14).

Table 14:

Generalized linear mixed model between Mood Regulation subscale of eBMRQ and CA-BAT. These results are not significant since *p*=.22. (*p*<.05 is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(Intercept)	2.79	0.57	4.86	<.001
Stimuli	-3.99	0.66	-6.04	<.001
Mood Regulation	0.03	0.03	0.96	0.34
Stimuli:Mood Regulation	-0.05	0.04	-1.22	0.22

The analysis carried out on the subscales show that almost all the facets of musical hedonia play a role in the sensitivity to the task.

In the next Figure (Figure 15) it can be seen the generalized mixed model, in which on the abscissa there are the eBMRQ values and on the ordinate the accuracy value in MET. The hypothesis H_0 is that there is no significant difference in the accuracy in MET and the values of eBMRQ. In Table 15 the z value shows that $z=1.38$, $p>.05$, so the interaction is not significant but it can be said that there is a tendency in being more accurate if the eBMRQ values are higher.

Figure 15:

Generalized linear mixed model between total values of eBMRQ and MET. In the abscissa there are eBMRQ values from 40 to 120, in the ordinate there is the accuracy in completing the MET.

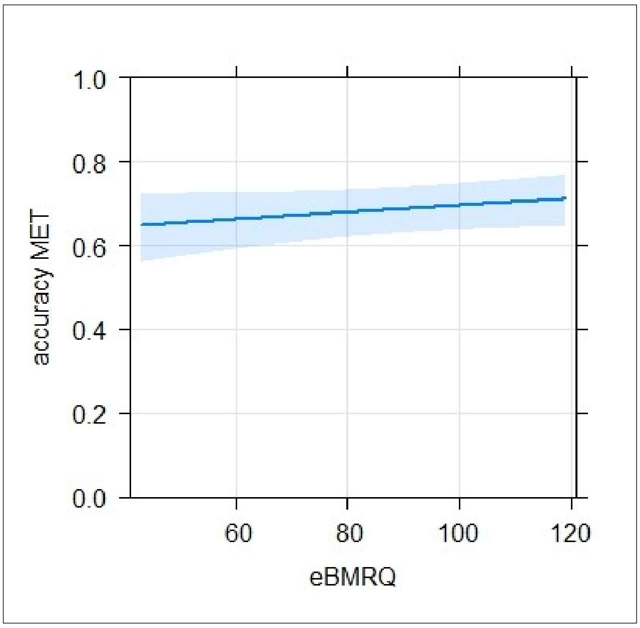


Table 15:

Generalized linear mixed model between total values of eBMRQ and MET. These results are not significant since $p=.17$. ($p<.05$ is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*P*
(intercept)	0.79	0.13	6.10	<.001
Scale (eBMRQtot_120)	0.06	0.04	1.38	0.17

If every subscale of eBMRQ is put in interaction with MET, it can be seen that the only interaction that is significant is the one with the Sensory Motor subscale, as showed in Figure 16 and the related table (Table 16), with z=2.26, p<.05.

Figure 16:

Generalized linear mixed model between Sensory Motor subscale of eBMRQ and MET.

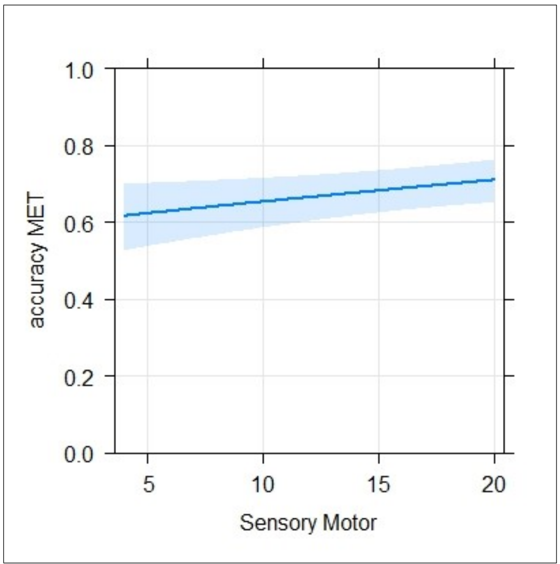


Table 16:

Generalized linear mixed model between Sensory Motor subscale of eBMRQ and MET. (p<.05 is significant)

FIXED EFFECTS:				
	Est.	S.E.	z val.	*P*
(intercept)	0.37	0.22	1.66	0.10
SensoriMotor	0.03	0.01	2.26	0.02

The other Tables (Table 17, Table 18, Table 19, Table 20 and Table 21) are displayed to show non-significant results of the interception between remaining eBMRQ subscales and MET.

Table 17:

Generalized linear mixed model between Music Seeking subscale of eBMRQ and MET. These results are not significant since *p*=.11. (*p*<.05 is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	0.53	0.21	2.53	0.01
MusicSeeking	0.02	0.01	1.58	0.11

Table 18:

Generalized linear mixed model between Emotion Evocation subscale of eBMRQ and MET. These results are not significant since *p*=.54. (p<.05 is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	0.61	0.32	1.91	0.06
EmotionEvocation	0.01	0.02	0.61	0.54

Table 19:

Generalized linear mixed model between Mood Regulation subscale of eBMRQ and MET. These results are not significant since *p*=.39. (*p*<.05 is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	0.59	0.26	2.30	0.02
MoodRegulation	0.01	0.01	0.85	0.39

Table 20:

Generalized linear mixed model between Social Reward subscale of eBMRQ and MET. These results are not significant since *p*=.65. (*p*<.05 is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	0.70	0.23	3.12	<.001
SocialReward	0.01	0.01	0.45	0.65

Table 21:

Generalized linear mixed model between Musical Absorption subscale of eBMRQ and MET. These results are not significant since *p*=.58. (*p*<.05 is significant).

FIXED EFFECTS:				
	Est.	S.E.	z val.	*p*
(intercept)	0.70	0.20	3.46	<.001
MusicalAbsorption	0.01	0.01	0.45	0.58

9. DISCUSSION

The aim of the study was to investigate if they had a better rhythmic production, a better rhythmic perception and a better rhythmic memory. To this aim, 121 participants participated to the study and they were evaluated to understand if higher musical hedonia predict higher rhythmic abilities

First of all, to proceed the analysis, it was important to evaluate the level of musical hedonia of the participants (hence eBMRQ results). From the results it can be seen that the sample is composed by more hedonic people, in fact it is seen that out of a total of 121 people, 91 (ca. 75%) have a result higher than 80 in the eBMRQ.

After evaluating the hedonic values, the different facets of rhythmic abilities were studied with FTT, CA-BAT and MET.

FTT (Horton & Hartlage, 1994) was completed by all the participants using their dominant hand and it appeared from the data that, going on with the Continuation Phase of the task, participant tend to be less accurate in time. The sample in exam showed that it tended to lag behind the ISI. Participant to complete this task needed their motor ability intact and, as found by Thaut et al. (2008), it is probable that during the execution of the task participants had an activation in the supplementary motor areas, contralaterally cerebellum and ipsilaterally supermarginal gyrus and caudate-putamen, since these were the areas studied by Thaut et al. (2008) during the performance of a rhythmic movement, while listening an acoustic cue, a task that is quite similar to the FTT.

Probably, other areas activated during this task are the basal ganglia (Grahn, 2009). Others authors (Fujii & Schlaug, 2013; Schwartze et al., 2012) confirmed that the ability in producing a rhythm is associated with cerebellum and basal ganglia, both of which are responsible for movements in humans. The analysis done on CA-BAT showed that half of the sample had an accuracy between 50% and 60%, which is comparable to a random choice in response selection. These results could be caused by the difficulty of the task or the fact that the participants were too focused on the musical pieces rather than on the superimposed rhythm, as well as it could be lack of attention. The last rhythmic task was MET. Participants were quite accurate scoring, in fact more than 50% of the participants scored more than 60% of accuracy in the task, probably because the task was easier than CA-BAT and because the abilities involved are of course different. Probably the sample in question has a better short-term auditory working memory and greater difficulties in rhythmic perception.

Moving on to the rest of the analysis, a linear mixed-effect model was conducted, first, between FTT and eBMRQ values to see how the influence of musical hedonia has on the responses over the Continuation Phase in FTT. It can be seen that there are differences in producing a rhythm based on the pleasure perceived by music. In fact, participants which have higher values of hedonia tend to be more accurate with time instead of participants with lower level of hedonia. This result confirmed what was found from Matthews et al. (2020), who found that movement is strongly related to reward response and rhythm. As seen before, in particular basal ganglia, are important part of the networks related to movement and interact in the response to music, but they are also important for the emotion recognition and evaluation of reward (Pierce & Péron, 2020). The same type of analysis was carried out for the subscales of eBMRQ, and it was found that the subscales with significant results are the Emotion Evocation one and the Sensory Motor one, corroborating again the theses of Matthews (2020) and Pierce and Péron (2020).

A generalized linear mixed model has been used to analyzed if musical hedonia predict better rhythmic perception. It was found that perception of a rhythm is better when the sample scored higher values of eBMRQ. These results can confirm what Grahn (2009) and Pierce & Pétron (2020) said. In fact, Grahn wrote that basal ganglia and cerebellum are central for the beat perception and Pierce & Pétron in their review wrote that the same areas are important in emotion recognition and evaluation of reward but also elicitation of feelings. It is essential to report that no neuroimaging was used in this study, so every connection made could be confirmed by future studies. Since from the analysis is showed that at higher hedonic values is associated a better accuracy in the CA-BAT, it can be said that both basal ganglia and cerebellum play a fundamental role in these abilities. The same analysis was done for every eBMRQ subscale. The interaction between participants' accuracy and all the subscales of eBMRQ are significant except for the Mood Regulation subscale, probably because, even if in CA-BAT music excerpts are present, the task did not focus on participants' mood or their emotions.

The last analysis was done with a generalized mixed model between eBMRQ and MET. The results showed that the interaction is not significant. What would be expected was that more hedonic participants show a better memory, hence better performance. Since it was found from Ferreri and Rodriguez-Fornells (2017) that music reward could help episodic memory, it was thought that music reward could help also the working memory in humans. The same analysis for every subscale of eBMRQ was conducted and it was found that only the interaction with Sensory Motor subscale was significant.

After analyzing the interaction between every subscale of eBMRQ and rhythmic tasks performed by the sample, in order to investigate what are the facets of music-specific hedonia that predict better rhythmic abilities, it was found that the Sensory Motor subscale was significant. This result confirmed again what Matthews et al. (2020) wrote in their article, and confirmed that there is a strong correlation between reward, rhythm and movement, and that the sensation of "groove" is important not only for the production ability but probably also for perception and memory.

What was expected was also to find that the interactions between the subscale Mood Regulation of eBMRQ and the rhythmic tasks were significant, since the important role in music in this particular facet of musical hedonia (Dubé & Le Bel, 2003), but this was not found. In fact, in this study was not evaluated the emotional state, before and after the tasks, of participants nor were the music excerpts mood related, indeed in FTT the sample did listen to a beat, in CA-BAT there were musical pieces but it was asked the participants to focus on the rhythmic structure and in MET, again there were only rhythmic excerpts.

A strength of this study is definitely that it is an innovative study because it is the first study that put in interaction two aspects of human beings, hence rhythmic abilities and music-specific hedonia, which could open the door to numerous future studies. Moving on, what lacked in this study was probably the fact that the participants were in rooms, which were not adequately soundproof or participants were distracted from external factors. Another limit was the technology that participants owned, in fact there were participants without headphones, or the same headphones did not work properly. Furthermore, since the sample was created by volunteers, there is a lack of homogeneity with regard to the gender of the participants (81 females and 40 males).

Future studies could analyze the same hypotheses in different life stages (childhood, adolescence and elderly) to see if the results are the same. Other studies could change the setting and maintain the online modality but participants could be taken in soundproof rooms and given specific headphones to do the rhythmic tasks. Moreover, one idea could be also to evaluate if there is a difference in the interaction between musical hedonia and rhythmic abilities gender-related. It is important also to understand if there are cultural differences, so in future studies it could be decided to choose people from different ethnicity and different excerpts of all type of music (western and eastern) could be used to see if the pleasure perceived and the rhythmic abilities are the same independently or there are differences that depends on the culture.

Another idea for future studies could be if children with Specific Learning Disorders as dyslexia, would show the same results. Based on the study of Couvignou & Kolinsky (2021), a large part of the dyslexic sample showed an incapacity in pitch perception (congenital amusia), that could expand also in rhythmic perception. Probably their accuracy in rhythmic task would be lower since rhythm is important also in language (Langus et al., 2017).

What will be important for future studies would be using neuroimaging to investigate if there are specific areas related to the interactions observed in the study.

10. CONCLUSIONS

This elaborate delved into collecting data, both behavioral data at rhythm tasks and subjective reports of musical hedonia, to investigate the interaction between rhythmic abilities and music-related pleasure in healthy young adults from 18 to 35 years.

Music is a great part of everyone life since before birth, be it in concerts, in movies or just as a hobby, it has the ability to elicit different emotions and it is used for adaptive motive. There are multiple cognitive processes that are related to music and its components (pitch, beat and rhythm…), which were analyzed with neuroimaging studies and behavioral studies during the years. Even if it is thought that music has not a tangible advantage, different studies focused on the benefits related to music-specific hedonia, showing that music could be relevant at biological level. What is missing the literature is how music-specific hedonia could predict rhythmic abilities. The aim of this study was to investigate if higher music-specific hedonia could predict higher rhythmic abilities, in particular rhythmic production, rhythmic perception and rhythmic memory. Almost all the results satisfied the hypothesis formulated, except for the prediction of higher rhythmic memory.

Future studies could focus on other age groups, with more appropriate settings, or focus on abilities gender-related, as well as if they depend on ethnicity and the type of music/rhythm presented (western or eastern). This study focused on healthy people, in future there could be done studies with children with Specific Learning Disorder, like dyslexia, to understand if the prediction of better abilities is still present even if specific deficits are present. Future studies could, finally, focus on the use of neuroimaging tools to investigate which areas are responsible for these abilities, also in order to have a tangible confirmation of previous studies in the literature.

11. BIBLIOGRAPHY

Albiero, P., Ingoglia, S., & Lo Coco, A. (2006). Contributo all’adattamento italiano dell’Interpersonal Reactivity Index. *TPM*, *13*(2).

Bégel, V., Benoit, C. E., Correa, A., Cutanda, D., Kotz, S. A., & Dalla Bella, S. (2017). “Lost in time” but still moving to the beat. *Neuropsychologia*, *94*. https://doi.org/10.1016/j.neuropsychologia.2016.11.022

Bernardini, F., Scarponi, L., Attademo, L., … P. H.-, & Of, a new edition of W. (2020). Musical anhedonia: a review. *Journal of Psychopathology*, *26*.

Berridge, K. C., & Kringelbach, M. L. (2015). Pleasure Systems in the Brain. In *Neuron* (Vol. 86, Issue 3). https://doi.org/10.1016/j.neuron.2015.02.018

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences of the United States of America*, *98*(20). https://doi.org/10.1073/pnas.191355898

Cardona, G., Ferreri, L., Lorenzo-Seva, U., Russo, F. A., & Rodriguez-Fornells, A. (2022). The forgotten role of absorption in music reward. *Annals of the New York Academy of Sciences*, *1514*(1). https://doi.org/10.1111/nyas.14790

Cardona, G., Rodriguez-Fornells, A., Nye, H., Rifà-Ros, X., & Ferreri, L. (2020). The impact of musical pleasure and musical hedonia on verbal episodic memory. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-72772-3

Carraturo, G., Ferreri, L., Cardona, G., Lorenzo-Seva, U., Rodriguez-Fornells, A., & Brattico, E. (2023). The Italian Version of the extended Barcelona Music Reward Questionnaire (eBMRQ): A Validation Study and Association with Age, Gender, and Musicianship. *PsyArXiv*.

Cheung, V. K. M., Harrison, P. M. C., Meyer, L., Pearce, M. T., Haynes, J. D., & Koelsch, S. (2019). Uncertainty and Surprise Jointly Predict Musical Pleasure and Amygdala, Hippocampus, and Auditory Cortex Activity. *Current Biology*, *29*(23). https://doi.org/10.1016/j.cub.2019.09.067

Correia, A. I., Vincenzi, M., Vanzella, P., Pinheiro, A. P., Lima, C. F., & Schellenberg, E. G. (2022). Can musical ability be tested online? *Behavior Research Methods*, *54*(2). https://doi.org/10.3758/s13428-021-01641-2

Couvignou, M., & Kolinsky, R. (2021). Comorbidity and cognitive overlap between developmental dyslexia and congenital amusia in children. *Neuropsychologia*, *155*. https://doi.org/10.1016/j.neuropsychologia.2021.107811

Dalla Bella, S., Peretz, I., Rousseau, L., & Gosselin, N. (2001). A developmental study of the affective value of tempo and mode in music. *Cognition*, *80*(3). https://doi.org/10.1016/S0010-0277(00)00136-0

Davis, M. H. (1983). Measuring individual differences in empathy: Evidence for a multidimensional approach. *Journal of Personality and Social Psychology*, *44*(1). https://doi.org/10.1037/0022-3514.44.1.113

Dellacherie, D., Egrlé, N., & Samson, S. (2008). Is the neutral condition relevant to study musical emotion in patients? *Music Perception*, *25*(4). https://doi.org/10.1525/mp.2008.25.4.285

Dubé, L., & Le Bel, J. L. (2003). The content and structure of laypeople’s concept of pleasure. In *Cognition and Emotion* (Vol. 17, Issue 2). https://doi.org/10.1080/02699930302295

Feldman, R., Magori-Cohen, R., Galili, G., Singer, M., & Louzoun, Y. (2011). Mother and infant coordinate heart rhythms through episodes of interaction synchrony. *Infant Behavior and Development*, *34*(4). https://doi.org/10.1016/j.infbeh.2011.06.008

Ferreri, L., Mas-Herrero, E., Zatorre, R. J., Ripollés, P., Gomez-Andres, A., Alicart, H., Olivé, G., Marco-Pallarés, J., Antonijoan, R. M., Valle, M., Riba, J., & Rodriguez-Fornells, A. (2019). Dopamine modulates the reward experiences elicited by music. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(9). https://doi.org/10.1073/pnas.1811878116

Ferreri, L., & Rodriguez-Fornells, A. (2017). Music-related reward responses predict episodic memory performance. *Experimental Brain Research*, *235*(12). https://doi.org/10.1007/s00221-017-5095-0

Fitch, W. T. (2013). Rhythmic cognition in humans and animals: distinguishing meter and pulse perception. *Frontiers in Systems Neuroscience*, *7*. https://doi.org/10.3389/fnsys.2013.00068

Fiveash, A., Bella, S. D., Bigand, E., Gordon, R. L., & Tillmann, B. (2022). You got rhythm, or more: The multidimensionality of rhythmic abilities. *Attention, Perception, and Psychophysics*, *84*(4). https://doi.org/10.3758/s13414-022-02487-2

Fiveash, A., Ferreri, L., Bouwer, F. L., Kösem, A., Moghimi, S., Ravignani, A., Keller, P. E., & Tillmann, B. (2023). Can rhythm-mediated reward boost learning, memory, and social connection? Perspectives for future research. In *Neuroscience and Biobehavioral Reviews* (Vol. 149). https://doi.org/10.1016/j.neubiorev.2023.105153

Fujii, S., & Schlaug, G. (2013). The Harvard Beat Assessment Test (H-BAT): a battery for assessing beat perception and production and their dissociation. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00771

Grahn, J. A. (2009). The Role of the Basal Ganglia in Beat Perception. *Annals of the New York Academy of Sciences*, *1169*(1). https://doi.org/10.1111/j.1749-6632.2009.04553.x

Hannon, E. E., & Trehub, S. E. (2005). Metrical categories in infancy and adulthood. *Psychological Science*, *16*(1). https://doi.org/10.1111/j.0956-7976.2005.00779.x

Harrison, P. M. C., & Müllensiefen, D. (2018). Development and Validation of the Computerised Adaptive Beat Alignment Test (CA-BAT). *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-30318-8

Horton, A. M., & Hartlage, L. C. (1994). The Halstead-Reitan neuropsychology test battery: Theory and clinical interpretation second edition. *Archives of Clinical Neuropsychology*, *9*(3). https://doi.org/10.1093/arclin/9.3.289

Ingold, T. (2017). *Anthropology and/as Education* (1st ed.). Routledge.

Iversen, J. R., & Patel, A. D. (2008). The Beat Alignment Test (BAT): Surveying beat processing abilities in the general population. *Proceedings of the 10th International Conference on Music Perception and Cognition*, *Icmpc 10*.

J. Trost, W., Labbé, C., & Grandjean, D. (2017). Rhythmic entrainment as a musical affect induction mechanism. In *Neuropsychologia* (Vol. 96). https://doi.org/10.1016/j.neuropsychologia.2017.01.004

Kaas, J. H., Hackett, T. A., & Tramo, M. J. (1999). Auditory processing in primate cerebral cortex. *Current Opinion in Neurobiology*, *9*(2). https://doi.org/10.1016/S0959-4388(99)80022-1

Kathios, N., Patel, A. D., & Loui, P. (2024). Musical anhedonia, timbre, and the rewards of music listening. *Cognition*, *243*. https://doi.org/10.1016/j.cognition.2023.105672

Kujala, T., Tervaniemi, M., & Schröger, E. (2007). The mismatch negativity in cognitive and clinical neuroscience: Theoretical and methodological considerations. *Biological Psychology*, *74*(1), 1–19. https://doi.org/10.1016/j.biopsycho.2006.06.001

Langus, A., Mehler, J., & Nespor, M. (2017). Rhythm in language acquisition. In *Neuroscience and Biobehavioral Reviews* (Vol. 81). https://doi.org/10.1016/j.neubiorev.2016.12.012

Lisman, J., Grace, A. A., & Duzel, E. (2011). A neoHebbian framework for episodic memory; role of dopamine-dependent late LTP. In *Trends in Neurosciences* (Vol. 34, Issue 10). https://doi.org/10.1016/j.tins.2011.07.006

Malloch, S., & Trevarthen, C. (2018). The human nature of music. *Frontiers in Psychology*, *9*(OCT). https://doi.org/10.3389/fpsyg.2018.01680

Mas-Herrero, E., Maini, L., Sescousse, G., & Zatorre, R. J. (2021). Common and distinct neural correlates of music and food-induced pleasure: A coordinate-based meta-analysis of neuroimaging studies. In *Neuroscience and Biobehavioral Reviews* (Vol. 123). https://doi.org/10.1016/j.neubiorev.2020.12.008

Mas-Herrero, E., Marco-Pallares, J., Lorenzo-Seva, U., Zatorre, R. J., & Rodriguez-Fornells, A. (2013). Individual Differences in Music Reward Experiences. *Music Perception*, *31*(2). https://doi.org/10.1525/mp.2013.31.2.118

Matthews, T. E., Witek, M. A. G., Heggli, O. A., Penhune, V. B., & Vuust, P. (2019). The sensation of groove is affected by the interaction of rhythmic and harmonic complexity. *PLoS ONE*, *14*(1). https://doi.org/10.1371/journal.pone.0204539

Matthews, T. E., Witek, M. A. G., Lund, T., Vuust, P., & Penhune, V. B. (2020). The sensation of groove engages motor and reward networks. *NeuroImage*, *214*. https://doi.org/10.1016/j.neuroimage.2020.116768

McAuley, J. D. (2010). *Tempo and Rhythm* (pp. 165–199). Springer. https://doi.org/10.1007/978-1-4419-6114-3_6

McDermott, J. H., & Oxenham, A. J. (2008). Music perception, pitch, and the auditory system. In *Current Opinion in Neurobiology* (Vol. 18, Issue 4). https://doi.org/10.1016/j.conb.2008.09.005

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). Measuring the facets of musicality: The Goldsmiths Musical Sophistication Index (Gold-MSI). *Personality and Individual Differences*, *60*. https://doi.org/10.1016/j.paid.2013.07.081

Paquette, S., Fujii, S., Li, H. C., & Schlaug, G. (2017). The cerebellum's contribution to beat interval discrimination. *NeuroImage*, *163*. https://doi.org/10.1016/j.neuroimage.2017.09.017

Patel, A. D. (2008). *Music, Language and Brain*. Oxford University Press.

Pavlicevic, M. (1997). *Music Therapy in Context: Music Meaning and Relationship.* (J. Kingsley, Ed.).

Pavlicevic, M. (1999). *Music Therapy: Intimate Notes.* (J. Kingsley, Ed.).

Pavlicevic, M. (2000). Improvisation in music therapy: Human communication in sound. *Journal of Music Therapy*, *37*(4). https://doi.org/10.1093/jmt/37.4.269

Peretz, I., Ayotte, J., Zatorre, R. J., Mehler, J., Ahad, P., Penhune, V. B., & Jutras, B. (2002). Congenital Amusia: A disorder of fine-grained pitch discrimination. *Neuron*, *33*(2). https://doi.org/10.1016/S0896-6273(01)00580-3

Peretz, I., Gosselin, N., Nan, Y., Caron-Caplette, E., Trehub, S. E., & Beland, R. (2013). A novel tool for evaluating children's musical abilities across age and culture. *Frontiers in Systems Neuroscience*, *JUNE*. https://doi.org/10.3389/fnsys.2013.00030

Phillips-Silver, J., Toiviainen, P., Gosselin, N., Piché, O., Nozaradan, S., Palmer, C., & Peretz, I. (2011). Born to dance but beat deaf: A new form of congenital amusia. *Neuropsychologia*, *49*(5). https://doi.org/10.1016/j.neuropsychologia.2011.02.002

Phillips-Silver, J., & Trainor, L. J. (2005). Feeling the Beat: Movement Influences Infant Rhythm Perception. *Science*, *308*(5727), 1430–1430. https://doi.org/10.1126/science.1110922

Pierce, J. E., & Péron, J. (2020). The basal ganglia and the cerebellum in human emotion. *Social Cognitive and Affective Neuroscience*, *15*(5). https://doi.org/10.1093/scan/nsaa076

Porter, J., Blacking, J., & Byron, R. (1996). Music, Culture and Experience: Selected Papers of John Blacking. *Western Folklore*, *55*(2). https://doi.org/10.2307/1500182

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience*, *14*(2). https://doi.org/10.1038/nn.2726

Salimpoor, V. N., Benovoy, M., Longo, G., Cooperstock, J. R., & Zatorre, R. J. (2009). The rewarding aspects of music listening are related to degree of emotional arousal. *PLoS ONE*, *4*(10). https://doi.org/10.1371/journal.pone.0007487

Salimpoor, V. N., van den Bosch, I., Kovacevic, N., McIntosh, A. R., Dagher, A., & Zatorre, R. J. (2013). Interactions Between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value. *Science*, *340*(6129), 216–219. https://doi.org/10.1126/science.1231059

Sandstrom, G. M., & Russo, F. A. (2013). Absorption in music: Development of a scale to identify individuals with strong emotional responses to music. *Psychology of Music*, *41*(2). https://doi.org/10.1177/0305735611422508

Santangelo, M., Persici, V., Caricati, L., Corsano, P., Gordon, R. L., & Majorano, M. (2024). The adaptation and validation of the Goldsmiths Musical Sophistication Index (Gold-MSI) in Italian: The Gold-MSI-IT. *Psychology of Music*, *52*(4). https://doi.org/10.1177/03057356231204855

Savage, P. E., Loui, P., Tarr, B., Schachner, A., Glowacki, L., Mithen, S., & Fitch, W. T. (2021). Music as a coevolved system for social bonding. *Behavioral and Brain Sciences*, *44*. https://doi.org/10.1017/S0140525X20000333

Schwartze, M., Tavano, A., Schröger, E., & Kotz, S. A. (2012). Temporal aspects of prediction in audition: Cortical and subcortical neural mechanisms. In *International Journal of Psychophysiology* (Vol. 83, Issue 2). https://doi.org/10.1016/j.ijpsycho.2011.11.003

Small, C. (1999). Musicking — the meanings of performing and listening. A lecture. *Music Education Research*, *1*(1). https://doi.org/10.1080/1461380990010102

Sowiński, J., & Dalla Bella, S. (2013). Poor synchronization to the beat may result from deficient auditory-motor mapping. *Neuropsychologia*, *51*(10). https://doi.org/10.1016/j.neuropsychologia.2013.06.027

Swaminathan, S., Kragness, H. E., & Schellenberg, E. G. (2021). The Musical Ear Test: Norms and correlates from a large sample of Canadian undergraduates. *Behavior Research Methods*, *53*(5). https://doi.org/10.3758/s13428-020-01528-8

Thaut, M. H., Demartin, M., & Sanes, J. N. (2008). Brain networks for integrative rhythm formation. *PLoS ONE*, *3*(5). https://doi.org/10.1371/journal.pone.0002312

The muse within: creativity and communication, song and play from childhood through maturity. (1993). *Choice Reviews Online*, *30*(09). https://doi.org/10.5860/choice.30-4915

Trehub, S. E. (2003). The developmental origins of musicality. In *Nature Neuroscience* (Vol. 6, Issue 7). https://doi.org/10.1038/nn1084

Visser, G. H. A., Mulder, E. J. H., & Precht, H. F. R. (1992). Studies on developmental neurology in the human fetus. *Developmental Pharmacology and Therapeutics*, *18*(3–4). https://doi.org/10.1159/000480620

Winkler, I., Háden, G. P., Ladinig, O., Sziller, I., & Honing, H. (2009). Newborn infants detect the beat in music. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(7). https://doi.org/10.1073/pnas.0809035106

Zatorre, R. J. (2015). Musical pleasure and reward: Mechanisms and dysfunction. *Annals of the New York Academy of Sciences*, *1337*(1). https://doi.org/10.1111/nyas.12677

12. SITOGRAPHY

1. Treccani (n.a.). *Musica*. https://www.treccani.it/vocabolario/musica/

2. Treccani (n.a.). *Piacere*. https://www.treccani.it/vocabolario/piacere1/