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Evolutionary origins of music. Classical and recent hypotheses

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Abstract: The aim of this paper is to review recent hypotheses on the evolutionary origins of music in *Homo sapiens*, taking into account the most influential traditional hypotheses. To date, theories derived from evolution have focused primarily on the importance that music carries in solving detailed adaptive problems. The three most influential theoretical concepts have described the evolution of human music in terms of 1) sexual selection, 2) the formation of social bonds, or treated it 3) as a byproduct. According to recent proposals, traditional hypotheses are flawed or insufficient in fully explaining the complexity of music in *Homo sapiens*. This paper will critically discuss three traditional hypotheses of music evolution (music as an effect of sexual selection, a mechanism of social bonding, and a byproduct), as well as and two recent concepts of music evolution - music as a credible signal and Music and Social Bonding (MSB) hypothesis.

Key words: evolutionary psychology, music, biomusicology, evolutionary theories of music, functions of music

Introduction

Explaining the phenomenon of music in evolutionary terms was already a problem for Darwin, who, unable to fully explain the phenomenon of music on the basis of an early version of the theory of evolution, noted that man's capacities for music *"must be ranked amongst the most mysterious with which he is endowed"*. (Darwin 1871). Despite the fact that the explanation of music genesis is consid-

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ered crucial in the context of language evolution (Huron 2001), and music itself is treated as a second and equally important communication channel of *Homo sapiens* (Harvey 2020), the issue of the evolutionary origins of music is still unclear. This is due to the complexity of music. According to Fitch (2006), the term "music" itself should be treated as an ''umbrella term'', and it is crucial to distinguish between the different components of capacity for music, which may have evolved at different times independently of each other. The fact that music does not constitute a single detailed capacity makes answering the question *"Why did music evolve?"* considerably challenging.

Music has seemingly accompanied *Homo sapiens* since at least the Paleolithic period. The oldest surviving artefacts, which are indisputably considered musical instruments, are ca. 43 and were found in the caves of the Swabian Jura region (Higham et al. 2012; Blake and Cross 2008; Kunej and Turk 2000; d'Errico et al. 2000). Some researchers push this boundary even further – according to Steven Mithen's hypothesis, singing phylogenetically preceded the emergence of articulate speech in *Homo sapiens* and was present among Neanderthals (Mithen 2011). Evidence of the presence of music among Neanderthals is an instrument discovered in the Slovenian Divje babe I cave, which was allegedly made by made by them . However, due to the poor condition of the artefact, the discovery is questionable, and according to some researchers, the *"Neanderthal flute"* should be interpreted as a bone nibbled by predators (Tuniz et al. 2010; Diedrich 2015; Turk et al. 2020).

Previous theories explaining the emergence of music in evolutionary terms can be based on three main concepts (Mehr et al. 2020; Fitch 2006; Huron 2001; Cross 2009). Music in *Homo sapiens*was interpreted as: 1) a byproduct of evolutionary processes, 2) sexual selection, and 3) a social bonding mechanism. These concepts allowed the creation of hypotheses that can be empirically and experimentally verified (Miller 2001; Tifferet et al. 2015; Kreutz 2014; Launay et al. 2015; Wilks 2011). Nonetheless data collected to date are not sufficient enough to fully accept one of the traditional hypotheses (Fitch 2006; Mehr et al. 2020, Savage et al. 2020).

A novel and more comprehensive approach to the problem of the origins of music is offered by recent hypotheses analyzing the evolutionary origin of music in terms of credible signal (in at least two contexts – coalitional interactions and infant care) (Mehr et al. 2020) and Music and Social Bonding (MSB) hypothesis, (Savage et al. 2020). The two, new alternative scenarios for the genesis of music fill gaps that previous concepts have not dealt with and set the stage for further research. Most importantly, they are not limited to single adaptation problems, which was perhaps the biggest drawback of traditional concepts. Biomusicology, as the field that attempts to answer the question of the evolutionary origins of music, is an interdisciplinary area (Honning 2018; Peretz 2006). Accordingly, both the music as the credible signal hypothesis and the MSB hypothesis integrate contributions from biology, archaeology, evolutionary psychology, neuroscience, primatology, and comparative cultural studies.

Before presenting music as a credible signal hypothesis and the MSB hypothesis, three groups of theories that have dominated biology and psychology for over two decades will be discussed along with critical comments. Theories that describe music as 1) an effect of sexual selection, 2) social bonding, and 3) a byproduct.

Sexual selection theories of music

The hypothesis of the evolution of music as an activity to promote one's genetic quality and increase fitness through individual reproductive success is very popular not only in evolutionary psychology but also in the popular science literature.

Not only does it confirm common human intuitions derived from folk psychology, but such an explanation seems particularly attractive given that love, betrayal, or intimate relationships are often central themes of musical works in many cultures (Mehr et al. 2019). Nonetheless, particular cultures may have indigenous themes dominating their music, e.g., Aboriginal Australians and their music and dreaming ceremonies devoted to spirits and land creation. (Curan et al. 2019; Hume et al, 2007; Boyd 2018).

From among an infinite number of topics, the authors of the lyrics usually choose one – love, sex and their consequences (positive and negative). Hobbs and Gallup (2011) analysed the content of music hits on the Billboard list (in genres of pop, country and rap music). They were looking for "reproductive content" in the lyrics. As positive "content", topics included falling in love, romance, sex, close relationships, attachment and admiration for a romantic partner. As negative "content" it was checked whether the songs discussed unrequited love, betrayal, abandonment or the memory of the old happy moments in a previous relationship. Overall, over 92% of all songs had some "reproductive content". When Hobbs and Gallup compared the songs of artists who entered the charts and other randomly selected songs by the same artists, the conclusions were very clear. "Hits" had much more reproductive content than songs that were less successful. The love threads in the songs are nothing new – in pop and country music they have been prevalent at least since the 1960s, as shown by Hobbs and Gallup. They went even further and analysed the content of the most famous opera arias (some of them from the 16th century). Again, the majority of songs (90%) concerned "reproductive content".

The roots of perceiving music as a result of the mechanism of sexual selection can be found in the works of Darwin (1871). However, songs may represent only some kind of ideal which western culture can no longer enact due to cultural changes and progressing fertility decline (Westoff 1983; Teitelbaum 2013; Caldwell 2006).

However, Darwin himself did not devote much attention to music and treated it on a par with other characteristics that increase reproductive success, such as deer antlers or a peacock's tail (Fitch 2006; Bannan 2017).

The works of Miller (2000, 2001) should be considered the beginning of empirical verification of Darwin's intuitions in the field of music. According to Miller's concept, music is a "cognitive peacock tail", and the proficiency in producing it translates into reproductive success and serves men to attract female sexual partners. Indirect evidence to support the concept of music as an effect of sexual selection is the predominance of male artists, not only in music, but also in other areas of art, such as literature (Lange et al. 2013; Euler 2014; Sternberg and Lubart 1991).

Despite the popularity of this concept, it is supported by surprisingly little empirical data, and some of which even contradicts the music sexual selection hypothesis.

According to the Theory of Parental Investments(Trivers 1972), grater mating efforts are typical to sex that invests less in child-rearing; therefore, the predominance of male musicians can be expected. (Trivers 1972). Despite some data showing the predominance of male performers (Miller 2000, 2001), the unequal gender distribution can be explained equally well by cultural factors. In modern orchestras, gender proportions are evenly distributed (Sergeant and Himonides 2019), with the percentage of female performers increasing per decade (Dukes et al. 2003). Secondly, the structure of the music itself does not contain any characteristics that would allow the performer's gender to be identified (which cannot be inferred from recorded music) (Sergeant and Himonides 2014). The few gender differences documented concern low level perception of music as transient evoked otoacoustic emissions (Cassidy and Ditty 2001), and pitch memory (Gaab et al. 2003), which do not take into account the complexity of music. An important gender difference is a better recognition of familiar melodies in the case of women (Miles et al. 2016).

The assumption that musical capacities, which are a manifestation of high genetic quality, that will be passed on to future generations, is the core of Miller's hypothesis. This applies in particular to such aspects as cognitive abilities, which, according to Miller (2000), are the main indicator of the so-called "good genes". The most serious objection is the lack of confirmation of music as mechanism of sexual selection hypothesis in genetic research (Mosing et al. 2015). The largest study of this type to date collected data supporting the hypothesis of music with sexual selection to a minor extent. Admittedly, moderate genetic influences on musical aptitude for both sexes, but genetic influences were low and nonsignificant for female heritability. The music as sexual selection hypothesis is contradicted by the fact that people who had greater musical ability were scoring lower on the measures of mating success. Additionally, music serves far more functions than in the area of human mating (Cross, 2009; Schäfer et. Al., 2013).

Music as social bonding

Music is a universal part of *Homo sapiens'* social life and is directly linked to the core processes of human social life (Loersch and Arbuckle 2013). Regardless of culture, music accompanies people at important life events like weddings and funerals. The phenomenon cannot be considered in terms of religious rituals; songs are equally present in secular societies (Savage et al. 2020, Mehr et al. 2019). As Huron (2001) notes, much about the social nature of music is told by the most popular songs in history. In his view, if the number of performances is taken as a measure of popularity, the undisputed winner is the song *"Happy Birthday"*.

In hypotheses describing the evolutionary origin of music as social bonding, music is a mechanism that creates and strengthens bonds between group members. Social bonding hypotheses are supported by comparative data. Vocalizations as a bonding behavior and a preference for responses from pack members among which grooming occurs has been observed most frequently in non-human primates like macaques (Arlet et al. 2015) bonobos (Levréro et al. 2019) and lemurs of the Lepilemur edwardsi species (Méndez-Cárdenas and Zimmermann 2009).

Concepts of the evolutionary origins of music as a social bonding mechanism were already proposed by Roederer (1984), who emphasized the social bonding role of music that accompanies modern religious and military rituals and its adaptive role in the past. The contemporary popularity of social bonding theory is related to Dunbar's hypothesis, which assumes that in groups such as human gatherings, where numbers do not allow for time-costly grooming, music and laughter have replaced it as a bonding mechanism (Dunbar 2012; Dunbar 1991). According to Dunbar (1993, 1996), music serves the function of "vocal grooming", and together with laughter solved the problem of the "bonding gap" in groups with large numbers by being a much more effective mechanism for strengthening bonds than grooming. Phylogenetically, music was a precursor to the emergence of articulated speech (Dunbar 2017; Dunbar 2003).

Subsequent works have highlighted numerous neurohormonal mechanisms accompanying music that enhance social bonding such as opioid release that also occurs with social laughter (Dunbar et al. 2012) and which may play a key role in human sociality (Machin and Dunbar 2011;Tarr et al. 2014; Weinstein et al. 2016). Music also increases oxytocin levels (Riedl et al. 2017; Harvey 2016; Nilsson 2009) and decreases cortisol (Uedo et al. 2004; Koelsch et al. 2014; Khalfa et al. 2003).

Numerous data support the social bonding hypothesis. However, not only can music have a beneficial effect on mood (Van Goethem and Sloboda 2011; Campbell and Berezina Gill 2020). The ability to discriminate tones and particular preferences developed during infancy also plays a vital role in early ontogeny (Trehub 2015). Preferences are present among newborns as early as day two after birth, even in deaf parents (Matasaka 2006). Mother-infant singing alleviates anxiety and strengthens bonds (Fancourt and Perkins 2018; Kostilainen et al. 2020).

Music can be used to justify some ideologies, such as the Nazi's use of Wagnerian music as a kind of Aryan archetype that plays a central role in the Nazi mythos of the glorious Nordic/Germanic warrior tradition (Ticker 2016). As Woody Allen mentioned in his famous quote, "I just can't listen to any more Wagner, you know... I'm starting to get the urge to conquer Poland." Music can be used to reaffirm in-group/out-group distinctions and reify inter-group boundaries. For that reason, Jewish composers were banned by the Nazis (Haas 2013).

A literature review on the topic of mother-infant singing was recently presented by Arrasmith (2020). According to recent work by Alessandronia et al. (2020), in addition to dyadic interactions (adult-baby), music in the first months of life, may also play a role in shaping early triadic interactions (adult-object-baby).

Music also strengthens in-group bonds between unrelated individuals (Pearce et al. 2016) facilitates fast cohesion between unfamiliar individuals – the so-called "ice-breaker effect" (Pearce et al. 2016), singing improves health and well-being (Pearce et al. 2016; Grape 2020), music training increases prosocial skills in children (Schellenberg et al. 2015), it improves social communications even in children with autism (Sharda 2018), increases cooperative and prosocial behaviours (Kniffin et al. 2017; Ilari et al. 2020) or empathy skills (Cho 2019). Interesting evidence in favor of music as social bonding hypothesis comes from recent research indicating the advantage of live-performed music in bonding. Music listened to live, in the company of other people, engages listeners more than recordings (Swarbrick et al. 2019), and increases cardiac synchrony (Ardizzi et al. 2020).

However, traditional theories of music as social bonding fail to explain many aspects of human music (Mehr et al. 2020). According to Carr, hypotheses of music as a social bonding mechanism ignore the positive impact of music at the individual level, although facilitating communicative interactions (Carr 2009). Some researchers question Dunbar's hypothesis itself, which is the core of the social bonding concept. In their view, interpreting grooming as a mechanism whose primary function was to reduce stress and create bonds is flawed (Port et al. 2020; Mehr et al. 2020). The main selective pressures for group-living in primates are predator avoidance and communal resource defense (Port et al. 2020, Mehr et al. 2020).

According to Fitch (2006), further investigation of specific factors is needed to determine to what extent group cohesion and social bonding are influenced by the phenomenon of music itself, and to what extent it is the result of performing an activity together.

Additionally, classical explanations of music as social bonding are accused of confusing proximate with ultimate mechanisms. As noted by Mehr et al. (2020) *"proximate mechanisms, such as release of neurohormones, are themselves subject to selection, and therefore cannot serve as ultimate-level explanations for the genetic evolution of a social bonding strategy"* (Mehr et al. 2020, p. 9).

Another of the pillars of the music as social bonding hypothesis assumes that music is an activity closely related to rhythm and synchronization, which brings many beneficial effects for the group and is associated with an advantage in competition with other groups. However, the supporters of music as social bonding do not take into account the recently documented adverse effects of synchrony on the group (Cirrelli 2018; Hoehl et al. 2021). As most studies focus on the positive aspects of synchrony, the social bonding hypotheses generally ignore the fact that it is not always beneficial at the group level. Synchrony reduces creativity, the tendency to express different views and impedes self-regulation of affect (Galbusera et al. 2019; Mehr et al. 2020; Gelfand et al. 2020). In addition, synchrony results in the fact that the members of the group feel more similar to and dependent on others and reduces the pain sensation (Vicaria and Dickens 2016; Rabinowitch et al. 2015; Tarr et al. 2015; Galbusera et al. 2019).

Music as byproduct

The null hypothesis treats music as a byproduct of natural selection.. The origins of this approach can be traced back to the work of William James, who considered music solely as "a mere incidental peculiarity of the nervous system" (Patel 2010). The necessity of including in the explanation of human behavior not only adaptations, but also byproducts – that is, the characteristics that evolved for a completely different purpose from the one currently used – was pointed out by Stephen Jay Gould (Gould and Lewontin 1979; Gould and Vrba 1982). To describe them, he proposed the term spandrel, currently popular especially in the philosophy of biology. It is a term derived from spandrel- tapering triangular spaces formed by the intersection of two rounded arches at right angles. The void formed at the junction of the two arches was richly decorated, but that was not its original function. Such activity that uses mechanisms evolved for another purpose is central tenets in music hypotheses as a byproduct. The production of music and its reception within these hypotheses is connected with the exploitation of such mechanisms of human cognitive architecture such as memory, emotional, perceptual, motor mechanisms, etc.

The contemporary popularity of these theories stems from Steven Pinker's influential concept (Pinker 1997). In his famous "auditory cheesecake" metaphor, Pinker notes that music is an evolutionary byproduct (1997). According to Pinker,if music confers no survival advantage, where does it come from and why does it work? I suspect that music is auditory cheesecake, an exquisite confection crafted to tickle the sensitive spots of at least six of our mental faculties (Pinker 1997, p. 534). Six mental faculties according to Pinker are 1) language 2) auditory scene analysis 3) emotional calls 4) habitat selection 5) motor control 6) something else (Pinker 1997).

According to Carr (2009), Pinker's concept is characterized by Western ethnocentrism, which has influenced the simplification of the very definition of the phenomenon of "music" which disqualifies the hypothesis of music as byproduct. As Carr notes – "*However, Pinker appears to subscribe to a simple version of the Western folk-theory of music as a commodified set of complex sound patterns produced by the few and consumed by the many simply for pleasure, rather than as the complex and socially significant interactive medium that it is and has been both in the West and in other cultures, places, and times. This unacknowledgedly ethnocentric treatment of music effectively nullifies the value of his discussion of its relationship to evolutionary processes*" (Carr 2009, p. 9,).

As the authors of the concept of music as credible signal note, Pinker's concept cannot be described as completely wrong, but neither can it be considered correct (Mehr et al. 2020). In their view, music admittedly exploits mechanisms that have evolved for a different purpose, and in this sense, the "auditory cheesecake" metaphor is valid. However, in light of their hypothesis, music is also the result of biological adaptations in at least two key areas – coalitional interaction and infant care (Mehr et al. 2020).

According to Fitch (2006), the strongest argument refuting the music as byproduct hypothesis is the age of music itself and the fact that music is one of the human universals, just as dance, for example, is found in every human culture (Brown 2004; Netl 2000; Mehr et al. 2019). The fact that music is a human universal is supported by, among other things, the fact that tone discrimination is universal and possible despite a lack of knowledge about a particular culture (Kessler et al. 1984: Balkwill and Thompson 1999; Popescu et al. 2020), and that process does not require prior learning (Tillmann et al. 2000; Battcock and Schutz 2021). Fitch (2006) also points out that music production is an energetically expensive and potentially dangerous activity. Additionally, the byproduct hypothesis is challenged by the deficit of congenital amusia described by Peretz (2003). Individuals suffering from congenital amusia are characterized by a lack of awareness of acquired musical pitch knowledge (Gosselin et al. 2017). Congenital amusia affects approximately 4% of the population and is indicative of both the presence of the genetic variance necessary for music production among human populations, as well as the neural specialization responsible for music (Peretz and Vuvan 2017; Peretz et al. 2015) suggested in previous works (Zatorre and Salimpoor 2013; Habibi and Damasio 2014). Additionally, the sheer complexity of music resembles a grammatical structure analogous to natural language, for which there is now little doubt that it is a biological adaptation (Fitch 2016; Pinker and Bloom 1990).

Another key argument that weakens the power of the music as byproduct thesis is the convergent evolution of musical abilities among different genres. McDermott and Hauser's (2006) thesis that music is an activity unique to humans cannot be supported. Music-related behaviors have evolved independently among many species, and the reasons for their emergence cannot be explained by the mechanism of evolution of homologous traits-they are in the nature of analogous traits that have evolved independently of each other. E.g., singing (not only in a mating context as believed for decades) is also found among birds (Catchpole and Slater 2003; Riebel et al. 2017), marine mammals (Stafford et al. 2018; Kello et. al. 2018) or gibbons (Geissmann 2000). According to some hypotheses, we share some of the perceptual mechanisms involved in the production and reception of music with the first jawed vertebrates which date back to approximately 500 million years ago. Koi fish (*Cyprinus carpio*) are able to distinguish baroque music from the blues (Chase 2001), and naïve goldfish distinguished a Bach piece from a Stravinsky piece (Shinozuka et al. 2013).

Flaws in traditional hypotheses and the need for new proposals

Traditional hypotheses do not provide a sufficient answer to the question of the evolutionary origins of music. The music as by product hypothesis is unsustainable in the light of collected data (Mehr et al. 2020; Huron 2001; Fitch 2006; Cross 2009; Savage et al. 2020). The greatest disadvantage of adaptationist hypotheses to date seems to be their excessive reductionism. Music as a complex cognitive process performs more functions than traditional adaptationist hypotheses assume (Cross 2009; Schäfer et al. 2013). Schäfer et al. (2013), in one of the more comprehensive reviews of the issue, distinguished 129 non-redundant functions of music. According to Schäfer et al. (2013) the functions of music can be reduced to three dimensions 1) regulate arousal and mood 2) achieve self-awareness and 3) expression of social relatedness. It seems impossible to explain such a wide variety of music functions on the basis of traditional theories. The reductionism of traditional hypotheses results from treating the cognitively complex and interculturally universal phenomenon of music as the effect of adaptation to solving a relatively narrow class of adaptation problems. As with other complex processes, such as perception (Hoffman and Singh 2014; Hoffman 2016) or language (Barrett 2016; Scott-Phillips 2015; Gibson et al. 2019), it is necessary to consider music in a broader context, e.g. including cultural and developmental factors. Such an attempt to describe origins of music in a broader theoretical context and an alternative to the existing hypotheses are new theoretical propositions – music as credible signal (Mehr et al. 2020) and Music and Social Bonding (MSB) hypothesis (Savage et al. 2020).

Music as credible signal

The hypothesis of Mehr et al. (2020) assumes that music has evolved as a credible signal in two contexts – coalitional interactions and infant care, where music plays the role of a credible signal drawing the attention of caregivers.

Music as a credible signal derives from Zahavi's handicap principle (1975, 1977). A costly signal is a type of signal, the sending of which seems to reduce an individual's fitness, e.g. a peacock's tail or deer antlers, which requires spending additional energy to produce and maintaining them. The cost of sending is a guarantee of its honesty – only individuals with high biological quality are able to produce a credible signal, which is a greater burden for an individual informing about its quality "unfairly". Music, like dance, is undoubtedly an expensive, and thus a credible signal (Hagen and Bryant 2003). Its production is not only energy-costly behavior, but music can also be loud and may increase the threat from predators or hostile groups.

Music as credible signal of coalition

The hypothesis of music as credible signal does not reject the classical concepts discussed above in their entirety but supplements them with new areas. The authors share, among others, the view derived from the Music as Sexual Selection Theory that music is a form of a credible signal. However, they caution that it serves far more functions than merely promoting the mate quality of an individual, such as territorial advertisements. In the natural world, loud vocalizations are often associated with territorial advertisements. The phenomenon occurs among rodents (Rieger and Marler 2018; Siracusa et al. 2017), amphibians (Lingnau and Bastos 2007), marine mammals (McComb and Reby 2009; Frey and Gebler 2010; Dudzinski et al. 2009), primates (Willems and van Schaik 2015; Torti et al. 2013; Caselli et al. 2014) and insects, among which cicadas show behavioral patterns based on prime numbers (Grant 2005; Tanaka et al. 2009). Interestingly, in one of the most original experiments in topic lady beetles, those exposed to AC/DC music ate fewer aphids than their counterparts who were exposed to silence or to the softer sounds of country music (Barton et al. 2018).

According to Mehr et al. (2020), human ancestors announced territory ownership in an analogous way, and such territorial vocalizations represented the evolutionary origin of music. According to their concept, music evolved to credibly signal a group's quality, size, and power to other groups. Contrary to social bonding hypotheses, they argue that music plays an important role in social life, not because it directly influences group cohesion and strengthens bonds, but in the course of evolution it has been the most effective tool to show already existing social cohesion and coalitions to foreign groups (Mehr et al. 2020).

Their hypothesis is supported by cross-cultural comparative data and data from hunter gatherer communities (Mehr et al. 2020; Netl 2015). Contemporary examples of music as credible signal of traditional coalitions are the Maori haka "Ka Mate", which is intended to show strength and group cohesion, increases identification with the group and continues to accompany e.g. sporting events (Balme 1999) or songs with specific themes present during warfare (Dimijian 2010; Volgsten and Brown 2006).

The advantage of this hypothesis is that it explains why music is produced in front of strangers, which is the case with today's mass concerts. Of course, as the authors point out, terrestrial advertisement and group cohesion are not the only areas of social life where music acts as a credible signal (Mehr et al. 2020). Nonetheless, territorial signals were supposed to be precursors of rhythmic features present among other primates (Larsson et al. 2019; Schruth et al. 2020).

Music as credible signal of parental attention

The second adaptive area that, according to the concept of music as a credible signal, concerns the evolutionary origin to produce music as an adaptation to parental care. In the case of Homo sapiens newborns, and the extended childhood characteristic of humans, parental care is crucial for survival (Voland and Dunbar 1995; Alonso and Ortiz-Rodríguez 2017).

Mehr et al. (2020) noted the universality of the phenomenon of child-directed songs, their richly documented cross-cultural structural similarity, stress reduction, and recognition of infant directed songs by adults regardless of culture (Moser et al. 2020; Bainbridge et al. 2020; Trainor 1997; Trehub 2001; Trehub et al. 1993; Cirelli and Trehub 2020).

Children directed songs are, according to Mehr et al. (2020), a credible signal that the caregiver is paying attention to the child's needs. During their performance, for example, interaction with other individuals or physical distance is not possible – parent-infant songs are also a signal of physical closeness of the caregiver (Mehr et al. 2020).

According to the authors (Mehr et al. 2020), while vocalizations for coalitioin interactions were the precursor to the universal phenomenon of rhythm in music, songs directed to children are responsible for the evolution of another universal music feature, i.e. melodic features. According to recent studies, melodic feature recognition is present as early as 6 months of age (Hahn et al. 2020; Mehr et al. 2020). Recent genetic data also support the hypothesis. Children with Angelman syndrome are characterized by decreased responsiveness to music and its relaxation function, with increased parental care expectations (Kotler et al. 2019). In contrast, in children with Prader-Willi syndrome, the opposite pattern is observed; decreased demands of parental care with enhanced relaxation responses to songs (Mehr et. al. 2017). These findings are the first to point to a common biological basis for parental care mechanisms and music opening promising perspectives for further research.

Music and Social Bonding (MSB) hypothesis

The Music and Social Bonding (MSB) hypothesis (Savage et al. 2020) was published concurrently with the music as credible signal hypothesis. The MSB hypothesis interprets music as a coevolved system for social bonding that strengthened group ties and became widespread through gene-culture coevolution (Savage et al. 2020). The authors distinguish between the concept of "musicality," which refers to the biological capacities that enable the production and reception of music, and "music" itself, which they regard as a cultural product derived from human "musicality" (Savvage et al. 2020). According to Savage et al. (2020), focusing on single adaptive problems that music is supposed to solve ignores the complexity and nature of the phenomenon itself, and in practice generates if not false then incomplete hypotheses.

Under the MSB hypothesis, the key biological capacities responsible for human musicality should be viewed as mechanisms that strengthen social bonds. The authors' argument at this stage, starts from Dunbar's classical hypothesis and overlaps with the music as social bonding hypotheses discussed above (Savage et al. 2020).

The key feature that distinguishes the MSB hypothesis from other theoretical proposals, and its greatest strength, is its emphasis on the role of gene-culture coevolution which allows it to go beyond group selection mechanisms. The authors cite recent work by Patel (2018) and Podlipniak (2017), who suggested that the cause of human musicality may be the Baldwin effect – music arose as a product of culture and over time was transformed into an instinctive trait by the means of natural selection (Savage et al. 2020). Proto-musical abilities, under the MBS hypothesis, were important behavioral innovations that strengthened group bonds to such a significant degree that they initiated gene-culture coevolution (Savage et al. 2020).

The arguments that Savage et al. (2020) cite in support of the MBS hypothesis boil down to the areas of 1) cross-cultural evidence describing the cross-cultural universality of music 2) historical-archaeological data describing the oldest human instruments 3) developmental-the role music plays in the creation of bonding, infant-directed songs and their universality and 4) psychological-the strengthening of group bonds. These arguments do not go beyond the research cited above in analyzing classical conceptions of the evolutionary origins of music.

The basic objection against the MBS hypothesis is the lack of a reason why music is treated as a mechanism that coevolved uniquely with social-bonding mechanisms. The assumptions of the MBS hypothesis equally explain the evolutionary origins of language or any other social-bonding behavior that is beneficial to the group. As the authors themselves point out, further research is needed to narrow the scope of the MBS hypothesis to music (Savage et al. 2020).

Summary

Music as credible signal and MSB hypothesis proposed in 2020 should be considered as valuable contributions to explaining the phenomenon of music in humans. Hypotheses treating music as a byproduct are difficult to sustain in light of data collected. In contrast, other traditional adaptationist hypotheses have treated music as one general ability of the human brain that has evolved to solve a specific adaptive problem. However, in the case of more complex processes such as vision, memory, or just music, this hypothesis cannot lead to a comprehensive explanation of the phenomenon. The charge of reductionism is justified in this case. Neither music as credible signal nor the MSB hypotheses reject previous theoretical positions entirely. They can be regarded as a valuable additions and new perspectives that may contribute to breaking down the perception of music in narrow categories of one adaptive area. It seems unlikely that an explanation of any area of human behavior, which is after all both the result of biology and culture, will be possible on the basis of traditional, reductionist hypotheses. The new hypotheses are holistic in nature. Music as credible signal and MBS hypotheses do not analyze music in isolation from psychological, developmental, social, and cultural factors, and may open promising perspectives for further research.

The Author's contribution

Conceptualization: KK; investigation: KK, MM, AK, DD; writing – KK, MM, DD; writing – review and editing: KK, MM, AK, DD

Conflict of interest

The authors declare that there is no conflict of interest.

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References

Alonso DL & Ortiz-Rodríguez IM. 2017. Offspring mortality was a determinant factor in the evolution of paternal investment in humans: An evolutionary game approach. Journal of theoretical biology, 419, 44–51.

Ardizzi M, Calbi M, Tavaglione S, Umiltà MA & Gallese V. 2020. Audience spontaneous entrainment during the collective enjoyment of live performances: physiological and behavioral measurements. Scientific reports, 10(1), 1–12.

Arlet M, Jubin R, Masataka N & Lemasson A. 2015. Grooming-at-a-distance by exchanging calls in non-human primates. Biology letters, 11(10), 20150711.

Arrasmith K. 2020. Infant Music Development and Music Experiences: A Literature Review. Update: Applications of Research in Music Education, 38(3), 9–17.

Bainbridge CM, Bertolo M, Youngers J, Atwood S, Yurdum L, Simson J & Mehr SA. 2020. Infants relax in response to unfamiliar foreign lullabies. Nature Human Behaviour, 1–9.

Baird A. 2018. Group singing enhances positive affect in people with Parkinson's disease. Music and Medicine, 10(1), 13–7.

Balkwill LL & Thompson WF. 1999. A cross-cultural investigation of the perception of emotion in music: Psychophysical and cultural cues. Music perception, 17(1), 43–64.

Balme CB. 1999. Hula and haka: performance, metonymy and identity formation in colonial Hawaii and New Zealand. Humanities research, (3), 41–58.

Bannan N. 2017. Darwin, music and evolution: new insights from family correspondence on The Descent of Man. Musicae Scientiae, 21(1), 3–25.

Barrett M Ed. 2016. The development of language. Psychology Press.

Barton BT, Hodge ME, Speights CJ, Autrey AM, Lashley MA & Klink VP. 2018. Testing the AC/DC hypothesis: Rock and roll is noise pollution and weakens a trophic cascade. Ecology and Evolution, 8(15), 7649–56.

Battcock A & Schutz M. 2021. Emotion and expertise: how listeners with formal music training use cues to perceive emotion. Psychological Research, 1–21.

Blake EC & Cross I. 2008. Flint tools as portable sound-producing objects in the upper palaeolithic context: an experimental study. Experiencing archaeology by experiment, 1–19.

Boer D. 2009. Music makes the people come together: Social functions of music listening for young people across cultures.

Boyd A. 2018. Landscape, spirit and music: An Australian story. In The Soundscapes of Australia (pp. 11–33). Routledge.

Brown DE. 2004. Human universals, human nature & human culture. Daedalus, 133(4), 47–54.

Caldwell JC. 2006. The globalization of fertility behavior. In Demographic Transition Theory (pp. 249-271. Springer, Dordrecht.

Campbell EA, Berezina E & Gill CHD. 2020. The effects of music induction on mood and affect in an Asian context. Psychology of Music, 0305735620928578.

Caselli CB, Mennill DJ, Bicca-Marques JC & Setz EZ. 2014. Vocal behavior of black-fronted titi monkeys (Callicebus nigrifrons): Acoustic properties and behavioral contexts of loud calls. American Journal of Primatology, 76(8), 788–800.

Cassidy JW & Ditty KM. 2001. Gender differences among newborns on a transient otoacoustic emissions test for hearing. Journal of Music Therapy, 38(1), 28–35.

Catchpole CK & Slater PJ. 2003. Bird song: biological themes and variations. Cambridge university press.

Chase AR. 2001. Music discriminations by carp (*Cyprinus carpio*. Animal Learning & Behavior, 29(4), 336–53.

Cho E. 2019. The relationship between small music ensemble experience and empathy skill: A survey study. Psychology of Music, 0305735619887226.

Cirelli LK. 2018. How interpersonal synchrony facilitates early prosocial behavior. Current opinion in psychology, 20, 35–9.

Cirelli LK & Trehub SE. 2018. Infants help singers of familiar songs. Music & Science, 1, 2059204318761622.

Cirelli LK & Trehub SE. 2020. Familiar songs reduce infant distress. Developmental psychology, 56(5), 861.

Cross I. 2009. The nature of music and its evolution. The Oxford handbook of music psychology, 3–13.

Cross I. 2014. Music and communication in music psychology. Psychology of music, 42(6), 809–19.

Cross I. 2015. Music, Speech and Meaning in interaction. Music, Analysis, Experience. New Perspectives in Musical Semiotics, 19–30.

Curran G, Barwick L, Turpin M, Walsh F & Laughren M. 2019. Central Australian Aboriginal Songs and Biocultural Knowledge: Evidence from Women's Ceremonies Relating to Edible Seeds. Journal of Ethnobiology, 39(3), 354–70.

Darwin CR. 1871. The descent of man and selection in relations to sex. London: John Murray.

d'Errico F, Henshilwood C, Lawson G, Vanhaeren M, Tillier AM, Soressi M & Julien M. 2003. Archaeological evidence for the emergence of language, symbolism, and music – an alternative multidisciplinary perspective. Journal of World Prehistory, 17(1), 1–70.

Diedrich CG. 2015. 'Neanderthal bone flutes': simply products of Ice Age spotted hyena scavenging activities on cave bear cubs in European cave bear dens. Royal Society Open Science, 2(4), 140022.

Dimijian GG. 2010. Warfare, genocide, and ethnic conflict: a Darwinian approach. In Baylor University Medical Center Proceedings (Vol. 23, No. 3, pp. 292–300. Taylor & Francis.

Dudzinski KM, Thomas JA & Gregg JD. 2009. Communication in marine mammals. In Encyclopedia of marine mammals (pp. 260–9. Academic Press.

Dukes RL, Bisel TM, Borega KN, Lobato EA & Owens MD. 2003. Expressions of love, sex, and hurt in popular songs: A content analysis of all-time greatest hits. The Social Science Journal, 40(4), 643–50.

Dunbar RI. 1996. Grooming, gossip and the evolution of language. Cambridge, MA: Harvard University Press.

Dunbar RI. 1991. Functional significance of social grooming in primates. Folia primatologica, 57(3), 121–31.

Dunbar RI. 2003. The social brain: mind, language, and society in evolutionary perspective. Annual review of Anthropology, 32(1), 163–81.

Dunbar RI. 2012. On the evolutionary function of song and dance. Music, language, and human evolution, 201–14.

Dunbar RI. 2017. Group size, vocal grooming and the origins of language. Psychonomic bulletin & review, 24(1), 209–12.

Dunbar RI, Baron R, Frangou A, Pearce E, Van Leeuwen EJ, Stow J & Van Vugt M. 2012. Social laughter is correlated with an elevated pain threshold. Proceedings of the Royal Society B: Biological Sciences, 279(1731), 1161–7.

Fancourt D & Perkins R. 2018. The effects of mother–infant singing on emotional closeness, affect, anxiety, and stress hormones. Music & Science, 1, 2059204317745746.

Fitch WT. 2006. The biology and evolution of music: A comparative perspective. Cognition, 100(1), 173–215.

Fitch WT. 2015. Four Principles of Bio-Musicology. Philosophical Transactions of the Royal Society B: Biological Sciences, 370(1664), 20140091.

Frey R & Gebler A. 2010. Mechanisms and evolution of roaring-like vocalization in mammals. In Handbook of Behavioral Neuroscience (Vol. 19, pp. 439–50. Elsevier.

Gaab N, Keenan JP & Schlaug G. 2003. The effects of gender on the neural substrates of pitch memory. Journal of cognitive Neuroscience, 15(6), 810–20.

Galbusera L, Finn MT, Tschacher W & Kyselo M. 2019. Interpersonal synchrony feels good but impedes self-regulation of affect. Scientific reports, 9(1), 1–12.

Geissmann T. 2000. Gibbon songs and human music from an evolutionary perspective. The origins of music, 103–23.

Gelfand MJ, Caluori N, Jackson JC & Taylor MK. 2020. The cultural evolutionary trade-off of ritualistic synchrony. Philosophical Transactions of the Royal Society B, 375(1805), 20190432.

Gibson E, Futrell R, Piantadosi SP, Dautriche I, Mahowald K, Bergen L & Levy R. 2019. How efficiency shapes human language. Trends in cognitive sciences, 23(5), 389–407.

Gosselin N, Paquette S & Peretz I. 2015. Sensitivity to musical emotions in congenital amusia. Cortex, 71, 171–82.

Gould SJ & Lewontin RC. 1979. The spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme. Proceedings of the royal society of London. Series B. Biological Sciences, 205(1161), 581–98.

Gould SJ & Vrba ES. 1982. Exaptation-a missing term in the science of form. Paleobiology, 4–15.

Grant PR. 2005. The priming of periodical cicada life cycles. Trends Ecol. Evol. 20, 169–174. doi: 10.1016/j.tree.2005.01.016

Grape C, Sandgren M, Hansson LO, Ericson M & Theorell T. 2002. Does singing promote well-being?: An empirical study of professional and amateur singers during a singing lesson. Integrative Physiological & Behavioral Science, 38(1), 65–74.

Haas M. 2013. Forbidden Music: The Jewish Composers Banned by the Nazis. Yale University Press.

Habibi A & Damasio A. 2014. Music, feelings, and the human brain. Psychomusicology: Music, Mind, and Brain, 24(1), 92.

Hagen EH & Bryant GA. 2003. Music and dance as a coalition signaling system. Human nature, 14(1), 21–51.

Hahn LE, Benders T, Snijders TM & Fikkert P. 2020. Six-month-old infants recognize phrases in song and speech. Infancy, 25(5), 699–718.

Harvey AR. 2020. Links Between the Neurobiology of Oxytocin and Human Musicality. Frontiers in Human Neuroscience, 14, 350.

Hobbs DR, Gallup Jr GG. 2011. Songs as a medium for embedded reproductive messages. Evolutionary Psychology 9(3): 390–416.

Higham T, Basell L, Jacobi R, Wood R, Ramsey CB & Conard NJ. 2012. Testing models for the beginnings of the Aurignacian and the advent of figurative art and music: The radiocarbon chronology of Geißenklösterle. Journal of human evolution, 62(6), 664–76.

Hoehl S, Fairhurst M & Schirmer A. 2021. Interactional synchrony: signals, mechanisms and benefits. Social Cognitive and Affective Neuroscience, 16(1-2), 5–18.

Hoffman DD. 2016. The interface theory of perception. Current Directions in Psychological Science, 25(3), 157–61.

Hoffman DD & Singh M. 2012. Computational evolutionary perception. Perception, 41(9), 1073–91.

Honing H. Ed. 2018. The origins of musicality. MIT Press.

Hume L. 2004. Accessing the eternal: Dreaming “the dreaming” and ceremonial performance. Zygon®, 39(1), 237–58.

Huron D. 2001. Is music an evolutionary adaptation?. Annals of the New York Academy of sciences, 930(1), 43–61.

Ilari B, Helfter S & Huynh T. 2020. Associations Between Musical Participation and Young Children’s Prosocial Behaviors. Journal of Research in Music Education, 67(4), 399–412.

Kello CT, Bella SD, Médé B & Balasubramaniam R. 2017. Hierarchical temporal structure in music, speech and animal vocalizations: jazz is like a conversation, humpbacks sing like hermit thrushes. Journal of The Royal Society Interface, 14(135), 20170231.

Kessler EJ, Hansen C & Shepard RN. 1984. Tonal schemata in the perception of music in Bali and in the West. Music Perception, 2(2), 131–65.

Khalfa S, Bella SD, Roy M, Peretz I & Lupien SJ. 2003. Effects of relaxing music on salivary cortisol level after psychological stress. Annals of the New York Academy of Sciences, 999(1), 374–6.

Kniffin KM, Yan J, Wansink B & Schulze WD. 2017. The sound of cooperation: Musical influences on cooperative behavior. Journal of organizational behavior, 38(3), 372–90.

Koelsch S, Fuermetz J, Sack U, Bauer K, Hohenadel M, Wiegel M & Heinke W. 2011. Effects of music listening on cortisol levels and propofol consumption during spinal anesthesia. Frontiers in psychology, 2, 58.

Kostilainen K, Mikkola K, Erkkilä J & Huotilainen M. 2020. Effects of maternal singing during kangaroo care on maternal anxiety, wellbeing, and mother-infant relationship after preterm birth: a mixed methods study. Nordic Journal of Music Therapy, 1–20.

Kotler J, Mehr SA, Egner A, Haig D & Krasnow MM. 2019. Response to vocal music in Angelman syndrome contrasts with Prader-Willi syndrome. Evolution and Human Behavior, 40(5), 420–6.

Kreutz G. 2014. Does singing facilitate social bonding. Music and Medicine, 6(2), 51–60.

Kunej D & Turk I. 2000. New perspectives on the beginnings of music: Archaeological and musicological analysis of a Middle Paleolithic bone ‘flute’. The origins of music, 235–68.

Lange BP & Euler HA. 2014. Writers have groupies, too: High quality literature production and mating success. Evolutionary Behavioral Sciences, 8(1), 20.

Lange BP, Schwarz S & Euler HA. 2013. The sexual nature of human culture. The Evolutionary Review: Art, Science, Culture, 4(1), 76–85.

Larsson M, Richter J & Ravignani A. 2019. Bipedal steps in the development of rhythmic behavior in humans. Music & Science, 2, 2059204319892617.

Launay J, Tarr B & Dunbar RI. 2016. Synchrony as an adaptive mechanism for large-scale human social bonding. Ethology, 122(10), 779–89.

Levréro F, Touitou S, Frédet J, Nairaud B, Guéry JP & Lemasson A. 2019. Social bonding drives vocal exchanges in bonobos. Scientific reports, 9(1), 1–11.

Lingnau R & Bastos RP. 2007. Vocalizations of the Brazilian torrent frog Hylodes heyeri (Anura: Hylodidae): Repertoire and influence of air temperature on advertisement call variation. Journal of Natural History, 41(17–20), 1227–35.

Loersch C & Arbuckle NL. 2013. Unraveling the mystery of music: Music as an evolved group process. Journal of Personality and Social Psychology, 105(5), 777.

Machin AJ & Dunbar RI. 2011. The brain opioid theory of social attachment: a review of the evidence. Behaviour, 148(9–10), 985–1025.

Masataka N. 2006. Preference for consonance over dissonance by hearing newborns of deaf parents and of hearing parents. Developmental science, 9(1), 46–50.

McComb K & Reby D. 2009. Communication in terrestrial mammals. Encyclopedia of Neuroscience, 2, 1167–71.

McDermott J & Hauser M. 2005. The origins of music: Innateness, uniqueness, and evolution. Music perception, 23(1), 29–59.

Mehr SA, Kotler J, Howard RM, Haig D & Krasnow MM. 2017. Genomic imprinting is implicated in the psychology of music. Psychological science, 28(10), 1455–67.

Mehr SA, Krasnow MM, Bryant GA & Hagen EH. 2020. Origins of music in credible signaling. Behavioral and Brain Sciences, 1–41.

Mehr SA, Singh M, Knox D, Ketter DM, Pickens-Jones D, Atwood S & Glowacki L. 2019. Universality and diversity in human song. Science, 366(6468).

Mehr SA, Song LA & Spelke ES. 2016. For 5-month-old infants, melodies are social. Psychological Science, 27(4), 486–501.

Méndez-Cárdenas MG & Zimmermann E. 2009. Duetting – A mechanism to strengthen pair bonds in a dispersed pair-living primate (Lepilemur edwardsi)? American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists, 139(4), 523–32.

Miles SA, Miranda RA & Ullman MT. 2016. Sex differences in music: A female advantage at recognizing familiar melodies. Frontiers in psychology, 7, 278.

Miller G. 2000. Evolution of human music through sexual selection (pp. 329–60). na.

Miller GF. 2001. The mating mind: How sexual choice shaped the evolution of human nature. New York: Doubleday

Mithen S. 2011. The singing Neanderthals: The origins of music, language, mind and body. Hachette UK.

Moser CJ, Lee-Rubin H, Bainbridge CM, Atwood S, Simson J, Knox D & Mehr SA. 2020. Acoustic regularities in infant-directed vocalizations across cultures.

Mosing MA, Verweij KJ, Madison G, Pedersen NL, Zietsch BP & Ullén F. 2015. Did sexual selection shape human music? Testing predictions from the sexual selection hypothesis of music evolution using a large genetically informative sample of over 10,000 twins. Evolution and Human Behavior, 36(5), 359–66.

Nettl B. 2000. An ethnomusicologist contemplates universals in musical sound and musical culture. The origins of music, 3(2), 463–72.

Nettl B. 2015. The study of ethnomusicology: Thirty-three discussions. University of Illinois Press.

Nilsson U. 2009. Soothing music can increase oxytocin levels during bed rest after open-heart surgery: a randomised control trial. Journal of clinical nursing, 18(15), 2153–61.

Parker ST. 2015. Re-evaluating the extractive foraging hypothesis. New Ideas in Psychology, 37, 1–12.

Patel AD. 2010. Music, biological evolution, and the brain. Emerging disciplines, 91–144.

Patel AD & Honing H. 2018. Music as a transformative technology of the mind: An update. The origins of musicality, 113–126.

Pearce E, Launay J & Dunbar RI. 2015. The ice-breaker effect: Singing mediates fast social bonding. Royal Society open science, 2(10), 150221.

Pearce E, Launay J, Machin A & Dunbar R. I. 2016. Is group singing special? health, well-being and social bonds in community-based adult education classes. Journal of community & applied social psychology, 26(6), 518–33.

Pearce E, Launay J, van Duijn M, Rotkirch A, David-Barrett T & Dunbar RI. 2016. Singing together or apart: The effect of competitive and cooperative singing on social bonding within and between sub-groups of a university Fraternity. Psychology of music, 44(6), 1255–73.

Peretz I. 2006. The nature of music from a biological perspective. Cognition, 100(1), 1–32.

Peretz I & Hyde KL. 2003. What is specific to music processing? Insights from congenital amusia.

Peretz I & Vuvan DT. 2017. Prevalence of congenital amusia. European Journal of Human Genetics, 25(5), 625–30.

Peretz I, Vuvan D, Lagrois MÉ & Armony JL. 2015. Neural overlap in processing music and speech. Philosophical Transactions of the Royal Society B: Biological Sciences, 370(1664), 20140090.

Pinker S. 1997. How the Mind Works.London: Allen Lane.

Pinker S & Bloom P. 1990. Natural language and natural selection. Behavioral and brain sciences, 13(4), 707–27.

Podlipniak P. 2017. The role of the Baldwin effect in the evolution of human musicality. Frontiers in neuroscience, 11, 542.

Popescu T, Widdess R & Rohrmeier M. 2021. Western listeners detect boundary hierarchy in Indian music: a segmentation study. Scientific reports, 11(1), 1–14.

Port M, Hildenbrandt H, Pen I, Schülke O, Ostner J & Weissing FJ. 2020. The evolution of social philopatry in female primates. American Journal of Physical Anthropology, 173(3), 397–410.

Rabinowitch T, Knafo-Noam A & Kotz S. Synchronous rhythmic interaction enhances children's perceived similarity and closeness towards each other. PLoS One 10, e0120878, https://doi.org/10.1371/journal.pone.0120878 (2015).

Riebel K, Odom KJ, Langmore NE & Hall ML. 2019. New insights from female bird song: towards an integrated approach to studying male and female communication roles. Biology letters, 15(4), 20190059.

Riedl R, Javor A, Gefen D, Felten A & Reuter M. 2017. Oxytocin, trust, and trustworthiness: The moderating role of music. Journal of Neuroscience, Psychology, and Economics, 10(1), 1.

Rieger NS & Marler CA. 2018. The function of ultrasonic vocalizations during territorial defence by pair-bonded male and female California mice. Animal behaviour, 135, 97–108.

Robert T. 1972. Parental investment and sexual selection. Sexual Selection & the Descent of Man, Aldine de Gruyter, New York, 136–79.

Roederer JG. 1984. The search for a survival value of music. Music perception, 1(3), 350–6.

Savage PE, Loui P, Tarr B, Schachner A, Glowacki L, Mithen S & Fitch WT. 2020. Music as a coevolved system for social bonding. Behavioral and Brain Sciences, 1–36.

Schäfer T, Sedlmeier P, Städtler C & Huron D. 2013. The psychological functions of music listening. Frontiers in psychology, 4, 511.

Schellenberg EG & Weiss MW. 2013. Music and cognitive abilities.

Schellenberg EG, Corrigall KA, Dys SP & Malti T. 2015. Group music training and children's prosocial skills. PLoS One, 10(10), e0141449.

Schruth D, Templeton CN & Holman DJ. 2019. A definition of song from human music universals observed in primate calls. BioRxiv, 649459.

Scott-Phillips TC, Cartmill EA, Crockford C, Gärdenfors P, Gómez JC, Luef EM & Scott-Phillips TC. 2015. Nonhuman primate communication, pragmatics, and the origins of language. Current Anthropology, 56(1), 000-000.

Sergeant DC & Himonides E. 2014. Gender and the performance of music. Frontiers in psychology, 5, 276.

Sergeant DC & Himonides E. 2019. Orchestrated sex: The representation of male and female musicians in world-class symphony orchestras. Frontiers in psychology, 10, 1760.

Sharda M, Tuerk C, Chowdhury R, Jamey K, Foster N, Custo-Blanch M & Hyde K. 2018. Music improves social communication and brain connectivity outcomes in children with autism: A randomized controlled trial.

Shinozuka K, Ono H & Watanabe S. 2013. Reinforcing and discriminative stimulus properties of music in goldfish. Behavioural processes, 99, 26–33.

Siracusa E, Morandini M, Boutin S, Humphries MM, Dantzer B, Lane JE & McAdam AG. 2017. Red squirrel territorial vocalizations deter intrusions by conspecific rivals. Behaviour, 154(13–15), 1259–73.

Snihur AW & Hampson E. 2011. Sex and ear differences in spontaneous and click-evoked otoacoustic emissions in young adults. Brain and cognition, 77(1), 40–7.

Stafford KM, Lydersen C, Wiig Ø & Kovacs KM. 2018. Extreme diversity in the songs of Spitsbergen's bowhead whales. Biology letters, 14(4), 20180056.

Sterelny K. 2016. Cumulative cultural evolution and the origins of language. Biological Theory, 11(3), 173-186.

Sternberg RJ & Lubart TI. 1991. An investment theory of creativity and its development. Human development, 34(1), 1–31.

Swarbrick D, Bosnyak D, Livingstone SR, Bansal J, Marsh-Rollo S, Woolhouse MH & Trainor LJ. 2019. How live music moves us: head movement differences in audiences to live versus recorded music. Frontiers in psychology, 9, 2682.

Tanaka Y, Yoshimura J, Simon C, Cooley JR & Tainaka K-I. 2009. Allele effect in the selection for prime-numbered cycles in periodical cicadas Proc. Natl. Acad. Sci. U.S.A. 106, 8975–9. doi: 10.1073/pnas.0900215106

Tarr B, Launay J & Dunbar RI. 2014. Music and social bonding:“self-other” merging and neurohormonal mechanisms. Frontiers in psychology, 5, 1096.

Tarr B, Launay J, Cohen E & Dunbar RI. Synchrony and exertion during dance independently raise pain threshold and encourage social bonding. Biology Letters 11, 20150767, https://doi.org/10.1098/rsbl.2015.0767 (2015).

Teitelbaum MS. 2013. The fear of population decline. Academic Press.

Ticker CS. 2016. The Effect of Richard Wagner's Music and Beliefs on Hitler's Ideology. Musical Offerings, 7(2), 1.

Tifferet S, Gaziel O & Baram Y. 2012. Guitar increases male facebook attractiveness: preliminary support for the sexual selection theory of music. Letters on Evolutionary Behavioral Science, 3(1), 4-6.

Tillmann B, Bharucha JJ & Bigand E. 2000. Implicit learning of tonality: a self-organizing approach. Psychological review, 107(4), 885.

Torti V, Gamba M, Rabemananjara ZH & Giacoma C. 2013. The songs of the indris (Mammalia: Primates: Indridae): contextual variation in the long-distance calls of a lemur. Italian Journal of Zoology, 80(4), 596–607.

Trainor LJ, Clark ED, Huntley A & Adams BA. 1997. The acoustic basis of preferences for infant-directed singing. Infant Behavior and Development, 20(3), 383–96.

Trehub SE. 2001. Musical predispositions in infancy. Annals of the New York Academy of Sciences, 930(1), 1–16.

Trehub SE. 2015. Infant musicality. The Oxford handbook of music psychology, 387–98.

Trehub SE. 2019. Nurturing infants with music. International Journal of Music in Early Childhood, 14(1), 9–15.

Trehub SE, Unyk AM & Trainor LJ. 1993a. Adults identify infant-directed music across cultures. Infant Behavior and Development, 16(2), 193–211.

Trends in Cognitive Sciences, 7, 336–62.

Tuniz C, Bernardini F, Turk I, Dimkaroski L, Mancini L & Dreossi D. 2012. Did Neanderthals play music? X-ray computed micro-tomography of the divje babe 'flute'. Archaeometry, 54(3), 581–90.

Turk M, Turk I & Otte M. 2020. The Neanderthal Musical Instrument from Divje Babe I Cave (Slovenia): A Critical Review of the Discussion. Applied Sciences, 10(4), 1226.

Uedo N, Ishikawa H, Morimoto K, Ishihara R, Narahara H, Akedo I & Fukuda S. 2004. Reduction in salivary cortisol level by music therapy during colonoscopic examination. Hepato-gastroenterology, 51(56), 451–3.

Van Goethem A & Sloboda J. 2011. The functions of music for affect regulation. Musicae scientiae, 15(2), 208–28.

Vicaria IM & Dickens L. 2016. Meta-analyses of the intra-and interpersonal outcomes of interpersonal coordination. Journal of Nonverbal Behavior, 40(4), 335–61.

Voland E & Dunbar RI. 1995. Resource competition and reproduction. Human Nature, 6(1), 33–49.

Volgsten U & Brown S. 2006. Between ideology and identity. Music and manipulation: On the social uses and social control of music, 74–100.

Weinstein D, Launay J, Pearce E, Dunbar RI & Stewart L. 2016. Singing and social bonding: changes in connectivity and pain threshold as a function of group size. Evolution and Human Behavior, 37(2), 152–8.

Westoff CF. 1983. Fertility decline in the West: Causes and prospects. Population and Development Review, 99–104.

Wilks L. 2011. Bridging and bonding: Social capital at music festivals. Journal of Policy Research in Tourism, Leisure and Events, 3(3), 281–97.

Willems EP & van Schaik CP. 2015. Collective action and the intensity of between-group competition in nonhuman primates. Behavioral Ecology, 26(2), 625–31.

Zahavi A. 1975. Mate selection – a selection for a handicap. Journal of theoretical Biology, 53(1), 205–14.

Zahavi A. 1977. Reliability in communication systems and the evolution of altruism. In Evolutionary ecology (pp. 253–9. Palgrave, London.

Zatorre RJ & Salimpoor VN. 2013. From perception to pleasure: music and its neural substrates. Proceedings of the National Academy of Sciences, 110(Supplement 2), 10430–7.

Zeki S. 2002. Inner vision: An exploration of art and the brain.