Effects of Music on Prosocial Behavior and Its Underlying Mechanisms

Authors: Junpeng Li, Zhou Linshu, Jiang Jun, Wang Danni, Jiang Cunmei, Zhou Linshu

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Abstract

The value of music in human evolution may be associated with its social functions. Research indicates that music listening and joint musical activities facilitate prosocial behavior and the development of prosocial skills. To account for these effects, this article proposes a theoretical model positing that music enhances individuals' empathy and positive emotional experiences through emotional contagion, while the entrainment generated by its rhythm promotes interpersonal synchrony; furthermore, the interaction between emotional contagion and rhythmic entrainment may augment the prosocial effects of music. Oxytocin, the endogenous opioid system, the dopaminergic reward system, and auditory-motor coupling may represent potential neurobiological substrates underlying music's prosocial effects. Future research could investigate the prosocial effects of music and their mediating mechanisms based on a multi-pathway theoretical model, thereby providing further evidence for the music-social bonding hypothesis.

Full Text

The Influence of Music on Prosocial Behaviors and Its Mechanisms

LI Junpeng, ZHOU Linshu, JIANG Jun, WANG Danni, JIANG Cunmei
(Music College, Shanghai Normal University, Shanghai 200234, China)

Abstract: The value of music in human evolution may be attributed to its social functions. Research has shown that both music listening and joint music-making foster prosocial behaviors and the development of prosocial skills. In order to explain these effects, we propose a theoretical model, suggesting that music enhances individuals'empathy and positive emotional experiences through

emotional contagion, while the entrainment effect of rhythm facilitates interpersonal synchrony. Furthermore, the interaction between emotional contagion and rhythmic entrainment can further enhance the prosocial effects of music. Oxytocin, the endogenous opioid system, the dopamine reward system, and auditory-motor coupling may serve as potential neurobiological foundations for the prosocial effects of music. Future research could employ the multi-pathway theoretical model to examine the prosocial effect of music and its mediating mechanisms, providing further evidence for the music-social bonding hypothesis.

Keywords: musical emotion, rhythmic entrainment, prosocial behaviors, empathy, interpersonal synchrony
Classification Numbers: B842; C91

Music is a product of human consciousness that exists in all known human cultures, including primitive tribal cultures without written language (Mehr et al., 2019). Music is not essential for human survival, so what role and function has it played in human evolution? This question has attracted the attention of researchers in anthropology, biology, psychology, philosophy, and other fields. Recent theories suggest that music served to promote social bonding during human evolution, which may explain its evolutionary value (Savage et al., 2021). Indeed, as social beings, humans rely on interpersonal interaction and cooperation with other members of society to survive and develop more effectively. In addition to its artistic and aesthetic functions, music may also have many practical functions, such as cultivating personal character, regulating moral behavior, and promoting social harmony. These effects may have had a sustained impact on both cultural and biological evolution.

Some individuals tend to engage in behaviors that benefit others or society, such as helping, volunteering, and sharing. In the field of social psychology, these behaviors can be collectively referred to by a single concept—prosocial behavior. If music played a role in promoting social bonding during human evolution, can it promote individuals' prosocial behavior? What are its mechanisms? Exploring these questions can help verify the social functions of music and provide valuable evidence for understanding its significance and role in human evolution. Additionally, relevant conclusions can reveal how music influences social cognition and behavior, thereby facilitating the application of music in social life, education, and technology. Based on this, we will analyze existing evidence regarding the relationship between music and prosocial behavior and discuss potential psychological mechanisms and neurobiological foundations.

2 The Influence of Music on Prosocial Behavior

Musical activities mainly include listening to, performing, creating, and learning music, which involve various music culture-related products such as songs, instrumental music, dance, and religious music. Reviewing the existing literature, empirical research on the prosocial functions of music can be broadly divided

into two aspects: first, examining the prosocial effects of music listening at the intra-individual level, and second, investigating the prosocial effects caused by multi-person musical activities (such as choral singing, ensemble playing, and musical interaction) at the inter-individual level. Therefore, we will first analyze existing evidence on the relationship between music listening and prosocial behavior, and then discuss relevant evidence on how joint musical activities influence prosocial behavior.

2.1 The Influence of Music Listening on Prosocial Behavior

Some studies have examined the prosocial effects of listening to prosocial songs. So-called prosocial songs mainly refer to songs whose lyrics contain prosocial messages (Grimani et al., 2024). Greitemeyer (2009b) compared the effects of listening to prosocial songs versus neutral songs on volunteering and cooperative behavior, finding that compared to neutral songs, participants who listened to prosocial songs were more willing to participate in an additional unpaid study and were willing to spend more time on it. Similarly, in the Dictator Game, participants who listened to prosocial songs showed more prosocial tendencies than those who listened to neutral songs. Other studies have verified this conclusion: compared to participants who listened to neutral songs, those who listened to prosocial songs were more willing to donate income or potential income to nonprofit charitable organizations (Greitemeyer, 2009a; Ruth & Schramm, 2021), picked up more pens in the pen-drop test (Greitemeyer, 2011a; Kennedy, 2013), and were willing to distribute more flyers (Greitemeyer & Schwab, 2014), indicating that listening to prosocial songs can promote helping behavior. At the same time, listening to prosocial songs can help reduce aggressive behavior. For example, compared to participants who listened to neutral music, those who listened to prosocial songs gave their partners less hot sauce in a food-sharing task (Greitemeyer, 2011b), and expressed fewer aggressive behaviors (Greitemeyer & Schwab, 2014) and aggressive thoughts (Jacob et al., 2010). These effects are independent of music production methods and timbre (Ruth & Schramm, 2021), but are related to gender, attention level, and music familiarity. For instance, women are more easily influenced by prosocial songs than men (Böhm et al., 2016), and compared to familiar music, the prosocial effect induced by unfamiliar music depends more on participants' attention level during listening (Ruth, 2019).

The effects of prosocial songs can also be observed in real-life scenarios. Jacob et al. (2010) investigated the impact of playing prosocial songs on restaurant customers' consumption willingness and tipping behavior. The researchers found that compared to neutral songs, customers who heard prosocial songs showed higher consumption willingness and were willing to give more tips. Similarly, Ruth (2017) examined the effect of playing prosocial songs on customers' ordering of environmentally friendly coffee and tipping behavior in a café. The results showed that compared to neutral songs, customers purchased more environmentally friendly coffee when prosocial songs were played, even though this

coffee was sold at a higher price than regular coffee. However, this study did not find an effect of prosocial songs on tip amounts, possibly because local servers' income was less dependent on tips.

So, do the effects of prosocial songs stem from the lyrics or the music itself? Yu et al. (2019) explored the influence of the prosocial attributes of lyrics and their presentation methods. The results showed that with music accompaniment, prosocial lyrics had a more positive impact on college students' willingness to participate in unpaid experiments than neutral lyrics, but without music, reading prosocial lyrics did not affect this volunteering decision. Correspondingly, if the lyrics had prosocial attributes, presenting them through music was more conducive to prosocial behavior decisions than reading them; but if the lyrics were neutral, there was no effect regardless of whether music was present. This result suggests that the role of lyrics in the effect of prosocial songs is relatively complex, and the prosocial nature of songs depends on the musical presentation method and its interaction with lyrical content, and may also be related to the emotional attributes or rhythmic characteristics of the melody itself.

Some studies have focused on the prosocial effects of music without lyrics. For example, Kniffin et al. (2017) examined changes in the number of tokens college students voluntarily donated after listening to happy and sad music. The results showed that compared to sad music and quiet conditions, participants who listened to happy music donated more tokens, suggesting that listening to happy music may be more likely to promote prosocial behavior than listening to sad music. This effect can be observed in early development. Siu and Ho (2021) studied the influence of happy and sad music on prosocial behavior in young children. Seventy-five 18-month-old infants were randomly assigned to different music groups, and researchers observed their helping behavior in different musical environments. The results indicated that compared to sad music, happy music promoted children' s action-based helping (helping to pick up things) rather than empathy-based helping (helping a peer in difficulty). These studies mainly focused on the basic emotional types expressed by music itself, with less attention paid to complex or mixed emotions and the types of emotions individuals experience from music. For example, sadness in music can be expressed as different mixed emotions: relaxed sadness, moving sadness, and tense sadness. Relaxed and moving sad music is associated with positive emotional experiences, while tense sad music induces negative emotional experiences such as anxiety and fear (Eerola et al., 2016). Research on these complex emotions may help further understand the role of musical emotions.

Other studies have examined the relationship between musical emotional dimensions (i.e., valence and arousal) and individuals' prosocial behavior. Fried and Berkowitz (1979) found that soothing and stimulating music induced positive emotional experiences, while aversive music induced negative emotional experiences, and participants in the soothing and stimulating music groups showed stronger helping intentions than those in the aversive music and quiet groups, indicating that prosocial behavior decisions may be related to the valence of mu-

sical emotional experiences. In contrast, musical arousal may not have prosocial effects. Ganser and Huda (2010) showed that there was no difference in the impact of listening to uplifting music versus quiet conditions on participants'virtual donation amounts. Another study showed that after controlling for the effects of emotional valence and arousal experiences, listening to prosocial songs still promoted helping behavior more than listening to neutral songs (Kennedy, 2013). In addition, experimental results may be influenced by individual factors such as age and music preference. Beer and Greitemeyer (2019) compared the effects of uplifting music, melancholic music, and general ambient music on customers' tipping in a Munich restaurant. The results showed that compared to younger guests, older guests' tip amounts were more easily influenced by music conditions, with uplifting music making them more generous, followed by melancholic music, indicating that the influence of musical emotion on prosocial behavior may be moderated by age. Fukui and Toyoshima (2014) had participants listen to their favorite "thrilling" music and disliked music, and compared changes in participants' money distribution behavior in the Dictator Game before and after listening to music. The results showed that compared to quiet conditions, participants gave recipients more money after listening to liked music, and conversely, gave less money after listening to disliked music. The researchers suggested that this might be because preferred music induced positive emotional experiences, thereby promoting altruistic behavior, while disliked music-induced negative emotions caused selfish behavior.

Correspondingly, some negative musical content may increase people' s aggressive or antisocial behavior. For example, hip-hop and rap music are often defined as "problem music" because they are associated with antisocial attitudes and unhealthy lifestyles (Pawelz & Elvers, 2018). Chen et al. (2006) investigated the relationship between different types of music and alcohol use, illegal drug use, and aggressive behavior, with 1,056 college students participating in the study. The researchers found that after controlling for variables such as age, gender, race/ethnicity, and sensation-seeking levels, listening to rap music was positively correlated with alcohol use, illegal drug use, and aggressive behavior. At the same time, listening to electronic dance music and reggae music was positively correlated with alcohol use and illegal drug use, indicating that young people' s alcohol and drug use and aggressive behavior are related to their frequent exposure to music containing violent content. Longitudinal studies have also confirmed that exposure to violent music is associated with higher aggression and lower prosocial behavior during adolescence (Coyne & Padilla-Walker, 2015), and that preferences for rock, heavy metal, gothic, punk, R&B, hip-hop, and electronic dance music can predict aggression or minor delinquency (Ter Bogt et al., 2013). Experimental studies have also shown that compared to listening to neutral music, participants who listened to violent music or antisocial songs showed more hostility and aggressive attitudes (Anderson et al., 2003; Barongan & Hall, 1995; Fischer & Greitemeyer, 2006).

The relationship between music and antisocial behavior is constrained by individual factors. Selfhout et al. (2008) explored the relationship between adoles-

cents' externalizing problem behaviors and their preferences for heavy metal and hip-hop music, finding that preference for hip-hop music could predict subsequent externalizing problem behaviors in both boys and girls, but preference for heavy metal music could only predict problem behaviors in boys. Took and Weiss (1994) compared adolescents who liked heavy metal and rap music with those who liked other types of music, finding that adolescents who liked heavy metal and rap music had higher incidences of academic performance problems, school behavior problems, sexual behavior, drug and alcohol use, and detention than those who liked other types of music. However, when gender was controlled, differences were only found in academic performance and school problem counseling, indicating that the relationship between specific music preferences and antisocial behavior is not strong. We believe that the relationship between music preference and antisocial behavior cannot be simply generalized, and future research needs to examine the effects of music styles while excluding the influence of semantic content, and consider the roles of factors such as age, gender, and family environment.

The above research shows that compared to no-music or listening to antisocial music conditions, listening to prosocial songs or positive-emotion music can promote volunteering, cooperation, and helping behaviors, and effectively reduce aggressive behaviors and thoughts. Although most existing studies have not evaluated or controlled for acoustic and musical structural differences between different music conditions, the relevant effects may be related to the acoustic and structural features of music itself and its emotional connotations. At the same time, the prosocial nature of music may have a joint effect with the semantic content of lyrics outside of music, and is influenced by individual factors such as gender, familiarity, attention level, and music preference.

2.2 The Influence of Joint Musical Activities on Prosocial Behavior

Music is an effective tool for promoting meaningful social interaction between individuals (Beck & Rieser, 2020), which is particularly evident in joint musical activities. Joint musical activities refer to musical behaviors participated in by two or more people, including collective singing/playing, shared music listening, and musical interaction (Beck & Rieser, 2020). Anshel and Kipper (1988) conducted a study on adult males showing that in the Prisoner' s Dilemma Game, group members who sang together scored higher on trust questionnaires than other group members who read poetry, listened to music, or watched movies together. Kirschner and Tomasello (2010) found that compared to just chatting with peers, participating in joint musical activities (singing and dancing together) could promote spontaneous helping and cooperative behavior in 4-year-old children. At the same time, joint musical activities may have long-term effects. Williams et al. (2015) conducted a large-scale longitudinal study investigating 3,031 Australian children, finding that the frequency of their participation in joint musical activities (including playing music, singing, dancing, or doing other musical activities with family members) at ages 2 to 3 was pos-

itively correlated with their prosocial skill scores at ages 4 to 5, suggesting that early joint musical activities contribute to prosocial development. In addition, participation in joint musical activities during childhood is related to children' s prosocial skills. For example, Ilari et al. (2018) found that compared to children who participated in after-school sports classes and those who did not participate in after-school activities, children who participated in intensive after-school orchestra classes (6-7 hours per week) performed better in a synchronous drumming task after a 3-year course, and their performance in synchronous drumming was positively correlated with the number of stickers they gave to friends. A follow-up study recruited 3- to 4-year-old children to participate in a 10-week group music course, which was typically provided once a week for one hour, consisting of 12 children and their adult companions. The course activities included singing, movement, listening, creating, and improvisation together. The researchers found that the time and interest children invested in the music course were positively correlated with their helping behavior, and active music participation scores were positively correlated with sharing behavior (Ilari et al., 2020).

Nevertheless, the effects of joint musical activities may be related to the degree of interpersonal interaction. One study examined the relationship between children' s social behavior and their music learning. Eighty-two children aged 6 to 11 participated in an average of 22.9 months of one-on-one private music lessons and 5.1 months of less interactive off-campus group music lessons. The results found that music learning was positively correlated with various indicators of intelligence and academic ability, but not with indicators of social behavior and social skills (Schellenberg, 2006). Similarly, in another experimental study, 72 6-year-old children participated in 36 weeks of less interactive group keyboard or Kodály vocal lessons (6 children per group), once a week, and the results showed that their social behavior did not change before and after training, similar to children who did not participate in music lessons (Schellenberg, 2004). However, in a subsequent study by Schellenberg et al. (2015), third or fourth-grade children (average age 8) participated in a 10-month intensive school group music program, receiving 40 minutes of instrument training once a week, with at least 10 children participating together each time. The program encouraged children to interact and cooperate in music learning. The results showed that compared to control group children who did not participate in the music program, children in the music group showed greater improvements in empathy and prosocial behavior tendencies after training, an effect that may be attributed to more interactive group music training.

Synchronization may be a key component of joint musical activities, as synchronous activities are more likely to promote prosocial behavior tendencies than asynchronous activities. For example, Wiltermuth and Heath (2009) found that compared to not singing or singing asynchronously, students' cooperative behavior increased after choral singing. Similarly, Hove and Risen (2009) found that in a finger-tapping task, the degree of synchronization between participants and experimenters was related to subsequent affiliation ratings. Notably, this effect

depends on music itself. Stupacher et al. (2017a; 2017b) experimentally studied the effects of synchronous versus asynchronous tapping on the number of pens participants picked up in a helping situation. The results showed that in music conditions, participants in the synchronous tapping condition showed more helping behavior than those in the asynchronous condition; while in non-music conditions (tapping along with a tuneless metronome), there was no difference in the number of pens picked up between the two groups. This may be because the metronome only provides beats at discrete time points, while music provides a continuous stream of auditory information. The continuity of sound events may affect people' s perception, attention, and evaluation of movement synchrony, thereby influencing prosocial behavior. In addition, music is obviously more "groovy" than metronome sounds and may be more conducive to enhancing participants' positive emotions and auditory-motor coupling. The above research shows that compared to adults who participated in asynchronous musical activities or synchronous non-musical activities, adults who participated in synchronous musical activities were more likely to show prosocial behavior tendencies toward each other.

Interpersonal musical synchronization activities contribute to the prosocial development of infants and young children. Tunçgenç et al. (2015) investigated the influence of synchronous movement with audiovisual materials on social preferences in 12-month-old and 9-month-old infants. The results showed that in social contexts, 12-month-old infants preferred toys that moved synchronously rather than asynchronously; while in non-social contexts, infants showed no difference in preference between synchronous and asynchronous toys. In contrast, 9-month-old infants did not show this effect, indicating that synchrony may affect social preferences around 1 year of age. This suggests that synchronous musical activities may influence prosocial development in infants around 1 year old. Cirelli et al. (2014) further explored the influence of this movement synchrony on infants' helping behavior. Forty-eight 14-month-old infants moved synchronously or asynchronously with an experimenter while listening to music. These infants were then placed in a helping situation where they had the opportunity to help pass back something the experimenter had "accidentally" dropped. The results showed that compared to the asynchronous condition, infants in the synchronous condition showed more helping behavior tendencies. Similarly, this prosocial effect of music can also be observed in infants' caregivers. By singing to infants, caregivers can regulate their own arousal levels and strengthen their perception of emotional connection with their infants (Lense et al., 2022). Recently, Wan and Zhu (2021) examined the influence of the intensity of collaborative behavior in musical ensembles on children' s prosocial behavior. The results showed that compared to low-density collaboration (taking turns accompanying every 8 measures), children in high-density collaboration (taking turns every 1 measure) were more willing to help their partners in a subsequent block-building task and more willing to share stickers with unfamiliar children in the Dictator Game, indicating that musical collaboration can promote children' s prosocial development.

Thus, both music listening and joint musical activities can produce certain (short-term) prosocial effects. At the same time, the frequency of participation in joint musical activities during early childhood is positively correlated with prosocial skill performance in childhood, indicating that joint musical activities may promote the development of prosocial skills over a longer time scale, possibly benefiting from positive musical emotions, close interpersonal interaction, and early music exposure.

3 Mechanisms

3.1 Previous Related Theories

Some theoretical studies have attempted to explain the prosocial effects of music. Greitemeyer (2022) used the General Learning Model to explain the influence of prosocial songs on prosocial behavior, suggesting that exposure to prosocial media may affect individuals' internal states (including cognition, emotion, and arousal), which in turn influences their perception and interpretation of prosocial-related events. For example, observing or imitating the prosocial elements carried by music (such as prosocial lyrics) makes people more convinced that helping others is the right thing to do (injunctive norms) or what people usually do (descriptive norms). These internalized norms may increase observers' prosocial behavior, and this observation and imitation may also lead to increased empathy. Some studies have shown that empathy is a mediator of the short-term effect of music listening on prosocial behavior (Greitemeyer, 2009a), supporting the affective pathway of this theory. The cognitive and arousal pathways need to be tested. Although listening to prosocial songs can reduce the expression of aggressive thoughts (Jacob et al., 2010), there is currently no evidence showing that this cognitive priming is linked to prosocial behavior. In addition, this theory emphasizes the role of observation or imitation and is mainly used to explain the listening effects of music with prosocial lyrics.

Similarly, Wu and Lu (2021) believe there is a positive relationship between music training, emotional ability, and social interaction, and that intensive music training during childhood can promote the development of empathy and influence prosocial behavior. They believe this is due, on the one hand, to the rich emotional experiences in the process of music learning, and on the other hand, to the role of music training in developing complex sensory and motor skills. At the same time, music training itself is a process of social interaction with others, which helps establish cultural identity and cooperative networks. These positive effects may provide a neurocognitive foundation in aspects such as emotional recognition, experience sharing, and imitation of others' actions and emotions, thereby promoting the development of children' s empathy and prosocial abilities.

Cirelli (2018) emphasizes that interpersonal synchrony in musical activities is an important cue for identifying group membership, and this synchrony is a potential mechanism through which music influences various forms of prosocial

behavior. This research suggests that interpersonal synchrony accompanied by music can encourage infants to develop direct prosocial tendencies toward synchronously moving partners, and more importantly, this prosociality may even extend further to the synchronous partner' s social group. Based on this, long-term participation in joint musical activities may have a general impact on social cognition and behavior, as these musical activities encourage high levels of interpersonal synchrony in group contexts.

To more deeply explain the social functions of music, researchers have become increasingly interested in how music influences neurohormones (such as dopamine, endorphins, and oxytocin) in recent years. Some neurobiological foundations may mediate music' s influence on prosocial behavior because they are not only related to music but also to specific social skills. Hansen and Keller (2021) unified the neurobiological framework of music' s social functions through the social adaptation effects of oxytocin, suggesting that oxytocin release promotes music' s social functions by optimizing the ability to perceive, learn, predict, and respond to social environments. In contrast, Greenberg et al. (2021) emphasize the roles of oxytocin and dopamine systems, suggesting that both and their interactions can jointly affect music' s social functions. In the model proposed by Savage et al. (2021), auditory-motor coupling is the key to maintaining connections between music and other mechanisms, as music acts on the dopamine system, oxytocin, and the endogenous opioid system through auditory-motor coupling, thereby influencing social bonding.

It is evident that existing research explains the mechanisms of music' s prosocial effects from different perspectives, and supporting evidence also comes from different literature. For example, the General Learning Model' s explanation of music's prosocial effects emphasizes the changes in emotion, cognition, or arousal caused by observation or imitation, with evidence coming from the prosocial effects induced by song listening (Greitemeyer, 2022). Research on the effects of music training mainly explains the positive influence of early music learning on prosocial development from the perspectives of empathy (Wu & Lu, 2021) and interpersonal synchrony (Cirelli, 2018). Theoretical explanations from a neurobiological perspective discuss the mediating role of related neurohormones in music' s social functions for generalized, general musical activities (Greenberg et al., 2021; Hansen & Keller, 2021; Savage et al., 2021). It should be noted that although research on music listening mainly examines individuals' independent musical behaviors (not dependent on others), while research on joint musical activities mainly explores musical behaviors based on interpersonal interaction, in fact, most musical behaviors involve relatively comprehensive and complex, multiple components, and multiple mechanisms may work simultaneously. For example, the process of music listening not only involves individuals' perception and experience of music but also involves musical behaviors (such as swaying to music) generated on this basis. In this process, understanding the meaning of music and the coupling of perceptual and motor cortices caused by musical rhythm reflect the interpersonal communication process in which listeners decode others' (composers') intentions and synchronize with them. On the

other hand, joint musical activities not only involve interpersonal interaction but also involve individuals' own perception and experience of music (including emotional experience). Based on this, we believe that mechanistic explanations of music' s prosocial nature need to simultaneously consider the roles of different components or dimensions (such as emotion or interpersonal synchrony) and explore the different psychological and behavioral mechanisms that may coexist and their relationships.

3.2.1 Theoretical Model

Based on the aforementioned research evidence and previous theories, this paper proposes a model of the mechanisms through which music influences prosocial behavior. As shown in Figure 1 [Figure 1: see original paper], both in music listening and joint musical activities, prosocial behavior is mainly influenced through two pathways. At the intra-individual level, emotional contagion in musical activities can enhance individuals' empathy and/or positive emotional experiences, promote attention to, prediction of, and evaluation of prosocial information, thereby forming prosocial motivation and decision-making. This process mainly benefits from music' s stimulation of prosocial hormones and the dopamine reward circuit. At the inter-individual level, the entrainment effect of musical rhythm enhances synchrony between individuals, facilitating self-other merging, a process supported by coupling mechanisms between auditory and motor cortices. In addition, at both intra- and inter-individual levels, emotional contagion and rhythmic entrainment have bidirectional interactions, and their effects on empathy, positive emotional experiences, and interpersonal synchrony jointly encourage prosocial behavior tendencies and development. The following sections specifically elaborate on how musical emotional contagion and rhythmic entrainment influence related psychological mechanisms (empathy, positive emotional experiences, and interpersonal synchrony) and discuss the role of related neurobiological foundations in the process of music promoting prosocial behavior.

3.2.2 Music Influences Empathy and Positive Emotional Experience Through Emotional Contagion

Empathy is an important foundation for prosocial behavior because when others are in distress, bystanders develop an emotion directed toward the recipient. The stronger the level of empathy, the stronger the individual' s motivation to relieve others' distress, and the more likely they are to engage in prosocial behavior. We believe that during music listening, musical emotional contagion and its regulation of individuals'empathy levels may influence prosocial behavior tendencies. Emotional contagion refers to the process where listeners perceive the emotional expression of music and then "imitate"this emotion internally. It is an important mechanism of musical emotional experience (Huron & Vuoskoski, 2020; Juslin, 2013). For example, a tune that sounds exceptionally sad may initially be detected by the listener, and then through emotional contagion,

cause the listener' s own sadness. Emotional contagion is both the simplest form of empathy (Kim et al., 2021) and its evolutionary predecessor (de Waal & Preston, 2017). Empathy itself is a typical prosocial emotion, and many studies have shown that music can promote individuals' empathy levels and ability development (Rabinowitch et al., 2013; Wu & Lu, 2021). Therefore, we believe that music listening and joint musical activities can enhance individuals'empathy levels through emotional contagion. This enhancement of empathy strengthens attention to and perception of relevant prosocial cues, making individuals more likely to generate prosocial behavioral motivation or more inclined to make prosocial decisions.

Music' s influence on empathy may be related to the release of oxytocin and endogenous opioid substances. Oxytocin is a neuropeptide hormone synthesized in the hypothalamus. Evidence shows that oxytocin is released during joint musical activities such as singing training courses (Grape et al., 2003), group choral singing (Good & Russo, 2022), or group drumming (Yuhi et al., 2017). Oxytocin in turn also affects musical behavior and performance (Fukui & Toyoshima, 2023). At the same time, increased oxytocin levels are related to enhanced empathy levels (Eerola et al., 2021; Keech et al., 2018) and can improve the ability to predict others' behavior (Aydogan et al., 2018), making oxytocin an important foundation for prosocial learning (Pillerová et al., 2021). In addition to oxytocin, the endogenous opioid system may also mediate the prosocial effects of emotional music. Research shows that music listening and joint musical activities (such as participating in singing courses) not only increase pain thresholds (an indicator of opioid release) but also enhance social intimacy (Nummenmaa et al., 2021), while opioid antagonists reduce warmth and pleasure in social activities (Inagaki et al., 2016). More importantly, the endogenous opioid system is also related to empathy. When observing others' pain, brain regions related to empathy (such as bilateral insula and anterior cingulate cortex) are activated, and opioid antagonists affect pain empathy ratings and activation in these brain regions (Rütgen et al., 2015).

Music can also induce positive emotional experiences in individuals through emotional contagion. When music itself conveys positive emotional connotations, listeners' perception and internal "imitation" of this positive emotion trigger their own positive, pleasant emotional experiences through emotional contagion (Juslin, 2013). This pleasant experience is related to listeners' predictive processing of musical structure (Zhou et al., 2021), and combined with individuals' subjective evaluation of music, aesthetic judgment, or episodic memory processes, may also produce positive aesthetic emotional experiences such as awe, nostalgia, gratitude, and reverence (Juslin, 2013).

In research on prosocial and altruistic behavior, a long-standing question is whether people who feel good are also more likely to do good. Research based on a large body of evidence including correlational, experience sampling, diary, and experimental studies shows that happiness encourages people to act in more prosocial ways, with people who experience more positive emotions tending to

participate in more volunteer activities and charitable donations (Lyubomirsky et al., 2005). Subsequent research also shows that geographical differences in well-being can predict the incidence of special prosocial behaviors such as organ donation (Brethel-Haurwitz & Marsh, 2014). More importantly, the influence of positive emotions on prosocial behavior is causal: adults randomly assigned to experience positive emotions provided more help than those who did not experience positive emotions. This conclusion has been repeatedly verified by different emotion induction methods (Aknin et al., 2018). In addition, positive emotions benefit early prosocial behavior and development (Hammond & Drummond, 2019; Moore et al., 1973; Shiota et al., 2021). For example, compared to children who thought about sad or neutral events, 7- to 8-year-old children who thought about happy events allocated more money to others (Moore et al., 1973). Research on music also shows that compared to quiet conditions or listening to unpleasant music, listening to liked (Fukui & Toyoshima, 2014) or pleasant music (Kniffin et al., 2017; Siu & Ho, 2021) can promote altruistic behavior. The above evidence suggests that positive emotional experiences induced by music have value in encouraging prosocial behavior.

The positive emotions induced by musical emotional contagion may help establish and maintain social connections, enhance individuals' sense of belonging, and thereby increase prosocial behavior tendencies. Research shows that positive emotions enable individuals to meet relational needs in social interaction, including needs for security, commitment, status, trust, fairness, and belonging, thereby promoting social connection (Keltner et al., 2022). This mutual connection may cultivate a sense of shared responsibility and encourage individuals to contribute to the well-being of the group or others. On the other hand, some self-transcendent positive emotions induced by music, such as awe, reverence, and gratitude, may be conducive to cultivating prosocial behavior. For example, awe is a positive emotion, and research shows that the emotional experience of awe makes people feel small, which in turn reduces self-focus and inspires generosity (Piff et al., 2015). Similarly, Chen et al. (2022) emphasized the influence of gratitude on connection with nature and the mediating role of positive emotions in self-transcendence, showing that positive emotions can be transformed into the ability to establish positive social connections with others.

The influence of positive emotional experiences on prosocial behavior may be related to the dopamine reward system. The pleasant emotions induced by music have a direct connection with the dopamine reward system (Zhou et al., 2021; Belfi & Loui, 2020; Cheung et al., 2019; Ferreri et al., 2019; Skov & Nadal, 2020), and prosocial behavior decisions are also related to activation of reward brain regions, such as the striatum and ventral tegmental area (Hu et al., 2021; Park et al., 2019; Zoh et al., 2022). Possibly based on common neural foundations, the connection between positive emotional experiences and prosocial behavior is bidirectional (Aknin et al., 2018; Fredrickson & Joiner, 2018; Hui et al., 2020; Preston, 2013; Thoits & Hewitt, 2001), with positive emotions being able to cultivate and motivate individuals' prosociality (Shiota et al., 2021). Recent animal studies also suggest that by affecting neuronal activity

in key brain regions of the reward system (nucleus accumbens, medial prefrontal cortex), prosocial behavior can be regulated (Walsh et al., 2023; Wang et al., 2021). Therefore, we hypothesize that positive emotions experienced from music may increase individuals' future likelihood of engaging in prosocial behavior by regulating neuronal activity in the dopamine reward system.

The mechanisms through which musical emotional contagion influences empathy and reward may be overlapping (or partially overlapping). Both rely on the fundamental role of emotion and highly overlapping neurobiological foundations. For example, some reward system brain regions related to positive stimuli are also important for empathy, such as the amygdala, anterior insula, and medial prefrontal cortex. At the same time, opioid substances (such as endorphins) released in the endogenous opioid system are related to both empathy and musical pleasure experiences (Manninen, 2019; Mas-Herrero et al., 2023). For instance, the desire to hear pleasant songs is related to increased endogenous opioid substances. In addition, although the social functions of oxytocin and the dopamine reward system differ, there are many anatomical overlaps between oxytocin pathways and dopamine neuron populations (Greenberg et al., 2021). Oxytocin synthesis may be rapidly mapped to the brain' s limbic system through dopamine pathways, making it possible for them to independently mediate music' s influence on empathy and reward experiences, or to jointly affect music' s prosocial functions through bidirectional interactions between them. We have not distinguished this in the current theoretical hypothesis, mainly because existing research evidence is insufficient to separate the roles of empathy and reward mechanisms and their neurobiological foundations in music' s prosocial effects.

Therefore, we believe that music promotes individuals' empathy levels through emotional contagion, enhances perception of and sympathy for others' states, making individuals more inclined to engage in behaviors beneficial to others. At the same time, musical emotional contagion may enhance attention, prediction, and/or value calculation related to reward processing, thereby improving prosocial behavior decision-making levels. In this process, oxytocin, endogenous opioid substances, and the dopamine reward system are important neurobiological foundations. Their activities and changes are not only the result of musical emotional experiences but also powerful mechanisms for prosocial learning and its underlying neural computations, mediating music' s influence on prosocial behavior.

3.2.3 Music Strengthens Interpersonal Synchrony Through Rhythmic Entrainment

Synchrony may be one of the most critical components of joint musical activities. Interpersonal synchrony involves not only motor synchronization of behavioral actions but also synchrony of physiological activities or emotional processes over time (Lin et al., 2024; Mayo & Gordon, 2020). As mentioned earlier, musical behavior strengthens social bonds among group members and

helps promote the early development of altruistic behavior. Obviously, this effect is mainly attributed to the rhythm of music. In fact, most music contains relatively fixed rhythmic patterns with an underlying, regular beat structure. When people sing or play music together, their bodies synchronize with the underlying rhythmic regularity of the music. This synchronization process is called entrainment. Interpersonal synchrony under musical rhythmic entrainment may become a low-level cue for self-similarity, promoting within-group connections. Evidence shows that children and adults consider synchronous peers more similar to themselves than asynchronous peers (Rabinowitch & Knafo-Noam, 2015; Valdesolo & Desteno, 2011), and adults show more sympathy for synchronous peers than asynchronous peers (Valdesolo & Desteno, 2011). Research shows that body movements with synchronized timing lead to higher liking and affiliation ratings, followed by higher compliance, sympathy, and altruism (Baier et al., 2021). Therefore, joint musical activities may provide people with a safe space to imitate others, and this opportunity helps improve self-similarity and social identity, promoting self-other merging. Another possibility is that in musical rhythmic entrainment, people' s attention is more easily attracted to synchronous partners. In particular, music with a strong groove may affect the perception, attention, and evaluation of social information during synchronized movement, thereby having an entrainment effect on social relationships or behavior.

Synchrony in music and its prosocial effects may be related to auditory-motor coupling, which refers to the structural and functional connections between brain regions responsible for auditory perception (such as melody and rhythm perception) and movement (such as singing and dancing). Recent research shows that auditory-motor coupling involves a large brain network, including bilateral superior temporal cortex, supplementary motor area, cerebellum, basal ganglia, premotor cortex, temporal and parietal cortex (Damm et al., 2020). Neural oscillation theory describes it as periodic changes in the excitability level of neuronal clusters phase-locked with external rhythms (such as musical rhythm), that is, neural entrainment (Jones, 2019). This neural entrainment mechanism may further govern behavioral entrainment (Lakatos et al., 2019). Evidence shows that song-induced neural entrainment is stronger than that induced by speech (der Nederlanden et al., 2020), and musicians'neural entrainment activity is stronger than that of non-musicians (Celma-Miralles & Toro, 2019). This may explain musicians' stronger auditory-motor synchronization ability (Scheurich et al., 2020) and interpersonal synchronization ability (Tranchant et al., 2022) compared to non-musicians. In addition, an important pathway for auditory-motor coupling is the arcuate fasciculus, a bundle of axonal connections between the frontal lobe (including motor areas) and the temporal lobe, which may be one of the neural foundations through which musical activities promote prosocial behavior via auditory-motor coupling (Savage et al., 2021). Existing evidence shows that prosocial behavior involves the aforementioned brain network of auditory-motor coupling (Savage et al., 2021), neural oscillation mechanisms (Scheurich, 2021), and arcuate fasciculus activity (Savage et al., 2021).

Auditory-motor coupling is indispensable in both listening to and performing music (Cannon & Patel, 2021), because even without actual movement (such as pure listening), rhythm perception depends on auditory-motor interaction (Jin et al., 2018; Rouse et al., 2021). Although no empirical research has yet verified the role of auditory-motor coupling in music' s prosocial effects, there are several reasons to support auditory-motor coupling as an important mechanism for music to promote prosocial behavior. Auditory-motor coupling can support sensorimotor synchronization, that is, the temporal coordination between individuals' own movements and external musical rhythms (from listened music or others' singing/playing) (Repp, 2005). When individuals perceive their own behavior and synchronize it with rhythmic stimuli or others' musical behavior, it enhances interpersonal coordination, producing a sense of unity and synchrony. This may be because perception-behavior coupling itself is the foundation of a series of social skills, such as imitation and behavioral observation (Cracco et al., 2022). Music training may strengthen auditory-motor coupling ability, enabling individuals to better observe, understand, and simulate others' behaviors and intentions (Rizzolatti & Craighero, 2004). When individuals perceive musical rhythm or others' musical behavior, auditory-motor coupling leads to the replication and synchronization of these behaviors, promoting interpersonal coordination and synchrony. At the same time, auditory-motor coupling can also strengthen sensory feedback and prediction: in music listening and joint musical activities, auditory-motor coupling involves the integration of sensory feedback and motor actions, allowing individuals to adjust their movements and actions based on perception of musical rhythm or others' musical behavior (Kilner et al., 2003). This feedback loop achieves real-time coordination and synchrony by continuously updating and predicting others' musical behavior. Although inter-brain synchrony can promote prosocial behavior without the involvement of perception-motor coupling (Mogan et al., 2017), indicating that music is not a necessary condition for synchrony effects, evidence suggests that interpersonal synchrony in musical contexts that support perception-motor coupling is more conducive to promoting helping behavior (Cirelli et al., 2017). When individuals in a group all align their actions with the beat in the same piece of music (that is, when auditory-motor coupling occurs), they will ultimately align their actions with others by default. Therefore, in social situations created by music, interpersonal synchrony is easily achieved through auditory-motor coupling.

Some studies have revealed the influence of joint musical activities on prosocial behavior (Hove & Risen, 2009; Stupacher et al., 2017a, 2017b; Wiltermuth & Heath, 2009), and auditory-motor coupling has been used to explain these synchronous activities accompanied by music and music training effects (Novembre & Keller, 2014). Compared to individual music listening behavior, auditory-motor coupling may be more effective in joint musical activities (such as choral singing, ensemble playing, and teaching), because joint musical activities not only cause coupling between auditory and motor cortices through one' s own musical behavior but may also produce auditory-motor coupling based on perception of others' musical behavior. Therefore, joint musical activities may

be more conducive for individuals to synchronize or coordinate their music (or actions) with others, thereby promoting self-other merging and increasing the strength of social connections. In addition, research on music' s promotion of prosocial development also suggests the importance of auditory-motor coupling. A recent study by Lense et al. (2022) showed that during the process of singing to infants, periodic and predictable musical rhythms can entrain social visual behaviors between infants and their caregivers, thereby promoting their intimate relationship and prosociality. In this singing process, infants' gaze behavior revolves around the beat of the singing rhythm, while caregivers' facial expressions and eye movement rhythms are also consistent with it. Once the musical rhythm is disrupted, this effect is also interfered with. This suggests that auditory-motor coupling in parent-infant singing may provide infants with more opportunities for social learning and promote their prosocial development.

3.2.4 The Interaction Between Emotional Contagion and Rhythmic Entrainment

The influences of emotional contagion and rhythmic entrainment on empathy, positive emotional experiences, and interpersonal synchrony are not separate; there are interrelationships between different mechanisms. On the one hand, musical rhythmic entrainment can cause emotional contagion, thereby affecting empathy and positive emotional experiences. According to the BRECVEMA model' s (Juslin, 2013) explanation of musical emotion induction mechanisms, rhythmic entrainment is one of the mechanisms influencing positive affective experiences. The powerful external rhythm of music can affect listeners' internal body rhythms (such as heartbeat), and emotions induced in this situation can be enhanced. Therefore, rhythmic entrainment may strengthen music' s effect on emotional contagion within and between individuals, thus providing an intimate relationship-conducive context for empathy and positive emotional experiences. Existing evidence shows that children' s participation in group music courses (Schellenberg et al., 2015) or music interaction-based activities (Rabinowitch et al., 2013) contributes to their empathy development. Although it is currently impossible to determine whether this effect stems from music-induced emotional contagion or rhythmic entrainment, we speculate that interaction among individuals under the same rhythmic pattern is a social context beneficial to emotional contagion. When people participate in joint musical activities, they simultaneously focus on the unfolding of the same musical events and form interconnected attention and movement patterns (Parkinson, 2020). Stable and repetitive musical rhythmic patterns provide a meaningful emotional focus for group activities, enhancing the predictability of emotional signals, thereby increasing the likelihood of emotional contagion or affective entrainment occurring (Clayton et al., 2020; Tschacher et al., 2023). This process supports affective empathy and positive emotional experiences.

Conversely, emotional contagion may also cause better rhythmic entrainment effects, thereby explaining enhanced interpersonal synchrony. Musical emotion

is one of the factors influencing rhythm perception. Research shows that under the premise of the same musical tempo, changes in musical emotion affect walking speed (Leman et al., 2013). At the same time, compared to neutral emotional stimuli, emotional stimuli attract more attention and are conducive to the accumulation of perceptual time (Hoehl et al., 2021). In addition, emotional contagion helps physiological synchrony between individuals (Lin et al., 2024), which may explain why rhythmic patterns with music are more conducive to promoting sensorimotor synchronization (Carrer et al., 2023) and rhythmic entrainment (Rose et al., 2021) than metronome rhythms. Our recent research also shows that musical emotional contagion and its induced emotional experiences can affect individuals' time perception and further influence individuals' behavior (Zhou et al., 2022). Therefore, emotional contagion may not only directly enhance the alignment of listeners' behavioral or neural responses with musical rhythm at the intra-individual level but also stimulate rhythmic alignment between individuals, promoting synchrony in behavior and physiological activities between individuals. In this process, the main role of emotional contagion may be to enhance individuals' representation of musical rhythm or others' musical behavior (including its temporal organization) (Hoehl et al., 2021). The interaction between emotional regulation characteristics and rhythmic entrainment makes music participation an important social tool.

4 Summary and Outlook

Whether it is China' s earliest ritual music and dance "Yunmen Dajuan" or the statements of ancient Greek philosophers such as Pythagoras, they all reflect the attention and contemplation of ancient sages to music' s social functions. The role and value of music in human biological and cultural evolution remain unresolved, but music' s prosocial functions have received some preliminary exploration. This paper reviews research evidence on the relationship between music listening and joint musical activities and prosocial behavior, suggesting that musical activities can promote prosocial decision-making and prosocial skill development. Its short-term effects may be moderated by factors such as musical complexity, age, familiarity, musical experience, and preference, while in the long-term process of music learning, prosocial skill development may benefit from collective teaching models and early music exposure, producing long-term effects. Based on a synthesis of existing evidence and previous theories, we have also proposed a multi-pathway theoretical framework to explain the complex relationships between music, prosocial skills, psychological and behavioral mechanisms, and related neurobiological foundations. We suggest that music can promote individuals' empathy levels and reward experiences through emotional contagion at the intra-individual level, and influence interpersonal synchrony through rhythmic entrainment at the inter-individual level. Each mechanism relies on different neurobiological foundations but interacts with each other. Future research on the relationship between music and prosocial behavior needs to further explore the following issues.

First, it is necessary to further clarify the role of specific musical acoustic elements and structures and related influencing factors. As mentioned earlier, most current studies explore music' s prosocial effects through songs or complex activities, without comparing specific musical acoustic and structural differences between different experimental conditions. In this case, observed effects may be caused by a specific piece of music or stem from the relationship between musical and non-musical components in complex activities, making it difficult to explain music' s prosocial functions from the perspective of music itself and affecting the replicability of research results to some extent. Therefore, future research should, while excluding the influence of lyrical semantics, manipulate different musical acoustic features and structural factors to explore the relationship between music' s own elements and structural organization methods and related social functions, establishing a reproducible and practically applicable scientific discourse platform for research on music' s prosocial functions. At the same time, considering that musical structure and individual factors can interactively affect individuals' internal states (Gao et al., 2021; Ruth, 2018), the role of musical acoustic elements and structures may be moderated by factors such as environment, age, music familiarity, musical experience, and preference. Future research should comprehensively analyze the influence of factors such as the predictability of musical structure, emotional characteristics, and music interaction methods on prosocial-related cognitive and emotional activities, and explore music' s short-term and long-term effects on prosocial behavior while manipulating or controlling factors such as musical style, age, familiarity, musical experience, and preference. In addition, the long-term influence of joint musical activities on prosocial behavior or prosocial development still needs further verification. Although there is evidence that participating in interactive collective music classes (Ilari et al., 2018, 2020) and early family parent-child musical activities (Williams et al., 2015) are beneficial to children' s prosocial development, research conclusions are mainly based on correlational evidence (e.g., Ilari et al., 2020; Williams et al., 2015), with few experimental studies that can suggest causal relationships. Therefore, the view that music training promotes prosocial development needs to be carefully verified. Future research can verify the influence of joint musical activities on prosocial development through large-sample, longitudinal tracking, or twin experiments.

Second, the relationship between human musical activities and neuroendocrine processes is relatively complex, and future research needs to clarify their specific relationship patterns. Although the influence of musical activities on oxytocin, the endogenous opioid system, and the dopamine reward system has received increasing attention in recent years, overall, empirical research in this area is still in the exploratory stage. In particular, evidence for the relationship between oxytocin, the endogenous opioid system, and musical activities is relatively scarce. For example, current evidence for the influence of musical activities on the endogenous opioid system is relatively indirect, and it is unclear whether and how musical activities increase or inhibit the expression of endogenous opioid substances. At the same time, although evidence shows that opioid antagonists

(naltrexone) suppress the physiological response of "chills" during music listening, they do not affect the subjective pleasant experience of music (Laeng et al., 2021). Subsequent research should further confirm the role of the opioid system in musical activities. On the other hand, although a large number of studies have demonstrated the relationship between these neuroendocrine activities and prosocial behavior or related skills, conclusions are controversial. Future research should further examine these controversial points. For example, although most studies emphasize the prosocial effects of oxytocin, other evidence shows that oxytocin leads to antisocial effects, including distrust of unknown individuals (Keech et al., 2018), jealousy (Tabak et al., 2019), and competitive and aggressive tendencies (Erdozain & Peñagarikano, 2020). This divergence may be related to factors such as dosage, environment, and gender in the research. Similarly, there is also some controversy in the relationship between the endogenous opioid system and empathy and prosocial behavior. Although many studies support their correlation, there is also evidence suggesting that endorphin release is not related to individuals' donation behavior and willingness to help (Rauchbauer et al., 2023), which needs to be verified in subsequent research.

Third, more direct evidence is needed to test related mediating mechanisms and their relationships. For example, although there is evidence that the dopamine reward system is related to music's prosocial effects, showing that participants'activation levels in reward system-related brain regions (such as bilateral caudate nucleus) increased during synchronous drumming, and their prosocial behavior toward synchronous drumming partners also increased (Kokal et al., 2011), no study has yet demonstrated the mediating role of music reward experience and the dopamine reward system. At the same time, current research on the prosocial effects of different musical activities focuses on different mechanisms. For example, research on music listening focuses on musical emotional contagion, while research on joint musical activities emphasizes rhythm and its entrainment effects. If there are interactive effects between mechanisms, do emotional contagion and rhythmic entrainment play dominant roles in different forms of musical activities? In addition, at the neural mechanism level, both individual and group musical behaviors can cause coupling between auditory and motor cortices, but are there differences in intensity or nature in the effects of these two types of auditory-motor coupling on interpersonal synchrony? Future research should focus on examining the mediating roles of various psychological and behavioral mechanisms and their neurobiological foundations in music' s prosocial effects and their relationships. We speculate that in the process of music influencing prosocial behavior, the social functions, neural networks, or action paths corresponding to each psychological and behavioral mechanism and its neurobiological foundation are both separate and overlapping. Based on different environments or characteristics of prosocial behavior, they may independently influence certain prosocial skills during the process of mediating music' s prosocial effects, and can also act on prosocial behavior and its development in a synergistic manner. In addition, based on the similarity of social

functions and anatomical structures, we speculate that the interaction between the opioid system and the dopamine reward system can enhance empathy levels, while the connection between oxytocin and the dopamine reward system may further enhance reward prediction and value calculation. These processes may further strengthen the prediction and learning abilities for music. Future research can comprehensively use various technical means such as music analysis, behavioral science, brain imaging, neuromodulation, and pharmacology to explore the relationships between different mechanisms and their neurobiological foundations in the process of music influencing prosocial behavior. These explorations will help further understand music' s evolutionary value and provide broad thinking space for future research in music social psychology and music social neuroscience.

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Note: Figure translations are in progress. See original paper for figures.