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How is perception related to action? A neurophysiological perspective on music perception and learning

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ABSTRACT
Cognitive conceptions of action and perception have been seen for a long time as separate, peripheral processes. Here, we will introduce a new perspective on perception and action as an interacting developmental process. Evolutionary and neurophysiological research studies have demonstrated that cognitive processes arise from motor development. Empirical data and observational tests on cognitive abilities are related to the findings of evolutionary biology regarding brain functions. The morphologic structure of the primary auditory cortex exhibits high plasticity according to musical practice and determines different types of perception depending on the orientation to different aspects of the overtone spectrum. Based on these conditions, a neurophysiological perspective on music perception and cognition arises. According to Buzsáki's neurophysiological findings, there is no perception without action, and without perception, there is no cognition. Consequently, if perception and cognition are based on action and even more, if both originate from the same evolutionary development, then this must have immediate consequences for music teaching and learning.

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Introduction

There is a consensus that children construct their knowledge of the world within the scope of their abilities to act. This constitutes a central aspect of Piaget's theory of sensory-motor development (Bremner 1993). However, for a long time, cognitive conceptions of action and perception have been seen as separate, peripheral developmental processes. In contrast, recent research has focused on a close coupling of action and perception as exhibited by a strong auditory-motor link which can be explained by the neural auditory-motor loop (Maes et al. 2014; Zatorre, Chen, and Penhune 2007). This refers to a mechanism by which an auditory signal is transformed into a motor command (Boyer et al. 2013). This can be observed in instrumental learning and in language acquisition when children learn to pronounce a word correctly by listening to an articulating voice and trying to imitate it until it fits the perceived model. The underlying mechanism connects aural input with motor activation. A dysfunctional link emerges with people singing out of tune. The reason for this is a deficit in correct motor activation. Particularly, dysfunctions in speech and song acquisition often uncover malfunctions of the respective auditory-motor loop (Pfordresher and Brown 2007).

The human motor system plays a prominent role in auditory perception. This is confirmed by the everyday experience that one notices strong motor responses to music listening and playing. A common example is the embodiment of musical expression. A musicians body is involved in the performance, namely technically by the execution with the body, musically by responding to the musical structure with body movements and emotionally by gestures and facial expressions. The

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efficacy of auditory-motor coupling is especially confirmed by interruptions of that loop. The fact that motor dysfunctions cause a considerable deficit in subjects' auditory perception and cognition abilities underpins the importance of a functionally correctly working auditory-motor interaction. In this regard, Maes et al. (2014) refer to two different models to describe the internal relationship between body and perception: (1) the *inverse models,* which represent an information flow from perception to action, and (2) the *forward models,* which represent an information flow from action to perception. However, if we attribute a kinaesthetic quality to listening and accept the perspective of a strong coupling of action and perception, we remain within a mode of thinking of principally separable processes which focus on either the perception or the action. Otherwise, a new perspective through an evolutionary and neurophysiological lens argues that sound perception can and must be seen as a specific and genuine process which originates in a common evolutionary development of perception and action.

The evolutionary foundation of motor development and higher cognitive functions

Reasoning and thinking are part of higher cognitive functions. To construct the meaning of the perceived world is a prerequisite of human communication. Meaning is based on mental representations that are developed in the mind through experience and practical contact with the environmental conditions. A core element of perception applies to the activation of already established representations and their respective actions. According to Gibson (Gibson 1986), any object of the environment offers (or 'affords') different options to act on: a chair to sit on, a trumpet to blow in, etc. One acquires the meaning of objects and situations in a specific context by experiencing and executing the affordances of these objects by acting on and with them. Also, thinking and judging start with the activation of mental representations which arise from intentional actions that – in our context, evoke motor and auditory excitations as to sound and movement. Conjunctions and interactions strengthen the development of mental representations through mental activation patterns.

A fundamental aspect refers to the question of how consciousness and cognition develop in the human mind and constitute mental processes on a higher level. Every day experience seems to confirm the belief that an action or movement follows a conscious intention, which triggers a neural activation and releases a motor action. However, this assumption was shaken by a spectacular but controversial experiment by Benjamin Libet (Libet et al. 1983) in 1979, referred to as the experiment on free will and consciousness. In this experiment, a test person was asked to press a button at an arbitrary moment while observing a moving clock hand. Then, the person should keep in mind the position of the clock hand when he or she consciously decides to push the button. The surprising result revealed that the action potential arose 550 ms prior to the action and the conscious decision 200 ms prior to the action. This was somehow shocking because it seemed to indicate that our conscious decision *follows* the action by triggering an action potential which precedes the voluntary decision. How can that happen?

First, this result only reflects the time gap between the actual action and consciousness. Furthermore, this obvious discrepancy reflects what neurologist Daniel Wolpert has stated about the function of the brain. In a public talk, he said:

> When you are studying memory, cognition, sensory processing, they are there for a reason, and that reason is action. Movement is the only way we have of interacting with the world, whether foraging for food or attracting a waiter's attention. Indeed, all communication, including speech, sign language, gestures, and writing, is mediated via the motor system. […] You may reason that we have [a brain] to perceive the world or to think, and that's completely wrong. […] We have a brain for one reason and one reason only, and that's to produce adaptable and complex movements. (Wolpert 2011)

This is already reflected by the everyday colloquial speech where we use many metaphors which stem from motion (business *goes* well; we order *running* metres of a fabric or ask: how are you *doing*? etc.). This phenomenon becomes obvious when we look back on evolution. There is an animal, called the *Sea squirt*, which possesses a primitive nervous system that receives sensory information from the surrounding environment to navigate in the sea in search of a stable ground for a sessile position. When it has found this position, it literally digests its brain (a brain-like ganglion) because it is not necessarily used anymore. Because, there is no need to coordinate movement since the movement of the sea squirt is completely stimulated by the streaming of water in the shallows of the shelf sea, where it now will stay for the rest of its life. According to Rodolfo Llinás, the evolutionary development of a nervous system is an exclusive property of actively moving creatures' (Llinás 2001, 17).

From this evolutionary perspective, Llinás developed his theory of oscillations**.** Neural activity in the cells becomes manifest in the oscillations across the cell membrane. Larger electrical events occur as the basis of interneural communication. The simultaneity of neuronal activity (i.e. the synchronous interconnectivity of cells and cell assemblies), then, becomes the foundation of cognition. Consequently,

> the ability to think […] arises from the internalization of movement. […] The issue is that thinking ultimately represents movement, not just of body parts or of objects in the external world, but of perceptions and complex ideas as well. (Llinás 2001, 62)

Neurophysiological conditions of auditory perception and cognition

The German physiologist and physicist Hermann von Helmholtz (1821–1894) discovered that people respond differently to tones depending on whether they orientate themselves on the *fundamentals* or on the *tone spectrum* (overtones). A group of researchers collaborating with Peter Schneider and Annemarie Seither-Preisler (Schneider et al. 2022; Schneider et al. 2005; Seither-Preisler, Parncutt, and Schneider 2014) identified neurophysiological characteristics according to these preferences, which caused *holistic* versus *spectral* hearing types. The aural precondition induces neural correlates in the morphological structure of Heschl's Gyrus regarding volume and fissure, which depend on practice and determine preference (Figure 1).

These findings indicate a link between the neurophysiological (morphological) structure and musical practice, between musical performance (action) and listening. In the light of the

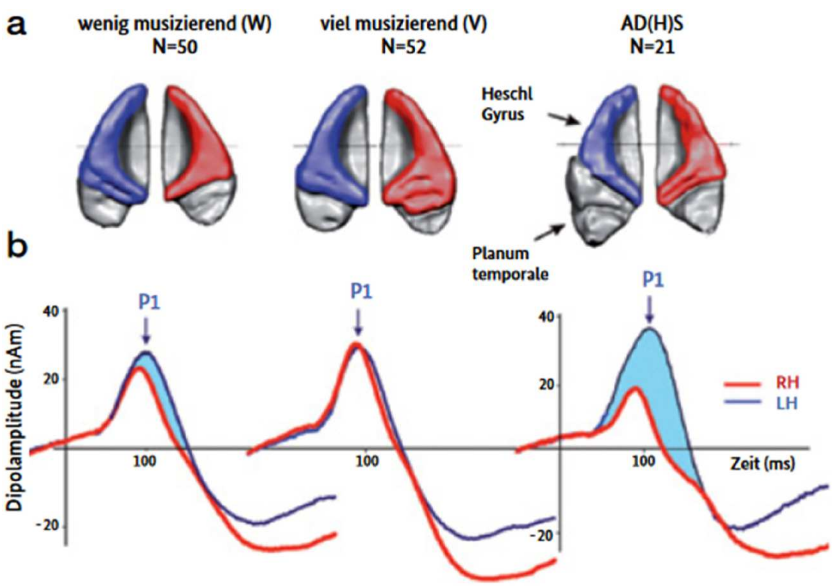

Figure 1. Morphological differences in Heschl's Gyrus of children with little (W) versus much (V) music practice compared to children with AD(H)S. From (Schneider and Seither-Preisler 2015, 35).

evolutionary development, this is not surprising because they are based on the same neural development.

In a former study with 16 preschool children regarding a possible association of music aptitude and motor coordination (Gruhn et al. 2012), an electromyography (EMG) technology was used to measure muscle activity under different conditions. The study exhibited a strong linear correlation between the percentile rank of Gordons *Primary Measures of Music Audiation* (Gordon 1979) and the measures of a *Motor Test for 4–6-Year-Old Children* (Zimmer and Volkamer 1984). The higher the percentile rank in the music aptitude test, the better the results in the test of motor coordination and synchronisation (Figure 2(a and b)). This was also confirmed by the *proprioceptive amplification ratio* (PAR quotient), which relates the magnitude of the muscle activation to the oscillations in a balance task and serves as an indicator for motor sensitivity. These findings do not exhibit a causal link between motor development and music aptitude, but they point to the development of interacting faculties growing simultaneously.

In early studies from the 1980s and 1990s on childrens music perception, Lyle Davidson (Davidson and Scripp 1988) and Jeanne Bamberger (Bamberger 1982, 1991, 2013) among others have demonstrated how much movement is integrated into their musical perception as reflected by their drawings as windows into their cognition. Very often, the early scribbles reflect the actual movement of children's hands while singing the respective tune or chanting a rhythm. At the very beginning of the development of cognitive structures, children do not count and measure (like adults), instead, they rely on the weight and flow of the music (according to Laban 1991, 2011), which are body dimensions of time and space. In terms of Bamberger's concept of music learning, this happens when a bodily ('figural') representation of sound transitions to a more abstract ('formal') representation (Bamberger 1991).

Regarding music learning, empirical studies have investigated how children learn ordinary musical issues such as the formal structure of musical phrases (periods) or the tonal difference between dorian and minor modes (Altenmueller and Gruhn 1997; Gruhn 1995, 1997). An EEG measurement was carried out on school-age children (aged 13–14) before and after a differentiated training. For this, the sample was divided into three subgroups: two different learner groups (L1 and L2) and a control group (L0). L1 addressed a declarative type of learning with different forms of verbal, visual, and aural information, but with a clear restriction to sing or move, whereas L2 addressed a procedural or explorative type of learning with all kinds of musical activities and body movements. The controls (L0) did not get any musical instruction, but a verbal introduction to music

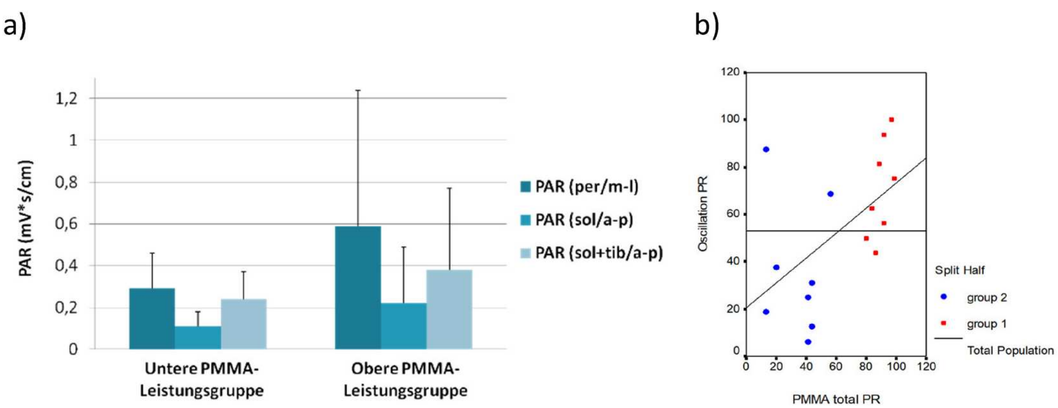

Figure 2. a: *Proprioceptive Amplification Ratio* (PAR) for children with higher (right) and lower (left) *Primary Measures of Music Audiation* (PMMA) scores. Data are taken from peroneus longus (movement m[edial] – l[ateral]), soleus (movement a[nterior] – p[osterior]) and tibialis (movement a[nterior] – p[osterior]). Reproduction with permission of Madeleine Haußmann. b: Achievement of motor oscillation of children with high (group 1) or low (group 2) percentile ranks related to their corresponding PMMA ranks.

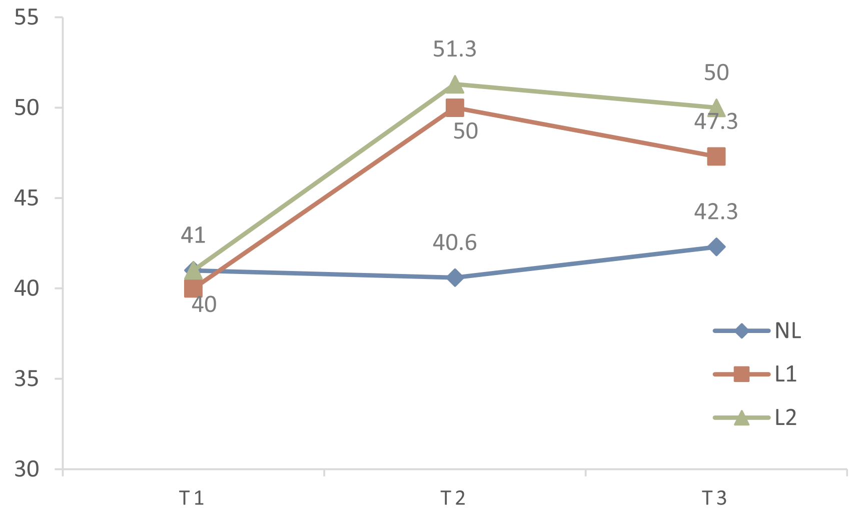

Figure 3. Development of learning scores in three subgroups with different instructions before instruction (T1), after 5 weeks (T2) and after one year without any further instruction (T3). Maximum 60 correct items.

history. Three tests were taken: before the beginning of instruction (T1), after five weeks when instruction had finished (T2) and finally one year later (T3) without any further instructions to measure a long-term effect (see Figure 3). All three groups started from the same starting point at just about a chance level (60% correct answers). Unexpectedly, after instruction, the two learners L1 and L2 reached the same level of about 83% correct answers no matter of the type of instruction, but – as expected – the L0 group did not exhibit any change because they had not learnt anything in terms of music. However, the data at T3 one year later showed a decrease in L1, whereas L2 remained nearly at the same level. The only distinction between the two groups was the application of singing and movement. Therefore, the reason for the stability of the acquired musical knowledge must be related to musical and motor activity as agents that contribute to the difference in the learning outcome. And this is not astonishing since many teachers confirm that students forget the content of lessons quickly after finishing a unit in math or history or music. However, this effect could be diminished by the inclusion of action – even without continued instruction.

This result was also confirmed by EEG measures (Figure 4) where the activation in the auditory cortex and the primary motor areas increased significantly (**). By and large, integrated learners (L2) exhibit the largest increase from t1 to t3 (Altenmueller and Gruhn 1997, 52), which obviously must be attributed to integrated action. Similarly, the neural representation of novel words in extended sensorimotor networks of language acquisition is stronger when learning is combined with iconic gestures (Macedonia and Müller 2016; Macedonia, Müller, and Friederici 2011). This indicates that learning benefits from the integration of perception and action.

All these observations, along with the neurophysiological data, confirm the evolutionary implications regarding a strong association of perception and action not only as a mutual accompaniment, but as an essential part of perception.

A new model of neural activities in perception and cognition

Apart from evolutionary aspects regarding the importance of action in the process of brain development, Buzsáki (2019) has refined the action theory and elaborated a new model of 'how the brain constructs the outside world' (Buzsáki 2022). Based on experiments with neural activities during spatial navigation and memory, he developed an alternative model to the generally accepted *Outside-In Framework* where perception is understood as an immediate copy of the exterior world in

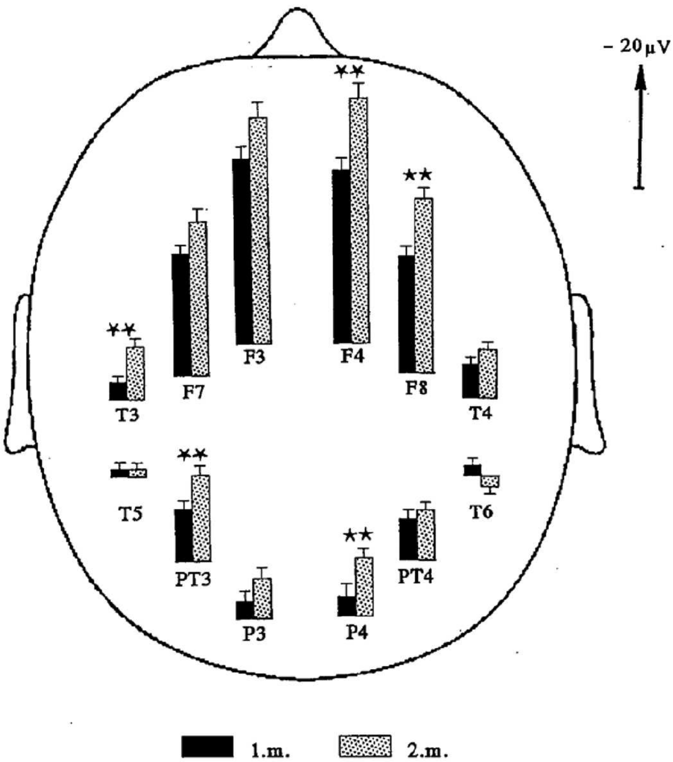

Figure 4. Mean amplitudes of EEG potentials for L2 at the first and second measurements (Altenmueller and Gruhn 1997, 44).

the mental mind by a process when a stimulus reaches the senses and evokes neuronal firing patterns. Rather, he favours the opposite, the *Inside-Out Framework,* which suggests that signals from action-initiating stimuli and sensorial reactions interact so that 'we come to understand the external world by taking actions' (ibid., 38). Since neurons have no direct access to the outside world, their firing rate is tied to changes in firing patterns as a reaction to a sensory input. The firing neurons themselves know nothing of the objects or events that cause their activity; they cannot see anything. Rather, they rely on an instance that interprets the input (the internal interpreter or individual mind). Therefore, Buzsáki states that 'more complex brains are organised in a 'multiple loop' pattern, that is, a series of interacting parallel loops are imposed between input and output' (Buzsáki, Peyrache, and Kubie 2014). The sensorial input, he concludes, becomes meaningful only when it was previously linked to a meaning gained by action. Any action of a person informs the rest of the cerebral cortex about that action by a message known as *corollary discharge*. The sensorial stimuli alone can never turn into signals of a particular meaning. 'Perception then can be defined as what we *do* – not what we passively take in through our senses' (Buzsáki 2022, 39).

As a result, Buzsáki differentiates between two different brain modes, an *engaged mode,* while firing when stimulated by an input signal, and a *disengaged* or *detached mode*, when processing continues independently of an input from the external environment. Then he concludes that 'our thoughts and plans are deferred actions, and disengaged brain activity is an active, essential brain operation. […] Disengaged neural activity, calibrated simultaneously by outside experience, is the essence of cognition' (Buzsáki 2022).

At large, Buzsáki bases his action theory on neural experiments with humans and animals. He found that mental maps in the hippocampus are made through motor action. For the map-based navigation system, he states that it 'requires a calibrated representation of the environment. The dictum 'no action – no perception' also applies to the navigation system' (Buzsáki 2006).

If cognitive processes that are represented by neural activities like thinking and listening arise from the internalisation of movement, then music perception and cognition as a meaningful relation of something to be something necessarily needs to be achieved through action because perception represents a specific form of action.

Conclusion

Considering the evolutionary and the neurophysiological data, an integrative theory of *music perception as action* has been developed (Gruhn 2019, 2022). The crucial question is how educators can support children's musical development through action as an adequate introduction to musical thinking. The theory is based on the common evolutionary roots of movement and higher cognitive functions like perception and cognition. What follows from this background is that perception is neurophysiologically linked with action because even aural activities impact on neuroanatomical structures. Therefore, music teachers should integrate sound and action in early learning environments. Through action, children can experience flow and weight in melodic lines and rhythmic pulses more easily, which will help them to transform figural into formal musical representations (Bamberger 1991) as the core of genuinely musical learning. The practical applications of this theoretical approach call for an integrative method. Whatever is to be learnt musically should be conveyed through and not only accompanied by movement. This is especially effective in early childhood music education programs. Since music making is always performed by vocal and/or instrumental actions, the special focus here is directed toward music perception while actively performing music. However, this requires an appropriate repertoire of body movements that support musical essentials such as metric regularities or irregularities, the gradation of weight in a series of pulses, the smooth flow of tones in a melody or its accentuation, respectively. This is quite different compared to the traditional implementation of movement as an additional activity that mirrors the content of a song or adds a playful tool to pure perception. On the contrary, movement should be introduced and used as a genuine means of musical expression. At the same time, this conception of action-based perception enables learners to acquire the intrinsic meaning of the music they perform or listen to. By this, it supports the development of 'thinking in music', which Gordon (1980, 2001) has called *audiation*. In this regard, it becomes necessary to develop a repertoire of systematically arranged movements (see Gruhn 2022) according to Rudolf von Laban's kinetics (Laban 1991, 2011) and in accordance with Edwin Gordon's Music Learning Theory (Gordon 2006).

Finally, a *gedankenexperiment* (thought experiment) by György Buzsáki might illuminate the basic roots of the above-mentioned theory.

> Imagine that the brain and the body would mature separately in a laboratory, and only several years later we would connect them. This newly united brain–body child would not be able to walk, talk, or even scratch her nose. Local stimulation of her hand or foot would trigger generalized startle reactions, as is the case in premature babies, rather than a spatially localized motor response that characterizes a full-term baby. The reason is that the motor or sensory relations generated in the brain grown in isolation would not match. In case of such mismatch, the concepts of sensation and perception will acquire no meaning. (Buzsáki 2006, 220)

What follows is that an efficient matching of motor and sensory relations should be initiated by an early age and with a consequent application of integrated perception and action because they are essentially linked with cognition. Through moving and acting, educators get immediate access to the developing mental representations. However, motor actions should no longer only accompany musical perception and songs or interrupt theoretical information; instead, action and perception are interwoven so that action must be seen as a genuine means of educating the musical ear. Hence, it enables genuinely musical thinking or thinking in musical actions, respectively. Further large-scale tests are needed to investigate the effects of embodied music learning; however, not with respect to transfer effects or general cognitive development rather to genuine music perception and cognition.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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