The Musical Brain – An Artful Biological Necessity

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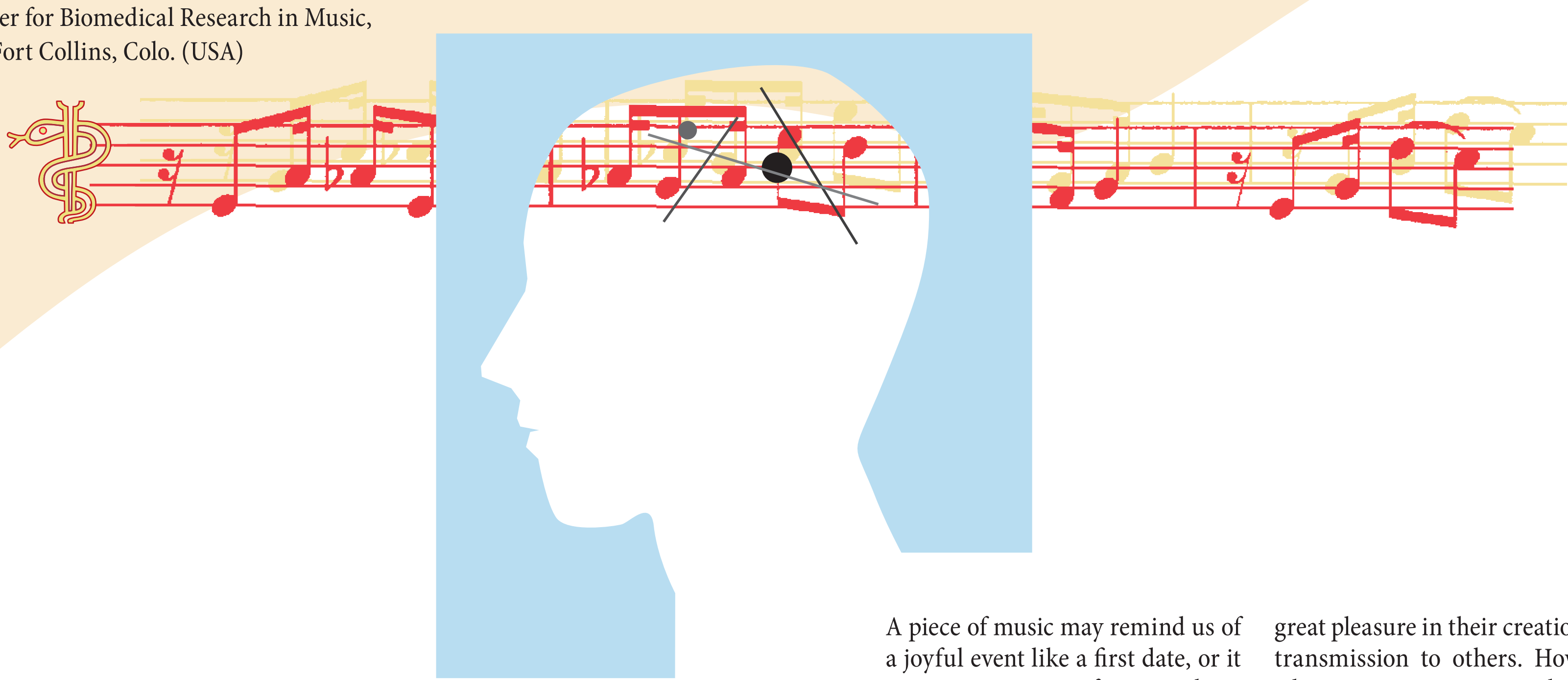

The modern human mind – i.e. a mind with a mental architecture similar to ours – came into being evolutionarily speaking perhaps sometime between 50,000 to 100,000 years ago. The archaeological records show the emergence of artifacts during that period that have to be attributed to cognitively modern minds. What is most fascinating about these records is the overwhelming evidence that, from the outset, these early human minds were artful minds and that artistic behavior was an integral part of human activities.

The Archaeological Evidence

Artworks and the evidence for an engagement in artistic endeavors date back much further than originally thought. Furthermore, this evidence predates that for written language and mathematical codes by tens of thousands of years. Paintings that depict societal functions such as hunting or religious rituals have been the prime archaeological discoveries suggesting the presence of artistic behavior. Cave paintings that strike the contemporary viewer as possessing significant aesthetic quality may be as old as 70,000 years. However, objects like weapons and tools that were shaped with more beauty than required for purely functional purposes have been attributed to humans living 200,000 years ago.

Of course, archaeological evidence for music is much harder to find than sculpted objects or paintings. The physical basis of music consists of temporal sound patterns created by vibrating objects and air molecules. We can therefore only infer from musical instruments the existence and possible sound of ancient music. However, flutes, rattles, whistles and percussion instruments as old as 30,000 years have been found. Rock engravings as old as 16,000 years depict dancers, thus implying the presence of music. Discoveries of musical instruments, at times amounting in number to the size of today's orchestras and created within the last 10,000 years, have been made in many parts of the world, including Egypt, Mesopotamia, Syria, South America, East Africa and China. An ancient set of six wooden pipes has been discovered in Ireland: dated at 4,100 years of age, tuned in octaves and executed in sophisticated craftsmanship beyond the normal Bronze Age levels, they are the oldest wooden instruments to have been found so far in Europe. The archaeologically oldest confirmed musical instrument is a 38,000-year-old bone flute, from Geissenkloesterle in southern Germany.

The oldest excavated figurative artworks – drawings with recognizable images or sculptures of identifiable forms – are over 50,000 years old. The appearance of such figurines in ancient arts marks an important step in the development of the cognitively modern human mind, because figurative artworks begin to embody symbolic representations, that is, the figures have been created to stand for something else. The simultaneous appearance of such highly sophisticated artworks with the emergence of modern human beings during the Ice Age in Europe suggests that artistic abilities did not evolve gradually but may, rather, have come into existence within a relatively short time span.

This evidence for the early existence of fully developed artistry on levels of sophistication, abstraction and representation similar or close to modern art, with little evidence for incremental progression, provokes some startling and provocative hypotheses concerning the role and nature of artistic talent in the human brain. The notion of the arts as the 'icing on the cake' of human brain development – after the basic needs of survival have been satisfied – are seriously questioned by these data. Why did visual art and music emerge as human behaviors? What role and function do they have? Why did art exist at such early stages of human history if it was not necessary for basic survival and societal progress relative to material needs? The archaeological findings imply that artistic engagement as part of human behavior may be much more fundamental to human brain function than originally imagined. The questions may have biological answers after all [1].

Music and the Mind

So what makes music so important for the human mind? Music has frequently been called the most elusive and intangible of the arts. Music cannot express meaning by referring to objects, concepts, events or feelings in a direct, semantically defined manner. It is purely abstract in expression. Certainly, we can learn to associate certain music with particular events or feelings. A piece of music may remind us of a joyful event like a first date, or it may create a sense of peace or happiness. However, these associations are not directly heard in the music. There are no happy chords or angry chords, and there are no pitches that signify joy. There are no melodies that stand for 'love' or translate 'wedding' into music. Recognizing this highly 'immaterial' nature of music, Plato once stated that it must have privileged access to the soul.

However, we are strongly convinced from our own experience that music does have communicative meaning. Music anthropology is full of examples demonstrating how music expresses emotions, concepts or events in specific cultures and societies [2]. Joy, happiness, sadness and loss; rituals of life events such as birth, marriage and death; social and political values and norms can all be expressed through music. But we must remember that in its material sense the communication takes place only through associations and extramusical definitions. Musicians, philosophers and scientists have long puzzled over this peculiar tension in music with regard to how and what music actually can communicate. The visual arts can function mimetically. A painting can pictorially represent war scenes or a wedding celebration; music can express only nonpictorial aspects of such events, and even those only through learned associations. The sound patterns of music cannot depict a wedding ceremony or directly express word meanings, not even for emotions.

Music as a Language of Sound Patterns

What then does music communicate? Fundamentally, music communicates the beauty and temporal architecture of its own sound patterns, and the human brain takes great pleasure in their creation and transmission to others. However, what is even more remarkable is that the human brain has created a very sophisticated and very diverse system of rules or 'grammars' for the assembly of these sound patterns. This process of building very complex musical language codes is only possible because all human beings appear to have the ability to think in abstract 'musical' sound patterns. This brings us to the key point of the argument regarding music and the human brain. The ability to 'think music' is fundamental to the existence of music, it is a universal ability, and therefore probably not learnt but hardwired biologically in the human brain. Without this universal ability, no music would exist, performers would have no audience, infants would not respond to music, and young children would not create music spontaneously.

A useful conceptual shift in our understanding of the nature of music is therefore to recognize that the ability to think music is part of a comprehensive system of mental representations that function in the brain in different modalities. The brain thinks in multiple languages. Verbal language is only one system of thinking, a system in which we think in words. But we also have other languages, for example a language of numbers and quantities, again necessary for thought and reasoning [3]. The nature of the languages of the visual arts and music is based on thinking in nonverbal structures. In music we think, create, perform and listen to aesthetically ordered auditory structures or percepts. The basic ability in music is fundamental to all human brains: we can all think in musical sound patterns.

With this multiple-language model, we can return to some of the questions raised earlier concerning the emergence of music in human culture at the moment when mod-

Fig. 1. The earliest undisputed musical instrument is a bone flute, made from the wing bone of a swan and dating to about 35,000 BC. Its remains were found in the Geissenklösterle, a cave near Blaubeuren in the Swabian Alb (southern Germany). (Photo courtesy of Hilde Jensen, Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, Eberhard-Karls-Universität Tübingen)

ern minds appear in the archaeological record. The ability to think in abstract symbolic sound structures must have been a critical function in the development of the human brain and its cognitive functions, so important in fact, that it appeared early on with other mental functions such as verbal language. Indeed, music and the arts in general are now proposed as precursors and cognitive prerequisites for the development of higher cognitive executive functions and the emergence of verbal language [4]. Considering music as a core language of the brain may also shed important light on the artistic activities of young children, who will all engage in singing, playing instruments and dance as a normal part of their development. These pursuits become significantly deemphasized in the learning environment when formal schooling starts and 'the arts' become relegated from the cognitive learning core. An interesting question could be raised in this respect: are the artistic pursuits of young children an ontogenetic repeat of a critical evolutionary cognitive development of the human mind?

How Is Music Processed in the Brain?

In listening, creating and performing music, we order abstract sound symbols into highly complex, temporally ordered sound patterns – a process that puts high demands on several mental operations. It challenges our perceptual system in several dimensions because we have to track one or several simultaneous pitches across time forming a single melody or a polyphony. These pitch patterns are structured into rhythmic time patterns. We track and distinguish instruments and voices based on different loudness levels and different timbres or tone colors which are based on the relative presence or absence of overtones in the notes. Overtones are additional pitch or vibration frequencies that are not consciously heard but that any acoustic object produces, because in nature all objects vibrate in multiple frequencies. At the same time – if we are listening to an orchestra, for example – we have to be able to track different sound sources in space. The auditory system is extremely sensitive to identifying differences in sound location.

In any musical task – regardless of its complexity – we have to be able to build a temporally ordered architecture of sound sequences in our mind in extremely rapid succession. Furthermore, music may be the only language of the brain that requires simultaneous perception-cognition processing of multiple strands of sound information in tandem with sequential comprehension. Finally, music fuses perception and cognition in complex ways – perception of complex sound structures trigger immediate cognitive pattern analysis, integrating perceiving and thinking into unified mental operations. And we may postulate that all these processes may be foundational to higher cognitive functions in general and the emergence of comprehensive intellectual development.

The Philosophy of Music Meets the Neurosciences

If this sounds farfetched, we may need to remember that our modern focus on music and the arts as carrying their foremost value in pleasure and entertainment, beauty and emotional expression is a relatively recent one shaped largely by the Romantic movement of the early 19th century. A closer look at philosophical views on music, however, reveals a long and continuous tradition of integrating music into models of scientific and philosophical thinking.

The earliest record of musical notation comes from the Sumeric culture 3,500 BC in Mesopotamia, using a 60-count numerical system to determine pitch frequencies and ratios. This system was deeply embedded into the mathematics and the religious symbolism of the culture and was probably still available to Plato (428–347 BC), whose philosophical thinking is still unique in human history by being deeply embedded in musical thought.

In classical Greek culture, music was part of the natural sciences. Plato emphasized – in a way similar to Confucius in China – the educational value of music, noting its ability to offer insight into the natural sciences and also to train the mind and intellect in general. He acknowledged the power of music to stir emotions (and was deeply suspicious of this power), and therefore stated in the famous dialogues in *The Republic* between Socrates and his young follower Glaucon the need to include in his perfect and ideal state only music that evokes praiseworthy emotions characterized by virtue, courage and restraint. Music, as a nonimitative art form, fared better in Plato than poetry and painting, which he considered as imitative art forms that are equally or even more dangerous than music in their ability to influence human character emotionally.

Almost 900 years later, Boethius (died AD 524) – a philosopher living at the transition between the decline and destruction of the classical world of the Roman Empire and the emerging period loosely described as the Middle Ages – summarized these multiple functions and understandings into a threefold division of music. *Musica mundana* is the reflection of the Pythagorean notion of music as a natural science with an intrinsic structure that embodies knowledge about the physical structure of the universe. *Musica humana* refers to the harmony between body and soul, perhaps a concept inspired by the educational and cathartic values ascribed to music by Plato and Aristotle. The lowest role for music lies closest to our modern understanding of music, in the form of *musica instrumentalis*, music as actual sound, sung and played. These subdivisions proved to be extremely influential in shaping a philosophical view on musical aesthetics, and Boethius' notions dominated music theory for over ten centuries.

A new reading of Immanuel Kant's (1724–1804) *Critique of Judgment* (1790), the third of his three famous *Critiques*, within the contemporary context of an emerging cognitive neuroscience of music may make his views surprisingly relevant for our current discussion. Kant's formulation of innate *a priori* knowledge – i.e. a knowledge not driven by external sensory-based learning – as a basic cognitive structure and mechanism imposed on perception and reasoning is echoed by notions of innate cognitive architectures put forward by modern theorists in cognitive neuroscience who are studying the neural substrates of cognitive processing.

For Kant aesthetic judgment comes from a specific form of pleasure through the 'disinterested' and objective contemplation of an art object. Kant states that the source of pleasure is related to the features of the object that are uniquely suited to an individual's perception. Kant claimed that the imagination (i.e., the mental faculty that allows one to apprehend the art object) and cognitive understanding (i.e. the faculty of comprehension and conceptualization) resonate in a synchronized perception-cognition process. It is as if the art objects were produced in order to be heard or seen by the perceiver. This view assumes so much innate *a priori* artistic thinking and reasoning ability that it seems defensible nowadays only in the context of modern brain science, which would assign to art a biological basis in brain function.

Music and Brain Research

With a model of music as an autonomous biological language of the brain as a working hypothesis, it is very interesting to look at the enormous amount of excellent brain research undertaken in the past 25 years. One immediate question that comes to mind within this model would be how brain regions involved in verbal language are distinct or similar to brain regions processing music. Brain research has shown that there is distinctive and shared neural circuitry between the two systems. In general, speech comprehension and speech production are more focally organized, predominantly in the left brain hemisphere, although the right hemisphere is active in speech encoding and decoding. The multiple elements of music processing are distributed much more widely across brain regions in both hemispheres. In addition, neuropsychological research with individuals with brain injuries has shown that linguistic syntactical and musical syntactical (rule-based) abilities can be dissociated, one can occur without the other [5]. However, neuroimaging research has also shown very interesting overlaps in activated brain areas for both speech and music. For example, similar electroencephalographic brain wave patterns were discovered in response to rule-based syntactical violations during musical and linguistic tasks [6]. Furthermore, similar areas in the dorsolateral prefrontal cortex are activated during musical improvisation/composition and linguistic verbal tasks like storytelling and sentence completion. A fairly large number of studies have shown the existence of shared networks between verbal language and musical language particularly in the inferior prefrontal gyrus regions (Brodman areas 44–47) that include Broca's area, which is strongly involved in speech encoding. Damage to Broca's area results in expressive aphasia. These regions may be involved in rule-based syntactical knowledge in both linguistic and musical knowledge. They may also be critical systems to mediate sequencing in perceptual, linguistic, musical and motor tasks. Thus, one may consider these regions as supramodal processing centers for syntactical knowledge and complex sequencing. These areas are also activated during rhythmic synchronization tasks, possibly mediating complex temporal motor and perceptual processes. Consequently, it may be a reasonable proposal that training and shaping this supramodal network using all languages of the brain, including music, may have a broad impact and potentially cross-modal effects on general cognitive fluidity and other behavioral and cognitive operations that draw on this network [7].

'Music is part of our nature and has the power to ennoble or degrade us.' Boethius
(Musicam naturaliter nobis esse coniunctam et mores vel honestare vel evertere.)

Recent experiments in our laboratories at Colorado State University have explored the connections between linguistic and musical tasks. In one study, we used the 'recognition without identification' paradigm, in which subjects are initially asked to learn word lists and are subsequently presented with the same word list with new words mixed in; however, all the words are fragmented by the removal of several letters. Typically, despite the fragmentation, subjects recognize as familiar more of the previously learned rather than the unlearned words. We translated that paradigm into a musical task where we fragmented melodies either by randomly removing notes or removing every other note in a melodic sequence. Results for recognition of musical fragments as familiar – although subjects could not identify the actual melodies –were very similar to recognition of word fragments, possibly showing similar perceptual recognition mechanisms for abstract musical sound patterns and verbal language patterns.

In another currently ongoing study we are investigating musical ability tests as predictors for cognitive test performance. In statistical regression analysis, among musical abilities, only rhythmic ability has a

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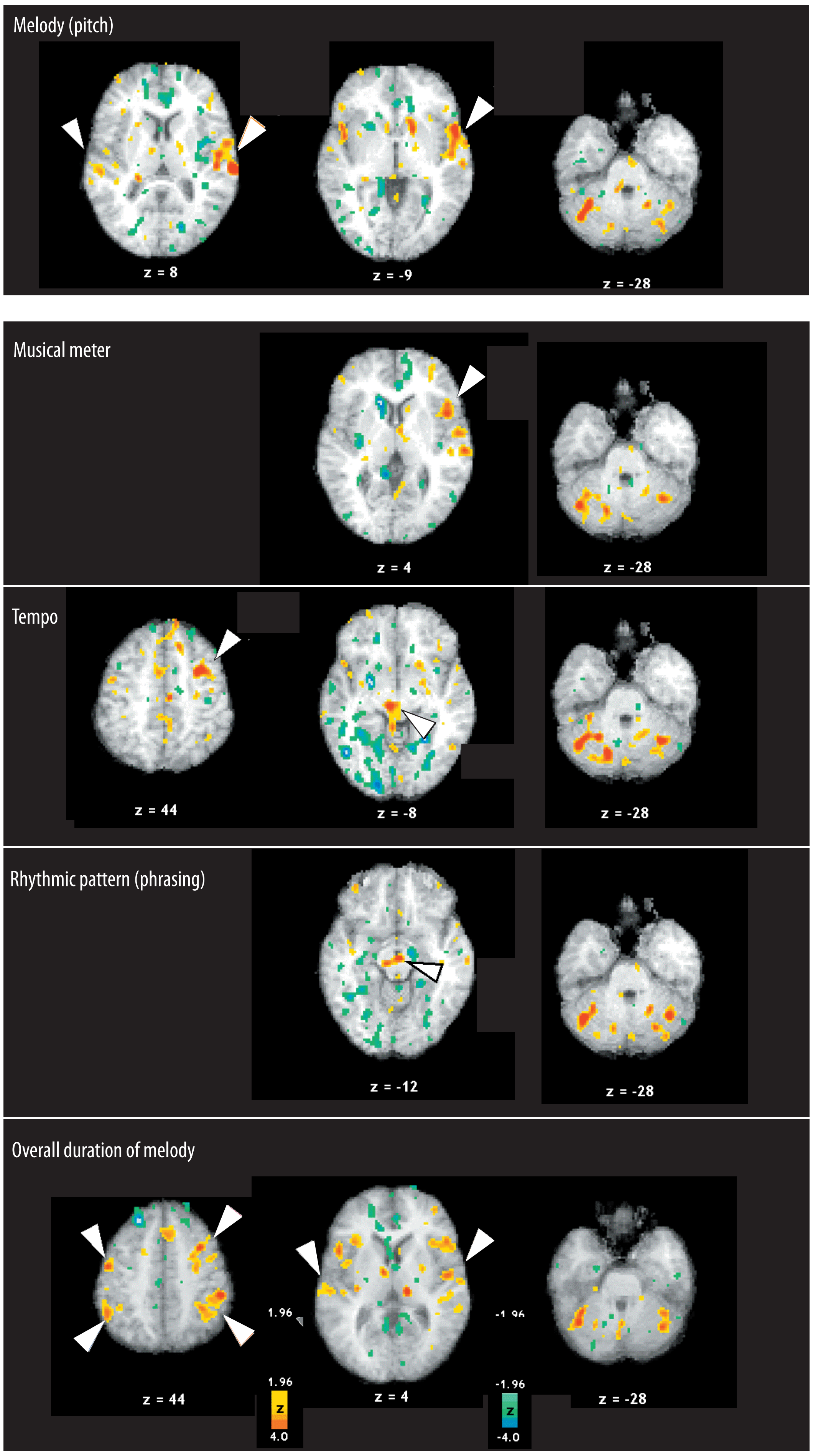

Fig. 2. The neural basis for musical rhythm is a highly complex and modular network system. Shown in these positron emission tomography scans is the brain architecture for perception of melodic contour **(a)** and different components of rhythm perception **(b)**. Measurements of oxygenation changes in the brain are an indicator of activity levels of brain structures: the yellow to red scale indicates increased activity, and the green to blue scale, reduced activity relative to the control situation. These scans show not only differences in primary activation areas between melodic and rhythmic perception networks in the brain, but also that the different musical components of rhythm perception (meter, tempo, pattern, duration) activate distinct networks.

been found to be a significant predictor for cognitive ability. Furthermore, strong rhythmic ability correlates with high scores in verbal ability but not in mathematics.

The Centrality of Rhythm

Rhythm – most broadly defined as an ordered distribution of temporal events – is a key component of musical language because it creates the temporal harness for the melodic and polyphonic elements. Within such a general definition, music without rhythm cannot exist. Metrical rhythms are a specific subform of rhythm as ordered time. Metrical rhythms in music are based on felt pulse patterns on which more complex time patterns are built, e.g. subdivisions in meters, fixed repetitive rhythm patterns in modes, or ostinati (varying melodic rhythms). The language of rhythm is extremely diverse across musical cultures, suggesting that the brain has very distinct abilities to build temporal architectures in music. While the melodic time flow of early medieval melismatic singing and chanting followed no fixed beat patterns, Western music has evolved to be organized in fixed time signatures (e.g. 3/4, 4/4 meters). West African music is built around complex polyrhythms. Indian Raga music consists of long rhythm patterns of up to 128 beats that repeat themselves throughout a piece. Furthermore, rhythm is not a singular term, it encompasses a number of time elements and time-creating devices such as pulses, beats, meters, accents and higher-order time units.

To study the neuroanatomy of complex musical rhythm perception, we first looked at meter, pattern, tempo and duration separately in discrimination tasks, and compared their anatomical distributions with those activated during a pitch discrimination task embedded in a complete melody sequence (Fig. 2) [8]. The results showed that the pitch/melodic contour system is separate from the rhythm perception system in the brain. In nonmusicians, pitch/melody discrimination activated right auditory cortex regions. Each rhythm component showed a different neural brain network subserving the different rhythmic elements. Meter prominently activated inferior frontal gyrus regions, pattern discrimination was mediated by activations mostly subcortically in midbrain regions, tempo discrimination activated prefrontal areas, and the duration judgments activated additional areas in the inferior prefrontal gyrus region. All tasks showed significant involvement of the cerebellum, demonstrating that the cerebellum is not only important for motor control but also for complex sensory perception without any movement. One of the most interesting insights from this study may be that the partial separation of networks in the brain subserving each rhythm function constitutes the neurological basis for the brain to be able to create very different rhythmic languages and vocabularies across music cultures.

The broad and widely distributed neural architecture of rhythm processing seems to emphasize its special role as a critical syntactical element in musical language. This critical role is accompanied by remarkable effects of rhythm on the human nervous system. We and other researchers have shown how auditory rhythm entrains movement patterns, i.e. drives them into the same frequencies, rapidly and precisely [9]. This entrainment effect can also be demonstrated when subjects tap their fingers or move their arms to rhythms that fluctuate in tempo so slightly that the tempo changes are not consciously audible. Despite the lack of conscious awareness, the subjects' finger taps will follow the subtle tempo changes in precise synchronization. We also discovered that rhythm is a highly effective stimulus to retrain movement ability in patients with stroke, Parkinson's disease and other motor disorders. Research over the past 15 years has shown impressively that auditory rhythm can be a very effective sensory timer or template to improve, for example, speed of walking and arm movements, stability of movements, as well as temporal and spatial precision and coordination in neurologic rehabilitation [9].

Finally, if we conceptualize music as a language of thinking in sound that is deeply ingrained in the emergence of early human cognition it may also come as no surprise that recent studies show that the ability for temporally precise rhythmic performance has been associated not only with increased scores on general intelligence tests but also increases in white matter volume in the prefrontal cortex [10]. And the accumulating evidence that musical training is associated with increases in academic and other cognitive abilities may indeed point to music and the arts as critical languages of the brain that train the brain's cognitive and perceptual systems in autonomous yet foundational ways. Furthermore, this view opens a very new avenue into understanding how music can operate in therapy and medicine. Instead of being an auxiliary system for emotional and relationship support it is a brain language that can help re-educate perception, cognition and movement in the injured brain [9].

The evidence is now strong that the early human brain was an artful one not as an accident or overflow development from other functional mental developments with little practical use. Quite the contrary: the artfulness and musicality of the human brain may have been the foundation for the emergence of the modern human mind.

About the author

Michael H. Thaut is Professor of Music and Professor of Neuroscience at Colorado State University and serves as Co-Director of the School of the Arts and Director of the Center for Biomedical Research in Music. His research focuses on brain function in music, especially time information processing in the brain related to rhythmicity and biomedical applications of music to neurologic rehabilitation of cognitive and motor function. Dr. Thaut has authored and co-authored several books which have been translated into German, Japanese, Korean, Italian and Spanish. Before he became a neuroscientist and music therapist, he was a professional violinist in the classical and folk genres.

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