Available online at www.sciencedirect.com
ScienceDirect
Physics of Life Reviews 7 (2010) 2–27
PHYSICS of LIFE reviews
www.elsevier.com/locate/plrev

Review

Musical emotions: Functions, origins, evolution

Leonid Perlovsky *

Harvard University, Cambridge, and Air Force Research Lab., Hanscom AFB, MA, USA

Received 25 October 2009; received in revised form 31 October 2009; accepted 31 October 2009

Available online 6 November 2009

Communicated by J. Fontanari

Abstract

Theories of music origins and the role of musical emotions in the mind are reviewed. Most existing theories contradict each other, and cannot explain mechanisms or roles of musical emotions in workings of the mind, nor evolutionary reasons for music origins. Music seems to be an enigma. Nevertheless, a synthesis of cognitive science and mathematical models of the mind has been proposed describing a fundamental role of music in the functioning and evolution of the mind, consciousness, and cultures. The review considers ancient theories of music as well as contemporary theories advanced by leading authors in this field. It addresses one hypothesis that promises to unify the field and proposes a theory of musical origin based on a fundamental role of music in cognition and evolution of consciousness and culture. We consider a split in the vocalizations of proto-humans into two types: one less emotional and more concretely-semantic, evolving into language, and the other preserving emotional connections along with semantic ambiguity, evolving into music. The proposed hypothesis departs from other theories in considering specific mechanisms of the mind–brain, which required the evolution of music parallel with the evolution of cultures and languages. Arguments are reviewed that the evolution of language toward becoming the semantically powerful tool of today required emancipation from emotional encumbrances. The opposite, no less powerful mechanisms required a compensatory evolution of music toward more differentiated and refined emotionality. The need for refined music in the process of cultural evolution is grounded in fundamental mechanisms of the mind. This is why today's human mind and cultures cannot exist without today's music. The reviewed hypothesis gives a basis for future analysis of why different evolutionary paths of languages were paralleled by different evolutionary paths of music. Approaches toward experimental verification of this hypothesis in psychological and neuroimaging research are reviewed.
Published by Elsevier B.V.

Keywords: Music; Emotions; Neural mechanisms; Mind; Language; Culture; Evolution; Knowledge instinct; Mathematical models; Cognitive dissonance

Contents

* Tel.: +1 781 377 1728.
E-mail address: leonid@seas.harvard.edu.

1571-0645/$ – see front matter Published by Elsevier B.V.
doi:10.1016/j.plrev.2009.11.001

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2009		**00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Musical emotions: Functions, origins, evolution	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Harvard University,Cambridge, and Air Force Research La,Hanscom AFB,MA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**26**	

"A poet's duty is to try to mend
The edges split between the soul and body
The talent's needle. And only voice is thread."

Joseph Brodsky

1. An unsolved mystery

Music is a mystery. According to Darwin [22], it "must be ranked amongst the most mysterious (abilities) with which (man) is endowed." A recent resurgence of research in relating music to emotions is summarized in [49]. The suggestion that music and emotions are linked opens more questions than answers: how music expresses or creates emotions, are these emotions similar or different from other emotions, what is their function? "Music is a human cultural universal that serves no obvious adaptive purpose, making its evolution a puzzle for evolutionary biologists" [62]. Kant [52], who so brilliantly explained the epistemology of the beautiful and the sublime, could not explain music: "(As for) the expansion of the faculties... in the judgment for cognition, music will have the lowest place among (the beautiful arts)... because it merely plays with senses." Pinker [97] follows Kant, suggesting that music is an "auditory cheesecake," a byproduct of natural selection that just happened to "tickle the sensitive spots." In 2008, Nature published a series of essays on music. Their authors agreed that music is a cross-cultural universal, still "none... has yet been able to answer the fundamental question: why does music have such power over us?" [29]. "We might start by accepting that it is fruitless to try to define 'music'." [4]. These are just a sampling of quotes from accomplished scientists.

After reviewing selected theories, we present a hypothesis based on arguments from cognitive science and mathematical models of the mind suggesting that music serves the most important and concrete function in evolution of the mind and cultures. We elucidate this function, discuss neural mechanisms, and suggest experimental verification of this hypothesis.

2. Theories of musical emotions and music origins

Functions and origins of music have challenged philosophical thought for thousands of years. Aristotle listed the power of music among the unsolved problems [2, p. 1434]. During the last two decades, the powers of music that previously seemed mysterious are receiving scientific foundations due to the research of scientists in several fields. Integration of this research in recent years provides evidence for the evolutionary origins and roles of music. This section provides a selection of views on the role of music in cognition from ancient philosophers to contemporary research.

2.1. 2500 years of Western music and pre-scientific theories (from Pythagoras to the 18th c.)

Pythagoras described the main harmonies as whole-number ratios of sound frequencies about 2500 years ago. He saw this as a connection of music to celestial spheres, which also seemed governed by whole numbers [45]. In the pre-scientific era, musical thoughts were led by composer's practice and philosophical thoughts followed behind. The tremendous potency of music to affect consciousness, to move people's souls and bodies since time immemorial was ambivalently perceived. Ancient Greek philosophers saw human psyche as prone to dangerous emotional influences and "proper" music was harmonizing human psyche with reason. Plato wrote about idealized imagined music of the Golden Age of Greece: "... (Musical) types were... fixed... Afterwards... an unmusical license set in with the appearance of poets... men of native genius, but ignorant of what is right and legitimate... Possessed by a frantic and unhallowed lust for pleasure, they contaminated... and created a universal confusion of forms... So the next stage... will be... contempt for oaths... and all religion. The spectacle of the Titanic nature... is reenacted; man returns to the old condition of a hell of unending misery." [98].

The same appeal to reason as a positive content of music we find 800 years later in Boethius (5 c.) "...what unites the incorporeal existence of reason with the body except a certain harmony, and, as it were, a careful tuning of low and high pitches in such a way that they produce one consonance?" (see in [115]; unreferenced quotes in this chapter refer to this book). According to foremost thinkers in the 4th and 5th centuries (including St. Augustine) the mind was not strong enough to be reliably in charge of senses and unconscious urges. Differentiation of emotions was perceived as a danger.

Only with the beginning of the Renaissance (13th–14th c.), for the first time since antiquity the European man felt the power of rational mind separating from collective consciousness. The millennial tradition of music understanding was changing. For twelve centuries, Plato, Boethius, and Erigena (from 4th c. BCE to 9th c. AD) saw the positive content of music in its relations to objective 'motion of celestial spheres' and to God-created laws of nature. This changed by the 13th century: The music was now understood as related to listeners, not to celestial spheres. J. Groceo [38] wrote: Songs for "average people... relate the deeds of heroes... the life and martyrdom of various saints, the battles..."; songs for kings and princes "move their souls to audacity and bravery, magnanimity and liberality...". Human emotions, the millennial content of music, were appreciated theoretically.

Whereas music appealed to emotions since time immemorial, a new and powerful development toward stronger and more diverse emotionality started during the Renaissance. It came with the tonal music developed for 500 years from the 15th to 19th c. with a *conscious* aim of appealing to musical emotions. (Tonality is the system of functional harmonic relations, governing most of the Western music. The tonal music is organized around tonic, a privileged key to which melody returns. Melody leads harmony, and harmony in turn leads melody. A melodic line feels closed, when it comes to rest on (resolved in) tonic. Emotional tension ends and a psychological relaxation is felt in the final move on to the tonic, to a resolution in a "cadence.")

Creating emotions was becoming the primary aim of music. Composers strived to imitate speech, the embodiment of the passions of the soul. At the same time conceptual content of texts increased, "the words (are to be) the mistress of the harmony and not its servant," wrote Monteverdi at the beginning of the 17th c. This became the main slogan of the new epoch of Baroque music. The opera music was born in Italy at that time.

The nature of emotions became a vital philosophical issue. Descartes [25] attempted a scientific explanation of passions. He rationalized emotions, explaining them as objects and relating to physiological processes. "Descartes descriptions of the physiological processes that underlay and determined the passions were extremely suggestive to musicians in search of technical means for analogizing passions in tones."

Based on Descartes' theory, Johann Mattheson [63] formulated a theory of emotions in music, called "The Doctrine of the Affections." Emotions "are the true material of virtue, and virtue is naught but a well-ordered and wisely moderate sentiment." Now the object of musical imitation was no longer speech, the exterior manifestation of emotions, but the emotions themselves.

Beginning from this time musical theory did not just trail musical practice but affected it to significant extent. Descartes and Mattheson understood emotions as monolithic objects. This simplified understanding of emotions soon led to deterioration of opera into a collection of airs, each expressing a particular emotion ("opera seria" or serious opera); the Monteverdi vision of opera as integrated text, music, and drama was lost. In the middle of the 18th c. Calzabigi and Gluck reformed opera back to the Monteverdi vision and laid a theoretical foundation for the next 150 years of opera development.

As we discuss later, music is different from other arts in that it affects emotions directly (not through concepts-representations). This clear scientific understanding of the differences between concepts and emotions did not exist. Nevertheless, an idea of music as expression, differentiating (creating new) emotions, was consciously formulated in the second half of the 18th c. (C. Avison, 1753 and J. Beattie, 1778). This idea of music as expression of emotions led to a fundamental advancement in understanding music as the art differentiating (creating new) emotions; it related the pleasures of music sounds to the 'meaning' of music. T. Twining (1789) emphasized an aspect of music, which today we would name conceptual indefiniteness: musical contents cannot be adequately expressed in words and do not imitate anything specific. "The notion, that painting, poetry and music are all Arts of Imitation, certainly tends to produce, and has produced, much confusion... and, instead of producing order and method in our ideas, produce only embarrassment and confusion." [115, pp. 293–294].

Yet understanding the nature of emotions remained utterly confused: "As far as (music) effect is merely physical, and confined to the ear, it gives a simple original pleasure; it expresses nothing, it refers to nothing; it is no more imitative than... the flavor of pineapple." Twinning expresses here correct intuition (music is not an imitation), but he confuses it with a typical error. Pleasure from musical sounds is not physical and not confined to the ear, as many have thought. As discussed later, pleasure from music is an aesthetic (not bodily) emotion in our mind unlike, for example, the flavor of a pineapple which promises to our body enjoyment of a physical food. Even the founder of contemporary aesthetics, Kant [52] had no room for music in his theory of the mind: "(As for) the expansion of the faculties which must concur in the judgment for cognition, music will have the lowest place among (the beautiful arts)... because it merely plays with senses." (Later we discuss a specific scientific reason preventing Kant from understanding the role of music in cognition.) Even today, as discussed in Section 2.3, the role of musical emotions and their interaction with cognition remain little known among musicologists; the idea of expression continues to provoke disputes, "embarrassment and confusion."

2.2. Whence beauty in sound?

A scientific theory of music perception began its development in the first half of the 19th century by Helmholtz's [42] theory of musical emotions, summarized in this section. A pressed piano key or plucked string produces a sound with many frequencies. In addition to the main frequency F, the sound contains overtones or higher frequencies, $2F, 3F, 4F, 5F, 6F, 7F, \ldots$, which sound quieter than F. The main tone corresponds to the string oscillating as a whole, producing F; on top of this, each part of a string ($1/2$, or $1/3$ or $2/3\ldots$) can oscillate on its own. A synthesizer can produce a sound with a single frequency F; it sounds similar to the ear as a piano key with the same main frequency, but more 'mechanical'. If one produces the key F, and at the same time $2F$ (quieter), then an untrained ear hears it very similar to the piano key. If all overtones are added, the sound will match the piano key. The interval between F and $2F$ (double frequency) is called an octave. If F is "Do, first octave (256 Hz)," then $2F$ is the Do of the second octave.

Our ear almost does not notice an overtone exactly one octave higher, because the eardrum oscillates as a string in concordance with itself. For the same reason all exact overtones ($2F, 3F, 4F, \ldots$) are perceived in concordance with the main frequency F and among themselves. Because of the mechanical properties of the eardrum, two sounds with close frequencies (say, F and $0.95F$) produce eardrum oscillations not only with the same frequencies but also with the difference of these frequencies ($F - 0.95F = 0.05F$). These low frequency oscillations are perceived as physically unpleasant (sounding "rough," and even painful, though at normal loudness they are barely perceived). Sounds with exactly same overtones (most loud ones) are perceived as concordant, agreeable, or 'mechanically pleasing.'

Is it possible to select concordant strings within octave, which main overtones equal $3F, 4F, 5F, 6F, 7F, \ldots$?—Yes, it could be achieved by dividing these frequencies by 2: $3/2F, 4/2F, 5/2F, 6/2F, 7/2F, \ldots$ (say, by taking a string twice as long). These sounds are perceived by the ear as concordant with the main key (F) and among themselves. This concordance is not as good as among overtones of a single string, but much better than for random sounds. That is the reason for musical importance of the octave: Strings (or keys) separated exactly by an octave (double or half the frequency) have many of the exact same overtones and they sound concordant. Note, only the first of the above sounds, $3/2F$, is within the fist octave (above F and below $2F$); the rest are in the second octave and above. For a key to sound in the first octave and its overtones to coincide with those of Do, we may bring down each overtone by one more octave (or two, or three): $5/4F, 7/4F, 9/8F$.

Notes obtained in this way, if we start with the three main overtones, make up the major scale, do, re, mi, fa, sol, la, ti—the white piano keys. They are perceived by the ear as concordant. The note fa, however, sounds more concordant if its first different overtone coincides with an overtone of do, $4F$ (therefore the fa key is chosen as fa $= 4/3F$). Concordance, or similarity of overtones, somewhat depends on the training of the ear, also not all overtones could be made completely concordant; therefore musical acoustics is not as simple as $2 \times 2 = 4$. Musical instruments were improved over thousands of years and they incorporate traditions and compromises. There are important differences among cultures in making musical instruments and tuning them. The most concordant keys do, fa, sol (or $F, 4/3F, 3/2F$) exist practically in all cultures (they are the most concordant because the first overtone of do is sol, and the first overtone of fa is do). Next four overtones closest in loudness and similarity add up to the major scale.

The minor scale is obtained if the three least concordant keys, mi, la, ti, are lowered by a half-tone (tone $= 1/7$th of an octave), so that they are more concordant with the other less loud overtones. If one chooses the most concordant note among these three less concordant keys, the note la, the resultant 5-notes are called the pentatonic scale; it is used in Chinese music, in folk music of Scotland, Ireland, and in Africa.

The scale of an accurately tuned piano slightly differs from what is described above. The reason is that all overtones of all keys cannot coincide; scale based on overtones of do is not as well concordant with overtones of other keys. For example, an overtone of mi, similar to sol, is $\frac{1}{4}$ tone different from sol and sounds as a strong dissonance. For string instruments, such as a violin, it is not too important; a violinist can take the correct interval for each note, similarly a singer. But for keyboard instruments, like piano, this sound error is not correctable. Therefore, in the 16th century a well-tempered scale was developed, which divides an octave into 12 equal intervals (half-tones), so that errors in the main overtones are equally spread and all keys are slightly discordant. Concordant musical sounds are called consonances, and less concordant, dissonances. The exact meanings of these words change with culture.

Notwithstanding the Helmholtz's acoustic theory, there is a principled difference between the 'mechanical' agreeableness of concordant overtones and esthetic beauty of music. For example, the minor scale is esthetically interesting exactly due to its slight discordance. Therefore, Helmholtz's theory could not be accepted as a basis for musicology. Sound "concordance" depends to some extent on musical ear training, and musical theory is not as simple as two plus two. Musical instruments have been perfected for thousands of years and there are important differences among cultures. Acoustic properties of the human voice and ear do not guarantee that Mozart sounds 'naturally.' A single string sounds naturally in complete concordance with its overtones, but classical musical harmony used natural mechanisms of perception of consonances and dissonances for complex esthetic effects. Fundamental significance of Helmholtz's theory remained unclear because it was not connected to the esthetic meaning of music.

Recent laboratory experiments confirmed that musical harmony is based on inborn mechanisms. Babies (beginning at 4-month) like consonant sounds and dislike dissonances. Evolution, it seems, used the mechanical properties of the ear for enhancing efficiency of the spoken communication channel. As a string made of inhomogeneous material sounds in discordance with itself, so does the human voice chord, when in stress or fear; it sounds discordant; and this discordance was perceived as unpleasant millions of years ago. In the basis of human voice communication, there are consonant combinations of sounds. These were gradually evolving into the emotionally filled melody of voice. Connection of voice sounds with the states of soul was inherent in our ancestors long before language began evolving toward conceptual content at the expense of the emotional one. Gradually, evolution shaped musical ability to create and perceive sound as something principally important, touching all of our being. This is why wolves howl at the Moon, whereas humans express such a diversity of emotions in sounds.

Another physical difficulty of Helmholtz's theory is that emotional perceptions of consonances and dissonances extends from contemporaneously sounding frequencies also to temporal sequences of tones, and this cannot be explained by beats of eardrum. Apparently, over millennia (or possibly over millions of years beginning in animals—this point might be contentious) neural mechanisms added to our perception of originally mechanical properties of ear. I'll add that Helmholtz did not touch the main question of why music is so important psychologically—this remained a mystery.

2.3. Current theories of musical emotions

Current theories of musical emotions attempt to uncover this mystery by looking into its evolutionary origins. Justus and Hustler [51] and McDermott and Houser [66] review evidence for evolutionary origins of music. They emphasize that an unambiguous identification of genetic evolution as a source of music origins requires innateness,

domain specificity for music, and uniqueness to humans (since no other animals make music in the sense humans do). The conclusions of both reviews are similar, i.e., "humans have an innate drive to make and enjoy music." There is much suggestive evidence supporting a biological predisposition for music. Certain basic abilities for music are guided by innate constraints.

Still, it is unclear that these constraints are uniquely human since they "show parallels in other domains." It is likely that many musical abilities are not adaptations for music, but are based on more general-purpose mechanisms. There are "some intriguing clues about innate perceptual biases related to music, but probably not enough to seriously constrain evolutionary hypothesis." "Available evidence suggests that the innate constraints in music are not specific to that domain, making it unclear, which domain(s) provided the relevant selection pressures." "There is no compelling reason to argue categorically that music is a cognitive domain that has been shaped by natural selection." In Nature's series of essays on music McDermott [67] writes: "Music is universal, a significant feature of every known culture, and yet does not serve an obvious, uncontroversial function."

In commentaries to these reviews, Trainor [113] argues that for higher cognitive functions, such as music, it is difficult to differentiate between adaptation and exaptation (structures originally evolved for other purposes and used today for music), since most such functions involve both "genes and experience." Therefore the verdict on whether music is an evolutionary adaptation should be decided based on advantages for survival. Fitch [31] comments that biological and cultural aspects of music are hopelessly entangled, and "the greatest value of an evolutionary perspective may be to provide a theoretical framework." Livingstone and Thompson [59] emphasize a multimodal nature of the engaging effect of musical experience and explore theories based on exaptations of "an earlier system of affective communication." It is therefore interesting, they suggest, exploring correlations between musicality and emotional intelligence. They emphasize human symbolic ability leading to art, including music and our capacity for "symbolic hierarchical systems."

Before reviewing other select authors, we would comment that the hypothesis advocated later in the current review corresponds to many of the suggestions and ideas in this section. In addition, we discuss a fundamental function of musical emotions in the evolution of language, mind, and culture, which is missing in other theories and which provides new directions to search for evolutionary mechanisms of music. The review relates to biological roots of music, to its origins in "an earlier system of affective communication," it bears on discussions of evolution vs. exaptation, and human symbolic ability.

Huron [43] emphasizes that in the search for evolutionary origins of music it is necessary to look for complex multistage adaptations, built on prior adaptations, which might have evolved for several reasons. He discusses social reasons for music origins and lists several possible evolutionary advantages of music: mate selection, social cohesion, the coordination of group work, auditory development, developing auditory skills, refined motor coordination, conflict reduction, preserving stories of tribal origins. However, the list of possible uses of music by itself does not explain musical power over human psyche; does not explain why music and not some other, nonmusical activities have been used for these purposes.

Cross [19,20], Cross and Morley [21] concentrate on evolutionary arguments specific to music. Cross integrates neuroscientific, cognitive, and ethnomusicological evidence and emphasizes that it is inadequate to consider music as "patterns of sounds" used by individuals for hedonic purposes. Music should be considered in the context of its uses in pre-cultural societies for social structuring, forming bonds, and group identities. A strong argument for evolutionary origins of music is its universality; music exists in all scientifically documented societies around the globe. Cross emphasizes that music possesses common attributes across cultures: it exploits the human capacity to entrain to social stimuli. He argues that music is necessary for the very development of culture. Cultural evolution is based on ability to create and perceive socio-intentional aspect of meaning. This is unique to human and it is created by music. Cross presents a three-dimension account of meaning in music, combining "biologically generic, humanly specific, and culturally inactive dimensions." Thus evolution of music was based on already existing in animal world biological and genetic mechanisms.

The capacity for culture [20] requires transmission of information, but also the context of communication. Therefore "music and language constitute complementary components of the human communicative toolkit." The power of language is in "its ability to present semantically decomposable propositions." Language, because of its concreteness, on one hand enabled exchange of specific and complicated knowledge, but on the other hand could exacerbate oppositions between individual goals and transform an uncertain encounter into a conflict.

Music is a communicative tool with opposite properties. It is semantic, but in a different way than language. Music is directed at increasing a sense of 'shared intentionality.' Music's major role is social, it serves as an 'honest signal' (that is it "reveals qualities of a signaler to a receiver") with nonspecific goals. This property of music, "the indeterminacy of meaning or floating intentionality," allows for individual interactions while maintaining different "goals and meanings" that may conflict. Thus music "promotes the alignment of participants' sense of goals." Therefore Cross hypothesized that successful living in societies promoted evolution of such communication system.

Cross suggests that music evolved together with language rather than as its precursor. Evolution of language required a re-wiring of neural control over the vocal tract, and this control had to become more voluntary for language. At the same time a less voluntary control, originating in ancient emotional brain regions, had to be maintained for music to continue playing the role of 'honest signal.' Related differences in neural controls over the vocal tract between primates and humans were reviewed in [76,78,81,84].

As juvenile periods in hominid lineages lengthened (altricialization), music took a more important role in social life [21]. The reason is that juvenile animals, especially social primates, engage in play, which prepares them to adult lives. Play involves music-like features, thus proto-musical activity has ancient genetic roots. Lengthening of juvenile periods was identified as possibly fundamental for proto-musical activity and for origin of music. Infant directed speech (IDS) has special musical (or proto-musical) qualities that are universal around the globe. This research was reviewed in [114]. She has demonstrated that IDS exhibits many similar features across different cultures. Young infants are sensitive to musical structures in human voice. Several researchers relate this sensitivity to the "coregulation of affect by parent and child" [27], and consider IDS to be an important evolutionary mechanism of music origin. Yet, arguments presented later tell that IDS cannot be a full story of musical evolution.

Dissanayake [28] considers music primarily as a behavioral and motivational capacity. Naturally evolving processes led to ritualization of music through formalization, repetition, exaggeration, and elaboration. Ritualization led to arousal and emotion shaping. This occurred naturally in IDS, in the process of mother–infant interaction, which in addition to specially altered voice involved exaggerated facial expressions and body movements in intimate one-to-one interaction. Infants 8 weeks old already are sensitive to this type of behavior, which reinforces emotional bonding. This type of behavior and the infants' sensitivity to it are universal throughout societies, which suggests an evolved inborn predisposition. Dissanayake further emphasizes that such proto-musical behavior has served as a basis for culture-specific inventions of ritual ceremonies for uniting groups as they united mother–infant pairs. The origins of music, she emphasizes, are multi-modal, involving aural, visual, and kinesic activity, which has occurred in social rather than solitary settings. She describes structural and functional resemblances between mother–infant interactions, ceremonial rituals, and adult courtship, and relates these to properties of music. All these, she proposes, suggest an evolved "amodal neural propensity in human species to respond—cognitively and emotionally—to dynamic temporal patterns produced by other humans in context of affiliation."

This combination of related adaptations was biologically motivated by co-occurrence of bipedalism, expanding brain size, and altricialization [21,28] and was fundamental to human survival. This is why, according to Dissanayake, proto-musical behavior produces such strong emotions, and activates brain areas involved in ancient mechanisms of reward and motivation, the same areas that are involved in satisfaction of most powerful instincts of hunger and sex.

A related theory of music origins is proposed by Parncutt [71]. He suggests that prenatal exposure to "the complex web of associations among patterns of sound, movement and emotion that characterize music" "creates a mother schema" that promotes postnatal survival. In this way, Parncutt suggests, one difficulty is overcome: the issues of music adaptivity and emotionality are dissociated, while both are supported. Many experiences of musical emotionality are explained, which otherwise seem mysterious. This might further be related to the origin of religion. Both, music and religion, he suggests, might be byproducts of prenatal experiences and the adaptive value of postnatal infant–mother bonding.

Mithen [68] presents an impressive array of evidence that Neanderthals possibly have had proto-musical ability. He argues that music and language have evolved by differentiation of early proto-human voice sounds "Hmmmm" undifferentiated proto-music-language. The development was facilitated by vertical posture and walking, which required sophisticated sensorimotor control, a sense of rhythm, and possibly ability for dancing.

The differentiation of Hmmmm, he dates to after 50,000 BP. Further evolution toward music occurred for religious purposes, which he identifies with supernatural beings. Currently music is not needed, it has been replaced by language, it only exists as inertia, as a difficult to get rid off remnant of the primordial Hmmmm. An exception could be religious practice, where music is needed since we do not know how to communicate with gods. (I have a difficulty

with dismissing Bach, Beethoven, or Shostakovich in this way; as well as with the implied characterization of religion, and discuss my doubts later.)

Mithen explains why music is often perceived as a conversation, and why we feel it as having a meaning, both of these are remnants of Hmmmm. Onomatopoeia is also a survival of Hmmmm. Among a number of properties of music explained by Mithen, I would emphasize relation of music to emotions, this was present in original Hmmmm. Songs recombine language and music into original Hmmmm, however Mithen gives no fundamental reason or need for this recombination.

Mithen summarizes the state of knowledge about vocalization by apes and monkeys. Unlike older views, calls could be deliberate, however their emotional–behavioral meanings are probably not differentiated; this is why primates cannot use vocalization separately from emotional–behavioral situations (and therefore cannot develop language), this area is still poorly understood. While addressing language in details, Mithen (and other scientists as well) give no explanation for why human learn language by about age of five, but the corresponding mastery of cognition takes the rest of lifetime; steps toward explaining this are taken in [79,80,86,87,89] and summarized in this review.

Mithen's view on religion contradicts the documented evidence for relatively late proliferation of supernatural beings in religious practice [46], and to mathematical and cognitive explanations for the role of religiously sublime in workings of the mind [55,74].

Juslin and Västfjäll [50] analyze mechanisms of musical emotions. They emphasize that in the multiplicity of reviews considering music and emotions, the very use of the word 'emotion' is not well defined. They discuss a number of neural mechanisms involved with emotions and different meanings implied for the word 'emotion'. I would mention here just two of these. First, consider the so-called basic emotions, which are most often discussed; we have specific words for these emotions: fear, sexual-love, jealousy, thirst... Mechanisms of these emotions are related to satisfaction or dissatisfaction of basic instinctual bodily needs such as survival, procreation, a need for water balance in the body... An ability of music to express basic emotions unambiguously is a separate field of study. Second, consider the complex or 'musical' emotions (sometimes called 'continuous'), which we 'hear' in music and for which we do not necessarily have special words. Mechanisms and role of these emotions in the mind and cultural evolution are subjects of this review.

Levitin [58] classified music in six different types, fulfilling six fundamental needs, and (as far as I understood him) eliciting six basic emotions. He suggests that music has originated from animal cries and it functions today essentially in the same way, communicating emotions. An ability to communicate emotions with voice and to correctly perceive emotions in voice has given and continues to give evolutionary advantage and is the basis for emotional intelligence. Emotions motivate us to act and neural connections facilitating this are bidirectional, action and movement may elicit emotions: "emotions and motivation are two sides of the same evolutionary coin." It is more difficult, he writes, "to fake sincerity in music than in spoken language." The reason that music evolved this way as an 'honest signal' because it "simply" co-evolved with brains "precisely to preserve this property." (Given the fact that even as simple animals as birds can fake their cries [60] I have my doubts about this "simply;" further doubts arise as soon as we think about actors, singers, and poets, not only contemporary professionals, but also those existing in traditional societies [65] since time immemorial.)

Mathematical modeling of the mechanisms of music perception and musical emotions was considered in [18,100, 101]. These modeling approaches can be used to obtain and verify predictions of various theories.

In the following sections we review mechanisms of music evolution from differentiation of original proto-music-language to its contemporary refined states. Discussions of mechanisms that evolved music from IDS to Bach and Beatles in previously proposed theories are lacking or unconvincing. Why do we need the virtual infinity of "musical emotions" that we hear in music (e.g. in classical Western music)? Is it an aberration or do they address potentially universal human needs? Dissanayake [28] suggests that this path went through ceremonial ritualization, due to "a basic motivation to achieve some level of control over events...". If "for five or even ten centuries... music has been emancipated from its two-million year history and its adaptive roots says more about the recency and aberrance of modernity...". Cross and Morley [21] argue against this conclusion: "...it would be impossible to remove music without removing many of the abilities of social cognition that are fundamental to being human." He concludes that "there are further facets to the evolutionary story (of the origins of music) requiring consideration. Investigation of the origins, emergence and nature of musical behaviors in humans is in its early stages, and has plenty more to reveal." In the following we review a novel hypothesis that clarifies some of these remaining "further facets" and provides bases for further research in several directions.

3. Fundamental mechanisms of the mind

This section summarizes fundamental mechanisms of the mind: concepts, instincts, emotions, and behavior; these serve as a first step toward more complicated mechanisms essential for understanding the role and evolution of music. The content of this section summarizes neuro-cognitive and mathematical arguments considered, in detail, in [64,73,77,80,82,83,88,93,94,96] and in references therein.

The most accessible to our consciousness is a mechanism of the mind, which operates with concepts. The mind understands the world in terms of concepts. *Concepts* operate as internal models of objects and situations. This analogy is quite literal, e.g., during visual perception of an object, a concept-model in the mind (memory, representation) projects an image onto the visual cortex, which is matched there to an image projected from the retina (this simplified description is discussed in more details in the above references). Experimental neuroimaging proof of this mechanism with detailed description of the brain regions involved is given in [5]. Perception occurs when the two images are successfully matched.

The "mechanism of concepts" evolved for instinct satisfaction. Instincts are mechanisms of survival that are much more ancient than mechanisms of concepts. Psychological literature actively discusses mechanisms of instincts and these discussions can be followed in the given references. Here we follow these references in considering the mechanism of *instincts* as similar to internal sensors that measure vital organism parameters, important for normal functioning and survival. For example, a low sugar level in blood indicates an instinctual need for food. This sensor measurement and the requirement to maintain it within certain limits we consider being an "instinct." The function of satisfying this instinct is considered by this review as an appropriate level of analysis. (Biologists and neuro-cognitive scientists may consider these mechanisms in much more detail, however our level of analysis is determined by our aim: to understand the fundamental mechanisms of music.)

Emotions designate a number of various mechanisms which are surveyed, for example, in [8,50]. Here we consider emotions as neural signals connecting instinctual and conceptual brain regions. Emotions (or emotional neural signals) communicate instinctual needs to conceptual recognition–understanding mechanisms of the brain, so that concept-models corresponding to objects or situations that can potentially satisfy instinctual needs receive preferential attention and processing resources in the brain [39,73,80]. Thus emotional signals evaluate concepts for the purpose of instinct satisfaction. This evaluation is not according to rules or concepts (like in rule-systems of artificial intelligence), but according to a different instinctual–emotional mechanism described in the given references.

Conceptual–emotional understanding of the world results in actions in the outside world or within the mind. We only touch on the *behavior* of improving understanding and knowledge, the behavior inside the mind directed at improving concepts. Let us mention that there are "lower-level" autonomous behavioral responses, which humans share with animals and which do not involve mechanisms of concepts. We would not need to consider them here for understanding the role of music.

The above theory describing conceptual–emotional recognition and understanding encompasses the mechanisms of intuition, imagination, planning, conscious, unconscious, and many others, including aesthetic emotions. Here we would touch on mechanisms that will be referred to later. For example, visual imagination occurs when one contemplates objects or situations with closed eyes. Contemplated concept-models project images on visual cortex causing visual imagination. Most of the brain operations are unconscious, for example, individual neuronal firings. A significant part of conceptual perception is an unconscious process; for example, visual perception takes about 150 ms, which is a long time when measured in neuronal firings (about 10 ms per neuron, while tens of thousands of neurons are participating in parallel). Initial concept-model projections on the visual cortex are vague and the human mind is not conscious of them. Only when concept-model projections match object-projections and become crisp do conscious perceptions occur. It is possible to make the vague concept-model projections conscious: close your eyes and imagine an object in front of you; this imagination is usually vague, not as crisp as perception of an object with open eyes. Let us now move to mechanisms of aesthetic emotions.

4. The knowledge instinct

To satisfy instinctual needs, e.g. eating or procreation, the mind first of all should perceive objects around and understand situations. As discussed, this task requires matching concept-models to the surroundings. But objects around would never exactly match old concept-model-memories. Angles, lightings, and positions are always different.

This has presented difficulties to artificial intelligence and pattern recognition since the 1950s until recently (e.g. see [73,80,88,89]). For this reason the initial projections of concept-models are vague and they approximately match many different objects. To actually perceive specific objects, the mind has to modify concepts so that they "fit" concrete objects and situations present in the ever-changing world. This mechanism operates independently of human desire "to perceive," it is an inborn autonomous mechanism, more fundamental than eating or procreation. It is aimed at satisfying a basic need, to understand the world around by making concept-models "similar" to surroundings. The mind has an inborn instinct that "senses" this similarity and maximizes it. This mechanism is called the knowledge instinct, KI [73,80,88,89]. Knowledge is the measure of correspondence between concepts and the world.

Emotions that evaluate satisfaction or dissatisfaction of this instinct are felt as harmony or disharmony between the knowledge and the world. They are not related directly to "lower" bodily needs, but only to "higher" need for knowledge. In this sense they are "higher," "spiritual," aesthetic emotions (emotions related to knowledge are called aesthetic since Kant [52]). This way Kant explained the emotion of the beautiful [52,75,77,83,90]. However, Kant could not complete his explanation, because he did not consider the need to constantly adapt concept-models, he did not know about KI. We would like to emphasize that aesthetic emotions are not peculiar to perception of art; they are inseparable from every act of perception and cognition. Relation of these emotions to the beautiful and to musical emotions will be considered later. During perception of everyday objects these emotions usually are below the threshold of conscious registration. We do not feel emotionally elated when correctly understand a simple everyday object in front of our eyes. But, due to scientific knowledge of cognitive neural mechanisms and their mathematical models we know that these emotional neural signals are there. And it is easy to prove experimentally. As soon as perception and understanding of the surrounding world does not work we feel disharmonious, disturbed, or even threatened—this is the routine matter of thriller movies, which show us situations that do not fit our concept-models. At the level of simple objects this perception mechanism is mostly autonomous, like workings of our stomach. As long as the stomach works perfectly, we do not notice its existence emotionally. But as soon as it fails, we feel it emotionally right away.

5. The hierarchy of the mind

The mind is not a strict heterarchy and many cognitive neuroscientists refer to the hierarchy of the mind. For simplicity we will use the word hierarchy in this review. At every level of the hierarchy, top-down signals generated by concept-models at this level are matched to bottom-up signals coming from concept-models recognized and understood at lower levels. The mind involves a hierarchy of multiple levels of concept-models, from simple perceptual elements (like edges, or moving dots), to concept-models of objects, to complex scenes, and up the hierarchy... toward the highest concept-models. These highest concept-models near the top of the hierarchy are essential for understanding the nature of the beautiful and spiritually sublime [75,77,80,83,90,95].

To understand this let us first attend to the perception-cognition of a simple situation-scene, say an office of a professor. It is not sufficient for our KI to understand individual objects in the office such as books, shelves, chairs, desk, computer... we can sit in a chair or read a book, but this understanding will only take us so far (animals also understand objects and what they can do with some of them). KI drives us to understand "the office" in its unity of constituent objects. A mathematical model of this process was developed in [32–35,44,91,92]. For understanding higher level abstract concepts we have corresponding concept-models, e.g. an "office." Similarly, we understand a concert "hall," and any other situation by using appropriate-level concepts that we have for this purpose. Let me repeat this word: purpose; every higher-level concept has a purpose to make a unified sense out of individual lower-level concepts. In this process lower-level concepts acquire higher-level "sense" or meaning of making up something "bigger," something more meaningful, than their lower-level meanings. In this way our understanding of the world can move from a "book" to "office," to "university," to "educational system," and so on... to concepts near the top of our minds. These concepts "attempt" to make sense, to understand the meaning of our entire experience. We understand-perceive-feel them as related to the meaning and purpose of our lives.

This last sentence requires several clarifications. First, let me remind that even a simple object, when imagined with closed eyes is vaguer and less conscious than when perceived with open eyes. But abstract concepts at higher levels of the mind hierarchy cannot be "perceived with open eyes." Correspondingly they are forever vaguer and less accessible to our consciousness than simple objects. This statement may sound startling; we do not necessarily experience all abstract concepts this way. The reason abstract concepts may sometimes seem crisp, clear, and conscious will be

addressed in the next section. Second, vaguer and less conscious concepts may also be mixed up with emotional contents. For example, talking about your favorite political party may require special efforts to separate conceptual understanding from emotional involvement. This is why concepts at the top of our mind could be at once less conscious and emotionally charged. This combination makes it difficult for us to discuss these concepts. Many of my friends (scientists) when asked: "Does your life have a meaning and purpose?" will reply with great doubts. However, as soon as the question is reformulated: "So your life does not have any more meaning and purpose than that piece of rock at the side of the road?" At this point most of people agree that the idea of the meaning and purpose of life might be vague and barely conscious, but it is so important that we cannot live without it. In fact reading this review would be a very boring exercise, if you do not believe that your life has a purpose. It would be more fun to get drunk or high on drugs.

Life experience does not convince us that our lives have meaning and purpose; random deaths and destructions abound. But believing in one's purpose is tremendously important for survival; it is necessary for concentrating the will and power on achieving higher goals in life. This is why even partial understanding of contents of the highest concept-models is so important. When we feel that indeed our lives have meaning, in these rare fleeting moments we feel KI satisfaction at the highest level as an aesthetic emotion of the beautiful.

This discussion is not necessarily novel in the history of philosophy. Aristotle and Kant discussed similar ideas. Aristotle wrote [2] that the beautiful is a "unity in manifold." The only way to understand the world in its unity, he wrote, is as if it had a purpose. Kant [52] understood the beautiful as "purposiveness without purpose" or "aimless purposiveness" of the faculty of judgment; Kantian judgment corresponds to mechanisms of aesthetic emotions as discussed in the previous section and mathematically modeled in [80]. Also, "aimless" in Kant means that it is not aimed at satisfying lower bodily needs. Kant did not appreciate the need for adaptation of concept-models and could not formulate the idea of KI. This caused him great difficulty, he goes around "aimless purposiveness" emphasizing that it is not aimless, that it is highly spiritual, but without the knowledge instinct idea he could not give a positive definition of the beautiful. I added a contemporary scientific context. My formulations might be crisper, because they are based on a mathematical theory [80].

6. The dual hierarchy of cognition and language

The mind hierarchy as discussed above tacitly assumed a single hierarchy of cognitive models. To resolve certain difficulties glossed over in the above, and to get closer to understanding musical emotions, we now consider the dual hierarchy of cognition and language; we summarize arguments discussed in details in Perlovsky [79,80,84,86,87].

Recognizing that cognition and language are not the same, that these abilities are served by different mechanisms of the mind, started a revolution in the 20th century linguistics initiated by Chomsky [16]. Many psycholinguists and evolutionary linguists today disagree with Chomsky's complete separation of language from cognition and denial of evolutionary origin of language [10,13,15]. Detailed discussions can be found in the given references and further references therein. Here we summarize conclusions important for understanding the role of music.

We start with few difficulties encountered when attempting to understand the mechanisms of interaction of cognition and language. Language plays such an important role in thinking that it is difficult to comprehend what cognition is without language, what are the mechanisms? Normal children acquire language by about the age of five, by seven they can talk about much content of the entire culture. If a mother is looking for a job, a child seems to know everything about this process. But of course the child cannot go on the street and find a job. What exactly is missing in terms of neural mechanisms? How do children learn which words and sentences correspond to which objects and situations? Many psychologists still adhere to "associationism," an idea due to Locke that kids just learn associations between words and objects, etc. But as discussed in the given references, this is mathematically impossible. Some people master language very well, while inept in the real world or with other people; opposite examples also abound. So, what are the mechanisms that make language and cognition so interdependent, and at the same time so separate? And what exactly the animals are missing that they cannot learn language?

According to given references, the main mechanism of interaction between cognition and language is a dual concept-model. Each concept has two parts, language part (a word or phrase) and cognitive part (an object or situation). When a child is born these are vague neural placeholders that later will acquire a concrete content. By the age of five much of language models are crisp, clear, and conscious, but the corresponding cognitive models may remain vague and unconscious. By the age of four, everyone knows e.g. about good and bad guys, but who can claim at 30 or

40 or 70, that he or she can use these concepts in real life without errors? Philosophers argue about the meanings of good and evil for millennia. Even for everyday concepts, the linguistic parts of which are crisp and conscious in every child's mind, it will take the rest of the child's life to acquire equally crisp and conscious cognitive models. Likely most of cognitive concept-models never attain equally conscious and crisp states. This is why most people most of the time speak with words without being fully conscious about cognitive contents of what they say. These properties of language-cognition interaction are explained by the mechanism of dual models.

The mechanism of dual models is fundamentally important for emergence of the hierarchy of the mind for the need to ground cognition [11,12,14,110]. Learning concept-models of cognition is grounded in experience only at the lower levels of concrete objects, at this level human abilities are no different from animals' [107]. But understanding situations and abstract concepts can not be based on experience. The referenced publications discuss in details why this is mathematically impossible: there are too many combinations of objects and events (more then all elementary events in the life of the Universe). Life experience would never be sufficient to learn which combinations are meaningful to form abstract concepts.

Possibly the mechanism of dual models is sufficient to make the difference between humans and animals. It is possible to teach a dog to bring shoes on verbal command. Does it mean that a dog possesses a mechanism of dual models? No, a dog can learn concepts of object-shoes and object-sound-"shoes" based on direct visual and hearing perception, and learns to associate these two concept-objects. But nobody would even attempt to teach abstract concepts such as rationality, abstractness, or law to a dog. Learning these abstract concepts requires the mechanism of dual models: KI drives the mind to find combinations of objects and events, which correspond to language models.

Learning cognitive models at higher levels is based on language models. Language hierarchy is learned "ready-made" from the surrounding language. KI drives the mind to learn cognitive hierarchy corresponding to language hierarchy. Cognitive models are grounded in language.

7. Differentiation and synthesis

The knowledge instinct operates in the dual hierarchy of the mind with two main mechanisms, differentiation and synthesis [80,84,85]. At every level of the hierarchy it drives the mind to achieve detailed understanding by creating more specific, diverse and detailed concepts—this is the mechanism of differentiation. At the same time (as we discussed), KI drives us to understand various situations and abstract concepts as a unity of constituent notions. This mechanism of KI operating across hierarchical levels creates higher meanings and purposes—this is a mechanism of synthesis.

The main "tool" of differentiation is language. Language gives our mind a culturally evolved means to differentiate reality in great detail. The evolution of language required neural rewiring of circuits controlling vocalization. Vocal tract muscles in animals are controlled from an old emotional center and voluntary control over vocalization is limited [23,24,54,102]. Humans, in contrast, possess a remarkable degree of voluntary control over voice, which is necessary for language. In addition to the old mostly involuntary control over vocal tract human have conscious voluntary control originating in cortex.

Correspondingly, conceptual and emotional systems (understanding and evaluation) in animals are less differentiated than in humans. Sounds of animal cries engage the entire psyche, rather than concepts and emotions separately. A well-known example is differentiated calls of vervet monkeys (e.g. see a review in [104]). The calls convey information about different types of predators nearby; however understanding of a situation (concept of danger), evaluation (emotion of fear), and behavior (cry and jump on a tree) are not differentiated, each call is a part of a single concept–emotion–behavior–vocalization psychic state with very little differentiated voluntary control (if any).

Emotions-evaluations in humans have separated from concepts-representations and from behavior (for example, when sitting around the table and discussing snakes, humans do not jump on the table uncontrollably in fear, every time "snakes" are mentioned). We hypothesize that gradual differentiation of psychic states with a significant degree of voluntary control over each part gradually evolved along with language and the brain rewiring.

Therefore, language contributed not only to differentiation of conceptual ability, but also to differentiation of psychic functions of concepts, emotions, and behavior. This differentiation destroyed the primordial synthesis of psyche. With the evolution of language human psyche started losing its synthesis, wholeness. Whereas for animals every piece of "conceptual knowledge" is inextricably connected to emotional evaluation of a situation, and to appropriate behavior, satisfying instinctual needs, this is not so for humans. Most of the knowledge existing in culture and ex-

pressed in language is not connected emotionally to human instinctual needs. This is tremendously advantageous for development of conceptual culture, for science, and technology. Humans can engage in deliberate conversations, and if disagree, do not have to come to blows. But there is a heavy price that humans pay for this freedom of conceptual thinking: human psyche is not automatically whole. Human knowledge accumulated in language is not automatically connected to instinctual needs; sometimes culturally developed conceptual knowledge contradicts instinctual needs inherited from the animal past. Moreover, various parts of knowledge may contradict each other. As discussed, synthesis, the feeling of being whole is closely related to successful functioning of the highest models at the top of the hierarchy of the mind, which are perceived as the meaning and purpose of life. Therefore contradictions in the system of knowledge, the disconnects between knowledge and instincts, the lost synthesis, lead to the internal crises and may cause clinical depressions. When psychic states missing synthesis preoccupy the majority of a population, knowledge loses its value, including knowledge and value of social organization and cultural calamities occur, wars and destructions [26,78,81,82,84,85]. The evolution of culture requires a balance between differentiation and synthesis. Differentiation is the very essence of cultural evolution. But it may lead to emotional disconnect between conceptual knowledge and instinctual needs, to the lost feeling of the meaning and purpose, including the purpose of any cultural knowledge, and to cultural destruction. Theoretical and experimental evidence suggest that different languages maintain different balances between the emotional and conceptual [3,7,40,41,84].

8. Toward modeling cultural evolution

The discussion in the previous section can be modeled mathematically [78,81,82,84,87]. In these references a mathematical model of KI was extended to the hierarchy of the mind, and then simplified using an approach similar to the mean field approximation in physics along with other approximations. In the result of these approximations, the hierarchy of the mind is described as a dynamic system with only three dynamic variables, differentiation D, measured as a mean number of model-concepts, synthesis, S, measured as a mean value of emotions per model, and hierarchy, H, a mean number of hierarchical levels. This mean field system approximating an "average" mind, should be better considered as representing culture (which is a collection of minds). The resulting dynamic equations yield two types of solutions, illustrated in Figs. 1, 2. In these figures values of dynamic variables D, S, H, are shown on the vertical axes and cultural evolution time is shown on the horizontal axes. Scales are arbitrary since we lack experimental data to fix them. These data are measurable in a laboratory setting. In first approximation D is a number of words in a dictionary, H could be obtained by a hierarchical clustering of words, and S can be measured by standard psychological experimental procedure by measuring skin conductance associated with various words in the language (this technique is used in lie detectors).

At moderate values of synthesis, a solution is shown in Fig. 1. The number of concepts grows until certain level, when it results in reduction of synthesis; then the number of models falls. As a number of models falls, synthesis grows, and the growth in models resumes. The process continues with slowly growing, oscillating number of models. Note, oscillations affecting up to 80% of knowledge indicate internal instability of the knowledge-accumulating process in this culture. Qualitative explanation for these oscillations is discussed near the end of the previous section. We note that this figure represents an important aspect of the history of western civilization: periods of flourishing and cultural growth alternate with periods of wars and destructions. Music as we discuss later evolved to reduce these oscillations.

Another solution corresponds to initially high level of synthesis, Fig. 2. Synthesis continues growing whereas differentiation levels off. The qualitative reason is that every concept is invested with so much emotion that deliberate thinking is impossible. Everyone has some conceptual ideas invested with too much emotion, say a favorite political party, or global warming, or family—these conceptual ideas could be "beyond" rational discussion. Fig. 2 suggests a hypothetical explanation for immobility of many traditional cultures: when every concept is "too emotional" the cultural development stagnates. Stability of such societies with high synthesis, is achieved due to stagnating differentiation.

While these two figures are rough simplifications of the processes of cultural evolution, I would emphasize first of all that they capture important known characteristics of cultures and secondly, I'll repeat that they are testable scientific hypotheses and several groups of psychologists currently test these hypotheses about relationships between differentiation, synthesis, and cultural evolution.

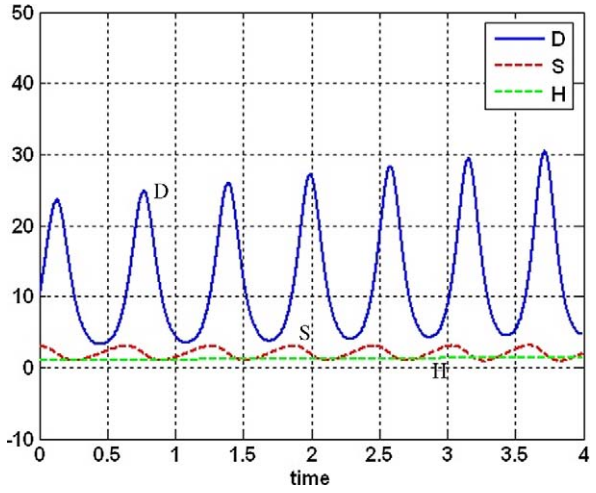

Fig. 1. "Knowledge-accumulating" dynamic culture. *D*, *S*, *H*, are shown on the vertical axis and cultural evolution time is on the horizontal axis. Scales are arbitrary. An ability to acquire knowledge causes instabilities.

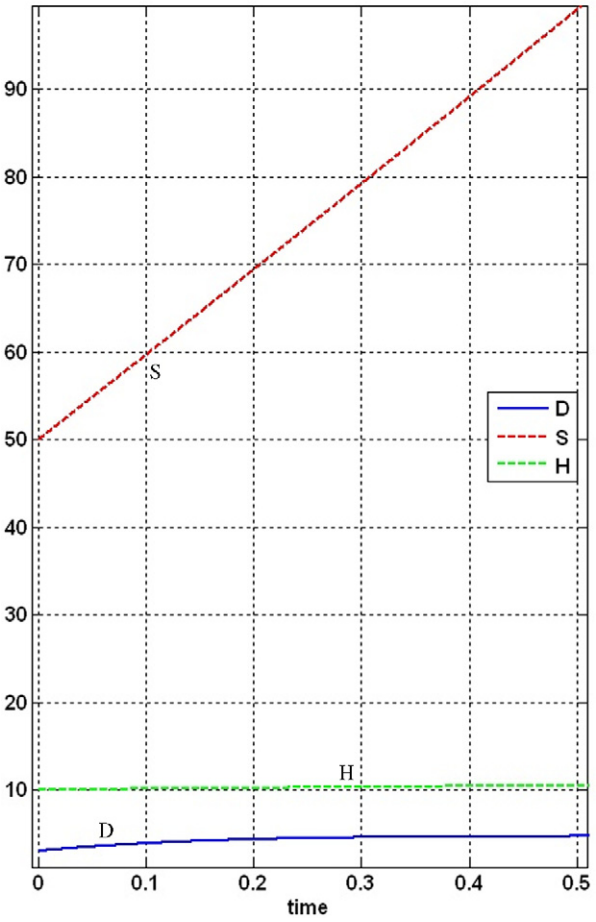

Fig. 2. "Traditional" culture. *D*, *S*, *H*, are shown on the vertical axis and cultural evolution time is on the horizontal axis. Scales are arbitrary. Stability is achieved due to high synthesis, at the expense of cultural immobility.

9. Differentiated knowledge instinct and musical emotions

Here we discuss the main hypothesis of this review: what constitutes the fundamental role of musical emotions in evolution of consciousness, cognition, and culture.

As discussed, the balance between differentiation and synthesis is crucial for the development of cultures and for emergence of contemporary consciousness. Those of our ancestors, who could develop differentiated consciousness, could better understand the surrounding world, and better plan their life had evolutionary advantage, if in addition to differentiation they were able to maintain the unity of self required for concentrating will. Maintaining balance between differentiation and synthesis gave our ancestors evolutionary advantage. Here we examine the mechanisms by which music helps maintaining this balance. The main hypothesis of this paper is that maintaining this balance is the very fundamental role that music plays and the reason for evolution of this otherwise unexplainable ability.

History keeps a long record of advanced civilizations, whose synthesis and ability to concentrate its will was undermined by differentiation. They were destroyed by less developed civilizations (barbarians) who's differentiation lagged behind, but who's synthesis and will was strong enough to overcome great powers of their times. These examples include Akkadians overrunning Sumerians some 3 millennia BCE, barbarians overcoming Romans and countless civilizations before and after these events. But I would like to concentrate on less prominent and more important events of everyday individual human survival from our ancestors to our contemporaries. If differentiation undermines synthesis, the purpose and the will to survive, differentiated consciousness and culture would never emerge.

Let us repeat, differentiation is the very essence of cultural evolution, but it threatens synthesis and may destroy the entire purpose of culture, and the culture itself [76,78,81,82,84,87]. This instability is entirely human, it does not threaten the animal kingdom because the pace of evolution and differentiation of knowledge from ameba to primates was very slow, and instinctual mechanisms of synthesis apparently evolved along with the brain capacity. This situation drastically changed with the origin of language; accumulation of differentiated knowledge vastly exceeded biological evolutionary capacity to maintain synthesis. Along with the origin of language another uniquely human ability evolved, the ability for music. Given references proposed a scientific hypothesis that music evolved for maintaining the balance between differentiation and synthesis. After reviewing arguments, we discuss empirical and experimental means by which this hypothesis can be verified.

Many scientists studying evolution of language came to a conclusion that originally language and music were one [19,22,62]. In this original state the fused language–music did not threaten synthesis. Not unlike animal vocalizations, sounds of voice directly affected ancient emotional centers, connected semantic contents of vocalizations to instinctual needs, and to behavior. This way Jaynes [46] explained stability of great kingdoms of Mesopotamia up to 4000 years ago. This synthesis was a direct inheritance from animal voicing mechanisms, and to this very day voice affects us emotionally directly through ancient emotional brain centers [70,112].

We would like to emphasize the already discussed fact that since its origin language evolved in the direction of enhancing conceptual differentiation ability by separating it from ancient emotional and instinctual influences (here we mean "bodily" instincts, not instincts for knowledge and language). While language was evolving in this more conceptual and less emotional direction, we suggest that 'another part' of human vocalization evolved toward less semantic and more emotional direction by enhancing already existing mechanisms of voice–emotion–instinct connection. As language was enhancing differentiation and destroyed the primordial unity of psyche, music was reconnecting differentiated psyche, restoring the meaning and purpose of knowledge and making cultural evolution possible. Was this process equally successful in every culture? Probably not, but this is a separate field of study for future research.

This was the origin and evolutionary direction of music. Its fundamental role in cultural evolution was maintaining synthesis in the face of increasing differentiation due to language. We now return to the basic mechanisms of the mind, including KI and analyze them in more details in view of this hypothesis.

Discussing KI in previous sections we described the mathematical model of its mechanism, an internal mind's "sensor" measuring similarity between concept-models and the world and related mechanisms of maximizing this similarity. But clearly it is a great simplification. It is not sufficient for the human mind to maximize an average value of the similarity between all concept-models and all experiences. Adequate functioning requires constant resolution of contradictions between multiple mutually contradicting concepts; as well as between individual concepts quickly created in culture and slowly evolving primordial animal instincts. Human psyche is not as harmonious as psyche of animals. Humans are contradictory beings; as Nietzsche [69] put it, "human is a dissonance." Those of our ancestors

who were able to acquire differentiated contradictory knowledge and still maintain wholeness of psyche necessary for concentration of will and purposeful actions had tremendous advantage for survival.

Therefore, we suggest that KI itself became differentiated. It was directed not only at maximizing the overall harmony, but also at reconciling constantly evolving contradictions. This is a hypothesis that requires theoretical elaboration and experimental confirmation. As discussed, emotions related to KI are aesthetic emotions subjectively felt as harmony or disharmony. These emotions had to be differentiated along with KI. Consider high value concepts such as one's family, religion, or political preferences. These concepts 'color' with emotional values many other concepts; and every contradictory conceptual relation requires a different emotion for reconciliation, a different dimension of an emotional space. In other words, a high value concept attaches aesthetic emotions to other concepts. In this way each concept acts as a separate part of KI: evaluates other concepts for their mutual consistency; this explains the notion of the differentiated knowledge instinct. Virtually every combination of concepts has some degree of contradictions. The number of combinations is practically infinite [80]. Therefore aesthetic emotions that reconcile these contradictions are not just several feelings for which we can assign specific words. There is an uncountable infinity, continuum of aesthetic emotions, and most likely the dimensionality of this continuum is huge. We feel this continuum of emotions (not just many separate emotions) when listening to music. We feel this continuum in Palestrina, Bach, Beethoven, Mozart, Chaikovsky, Shostakovich, Beatles, and Eminem... (and certainly this mechanism is not limited to western cultures).

I would mention that Spinoza [108] was the first philosopher to discuss the multiplicity of emotions related to knowledge. Each emotion, he wrote, is different depending on which object it is applied to. There is a principled difference between multiplicity of aesthetic emotions and 'lower' emotions corresponding to bodily instincts. Those emotions, as discussed, are referred to as 'basic' emotions in psychological literature (e.g. see [49,50,106]). As discussed, psychologists identify them; they all have special words, such as 'rage' or 'sadness.' Levitin [58] suggests that there are just six basic types of songs, basic emotions related to basic instinctual needs. But Huron [43] has already argued that this use of music for basic needs is just that, a utilitarian use of music, which evolved for a much more important purpose that cognitive musicologists had not yet been able to identify. Sloboda and Juslin [106] emphasized that musical emotions are different from other emotions. Emotions related to "mismatch" and "discrepancies" were discussed in [37,49]. It is proposed here that musical emotions have evolved for synthesis of differentiated consciousness, for reconciling contradictions that every step toward differentiation entails, for creating a unity of differentiated Self.

The referenced literature suggests that music has two interrelated purposes fundamental to the functioning of individual minds and to evolution of the mind and culture. The first purpose is to differentiate aesthetic emotions. Music creates differentiated emotions required to reconcile conceptual contradictions. The second purpose is to connect concepts to instinctual needs (including KI). Whereas language separates conceptual knowledge from instincts and emotions, music reconnects these ties. Both musical functions suggested here are scientific hypotheses that should be and are going to be further explored theoretically and verified experimentally.

10. Empirical evidence and tests

The previous section reviewed the hypothesis about the fundamental role and function of musical emotions in evolution. Here we review empirical evidence for this hypothesis. First, we consider historical evidence for parallel evolution of culture, consciousness, and musical styles. Much evidence has been accumulated concerning the latest 3000 years of cultural evolution, over which recorded evidence exists [46,76,78,81,85,115]. This evidence demonstrates that advances in consciousness and cultures were paralleled by advances in differentiation of musical emotions. Here we select few examples from this history. Second, we consider future directions for laboratory psychological and neuroimaging experiments that could verify this hypothesis and experimentally connect differentiation of musical emotions to synthesis of consciousness. Several groups of psychologists plan these experiments.

10.1. Role of music in cultural evolution (from King David to the 20th century)

Before getting to empirical examples we recollect the main theoretical ideas. Interaction of differentiation and synthesis considered in the previous sections is a general law of KI operations, characteristical of any epoch in human history. Accelerated differentiation of everyday life tips the balance of the everyday and the highest. "It is difficult to

keep the scissor blades together." [6]. It is difficult because the condition of the creative process is the combination of oppositions, differentiation and synthesis. Their complex dynamics determines the development of culture. When unity within the soul is achieved (synthesis), creative energy is directed at exploration of the outer and inner world, at widening the sphere of conscious—that is, diversification–differentiation of everyday concepts and emotions. (So, Judeo–Christian synthesis prepared the ground for understanding that human is the source of creative spirit, and this formed conditions for emergence of scientific thinking, although it took thousands of years to come to fruition. Only in the 17th c. Descartes completed "expelling spirit from matter"; and Newton, following him, could think about completely causal, that is scientific, explanation of the material world.)

In the process of history, diversity of everyday life gets complicated and overtakes concepts of the highest, which have served as a foundation for inspiration-synthesis. Lagging synthesis leads to a discord in the soul—concepts of the highest purpose do not correspond to everyday way of life, to variety of concepts and emotions, leading to a decline of culture. (So scientific thinking destroys ancient religious synthesis.) Overcoming crises and continuing the cultural process demands new concepts of the highest purpose, new synthesis, corresponding to a new level of the differentiation of psyche.

With increasing differentiation, synthesis requires ever increasing efforts of an individual human being. Balancing these two aspects of consciousness is difficult and is achieved through understanding of the purpose of life; Jung [47] called this the highest aim of every human life. Similar was Schopenhauer's [103] idea of individuation. Even more radical was Kant [52], who wrote that consciousness of the purposiveness coincides with the Christian ideal of sainthood. Consciousness and culture are developed on the edge of differentiation and synthesis. Too strong a synthesis fuses the conscious and the unconscious together into a fuzzy undividedness, the need and ability for the new disappears, as in pre-historic consciousness. Prevalence of synthesis is characteristic of Eastern cultures, striving for the peace of the soul. A payoff for the peace of soul is millennia of cultural immobility. Prevalence of differentiation is characteristic of Western cultures, when differentiation overtakes synthesis, the meaning of life disappears, and creative potential is lost in senselessness.

What has been the role of music in this complex process of "keeping the scissor blades together?" Let us start on the promised short historic excursion. Jaynes [46] analyzed the evolution of consciousness during the last 11,000 years. Weiss and Taruskin [115] analyzed the evolution of musical styles using available data during the last 3000 years. These two sets of changes in consciousness and in music were aligned in ([76,78,81,85]; also analysis in [46] was extended by adding the idea of synthesis). This alignment demonstrated first, that during the states of strong synthesis, advances in consciousness were driven by differentiation and music differentiated "lower" emotions, and second, that differentiation violated synthesis. To restore synthesis, music differentiated emotions of the "highest." These emotions helped to understand the violation of synthesis by bringing it from the unconscious into consciousness. The conscious understanding helped to cope with the violated synthesis and to continue the process of conceptual differentiation of consciousness and cultural evolution. From this continuous millennial process here we select several examples illustrating that every step in conceptual differentiation was paralleled by powerful advances in music, first, bringing a new level of emotional differentiation to everyday life, and second emotional differentiation of the "highest," which helped to restore synthesis.

Contemporary Western music originated from church and sinagogal singing; according to Weiss and Taruskin "Psalmody (the singing of psalms) is surely the oldest continuous musical tradition in Western civilization." However, the first Biblical description referring to King David time (3000 years ago) refers to "the clangorous noise of instruments… reminds the modern reader of no Western form of divine service… (similarly does a scene) of David dancing before the arc of God." Why? Possibly because there were no irresolvable contradictions in the souls of David and his contemporaries, the monotheistic idea was a sufficient basis for synthesis. Human imperfections were sins, for which one had to be accountable before God, but the notions of sin, freedom, and personal responsibility were not yet sufficiently differentiated to precipitate existential crises. This relatively undifferentiated type of consciousness we see in the book of prophet Amos written in the 8th c. BCE, 250 years after David. Consciousness presented in this book, was characterized as follows: "In Amos there are no words for the mind or think or feel or understand or anything similar whatsoever; Amos never ponders anything in his heart. In the few times he refers to himself, he is abrupt and informative…" [46]; his speech, voice, words, emotional and conceptual contents were fused, there were no deliberation, no arguments, no choices to be made. In this period of fuzzy consciousness, music of the divine service, like all creative forces, was directed at differentiation.

However, a new type of consciousness was already rising; consciousness with self-reflection and internal contradictions. Although the prophecy of Isaiah took place only one generation after Amos, Isaiah's consciousness was ahead of his contemporaries. The impending catastrophe that he foresaw created tensions in his soul between conscious and unconscious. This tension appeared in his vision as an antiphony of the voices of Seraphims. For the first time the principle of antiphony was mentioned in the Bible, the split choirs answering back and forth, which was to become a foundation of psalmody in Jewish and Christian divine service: "Seraphim… one cried to another, and said, Holy, holy, holy is the Lord of hosts." (Is. 6, 1–4). "The words sung by the Seraphim entered the Jewish liturgy… and were later adopted by the Christian church…"

Development of consciousness in Ancient Greece, Israel, and China remarkably coincides. In the 6th c. BCE the first Greek philosopher Thales repudiated myths, demanded conscious thinking, and pronounced the famous "know thyself." In Israel, Prophet Zechariah (Zech. 3–4) forbade prophecy, an outdated and already dangerous form of thinking; he demanded conscious thinking. Confucius in the 5th c. BCE [17] wrote "when we see men of a contrary character, we should turn inwards and examine ourselves," and his contemporary Lao-Tzu [53], "it is wisdom to know others; it is enlightenment to know one's self." Conscious thinking created a discord between personal and unconscious-universal, led to a feeling of separateness from the world; tensions appeared in psyche, which were mirrored in antiphonal singing.—Forms of music appeared, corresponding to the forms of consciousness.—Singing of split choirs symbolized differentiated nature of the highest principles, and brought closer to consciousness the feel of the split in psyche. Antiphonal singing, appealing to conscious and to unconscious, drew them closer, linked the feeling of the split with conscious perception of "self-world" relationships, and restored synthesis. Antiphon as a generally accepted form of divine service is mentioned in the Bible for the first time in the book of Nehemiah (Neh. 12, 27–43) in 445 BCE, just a century after Zechariah and Thales' "know thyself."

Let us move forward by two millennia, to the Renaissance (the 13th–16th c.). In the beginning of the Renaissance (the 13th–14th c.), synthesis was strong, backed up by both, a new symbol of the greatness of human reason and by ancient religious mystical symbols; the result was a creative explosion. From the "objective," music moved toward differentiating everyday human feelings. In the 14th c. the first musical avant-garde emerged; Ars Nova (The New Art) used notes of variable durations for further differentiation of emotions. Pope John XXII [99] criticized the new music: "By… dividing of beats… the music of the Divine Office is disturbed with these notes of quick duration. Moreover, they hinder the melody with hockets (interruptions), they deprave it with discants (high-voice ornamental melodies), and… pad out the music with upper parts made out of secular songs… The voices incessantly rock to and fro, intoxicating rather than soothing… devotion… is neglected, and wantonness… increases." The Pope as if foresaw the crisis of culture due to the lost beliefs and synthesis. The Christian symbol was losing autonomous power in the human soul. Trouble was all over Europe, strife among nations and social classes, Papal exile, schism within the Church, The Great Plague. The catastrophe coincided with a lost unity within the soul, and again, chasing the lost wholeness, a cycle of the restoration of synthesis wound up.

What kind of music could inspire people, when the power of the mysterious was lost and the dominating idea was humanism, the power of human reason? Beginning in the Renaissance, a musical system of tonality was developed for differentiation of emotions, and for connecting the everyday with sublime.

Music connecting differentiated emotions with the sublime emerged in the 15th c. John Dunstable, according to contemporary witnesses, changed all "music high and music low," music became more consonant and euphonious. Melody and rhythm were concentrated in the top part, supported by chordal harmonies. "Harmonies exalted even heaven… like angelic and divine melodies… (As if the) songs of angels and of divine Paradise had been sent forth from the heavens to whisper in our ears an unbelievable celestial sweetness." [115, pp. 81–82].

The Renaissance synthesis was based on humanism, human values: "music's true purpose and content… (is its) power to move" emotions (Glareanus, the 16th c.). This thought "a medieval thinker would have found incomprehensible… The new Renaissance attitude… valued the natural, spontaneous gift of the artist over the application of reason and mastery of theoretical doctrine." Attitude to emotions in music was changing. After 3500 years of monotheism man was becoming (to some extent) a master of the self. Untamed emotions were no longer considered a morbid threat to society, self, and spiritual interests. Humanistic ideal had inspired the Renaissance man to look for increasingly stronger emotions—and this search continues today (albeit not without interruptions).

The highest ideal of Christianity, improvement of inner spiritual life traditionally demanded repudiation of the material world perceived as temptation and distraction from the highest spiritual purpose. The best way to achieve the ideal of sainthood was supposed to be a monastic way of life and rejection of secular life. However, rejection of the

world acknowledged the absolute power of evil projected in the material world. By the 15th c. the ascetic ideal came to contradictions with developing rational thinking and the emerging capitalistic economy. Reformation in the 16th c. accepted that the highest human calling was in perfecting the inner spiritual world as well as the outer material world (and material conditions of one's life). The religious ideal was reconciled with new consciousness.

The Reformation reduced the absoluteness of the split between spiritual and material, good and evil, the contradiction between good and evil was taken from the heights of Heaven and the depths of Hades and placed into the human soul. Consequences were on one hand an inconceivable acceleration of the development of capitalism and improvement of material conditions of life. On the other, the autonomy of religious symbols was lost; their unconscious contents were to a large extent transferred into consciousness. The fundamental contradiction of human nature between finite matter and infinite spirit, which formed the mystical foundation of Christianity, was brought by the Reformation into everyday culture and made a part of collective consciousness. Tragic tensions originally projected onto the Christian symbol were assimilated by human psyche. Tensions in the human soul reached the maximum.

Luther [61] saw in music the synthetic power that unifies the Word of God with human passions: "Therefore… message and music join to move the listener's soul… The gift of language combined with the gift of song was only given to man… (so that he proclaims) the word through music."

Naive humanism of the 15th c. barely glimpsed into the contradictions of human thoughts. Consciousness of the mind's internal contradictions was an achievement of the Reformation, and this consciousness required new forms of synthesis to restore wholeness. In search of synthetic forms of art creative minds turned to the epoch of crisis long gone, when salvation was found in art. From the books of Plato, Aristotle, and other authors of antiquity it was known that tragic musical drama in Ancient Greece created catharsis, an intimate bond with the human soul, which miraculously calmed discontent, soothed character and behavior. 'Radical humanists' in the sixteenth century sought to recover the true music of antiquity, which according to their ideas was in close connection with rhetoric, the art of orators and actors. A literary expression of these ideas was given by Vincento Galilei (Florence, 1588; see [115]). A new form of music, 'musical speech,' or recitative, quickly led to a true opera "Orpheus" by Claudio Monteverdi (1600) and made a profound influence on the following development of Baroque music.

The Baroque was full of dualism and drama, expressing tensions imposed by the Reformation. It is a world searching for differentiated synthesis. Dualism was embodied in a new musical style, where opposition was emphasized: Vocal against instrumental, solo against ensemble, melody against bass, dynamic levels were contrasted, opposition of the dominant and tonic, all expressed emotional tension and resolution. The role of dissonances increased, and modulations became commonplace expressing more and more complex emotions in their continuous flow. Creating emotions was becoming the primary aim of music; composers strived to imitate speech, the embodiment of the passions of the soul. At the same time conceptual content of texts increased, "the words (are to be) the mistress of the harmony and not its servant," wrote Monteverdi. This became the main slogan of the new epoch of Baroque music. Thus, conscious aims of Baroque music were differentiation of emotions in parallel with synthesis of conceptual and emotional.

Tensions in human sole created by Reformation continued to propel a search for higher and higher synthesis, requiring stronger differentiation of emotions of the highest ideal, corresponding to the consciousness of the split between finiteness of human material being and infiniteness of spiritual aspirations. Until the end of the 16th c. dissonances were used sparingly, for a short pause, and mainly in secular music. Beginning in the seventeenth century dissonances were used more often, emphasizing the dramatic effect. A dissonance was always followed by a resolution in a consonant chord, later several dissonant chords were used in a row, increasing tension. The heightened sense of drama in musical dissonances corresponded to the tension between conceptual and emotional, material and spiritual, which in the result of the Reformation where assimilated by human heart and soul. Music became extremely expressive, conveyed passionate human emotions; theory of major and minor scales were developed for this purpose, chromatic scale was used. Chorale was unified with counterpoint, harmony with polyphony. These new musical forms were perfected in works of Buxtehude and then Bach.

The most complex and sublime form of polyphonic music was acquired in fugue. Fugue is a conversation of several musical voices, in which a topic "flies" from one voice to another; voices could talk politely or argue, interrupting each other. In Bach's fugues a human arguing with oneself turns to God or to the highest in oneself. Whereas old psalms affirmed an existence of the objectively sublime, as some collective purpose far removed from individual experiences, fugue expressed emotions of ones own contradictions in quest for the highest. Fugue was a way of individual consciousness turned to sublime, a combination of differentiation and synthesis. Rational understanding

of Church service introduced by the Reformation interacted in music with the highest spiritual values and mystical feelings of sublime, created during thousands of years by monotheistic religions.

However, the Reformation has laid unbearable responsibility on an individual and created too much tension within the human soul—humankind is not ready yet for individual consciousness. The string of tension connecting conscious and unconscious broke. Rational consciousness that came after the Baroque rejected mystery of sublime differentiated in fugue. Music that was natural to Bach seemed too intellectual and "not natural" to the next generation.

Differentiation of consciousness and development of corresponding musical forms tremendously accelerated. To fit the content of our discussion within the limits of this review, however, I would have to skip through fascinating developments of Rococo, Classicism, and Romanticism and to move to few examples of the 20th c. In the 20th c. all areas of human spiritual endeavor became more entangled than ever before. Attempts to create formalized mathematical logic in the 2nd half of the 19th c. were soon repeated in the idea of dodecaphonic music developed by Schoenberg. As if foreseeing the horrors of the coming world wars, Schoenberg aspired to move beyond emotions that could be created by tonal music. Much of music of the 20th century, for example those of thriller movies, evolved from Schoenberg's idea. This music often cannot be even written in traditional musical notations. In all areas of art "modern" looked for differentiation of human unconscious. The opposite tendency to restoring synthesis at all cost began at the same time, but only later, in the 1970s was recognized as such and called "postmodern."

Differentiation and synthesis evolved in parallel often intersecting in lives of individual artists. The contradiction can be seen in the art of Schoenberg. He formulated an atonal idea (dodecaphony) as a formal rule, but attempted to express in music unverbalizable nature of God. For more than sixteen years he worked on "Jacob's Ladder" and "Moses and Aron," still both works remained unfinished. The formal dodecaphonic rule did not fit the needs of human soul. I'd mention that similar was the fate of mathematical formalism, which inspired Schoenberg; in the 1930s Gödel proved its inconsistency.

The very idea of "objective" formal art contained antinomy manifested in the most unexpected ways. Malevich declared the aim of Suprematism—to free art from any symbolic content—but his "Black Square" was interpreted as a symbol of impenetrable unconscious content. In "Ulysses" Joyce created a form of language to express a 'stream of consciousness,' but an almost complete absence of consciousness was the outcome. C. Jung uses "Ulysses" to characterize a significant part the 20th c. art and collective consciousness as follows: "...A passive, merely perceiving consciousness, a mere eye, ear, nose, and mouth, a sensory nerve exposed without choice or check to... a stream of physical happenings... The stream... not only begins and ends in nothingness, it consists in nothingness. It is all infernally nugatory... Today it still bores me as it did then (in 1922). Then, why do I write about it?... (It) is a collective manifestation of our time... the collective unconscious of the modern culture... the modern artist immerses into destructive processes, to affirm in destructiveness the unity of his artistic personality... We still belong to the Middle Ages... For that alone would explain... why there should be books or works of art... (like) "Ulysses." They are drastic purgatives... for the soul... which is of use only where the hardest and toughest material must be dealt with." [48]. Those agreeing with Jung about roots of Joyce popularity would find many similar examples in music.

In music, like in visual art and philosophy, two contrary historical tendencies of evolution of consciousness collided again, differentiation and synthesis. It's not surprising that changes in musical forms paralleled visual arts, philosophy, and science. (Differentiation of self, as a penetration into the depths of unconscious was manifest in the psychology of Freud, paintings of Pollock, music of Scriabin and Shostakovich, to name just few.) Differentiation, however destroyed the wholeness of the world perception, and a contrary tendency emerged, postmodern, as a striving for synthesis based on the simplest notions (such as music of Cage). Whereas in the past centuries differentiation may have dominated one epoch and synthesis another, in the 20th c. all mixed up. While Modernism sought depths of self, Postmodern with equal force rushed to simplicity of the bases of aesthetic. The opposing tendencies of differentiation and synthesis were present in conscious and unconscious of an individual composer.

Mass culture is a logical step in evolution of consciousness, in interaction of differentiation and synthesis. There is a chasm between differentiated concepts existing in culture and capacity of a single person to assimilate this culture, while preserving synthesis within one's soul. Is this chasm unprecedented and unique for our times? Was this chasm smaller for Aristotle and Ancient Greek crowds? Surprising animalistic and satanistic styles of some rockers and rappers could be understood if we compare them to Ancient Greek dithyrambs. The dithyramb was an ancient way of creating synthesis, connecting the sublime with bestial unconscious bases of psyche. The rift between conscious and unconscious threatens the death of culture and "demands restoratory sacrifices" [69]. Rap (hip-hop) is contemporary dithyramb very similar in musical and performance style, restoring the connection between conscious and uncon-

scious. In both dithyramb and rap—quite regular thoughts are cried out at the edge of frenzy. As in Ancient Greece 2500 years ago, so today in a complex multiform culture, people, especially young people, are losing their bearings. Words no longer call forth emotional reactions, their prime emotional meaning is lost. By shouting words along with primitive melody and rhythm, a human being limits his or her conscious world, but restores synthesis, connection of conscious and unconscious. An internal world comes to wholeness, reunites with a part of the surrounding culture.

As postmodern art and music in particular was a return to pre-Aeschylean, Apollonian consciousness of pure notions—so Rap is a natural continuation of postmodern: Dionysian breaks forth into Apollonian consciousness. These types of consciousness antiquated about 2500 years ago. But consciousness does not whirl in a closed circle. Conceptual and emotional contents of contemporary culture have become much richer, and the previously unseen poles of differentiation are to be unified by the coming synthesis.

Leaning upon scientific analysis of the mind functioning in previous sections, this section reviewed changes of forms of consciousness parallel to changes of musical forms. Summarizing, I would emphasize that music is the most mysterious ability of a human soul; it contains differentiating and synthesizing powers. Necessity governs relationships between these powers: when rocking toward differentiation concepts lose their meanings and culture is destroyed, but when rocking toward synthesis strong emotions nail down thoughts to traditional values. Both lead to a slowdown of cultural evolution. As no other art, music can forestall cultural slowdown. Music transports reality into the hearts of listeners and restores a possibility of continuation of culture. But will the unity of differentiation and synthesis prevail over life? Or will our entire culture be torn into shreds? Answering this question is one of the directions of further development of ideas in this review as well as an empirical way of investigating scientific validity of the reviewed theory of musical emotions.

10.2. Future laboratory experiments

Laboratory experimentation should be directed at operational definition and measurements of musical emotions. According to the reviewed hypothesis, the function of musical emotions in cognition is to restore synthesis, when it is damaged by differentiation. Such a condition is similar to cognitive dissonance in psychology [30]. Therefore, well developed experimental techniques used to study cognitive dissonance can be used to study the proposed role of musical emotions in reconciling contradictions in consciousness. This approach would directly verify the review's proposal that the multiplicity of musical emotions is related to contradictions in consciousness among conceptual knowledge. First, various types of cognitive dissonances can be created in subjects using standard techniques [1]. Second, various types of music can be assessed for their efficiency in reconciling specific types of conceptual dissonances. In this way various types of music, which are known to create musical emotions [49,72,109] can be connected to reconciling specific dissonances (we would expect that the results would depend on psychological types of listeners, people who's feelings are less differentiated might be more affected by tonal music, whereas people consciously differentiating many emotions might be more susceptible to atonal music—this comment, however, is secondary to the main ideas discussed here); neuroimaging techniques can be used in parallel to identify the brain regions involved.

When significant experimental data are accumulated, dimensionality and structure of musical emotion space can be investigated by mathematical methods. Existing mathematical techniques of multidimensional scaling can be used. A future direction would be to develop methods for estimating dimensionality of a space of a very large dimension from limited number of measurements. Another direction for future mathematical research would be to develop techniques for exploring the notion of "continuous" musical emotions, as they are called in psychology. Of course, any number of measurements could only yield a finite number of data points. Can mathematical methods be developed to estimate a density of the space of musical emotions and a measure of their "continuum?"

Using existing and future mathematical techniques we would be able to explore the complexity of emotional spaces (structure, dimensions) and compare various types of music. It would be interesting to compare emotional spaces of Eminem and Beethoven to confirm or disprove various expectations.

The role of timbre in music and language might be related to the discussion in this review. Levitin [57] writes that timbre characterizes individual performers more than any other aspect of music. Patel [72] suggests that language uses timbre systematically more than music does. Is timbre evolved as "semantic," whereas melody "emotional?" Is harmony related to the mind hierarchy? Are these intuitions just shallow metaphors or meaningful, experimentally testable hypotheses related to the initial separation of voice into language and music, and to further evolution of cultures and consciousness?

We would like to emphasize possible directions for experimental verifications of the suggested mechanisms of KI and dual models, and their role in the mind functioning. The dual model of the neural mechanism connecting language and cognition can be studied using various neuroimaging techniques. A recent publication seems to support the dual model hypothesis [36]. They have demonstrated that certain cognitions based in the right brain hemisphere in prelinguistic infants are rewired to the left hemisphere as language is acquired. Varying brain imaging techniques can be used to study more diverse connections between language brain areas and conceptual representation areas. Identifying brain modules and neural connections involved in the dual models and knowledge instinct was discussed in [55,56]. Cabanac and Bonniot [9] initiated psychological studies of the knowledge instinct.

11. Summary and further directions

Musical power over human soul and body has remained mysterious from Aristotle to the 20th century cognitive science. Contemporary evolutionary psychologists have recognized music as a cultural universal of tremendous power; still its fundamental role and function in cognition, its role in evolution of consciousness and culture have remained hidden. Here we reviewed historical and contemporary scientific hypotheses of the role and function of music, and concentrated on one hypothesis. It explains musical emotional mechanisms by relating them to primordial connections between voicing and emotions. It explains the role and function of music in differentiating emotions for the purpose of restoring the unity of self. Musical emotions help maintain a sense of purpose of ones life in face of multiplicity of contradictory knowledge, or what is called the "synthesis of differentiated consciousness."

According to this hypothesis, the origins of music are tied to the origins of language. Language emerged by differentiating the original unity of primordial self. Original psychic states of unified concept–emotion–behavior–vocalization were differentiated, so that concepts shed off their inextricable connections to emotions and motivation, and deliberate thinking–conversations became possible. Language was emerging. The price for this differentiation was the loss of the unity of self, lost concentration of will. Our ancestors, who could maintain concentration of will, while differentiating the knowledge about the world, received evolutionary advantage. Therefore the emotional part of primordial vocalization evolved into music.

As language and culture were evolving into a powerful system with tremendous differentiation of knowledge about the world and self, the number of contradictions grew combinatorially. Every combination of conceptual pieces of knowledge led to its own shades of contradictions. Therefore, maintaining motivation for this diversified knowledge required virtually infinite number of shades of motivations. Musical emotions are called "continuous" by psychologists of emotions. All of these emotions–motivations are related to knowledge, and therefore, since Kant, are called aesthetic emotions.

Can this hypothesis be verified by scientific empirical methods? One direction discussed in Section 10.1 is to relate the changes in musical styles to the changes in cultures and consciousness. This connects evolution of music, consciousness, and cultures. A step in this direction was made in Perlovsky [78,81,85]. It was suggested for example that antiphonal music appeared about 2500 years ago along with contemporary consciousness, when fundamental contradictions in human psyche started penetrating into consciousness and created psychic tensions. Tonality was developed beginning in the Renaissance, when instinctual and emotional human nature was consciously accepted, creating tensions in psyche with received ideas of spiritually 'high.' Buxtehude and Bach were developing music that could reconcile new contradictions brought in consciousness by the Reformation. Popular songs restore synthesis by connecting conceptual contents of lyrics with emotional contents of music. And contemporary rap music was suggested to have a similar style and function to Ancient Greek dithyrambs, namely to reconcile instinctual needs with (at least some) basic concepts in culture and language. Further researches in this direction are virtually unlimited. They should extend from details in global changes of consciousness and cultures to changes in lives of individual composers. In this regard it is interesting to mention what musicologists call the "swan song" phenomenon [105]. Many composers created their most profound musical compositions in later years of their lives. Is it because synthesis becomes psychologically more important in later years? Examples of musical evolution in this review address western tradition, they should be extended to other cultures. Especial challenge is presented by tonal languages (e.g. Mandarin), in which melody might play both conceptual and emotional role. Is this conflation an advantage or an impediment for long-term cultural development?

Section 10.2 discussed laboratory experimental studies related to this hypothesis. Most of these are still future research. Among them, the first conceptual step would be to operationally define and model musical emotions. This has

been related to the well developed methods of studying cognitive dissonance, an unpleasant feeling experienced when becoming conscious of contradictions in ones system of knowledge and beliefs (in other words, threat to synthesis due to differentiation). Cognitive dissonance has been an important psychological tool in developing Tversky and Kahneman [111] theory of human irrationality (2002 Nobel Prize).

Laboratory experimental tests should be used to study emotional (melodic) contents of various languages vs. emotional contents of music developed in various cultures. These studies are difficult due to received prejudices. For example, the difference in emotionality between English and Italian people is often explained by climate, etc. But these explanations do not fit high emotionality of Russians. More fundamental studies are needed: which part of emotionality is related to behavior, cognition, and which to language alone? Does the increase in popularity of songs in English-speaking cultures compensate the reduced melodic contents of English language? Mathematical methods should be developed to study the spaces of musical emotions and ways to estimate large dimensional spaces and their structures from finite amount of measurements.

Classical psychological tests as well as brain imaging should be used to test the dual model, the inborn connections between cognitive and language brain modules. Tests and modeling should be used to understand how neural mechanisms of hearing enhance or suppress Helmholtz's dissonances originating in ear drums; is there scientific evidence for this Helmholtz's hypothesis? Why various species have different sensitivities to dissonances (or lack them at all). Which parts of musical ability are genetic and which are culturally developed?

The reviewed hypothesis suggests that language reduced direct connections between vocalization and ancient emotional centers. Neural imaging tests could reveal if music is connected to ancient emotional centers; is this connection direct? Is it different for music and language? To which extent and how does music involve emotional centers in cortex? Models of cultural evolution from Section 8 should be extended to include the effects of music.

The reviewed hypothesis of the origins and functions of musical emotions addresses numerous questions, many of which remained opened for millennia. Therefore, small steps revealing neural mechanisms as well as studies of the suggested hypothesis about the function of music are necessary along with experimental laboratory tests, empirical ethnomusicological, anthropological, and historical studies. This review is a first step identifying the fundamental role of musical emotions in cognition and cultural evolution. Possibly it will form a foundation for a unified field of a multidisciplinary study. In conclusion, I would like to repeat that music is the most mysterious of human abilities, appealing directly to our primordial emotions, while connecting them to language and cognition.

Acknowledgments

It is my pleasure to acknowledge contribution of my colleagues and co-authors M. Aranovsky, M. Bar, L. Barsalou, M. Bonfeld, R. Brockett, M. Cabanac, A. Cangelosi, T. Chernigovskaya, E. Coutinho, R. Deming, T. Dudochkin, F. Fontanari, M. Frank-Kamenetskii, J. Gleason, A. Goldwag, M. Houser, D. Huron, R. Ilin, N. Katonova, M. Karpovsky, R. Kozma, L. Leibman, D. Levine, D. Levitin, L. Levitin, R. Linnehan, T. Lyons, N. Masataka, M. Mazo, Y. Neuman, A. Ovsich, R. Parncutt, A. Patel, V. Rosenbaum, J. Sloboda, V. Smolensky, D. Sontag, W. Thompson, Y. Vinkovetsky, and B. Weijers for discussions, help, and advice. This work was supported in part by AFOSR under the Laboratory Tasks 05SN02COR PM Dr. Jon Sjogren; 08RY02COR PM Dr. Doug Cochran; 10RY01COR PM Dr. Jun Zhang. Especial acknowledgments are due to Y. Dimitrin who has inspired me to think about the role of musical emotions in human cognition, and to D. Vinkovetsky who inspires me to think profoundly.

References

[1] Akerlof GA, Dickens WT. The economic consequences of cognitive dissonance. In: Akerlof GA, editor. Explorations in pragmatic economics. New York: Oxford Univ. Press; 2005.
[2] Aristotle. In: Barnes J, editor. The complete works. Princeton, NJ: Princeton Univ. Press; 1995 [the revised Oxford translation; original work VI BCE].
[3] Balaskó M, Cabanac M. Grammatical choice and affective experience in a second-language test. Neuropsychobiology 1998;37:205–10.
[4] Ball P. Facing the music. Nature 2008;453:160–2.
[5] Bar M, Kassam KS, Ghuman AS, Boshyan J, Schmid AM, Dale, et al. Top-down facilitation of visual recognition. USA. Proceedings of the National Academy of Sciences 2006;103:449–54.
[6] Brodsky J. Interview with D. Betea. In: Brodsky J, Haven CL, Avedon R, editors. Joseph Brodsky: Conversations. University Press of Mississippi; 1991 [originally published in 1991];
Бродский И. Наглая проповедь идеализма. In: Большая книга интервью. Изд. 2. Москва: Захаров; 2000. p. 512 [in Russian].

[7] Buchanan TW, Lutz K, Mirzazade S, Specht K, Shah NJ, Zilles K, et al. Recognition of emotional prosody and verbal components of spoken language: An fMRI study. Cognitive Brain Research 2000;9:227–38.
[8] Cabanac M. What is emotion? Behavioural Processes 2002;60:69–84.
[9] Cabanac M, Bonniot M-C. Experimental studies of the knowledge instinct, preliminary results; 2009, unpublished.
[10] Cangelosi A, Bugmann G, Borisyuk R, editors. Modeling language, cognition and action. Proceedings of the 9th neural computation and psychology workshop. Singapore: World Scientific; 2005.
[11] Coventry KR, Lynott L, Cangelosi A, Knight L, Joyce D, Richardson DC. Spatial language, visual attention, and perceptual simulation. Brain and Language 2009, in press.
[12] Cangelosi A, Greco A, Harnad S. From robotic toil to symbolic theft: Grounding transfer from entry-level to higher-level categories. Connect Sci 2000;12:143–62.
[13] Cangelosi A, Parisi D, editors. Simulating the evolution of language. London: Springer; 2002.
[14] Cangelosi A, Riga T. An embodied model for sensorimotor grounding and grounding transfer: Experiments with epigenetic robots. Cogn Sci 2006;30:673–89.
[15] Cangelosi A, Tikhanoff V, Fontanari JF, Hourdakis E. Integrating language and cognition: A cognitive robotics approach. IEEE Computational Intelligence Magazine 2007;2(3):65–70.
[16] Chomsky N. Syntactic structures. Haag, Netherlands: Mouton; 1957.
[17] Confucius (551–479 BCE). Analects [Lau DC, Trans.]. Hong Kong, China: The Chinese University Press; 2000.
[18] Coutinho E, Cangelosi A. The use of spatio-temporal connectionist models in psychological studies of musical emotions. Music Perception 2009;27(1):1–15.
[19] Cross I. The evolutionary nature of musical meaning. Musicae Scientiae 2008:179–200. http://www.mus.cam.ac.uk/%7Eic108/PDF/IRMC_MS07_1.pdf.
[20] Cross I. Musicality and the human capacity for culture. Musicae Scientiae 2008:147–67 [special issue].
[21] Cross I, Morley I. The evolution of music: Theories, definitions and the nature of the evidence. In: Malloch S, Trevarthen C, editors. Communicative musicality. Oxford: Oxford Univ. Press; 2008. p. 61–82.
[22] Darwin CR. The descent of man, and selection in relation to sex. London, UK: John Murray; 1871.
[23] Davis PJ, Zhang SP, Winkworth A, Bandler R. Neural control of vocalization: Respiratory and emotional influences. J Voice 1996;10:23–38.
[24] Deacon T. The neural circuitry underlying primate calls and human language. Human Evolution Journal 1989;4(5):367–401.
[25] Descartes R. Passions of the soul. Cambridge: Hackett Publishing Company; 1989. p. 181 [originally published in 1646].
[26] Diamond J. Guns, germs, and steel: The fates of human societies. New York, NY: W.W. Norton & Co.; 1997.
[27] Dissanayake E. Antecedents of the temporal arts in early mother–infant interactions. In: Wallin N, Merker B, Brown S, editors. The origins of music. Cambridge, MA: MIT Press; 2000. p. 389–407.
[28] Dissanayake E. If music is the food of love, what about survival and reproductive success? Musicae Scientiae 2008:169–95 [special issue].
[29] Editorial. Bountiful noise. Nature 2008;453:134.
[30] Festinger L. A theory of cognitive dissonance. Stanford, CA: Stanford University Press; 1957.
[31] Fitch WT. On the biology and evolution of music. Music Perception 2004;24:85–8.
[32] Fontanari JF, Perlovsky LI. Evolving compositionality in evolutionary language games. IEEE Transactions on Evolutionary Computations 2007;11(6):758–69. doi:10.1109/TEVC.2007.892763.
[33] Fontanari JF, Perlovsky LI. How language can help discrimination in the Neural Modeling Fields framework. Neural Networks 2008;21(2–3):250–6.
[34] Fontanari JF, Perlovsky LI. A game theoretical approach to the evolution of structured communication codes. Theory in Biosciences 2008;127:205–14.
[35] Fontanari JF, Tikhanoff V, Cangelosi A, Ilin R, Perlovsky LI. Cross-situational learning of object–word mapping using Neural Modeling Fields. Neural Networks 2009;22(5–6):579–85. http://dx.doi.org/10.1007/s12064-008-0024-1.
[36] Franklin A, Drivonikou GV, Bevis L, Davie IRL, Kay P, Regier T. Categorical perception of color is lateralized to the right hemisphere in infants, but to the left hemisphere in adults. PNAS 2008;105(9):3221–5.
[37] Frijda NH. The emotions. Cambridge: Cambridge University Press; 1986.
[38] Groceo J. (14 c.). In [115, p. 63].
[39] Grossberg S, Levine D. Neural dynamics of attentionally modulated Pavlovian conditioning: Blocking, interstimulus interval, and secondary reinforcement. Applied Optics 1987;26:5015–30.
[40] Guttfreund DG. Effects of language usage on the emotional experience of Spanish–English and English–Spanish bilinguals. J Consult Clin Psychol 1990;58:604–7.
[41] Harris CL, Ayçiçegi A, Gleason JB. Taboo words and reprimands elicit greater autonomic reactivity in a first language than in a second language. Applied Psycholinguistics 2003;24:561–79.
[42] Helmholtz HLF. On the sensations of tone—as a physiological basis for the theory of music. Dover Publication; 1954 [originally published in 1863].
[43] Huron D. Ernest Bloch lectures. Berkeley, CA: University of California Press; 1999.
[44] Ilin R, Perlovsky L. Cognitively inspired neural network for recognition of situations. International Journal of Natural Computing Research 2009, in press.
[45] James J. The music of the spheres: Music, science, and the natural order of the Universe. New York: Springer; 1995.
[46] Jaynes J. The origin of consciousness in the breakdown of the bicameral mind. Boston: Houghton Mifflin Co.; 1976.
[47] Jung CG. Psychological types. In: The collected works, vol. 6. Bollingen series, vol. X. Princeton, NJ: Princeton Univ. Press; 1921.

[48] Jung CG. Ulysses. Rascher, Zurich: Wirklishkeit der Seele; 1934;
Translation mostly follows: Jung CG. Ulysses: A monologue [Hall FC, Trans.]. In: The spirit in man, art, and literature, vol. 15. Princeton Univ. Press; 1971. p. 109, 110, 115–9.
[49] Juslin PN, Sloboda JA. Music and emotion: Theory and research. Oxford, UK: Oxford Univ. Press; 2001.
[50] Juslin PN, Västfjäll D. Emotional responses to music: The need to consider underlying mechanisms. Behavioral and Brain Sciences 2008;31:559–75.
[51] Justus T, Hustler JJ. Fundamental issues in the evolutionary psychology of music: Assessing innateness and domain specificity. Music Perception 2003;23:1–27.
[52] Kant I. The critique of judgment [Bernard JH, Trans.]. Amherst, NY: Prometheus Books; 1790.
[53] Lao-Tzu (6th BCE). Tao Te Ching [Lau DC, Trans.]. New York, NY: Penguin Books; 1979.
[54] Larson CR. Activity of PAG neurons during conditioned vocalization in the macaque monkey. In: Depaulis A, Bandler R, editors. The midbrain periaqueductal gray matter. New York, NY: Plenum Press; 1991. p. 23–40.
[55] Levine DS, Perlovsky LI. Neuroscientific insights on Biblical myths. Simplifying heuristics versus careful thinking: Scientific analysis of millennial spiritual issues. Zygon, Journal of Science and Religion 2008;43(4):797–821.
[56] Levine DS, Perlovsky LI. A network model of rational versus irrational choices on a probability maximization task. In: World congress on computational intelligence (WCCI). Hong Kong, China; 2008.
[57] Levitin DJ. This is your brain on music: The science of a human obsession. London: Dutton; 2006.
[58] Levitin DJ. The world in six songs. London: Dutton; 2008.
[59] Livingstone SR, Thompson WF. Multi-modal affective interaction: A comment on musical origins. Music Perception 2006;24:89–94.
[60] Lorenz K. The foundations of ethology. New York: Springer-Verlag; 1981.
[61] Luther M. Preface to Symphoniae jucundae; 1538. See [115, p. 102].
[62] Masataka N. The origins of language and the evolution of music: A comparative perspective. Physics of Life Reviews 2009;6:11–22.
[63] Mattheson J. The complete music master; 1739. See [115, p. 217].
[64] Mayorga R, Perlovsky LI, editors. Sapient systems. London, UK: Springer; 2007.
[65] Meyer RK, Palmer C, Mazo M. Affective and coherence responses to Russian laments. Music Perception 1998;16(1):135–50.
[66] McDermott J, Houser M. The origins of music: Innateness, uniqueness, and evolution. Music Perception 2003;23:29–59.
[67] McDermott J. The evolution of music. Nature 2008;453:287–8.
[68] Mithen S. The singing Neanderthals: The origins of music, language, mind, and body. Cambridge, MA: Harvard University Press; 2007.
[69] Nietzsche F. Untimely meditations [Hollingdale RJ, Trans.]. Cambridge, England: Cambridge University Press; 1997 [originally published in 1876].
[70] Panksepp J, Bernatzky G. Emotional sounds and the brain: The neuro-affective foundations of musical appreciation. Behavioural Processes 2002;60:133–55.
[71] Parncutt R. Prenatal and infant conditioning, the mother schema, and the origins of music and religion. Musicae Scientiae 2008, in press.
[72] Patel AD. Music, language, and the brain. New York, NY: Oxford Univ. Press; 2008.
[73] Perlovsky LI. Neural networks and intellect. New York, NY: Oxford Univ. Press; 2000.
[74] Perlovsky LI. Mystery of sublime and mathematics of intelligence. Zvezda 2001;2001(8):174–90 [St. Petersburg; in Russian].
[75] Perlovsky LI. Aesthetics and mathematical theory of intellect. Iskusstvoznanie (Journal of History and Theory of Art) 2002;2:558–94 [Russian Academy of Sciences, Moscow, Russia; in Russian].
[76] Perlovsky LI. Evolution of consciousness and music. Zvezda 2005;2005(8):192–223 [St. Petersburg; in Russian].
[77] Perlovsky LI. Modeling field theory of higher cognitive functions. In: Loula A, Gudwin R, Queiroz J, editors. Artificial cognition systems. Hershey, PA: Idea Group; 2006. p. 64–105.
[78] Perlovsky LI. Music—the first principles. Musical Theater 2006. http://www.ceo.spb.ru/libretto/kon_lan/ogl.shtml.
[79] Perlovsky LI. Symbols: Integrated cognition and language. In: Gudwin R, Queiroz J, editors. Semiotics and intelligent systems development. Hershey, PA: Idea Group; 2006. p. 121–51.
[80] Perlovsky LI. Toward physics of the mind: Concepts, emotions, consciousness, and symbols. Physics of Life Reviews 2006;3(1):22–55.
[81] Perlovsky LI. Joint evolution of cognition, consciousness, and music. Lectures in musicology, school of music. Columbus, OH: University of Ohio; 2006.
[82] Perlovsky LI. Neural dynamic logic of consciousness: The knowledge instinct. In: Perlovsky LI, Kozma R, editors. Neurodynamics of higher-level cognition, consciousness. Heidelberg, Germany: Springer-Verlag; 2006.
[83] Perlovsky LI. Sapience, consciousness, and the knowledge instinct (Prolegomena to a physical theory). In: Mayorga R, Perlovsky LI, editors. Sapient systems. London: Springer; 2006.
[84] Perlovsky LI. Evolution of languages, consciousness, and cultures. IEEE Computational Intelligence Magazine 2007;2(3):25–39.
[85] Perlovsky LI. Music and consciousness. Leonardo, Journal of Arts, Sciences and Technology 2008;41(4):420–1.
[86] Perlovsky LI. Language and cognition. Neural Networks 2009;22(3):247–57. doi:10.1016/j.neunet.2009.03.007.
[87] Perlovsky LI. Language and emotions: Emotional Sapir–Whorf hypothesis. Neural Networks 2009;22(5–6):518–26.
[88] Perlovsky LI. 'Vague-to-crisp' neural mechanism of perception. IEEE Trans Neural Networks 2009;20(8):1363–7.
[89] Perlovsky LI. Neural mechanisms of the mind, Aristotle, Zadeh, & fMRI. IEEE Trans Neural Networks 2009, in press.
[90] Perlovsky LI. Intersections of mathematical, cognitive, and aesthetic theories of mind. Psychology of Aesthetics, Creativity, and the Arts 2009, in press.
[91] Perlovsky L, Ilin R. Computational foundations for perceptual symbol system; 2009, submitted for publication.
[92] Perlovsky LI, Ilin R. Neurally and mathematically motivated architecture for language and thought. The Open Neuroimaging Journal 2009, in press [special issue "Brain and language architectures: Where we are now?"].

[93] Perlovsky LI, Kozma R, editors. Neurodynamics of higher-level cognition and consciousness. Heidelberg, Germany: Springer-Verlag; 2006.
[94] Perlovsky L, Kozma R. Editorial. Neurodynamics of cognition and consciousness. Heidelberg, Germany: Springer-Verlag; ISBN 978-3-540-73266-2, 2006.
[95] Perlovsky LI, Mayorga R. Preface. Sapient systems. London: Springer; 2006.
[96] Perlovsky LI, McManus MM. Maximum likelihood neural networks for sensor fusion and adaptive classification. Neural Networks 1991;4(1):89–102.
[97] Pinker S. How the mind works. New York, NY: Norton; 1997.
[98] Plato (IV BCE). In: Cooper JM, Hackett DS, editors. Laws. Complete work [Sounders TJ, Trans.]. Cambridge; 700a–701b. p. 1388–9.
[99] Pope John XXII. Bull Docta sanctorum; 1323. See [115].
[100] Purwins H, Herrera P, Grachten M, Hazan A, Marxer R, Serra X. Computational models of music perception and cognition I: The perceptual and cognitive processing chain. Physics of Life Reviews 2008;5:151–68.
[101] Purwins H, Herrera P, Grachten M, Hazan A, Marxer R, Serra X. Computational models of music perception and cognition II: Domain-specific music processing. Physics of Life Reviews 2008;5:169–82.
[102] Schulz GM, Varga M, Jeffires K, Ludlow CL, Braun AR. Functional neuroanatomy of human vocalization: An H215O PET study. Cerebral Cortex 2005;15(12):1835–47.
[103] Schopenhauer A. Die Welt als Wille und Vorstellung; 1819. p. 191.
[104] Seyfarth RM, Cheney DL. Meaning and emotion in animal vocalizations. Ann NY Acad Sci 2003:32–55.
[105] Simonton DK. Genius and creativity. New York, NY: Ablex Publishing; 1997.
[106] Sloboda JA, Juslin PN. Psychological perspectives on music and emotion. In: Music and emotion: Theory and research. Oxford, UK: Oxford Univ. Press; 2001. p. 71–104.
[107] Spelke ES, Kinzler KD. Core knowledge. Developmental Science 2007;10:89–96.
[108] Spinoza B. Ethics [Curley E, Trans.]. New York, NY: Penguin; 2005 [originally published in 1677].
[109] Steinbeis N, Koelsch S, Sloboda JA. The role of harmonic expectancy violations in musical emotions: Evidence from subjective, physiological, and neural responses. Journal of Cognitive Neuroscience 2006;18:1380–93.
[110] Tikhanoff V, Fontanari JF, Cangelosi A, Perlovsky LI. Language and cognition integration through modeling field theory: Category formation for symbol grounding. Book series in computer science, vol. 4131. Heidelberg: Springer; 2006.
[111] Tversky A, Kahneman D. Judgment under uncertainty: Heuristics and biases. Science 1974;185:1124–31.
[112] Trainor L. Innateness, learning, and the difficulty of determining whether music is an evolutionary adaptation. Music Perception 2004;24:105–10.
[113] Trainor L. The neural roots of music. Nature 2008;453(29):598–9.
[114] Trehub SE. The developmental origins of musicality. Nature Neuroscience 2003;6(7):669–73.
[115] Weiss P, Taruskin R. Music in the Western World. New York, NY: Schirmer/Macmillan; 1984. p. 15.