Visions of Research in Music Education

Volume 20 *Special Edition: A Tribute to Jeanne Bamberger*

Article 9

2012

Representations of Music: Neural Foundations and Metaphoric Descriptions

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ISSN: 1938-2065

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Abstract

In Jeanne Bamberger's (1991) instructive case study on Jeff's learning, Bamberger observed and systematically ordered altering states of mental representations. In this study, Bamberger introduced and discussed a differentiated perspective on various forms of representation. In addressing the processing of music in the mind, mental representations can refer specifically to neural correlates of music or they can address more metaphoric ideas. Therefore, there is a proposed differentiation between mental representations if the mind is involved and neural representations if the brain is addressed. Furthermore, corporeal sensations and bodily excitations provide a necessary prerequisite for the development of mental and neural representations. Empirical movement studies support the essential role of body movement for music perception and production. These studies also confirm a strong interaction of motion control, motor coordination, and musical abilities as well as underpinning the complexity of learning through the development of musical representations as a core issue in music learning.

Gruhn, W. (2012). Representations of music: Neural foundations and metaphoric descriptions. *Visions of Research in Music Education, 20*. Retrieved from http://www-usr.rider.edu/vrme~/

Conscious actions in daily life are planned, processed, and conducted by the brain, mainly by the prefrontal cortex, but also by many other areas including sub-cortical areas. The cerebellum is strongly active in every motor execution, including music making, because it controls voluntary motor movement, balance, equilibrium, and the muscle tone. The interplay of cortical areas including auditory areas, prefrontal cortex, pre-motor and sensori-motor cortices is vital for music processing in perception and performance. Therefore, it has become customary to speak of mental representations in addressing aspects of music processing in the mind. Sometimes this term refers more closely to neural correlates of music, and sometimes it carries a more metaphoric meaning. In both situations, music listening, understanding, learning, and performing exist as brain activities and from this point of view, it is obvious that music educators deal with mental representations. These mental representations are genuinely musical, which means that they are not verbal or visual in nature, rather they are inseparably linked with motion.

The integration of auditory and motor sensations has moved into the focus of educational and neuro-musical research (Altenmueller, Weisendanger, & Kesselring, 2006; Bowman, 2010; Bresler, 2007), thereby opening a broader view on the understanding of music making and listening. A strong and immediate auditory-motor link is especially important for linguistic sound production (Brown, Martinez, Hodges, Fox, & Parsons, 2004; Mooney, 2004; Patel, 2008). However, neither the neural functions alone nor a mere metaphoric description are sufficient to illustrate the powerful meaning of mental musical representations in education. Mental musical representations become a highly relevant core issue in music teaching and learning if one draws a connection between the metaphoric figures and the concrete neural functions of the representations.

The "Story" of Jeff

In her illuminating book, *The Mind Behind the Musical Ear*, Bamberger (1991) describes very clearly the developmental steps which are performed by a little boy, Jeff, who worked with Montessori bells on some familiar tunes. His task was to build a bell path of a particular tune. Bamberger describes how Jeff developed a mental image of his actions and how he arranged the bells so he could play the melody using the bells. One important challenge during this process was the problem of how to find the next bell in the bell path. Because the Montessori bells all look the same and are of the same size, they did not provide any visual clue so Jeff needed to activate a mental image of the next melodic pitch in his mind. In other words, he activated a mental representation of what he expected to come next. He then compared the selected bell with his mental image and decided whether his mental image with the selected bell.

In order to arrange the bells in melodic sequence, Jeff developed his own practical arrangement of the bells that followed the sequence of pitches in the melody exactly. In other words, Jeff realized a concrete representation of the tune reflected by the bell path, which accurately corresponded to the sequence of pitches in the tune. This concrete representation of the tune also corresponded to his action path of hitting one bell and moving to the next. Because Jeff's bell path followed the melodic pitch order like a figure of the melody, Bamberger (1991) called it a *figural representation.* Jeff gradually learned how to play the same tune on the bells when they were arranged in a scale-like order, for which he had to remodel his figural representation. To achieve this task, he needed to undergo a number of cognitive transitions. He came to the understanding that pitch is an independent property of each bell, which remains the same wherever the bell appears. This cognitive step enabled Jeff to operate with pitches in his melodic conception. Suddenly, he could play many other tunes made of the same major scale. He then began to move up and down within the tonal space of the scale and was able to switch between pitches more freely. He no longer depended on a real "figure" of the tune; instead, he had developed a more abstract conception. This abstract conception enabled him to complete "formal" operations, which is why Bamberger called this process a transformation to a *formal representation*.

This brief summary illuminates the importance of the development of representations in children's learning. Based on the cognitive dimension of this development of how children build their mental representations, one can define learning in terms of a transformation from figural to formal thinking (Gruhn, 2008, 2010a). This definition of learning clearly indicates that, although memory plays an important role in learning, learning is not based on memory alone and is not constricted to mere actions. Rather, this definition shows that learning results from alterations and differentiations within the structure of the neural connectivity. Therefore, music educators must be aware that, beyond all observational changes, a mental transformation must take place for learning to occur. The question, then, is if there is a direct relation between observational actions and neurobiological changes. This question immediately refers to the neurobiological foundations of music learning in general (Gruhn & Rauscher, 2002) and the neural correlates for the shift from figural to formal representations.

Music in the Mind and Brain

The reflection on musical representations calls for a brief clarification concerning the understanding of representations in human minds and that of neural representations in the brain. Without opening the discussion on mind and brain (Elliott, 1995; Johnson, 1987), it is necessary to clarify that representations in psychological terms refer to processes in the mind including all conscious and cognitive processes by which humans think, feel, perceive, imagine, and memorize. Musical thinking, understanding, and cognition are a matter of the mind and happen in the body, as supported by Elliott’s (1995) statement that "actions are nonverbal forms of thinking" (p. 55). As such, the action of performing can serve as a "robust representation of [one's] level of musical understanding" (Elliott, 1995, p. 59). Bamberger's (1991) distinction of figural and formal representations is rooted in a child's mind. However, the stream of consciousness in the mind is always governed by and related to processes in the brain, the organ that provides the physiological machinery for cognitive processes. In order to illuminate the neural aspects of musical representation, the following discussion will concentrate on musical representations in the brain and describe neural correlates of musical thinking.

When considering areas of the brain, one finds not one single music center (Altenmueller, 2001), but many areas involved in music processing. These areas include the prefrontal cortex, the auditory and the sensory cortices, and the motor cortex, which respond to the sensorial input. The deeper structures of the brain are involved in more general operations such as the timing and synchrony of movements (cerebellum), long-term memory (hippocampus), and emotional reaction (limbic system and amygdala). Considering these various areas of the brain brings up questions of where and how music is represented in the brain.

A piece of music consists of pitches and durations, volumes and timbres, harmonic tensions and resolutions, and contours and structures. The performance of music calls for visual information processing from the notation, coordinated motor execution in synchrony, and immediate aural awareness of what is performed. As such a complex cognitive process, different areas of the brain must respond to the corresponding musical elements. As a listener recognizes a melody that belongs to a particular composition, the mind turns sensorial input into music (i.e. the mind responds to frequencies by recognizing them as a pitches). The aural perception cannot process pitch, which is a particular sound quality based on frequency (e.g., the *qualia* of a distinct note e.g. *c sharp* or *b natural*). When we talk of neural representations, we must talk of the representation of frequencies or dynamic differences of intensities. The distributed representations must then be reassembled and neurally connected to become recognizable in the mind. By this we interpret frequencies as a tone or interval, durations as a rhythm, and other elements of music as corresponding neural functions. Therefore, talking of neural musical representations always requires discussion of the need to activate complex networks of connected areas and activated synapses. These neural networks are established by synaptic strength and synchronized firing rate. The perception and cognition of what we call music strictly depends on the activation of internal cerebral excitation patterns caused by physical incidents like frequency or air pressure. The music we perceive is only generated in our minds.

This immediately brings up another question of how we can recognize something from the outside world if perception relies on an internal neural excitation. How is a neural representation related to the phenomena outside the brain and body if cognition is self-referential to the own neural excitation? This is a highly sophisticated epistemological question (Metzinger, 2009, 2000) which is outside the scope of this paper. Rather, we will continue to attain some clarification about Jeff's mental representations in neurobiological terms as discussed by Bamberger (1991).

Jeff developed a gradually growing network of connected areas in his brain. Because of his previous experience and his practical experiments with the bells and their sounds, he established new excitation patterns within this network, which led to more differentiated and extended connections. To be quite clear, there is no one neuron or no one single group of neurons alone that represents the whole tune that he wanted to construe with the bells. However, we can hypothesize that the transition from figural to formal thinking was somehow reflected by a change within the neural connectivity. Unfortunately, it is not yet researched by empirical brain studies how this transformation appears in the brain. Presently, we can only speculate that a figural image or mental representation is represented by cortical excitation patterns in those brain areas that are involved in that particular sound pattern.

When the figural imagination is transformed into a formal mental state or mental representation, it becomes more abstract and autonomous. This means, a formal representation does not need to be concretely executed or played on an instrument, rather a formally imagined sound (e.g., a dominant seventh chord) is independent of a concrete pitch, tone color, or instrumental timbre; rather, it can be thought of in a more holistic way as a complex sound quality. This means that the neural network gets smaller and needs less energy when a complex procedure becomes automatized and is subconsciously programmed. This, in turn, may indicate that the neural network has been reorganized on a deeper, subcortical level.

Motion and Emotion

This brings us back to the body and its function in musical performance and understanding. When we talk about embodied meaning in musical perception, we refer to the corporeal attributes of music. Listening to a minuet or to a military march evokes gestures and attitudes that can be outwardly executed in practical terms or internally in our imagination. Understanding can be seen as an internal execution of musical gestures (Godoy & Leman, 2010; Gruhn, 1989), an idea which is even more obvious in emotions. According to the etymological root, emotion exists as an extroverted motion. When we observe babies' and infants' behaviors, we realize that an emotional cry involves the entire body; joy and anger correspond to an intense somatic reaction including motor responses; threat generates a vegetative and somatic tension. Therefore, mood and emotion cannot be reduced to certain brain activation patterns, but need to be explored in a much broader cultural, anthropological, and psychological perspective (Juslin & Sloboda, 2010).

Research on musical gestures (Godoy & Leman, 2010) and somaesthetics (Shusterman, 2008) has shown that movement and corporeal reactions affect mental processes that go far beyond eurythmic gymnastics. Jaques-Dalcroze (1921) already claimed that music is not an exclusively acoustic phenomenon; rather he stressed the correspondences of music perception and performance with bodily reactions reflected by the whole organism. Currently it is common knowledge that emotion is seen as motion and that music understanding exceeds pure auditory skills. Music making and listening become entirely embodied activities. Moreover, music as an emotional and corporeal expression causes mental and somatic activations. Consequently, one cannot limit music learning and understanding to mental processes and representational changes alone. Although this is extremely important, it only reflects one aspect. However, only little empirical research has been conducted to investigate the interactive functions of motor coordination, motor control, and musical development (see Bowman & Powell, 2007).

From this, it seems obvious that music captures the body of a musician. Therefore, we would like to introduce the concept of musical embodiment as another type of representation, which might be called *corporeal representation*. Whatever we do and however we act, all of our motions engrave traces in the brain. This determines the process of how we can develop mental and neural representations. This process already starts prenatally (Parncutt, 2009). Whenever the fetus moves spontaneously, the movement causes feedback in the brain through the main neural conduction in the spinal cord that ends in the brain stem, the phylogenetically oldest part of the brain. This feedback evokes a neural excitement pattern, which initiates the development of a neural representation in the neo-cortex, the youngest part of the brain that plans and executes all conscious actions. This evolutionary determined process that connects the body with the brain makes us unmistakably aware that any experience and every sensorial input can only attain to the brain through the body by corporeal sensations (Gruhn, 2010b). This is why procedural learning forms such a powerful strategy in learning.

Although not all procedures in learning are mental, mental representations are always developed through sensorial stimulation. Music as a sound object is not acquired and performed by theoretical concepts and knowledge about the properties of this object, but rather by doing and making through practical experience (Elliott, 1995, 2005). We cannot explain what a resting tone or an upbeat is unless we can perform it. We can teach knowledge and give verbal explanations of how a musical phenomenon can be described, but we then do not teach music as a sound object. For musical understanding, we must feel and experience the sound and tension of a musical expression. However, it is then no longer an object outside our body and mind, but becomes a part of our personal behavior.

A longitudinal study observed young children from ages 3 to 5 with regard to their motor activities such as sustained flow of movement (i.e. the ability to move smoothly and fluently), motor coordination, and the degree to which their movements were in synchrony with their vocalizations and with other children or the teacher respectively (Gruhn, 2002). Additionally, children's vocal abilities (i.e., pitch and rhythmic accuracy) were also ranked and correlated with their motor data. The results were unexpected and striking (Gruhn, 2002). The study found the highest positive correlations between coordinated, synchronized movement and the accuracy of the performed rhythm patterns, the consistency of tempo, and the correct intonation (pitch matching) of songs and vocal patterns.

Table 1

Correlation coefficients indicating significant (*) or highly significant (**) correlations between vocal and motor activities in young children.

	vocal criteria				
	rhythm patterns		tonal patterns	songs	
motor criteria	consistent tempo	accuracy	intonation	pitch	rhythm
flow	**.77***	**.74***	**.86****	**.84****	**.83****
coordination	**.80****	**.74***	**.81****	**.70***	**.70***
synchronization	**.82****	**.80****	**.91****	**.81****	**.81****

This was surprising and unexpected because we did not anticipate a relevant effect of movement on children's vocal production. However, this robust positive correlation results from the fact that children who frequently sing and chant precisely while keeping a consistent steady beat develop a better sense of fine and gross motor coordination. The same ability that is needed for motor coordination is then applied to singing and chanting. Therefore, the more developed the gross motor control is, the better a child can control the fine motor activity in the vocal tract, which results in a better intonation. In the end, an interaction of body and vocalization, which actually is a body activity, is apparent.

Even at a very early age, children are able to synchronize their body movement to a musical pulse. For example, children move their hands or feet in synchrony with a tapped rhythm or a sung tune although they do not have any visual contact to the sound source (Thaut 2003; Trevarthen, 1999). This phenomenon is also documented for parrots who can adapt their head nodding to the pulse of the music they listen to (Patel, Iversen, Bregman, & Schulz, 2009; Schachner, Brady, Pepperberg, & Hauser, 2009). The ability to entrain movements to an external timekeeper raises questions regarding an endogenous predisposition to connect sound and movement by auditory motor interaction. Behavioral observation has shown that children prefer a rhythm to which they were bounced for some time (Phillips-Silver & Trainor, 2007, 2008). Thus, the discrimination of aurally presented sound is learned by moving the body.

A recent study of children ages 4 to 6 investigated possible interactions of motion control, motor coordination, and balance with music aptitude and cognitive development (Gruhn et al., 2011). The study stems from the scientific evidence of auditory-motor interaction in vocal learning and the observation of the importance of controlled body movement in children's musical behavior. The researchers collected empirical data that could help to unveil simultaneous developments of motor and musical abilities in young children. The general hypothesis was that body control and motor coordination are more pronounced in children who exhibit higher scores in music aptitude tests. The researchers gained information regarding motor and musical abilities from data collected from a standardized motor test (Zimmer & Volkamer, 1984) and a musical aptitude test (Gordon, 1979). Both sources included ratings of children's tonal and rhythm abilities given by the children's teachers as well as three non-verbal subtests of a standardized intelligence test (Kaufman & Kaufman, 2007). In the second part of the study, the researchers recorded biomechanical and neurophysiological data from electromyography (EMG), which measured the muscle tension on a Posturomed and the individual body oscillation. The researchers then correlated the empirical data with the observational results.

Overall, the biomechanical and neurophysiological data confirmed the behavioral measurements and exhibited a clear interaction between musical abilities and measures of motion control. The better the children performed on the music aptitude test, the better the measures of the motor tests. These results approve a vital interaction between coordinated body movements and musical abilities. This does not indicate a causal direction from one to the other; however, it confirms that motor and musical abilities interact mutually (see figure 1).

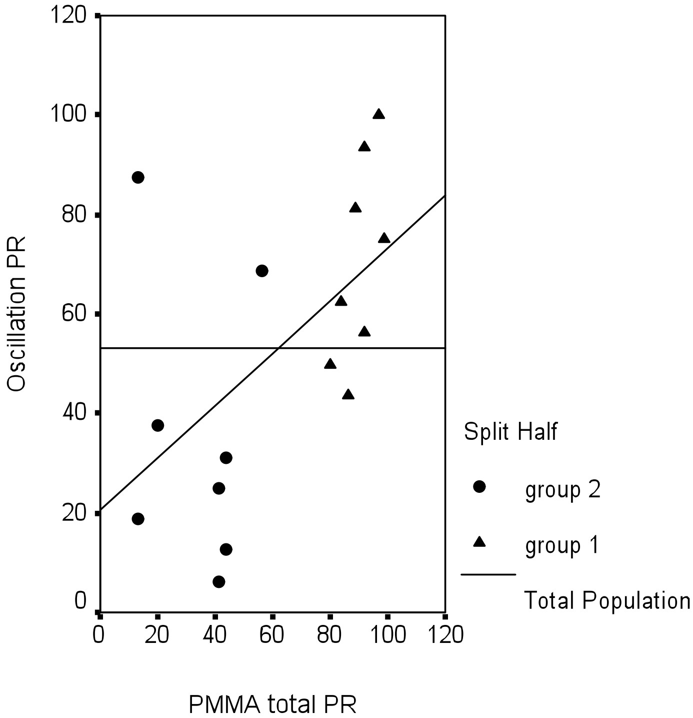

Figure 1. A split half procedure with a higher (1) and lower (2) group of subjects according to measures from the motor test exhibits a linear progression between the percentile rank (PR) of the total score of the PMMA test and the percentile rank (PR) of the measures from body oscillation. A clear separation of the two achievement groups (middle line) is apparent.

How can all of this be related to Jeff's transition from figural to formal representations? First, Jeff showed a mental progression in his non-verbal musical conceptions, which were initiated by his concrete corporeal actions. He started to understand the theoretical background of the melodic structure of the working tune according to his practical experience gained from his body activities, which caused the development of corporeal representations. Second, this process initiated an alteration of his neural network, which resulted in a differentiated mental representation. As a result of the entire developmental process, mental representations, neural networks, and corporeal activities finally coincided and determined the figural or formal state of representation.

Conclusion

Music exists as a complex sound structure and a highly sophisticated tool of self-expression, which is represented mentally, bodily, and neurally. Only the interaction of the three representational levels enables humans to learn music and to take it as a means of human communication, artistic exhibition, aesthetic expression, and corporeal activity. At the same time, this complex phenomenon provides a true educational challenge for teaching and learning. We must understand the interplay between the mental, neural, and corporeal levels of learning, which all interact and cooperate. For music education, Jeanne Bamberger's (1991) detailed observation and description of Jeff's mental growth is extremely powerful and valuable because it illuminates and empathizes the intellectual and musical development of a beginning learner. The body is in the mind, and the mind reflects what is experienced in the body. The neural correlate of this experience is stored in the brain. All three levels interact, therefore indicating a need for educational practice to address all three levels. Although we do not have immediate access to the brain, we are prompted to look for educationally appropriate pathways or channels into the mind. In sum, adequate mental and corporeal stimulation affects the development of neural representations and complements learning as a complex personal endeavor.

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