6
MUSICAL PROCESSING ACROSS THE LIFE COURSE

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Introduction

This chapter deals with the development of processing music in the musical mind throughout the lifespan. After an introduction to the general dimensions of musical processing, we follow the developmental ages from prenatal stages and early childhood (section 2) to the ages of schooling (section 3), adolescence and adulthood and to the maturation of cognitive abilities and their neural conditions (section 4), finally shedding some light on the opportunities of music-making in the third and fourth ages (section 5). The chapter concludes with some reflections on the constraints of cognitive processing and its application to music education in view of the enormous emotional power which accompanies any musical experience.

The development of musical processing has attracted many researchers from various fields and dimensions of interest, who have produced new insights and extended the knowledge of how humans process musical sound in their brains, how the mind and the body are involved in this process and how practitioners and listeners alike respond to music cognitively, emotionally and socially. This chapter provides readers with a survey of topical research from developmental psychology and neuroscience. Especially new insights from brain research have drawn the attention of a broad audience of musicians, educators and scientists as well as the interested public, attracted by the new possibilities of brain research related to music and music education (Gruhn & Rauscher, 2008; Koelsch, 2012; Peretz & Zatorre, 2003). Music psychology has also expanded and covers various dimensions of the developmental growth of musical processing (Hargreaves & Lamont, 2017). Although a great deal of our knowledge about cognitive processing is grounded in the results of neuroscience, it also plays on findings coming from behavioural studies and qualitative descriptions.

Along with behavioural and empirical findings, we aim to present a condensed review of the research on the development of music processing throughout the lifespan. By this, the chapter mainly intends to uncover the structural conditions for playing, listening and recognising sound to be something which transcends mere sensory stimulation. Therefore, although the general line of the review follows the chronological development over the life course, it comprehensively demonstrates tonal and temporal processing in music and language and considers general aspects, such as neuroplasticity, performance and practice, auditory imagery and memory,

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absolute pitch and sight-reading, and introduces perception as action. Therefore, it equally centres on the physiological, psychological, neurobiological, social and cultural dimensions of human behaviour that contribute to the musical mind and foster understanding of the growth of individuals' musical thinking and music performance.

Prenatal development and early childhood

Prenatal research on human development has become a new research focus because foetal development establishes the basis for further development and behaviour in childhood in terms of perceptive, cognitive, behavioural and psychological dimensions, all of which have prenatal origins. This applies to auditory abilities, the vestibular sense of balance and the proprioceptive sense of body orientation and movement (Parncutt, 2009). The foetal auditory system starts to process sound around 20 weeks of gestation (Parncutt, 2006). The auditory system is one of the first senses that is fully developed and functioning before birth.

Unlike the visual environment of the foetus, the auditory environment is rather rich and diverse; it consists of internal sounds (heartbeat, blood flow, breathing, digestive noise, body movement and even the mother's voice) and external sounds (voices, environmental noise, music). Initially, the frequency range to which the cochlea responds is rather small, ranging from 200 to 1000 Hertz (Parncutt, 2006). More important, the external sound is muffled and attenuated when it passes through the mother's body and the amniotic fluid. Therefore, internal sounds appear to be louder and clearer than external sounds. The mother's voice, especially, is perceived through bone conduction and, therefore, plays a prominent role in foetal auditory environment. The attenuation affects the prominence of vowels compared to consonants, and the fundamental frequency contour is more salient than spectral information.

It has been observed that the foetus responds to audible stimuli (music) by a change of heart rate and body movement. Heart beat acceleration evoked by sound perception begins at about 20 weeks (Lecanuet, 1996) and occurs regularly at about 26 weeks (Abrams, 1995). Motor responses to loud and rhythmically stimulating sounds become consistent at 28–32 weeks (Kisilevsky et al., 2004). The cochlear and vestibular systems are connected and develop in parallel. Through maternal communication, the foetus has access to the mental and emotional state of the mother via the perceived sound and movement and via biochemical information (hormone concentration in the blood). By this, the foetus connects the maternal emotional state with patterns of sound and movement, which is important for postnatal development of emotional behaviour and supports the bonding of the child and the mother.

Finally, there is a general interest in foetal learning. However, this primarily refers to habituation and memory (Hepper, 1991). It is obvious that a newborn can recognise their mother's voice but not their father's, even if the latter was equally present (DeCasper & Prescott, 1984; Lee & Kisilevsky, 2014). Similarly, newborns exhibit a different behaviour to music they have heard repeatedly before birth compared to unfamiliar music. This is primarily due to the habituation hypothesis, which explains the behaviour better than prenatal learning, and it supports the function of memory for musical tunes after prenatal exposure.

Infants exhibit a natural and vital interest in musical features (for a review, see Trehub, 2006, 2009). They show a high sensitivity to rhythmic pulsation and melodic pitches. This is especially true for premature neonates who keep bonding with their mother through body contact and maternal vocalisation. In recent times, music has been used more and more in special care units as a treatment for preterm infants, because exposure to music can induce changes in the functional brain architecture and cause an increase of those networks that are normally found to be decreased in premature neonates (Lordier, Loukas et al., 2019; Lordier, Meskaldji et al., 2019).

During the first months of life, infants are astonishingly proficient in processing pitch and time (metric) relations (Hannon & Johnson, 2004; Trehub et al., 1999). They develop a pronounced sensitivity to expressive maternal singing. From the very beginning, they clearly prefer infant-directed singing (motherese) to other types of singing or normal speech (Trainor, 1996). Furthermore, there is evidence that infants prefer consonant to dissonant sequences (Trainor & Heinmiller, 1998; Trainor et al., 2002). Infants are already skilful listeners with a remarkable ability to differentiate between small sound changes. In the early stages, they are sensitive to changes even in tonalities and metric systems of non-Western cultures (Hannon & Trehub, 2005; Trehub et al., 1999); however, by 12 months, this openness to all kinds of tonal and metric organisations gradually disappears as a result of cultural conditioning (Hannon & Trehub, 2005). This indicates a general openness of the mind for different tonal and metric systems which will consolidate with exposure and experience.

Early childhood is characterised by an impressive development of aural skills and the ability to differentiate aural information. However, we must consider that infants and children experience and process music in a quite different way. Whereas adults measure time and space while counting units of distance from one to the next, children rely on the present and relate what they hear to what they have just heard before. But, in doing so, they do not measure; instead they experience time and space by the continuous flow of movement and the felt weight of their body. This is in essence what Rudolf Laban has elaborated in his *Choreutics* (Laban, 1991). Accordingly, flow and weight are the two main modalities of infants' musical experience.

The cognitive processing of musical sound and mental development have been investigated by Edwin Gordon's music learning theory based on his concept of "audiation", which aims at the constitution of genuinely musical thinking (Gordon, 1990). This endeavour calls for an integration of corporeal experience (movement) into perception and cognition. Whatever infants do, they get their body involved. The communicative interaction between the mother or the environment and the infant underpins the communicative function of body movements. Gestural narrative patterns of voice and body build the foundation of communicative musicality (Malloch & Trevarthen, 2009, 2018), which links musical thinking and expressiveness with body movement (Llinás, 2001).

Gibson's (1986) ecological perception theory has introduced a new view on cognition as an interactive exploration of the environment by responding to the affordance of what is to be perceived and recognised. In this regard, the body plays an essential role in the development of perception and cognition. Therefore, perception and cognition in infancy and childhood must be seen as embodied and enacted processes (Hurley, 2013; MacRitchie et al., 2013; Rowlands, 2010; van der Schyff et al., 2018).

It has been argued that formal musical training enhances infants' music skills, if not their general cognitive development; however, research in early childhood confirms that informal musical exposure has the best effect on the development of musical competencies (Trainor & Corrigall, 2010). A major area of musical development comprises singing and vocal development, and there is a large body of research on this (for a review, see Welch, 2016). Vocal babblings antecede singing and speaking. Here, one has to differentiate between *vocal learning*, which is based on imitation generated by the vocal organs and is shared by a few mammals (humans, bats, cetaceans, seals, elephants) and birds (songbirds, parrots, hummingbirds), and *auditory learning*, which is grounded in memories of sounds heard without the ability to imitate them. First indications of vocal learning appear in baby cries that mirror the prosodic shape of the sound envelope of the mother tongue (Mampe et al., 2009; Prochnow et al., 2019). The cultural rootedness and emotional expression of a mother's vocal interactions with her infant are extremely important for its further development.

First approaches to singing are characterised by glides and instable pitches. Research has shown how young children primarily focus on pitch chroma instead of matching the precise pitch height (Stadler Elmer & Elmer, 2000). (See the sections on "Models of cognitive representation and neural processing" and "Absolute pitch" for further discussion of pitch chroma and pitch height.) Therefore, for infants' early musical guidance, it is important to develop and consolidate their singing voice in contrast to the speaking voice, which has a much smaller vocal range (Gudmundsdottir, 2018; Rutkowski, 1997, 2015). However, early vocal development exhibits large individual differences according to infants' musical aptitude and environmental stimulation. Therefore, it is quite problematic to indicate concrete dates and ages when children start using their singing voice; rather, one needs to distinguish the chronological age from the musical age (Gordon, 1990). In general, infants perform diverse vocal activities and different types of melodic development (Stadler Elmer, 2015) as precursors of their language acquisition.

The formation of the musical mind: Emerging cognitive abilities during schooling

The years from starting school up to adolescence are characterised by the growth of cognitive abilities. It is the time when the prefrontal cortex, where cognitive functions are mainly located, matures. As early childhood is characterised by an exuberant growth of synapses (Bruer, 1999; Eliot, 1999), it now becomes more relevant to strengthen those connections that are used most and to prune others that are no longer needed. Pruning becomes as important as synaptogenesis for the functional stabilisation of neural networks. This process is favoured by environmental stimulation (enriched environment). The experience-dependent plasticity of the brain opens a sensitive window to adapt to new demands and supports the cognitive development.

As Piaget (1996) has shown, many cognitive functions are established by observation, exploration, reflection and interaction with the environment. This dimension has become extremely prominent in recent cognitive psychology. A new science of the mind (Rowlands, 2010) accentuates the role of the interaction between the growing mind and its entanglement with external conditions. The philosopher Mark Rowlands rejects a Cartesian view of cognition that determines mental states and cognitive processes solely by neural mechanisms in the brain. On the contrary, he claims that external relations of the brain can become essential parts of the mind. Therefore mental states and cognitive processes are variously "embodied", "embedded", "enacted" and/or "extended" (the "4E conception of the mind"). This focuses on a salient interaction of mental development with environmental conditions.

The years of schooling aim at cognitive development in the processing of information and sensorial input. The blow-up of cognitive transfer effects has stimulated music education as a means to foster domain-general cognitive, social and personal competencies (Hallam, 2010). However, the Mozart effect has been discussed rather controversially (Gruhn, 2005). In general, one can state that musical activities exhibit a moderate positive near transfer effect (i.e., learning in a similar context of the same or related domain) on the development of music-related skills, but weak effects on far transfer (effects in a different domain), such as on general intelligence or social behaviour.

With regard to the development of genuine musical abilities, Edwin Gordon (2012) built his cognitive learning theory on the concept of audiation, which can be understood as the neural establishment of mental representations (Gruhn, 2018). Audiation describes a mental state which contains representations of musical phenomena (tonal and rhythmic). While listening to music, one audiates by activating a respective representation of what was previously heard and learned. This theoretical construct of music processing, however, doesn't represent a mere Cartesian understanding of the mind, because listeners – amateurs and professionals alike – respond to their bodily experience of the sound and the environmental and corporeal conditions of the cultural field in which they are rooted.

Through exposure and musical practice, students gain the abstract rules and structures of the grammar of their preferred familiar music because the brain functions as a rule-generating system. However, currently it is difficult to describe how one adopts the system of hierarchical orders as a model of cognition and predictions in public schooling, since there is no longer just one binding musical grammar in favour of various multicultural impacts. Therefore, one cannot pinpoint generally when or even if a student develops a sense of tonality or of the flow of metric pulsation. During schooling, students grow into a musical culture of their own through active participation and personal involvement and embodiment. The way they perceive and process musical sound depends on their cultural and social background. In the following section, we see how the mature brain processes music.

Music processing in the mature brain

Models of cognitive representation and neural processing

Since the earliest brain map was produced by Korbinian Brodman in 1909, we have learned a lot more about the 'what' and 'where' of neural activities while processing music. New brain imaging technologies, including high-resolution nanoscopies, have provided us with an extended knowledge about the location of brain areas and their functions. The Human Brain Project (a European Commission research project) pursues a detailed map of all neural connections (connectome). However, there are unsolved questions regarding the benefits of this knowledge for educational purposes.

Single neurons and cell assemblies are specialised in processing particular parameters of sound (pitch, duration, rhythmic time structure, direction of movement, etc.), and those modules must collaborate to generate an integrated impression of a musical sound (Fodor, 1983), described as parallel distributed processing (Rumelhart & McClelland, 1986). Therefore, the most important accomplishment of the musical mind is to integrate the particular parameters of sound events into a holistic impression of music which is based on a synchronous oscillation of the firing patterns of neurons involved in sound perception.

What we perceive as a musical tone consists of the pitch height (frequency) and pitch chroma (pitch class profile, independent of its height), which are the two dimensions of a tone; these are processed differently, but appear as one musical unit (tone). Krumhansl and collaborators have developed psychological models of the cognitive representation of pitch, on key relatedness and the representation of chord functions (Krumhansl, 1979; Krumhansl et al., 1982; Krumhansl & Kessler, 1982). These models may help to explain how participants of the same cultural environment cognitively represent pitch relations, but it has little relevance to music teaching and learning. However, what is important is to focus on the two dimensions of pitch qualities and their integration into perception, which might focus more on the one or the other and therefore influence the quality of perception.

Neuroplasticity

Brain architecture is determined by genetic factors regarding its general structure, but in detail it develops individually according to environmental and educational impacts and individual use. The brain is not firmly wired; its individual structure is rather plastic and moulds its internal structure in a dynamic process according to environmental demands and personal use. Thus, Elbert et al. (1995) have demonstrated that the cortical representation of the fingers of the left hand of violinists is increased compared with non-musicians. Previous studies have also reported structural brain changes in auditory, sensorimotor and visuospatial areas. Intensive musical training results in greater grey matter volumes in different brain areas, which cannot be ascribed only to brain maturation (Groussard et al., 2014). Because of their training of dependent structural and functional brain modifications, musicians have been used as a model of brain plasticity (Altenmüller & Furuya, 2016; Schlaug, 2015). Deliberate multisensory practice over a long period of time and strong commitment to this activity causes extended networks of multimodal sensorial integration regions. The cross-modal plasticity probably explains some near and far transfer effects associated with long-term musical training (Schlaug, 2009).

Music and language

Another important aspect of musical perception is time and the perceptional structuring of time flow. Music shares this aspect with language and, therefore, also shares neural resources (Patel, 2008). Recently, neurolinguists have started to refer to a dual-stream model of information processing, with partly identical neural pathways (Hickok & Poeppel, 2007; Saur et al., 2008) in which the dorsal (upper) stream is involved in signals to phonological representation and the ventral (lower) stream refers to the auditory processing of signals for semantic comprehension.

In line with linguistic experiments, it has been demonstrated by magnetoencephalography studies that the brain exhibits electrophysiological event-related potential signals independent of special musical training when unexpected irregular syntactic combinations are performed. The left anterior negativity is elicited by morphosyntactic violations (Koelsch, 2012). In music, an early right anterior negativity constitutes the neural correlate of music-syntactic processing; for example, in a regular or irregular chord progression (Koelsch, 2012).

Beyond that, it is more difficult to address musical semantics. In general, an N400 signal (a negative deflection peaking around 400 milliseconds after a post-stimulus onset) indicates the processing of intra-musical meanings (Koelsch, 2012). However, a neurophysiological reaction to structural hierarchies premises a certain degree of familiarity with the particular musical culture and separates this kind of "semantics" from formal "syntactic" regularities.

Performance and practice

To play a musical instrument demands a great deal of auditory-motor interaction. It calls for precise motor coordination with permanent simultaneous auditory control to enact fine motor reflexes. Ongoing feedback loops determine the timing of movements, the sequencing of motor patterns and the spatial organisation of finger positions (Zatorre et al., 2007). To position the fingers precisely in time and place them in the right position on the key or fingerboard involves several cortical and subcortical regions as well as the cerebellum and the basal ganglia. For the production of motor sequences, premotor and prefrontal cortices are activated. In the spatial organisation of finger movements, sensory-motor and premotor areas are involved (Zatorre et al., 2007). However, it needs a lot of repeated practising to automatise fast motor patterns and motor coordination so that these programs can be stored in subcortical regions. In general, musical performance and practice are built on a strong but complex auditory-motor interaction.

A dominant aspect of music processing is pitch, which is represented mentally lateral to the primary cortex (Heschl's gyrus). Pitch sequences that unfold over time engage neurons in anterior (front) and posterior (back) pathways. Therefore, different parameters of a melody (contour, interval size, durations, metric structures) might be processed in different streams (Zatorre et al., 2007). It is an interesting feature that musicians who listen to music they have studied co-activate auditory and motor areas, once again underlining the strong auditory-motor interaction in musicians (Bangert & Altenmüller, 2003; Zatorre et al., 2007). Furthermore, the neural interaction of auditory and motor activities is crucial for mental rehearsal where sound and motor patterns are practised mentally. An important ability for musicians is pitch discrimination. The discrimination sensitivity depends on physiological (genetic) and training-dependent factors. In early music aptitude tests, discrimination of fine pitch changes functioned as an indicator of music aptitude. Psychoacoustic and functional MRI (magnetic resonance imaging) studies have shown that musicians outperform non-musicians by a lower pitch discrimination threshold which is correlated with neural activity in the right auditory cortex (Bianchi et al., 2017).

Besides pitch discrimination, time structure (rhythm) plays an important role in musical performance. Here, the insula and the cerebellum are relevant to the development and representation of motor programs. In ensemble music, a precise synchronisation of all parts is essential. This ability is clearly linked with anticipation and prediction of the next beat. Neurophysiological studies have demonstrated that auditory temporal predictions during sensorimotor synchronisation reflect an extremely complex task and, therefore, recruit a distributed network of cortico-cerebellar brain areas (Pecenka et al., 2013).

Instrumental practice is often seen as training of repetitive motor patterns. However, recent findings from sport science show that it is not the repetition of the intended optimal motor patterns that results in an efficient behaviour, but exploring the diversity of different motor sequences adequate to the individual physiology to establish the most appropriate result. "Differential learning" demonstrates increased learning rates compared to repetitive learning. EEG (electroencephalography) measurements exhibit an increased involvement of parieto-occipital regions that facilitates early consolidation in motor learning (Henz & Schöllhorn, 2016). These results from motor learning in several sport disciplines have also been applied to instrumental practice, establishing a new systematics of motor learning in instrumental pedagogy (Widmaier, 2016).

Auditory imagery, audiation and memory

Auditory imagery is a form of a mental representation of an imagined, physically not present sound. Here, the same neural channels are activated as in real music. Therefore, it shares some traits with Gordon's (2012) concept of audiation. Through audiation, one activates a mental representation of a musical entity (an interval, a motif, a rhythmic cell, etc.) which has already been established and is a prerequisite to giving an internal or genuine musical meaning to what has been heard before or is just imagined. Unlike audiation, which is completely independent of physical sound, auditory imagery comes close to memory, as it can result from a sort of recall of what has already been heard. Thus, auditory imagery is purely a mental process and can be described as thinking in sound. This ability is a solid indicator of musical aptitude and, thus, a core issue in music learning, whereas auditory imagery is sometimes mixed with procedural memory and uses the same neural activations as in real music. Memory is a storage of musical information due to former sensorial experience, which can be retrieved and actualised. Memory capacity changes with age. However, it is striking how long and stable memory for some tunes and pieces can persist throughout the lifespan, and as a consequence, it is implemented in rehabilitation treatments.

Absolute pitch

Absolute pitch is the rare ability to identify or produce a given pitch without a reference tone. This ability is often associated with a higher level of musicianship (Levitin, 2008). However, it has been shown that even children are able to recall familiar songs on the precise pitch level that they had used or heard many times before. This type of a latent absolute pitch also indicates a relevant portion of pitch memory, which is involved in the recall of pitch independent of its octave invariant chroma, or physical spectrum (Jakubowski et al., 2017). Therefore, two subprocesses of absolute pitch recognition can be differentiated: perceptual structures of processing pitch chroma and cognitive associations with a verbal label (Elmer et al., 2015; Kim & Knösche, 2017).

During auditory perception, the human brain analyses time and frequency simultaneously. There is also psychophysical evidence that a musical tone is characterised by two distinct dimensions: pitch height represents a linear dimension caused by the increase of frequencies (e.g., by transposition by an octave), whereas pitch chroma is based on a cyclic octave-independent dimension of recurring tone qualities, so-called *Tonigkeit* (Révész, 1926; Wellek, 1963). Both have distinct representations in the human auditory cortex (Warren et al., 2003) and are crucial for absolute pitch recognition. Whilst chroma determines the harmonic and melodic aspects of music, it is robust in timbre and dynamics. Although it is not yet well understood how the two pitch properties interact in absolute pitch, it seems clear that chroma is highly relevant to pitch recognition ability (Korpell, 1965), which is why auditory perception and identification tasks focus on pitch class rather than octave position.

There are two different dimensions of sound perception that account for clearly distinguishable modes of pitch perception, depending on which aspect of the sound the perception is primarily focused: on tone as a whole with independent recognition of timbre and fundamental pitch; or on its spectral components. Thus, Schneider and Wengenroth (2009) differentiate between two types of listeners according to their aural orientation: holistic (or fundamental) and spectral listeners. It has been demonstrated that both modes are reflected by structural and functional asymmetries in Heschl's gyrus (Schneider, Sluming, Roberts, Bleeck & Rupp, 2005). Furthermore, has been shown that pitch labelling accuracy in absolute pitch possessors might be influenced by the pitch perception preference (Gruhn et al., 2018), indicated by the individual pitch as measured by the Pitch Perception Preference Test (Schneider & Bleeck, 2005; Schneider, Sluming, Roberts, Scherg et al., 2005). Absolute pitch can, therefore, be understood as a highly complex ability with strong associations with the type of pitch preference. This has implications for the teaching of listening skills and ear training methods.

Sight-reading

Music reading and playing from notation is an important faculty of music performance. It is based on the mental connection of a sign or symbol with sound. The notation uses symbols, instead of letter names or fingerings, to represent sound. Reading means to take all musical information from the notation and transfer it into a meaningful and expressive musical performance. Researchers have investigated how well professional musicians were able to connect visual symbols with audiated sound while silently reading scores of well-known themes embedded into a figuratively embellished notation (Brodsky et al., 2003; Brodsky et al., 2008). Only 80% of the participants achieved correct recognition scores for the themes.

Notational audiation as a core ability is essential, namely in situations with little or no preparation, which is indicated as prima vista and is common in ensemble situations and accompaniment (Lehmann & Kopiez, 2009). To study the mechanics of prima vista, sight-reading is necessary to consider the eye movements that are relevant to gathering information from sight. The eye does not fixate on an object (the notation) steadily, but in rapid movements (saccades) four to five times per second, followed by short fixation rests. The musical mind takes information from the notation via these saccadic movements and generates a consistent picture of the score. Eye movement patterns, necessary to perform a notated melody or to read a polyphonic score, can only develop through experience and training. Because it is not possible to fixate on every note in a piano score, one after the other, the eyes need to jump back and forth several times and construct a connected line of single events. For this, the eye–hand span – that is, the individual distance between the actual point of performance and the farthest point of fixation – is crucial for the ability to sight-read. Research has shown that subjects perform more accurately with a preview of two to four beats (Lehmann & Kopiez, 2009). The acquisition of expertise in piano sight-reading is supported by technical piano skills, size of repertoire and accumulated accompanying experience. Additionally, psychomotor effects (tapping speed, trill) and general cognitive abilities (reaction time, mental speed, working memory) have been investigated. Best predictors for an overall sight-reading score are the trill speed between third and fourth finger, the duration of sight-reading experience and auditory imagery (audiation) abilities (Kopiez & Lee, 2008). Since one cannot sight-read beyond the established level of performance experience, sight-reading must be seen as mainly a matter of training and experience (Lehmann & Kopiez, 2009).

Perception and action

In recent times, perception and cognition have been viewed in the context of evolutionary biology, where it is evident that cognitive processes such as thinking and audiating have evolved from bodily movements. As Rodolfo Llinás has demonstrated, "the evolutionary development of a nervous system [is] an exclusive property of actively moving creatures" (2001, p. 17). And these "external properties … have begun to be internalized in the brain" (p. 61). Therefore, "the ability to think … arises from the internalization of movement" (p. 62). This has been confirmed recently by the neurobiologist Daniel Wolpert (2011), who underlines the primary function of the brain to produce adaptable and complex movements. Consequently, the perception of music is strongly associated with corporeal activities. Even the perception itself can be seen as, and is based on, bodily actions (Gruhn, in press). This becomes obvious when musicians play their instrument. The sound is evoked by feeling the fingering. While listening to music, one activates the motor areas of finger movements and, vice versa, in moving the fingers, one senses the music corporally. If perception (audiation) must be taken as an act of internal musical thinking, it has evolved from movement. Therefore, the learning of music should strongly interact with body movements. Perception and the cognition in the musical mind are inseparably connected with action and result in processes of embodied cognition (Shapiro, 2011).

Demands and opportunities in the third and fourth ages

In Western cultures, since life expectancy has expanded significantly and humans are growing older in good health condition, music geragogy has moved into the focus of music educators, neuroscientists and gerontologists. There is a growing cohort of seniors with special needs beyond 60 or 65 years of age who show a pronounced interest in musical activities. And since our understanding of ageing has moved away from a deficit-oriented picture towards a vital model of lifelong learning, it offers more challenging options for active operations beyond former professional experience. Therefore, it has become common to differentiate between the younger elderly (third age; over 60) and the older elderly (fourth age; over 80) (Hartogh, 2018).

From neuroscience we know that the brain holds its plasticity to a certain extent and is, therefore, quite capable of gaining new information and developing extended networks. Although fluid intelligence decreases with age, it is compensated for by stability, or even increase, in crystallised intelligence, where accumulated experience and knowledge is stored. Therefore, many efforts are undertaken to counteract the age-dependent decline of mental capacities through musical activities. Here, music is expected to inhibit mental decline and support social and cognitive dimensions of positive ageing (Altenmüller, 2015; Kenny et al., 2018). The salutogenic effects of singing and music-making are often claimed to justify musical activities in therapeutic situations. However, in music geragogy, musical activities must be seen as an opportunity to open varied possibilities for active engagement.

Among the elderly, many musical abilities can be maintained or re-activated; but on the other hand, there are also distinct physical and mental restrictions, such as reduced mobility, fluency and speed of movement, loss of motor coordination, technical limitations, listening and sight disabilities and reduced cognitive speed and reaction time. These deficits can be partly compensated for by experience, high commitment and strong persistence. In education programmes and activities in community music, these advantages and disadvantages have to be balanced.

Pitch discrimination ability and rhythmic stability and precision are maintained even in higher age groups. Sight and hearing impairments may influence sight-reading accuracy and reaction time, but experience- and training-driven sight-reading skills in general (prima vista play) do not get lost. Musical performance no longer focuses on technical brilliance; rather, it stresses aspects of musical presentation and expression of musically meaningful phrasing and articulation which rise with musical experience. An ongoing question concerns whether it is possible to learn a new instrument. Even elderly people can achieve some instrumental faculties that enable them to play in an ensemble or alone, just for individual satisfaction (Bugos et al., 2004; Cabeza et al., 2002). This has been demonstrated even for people with mental diseases (Beatty et al., 1994; Cowles et al., 2003; Fornazzari et al., 2006).

Skills that have been developed at an early age and continuously practised over the lifespan keep their functionality. Although the *technical* aspect will not necessarily improve, the *artistic* performance can benefit from ageing, as internationally esteemed soloists like Vladimir Horowitz or Menahem Pressler have shown. They might be outperformed by younger pianists in terms of power, energy and technical virtuosity, but their artistic expertise and depth of musical interpretation will gain from their experience. However in everyday situations, the personal satisfaction and social interaction of people who engage in music enthusiastically contribute to positive ageing effects.

Conclusion

The brain is a dynamic system. Therefore, the mental processing of sensory input also corresponds to a dynamic structure. The old model whereby neurons grow, mature and die off should be replaced by a conception of neurons that are implemented in a system of dynamic adaptations according to individual environmental and personal demands with floating periods of activation. Therefore, lifelong changes in neuronal connectivity, an ongoing cerebral activity, and variable synaptic density according to individual application facilitate learning at all ages. Active engagement and deliberate practice keep the particular brain areas busy and enable musical processing and support learning. However, despite all neuroscientific power and sophisticated technology, we do not know why a certain piece music moves some to tears while others are left cold. The huge amount of brain studies cannot disenchant the myth of music and its power on humans, but it can help us better understand the mechanisms of musical processing in the mind.

In this regard, the newly emphasised focus of cognitive psychology on embodied cognition and the involvement of movement in the learning process indicates new ways of teaching and learning. If thinking is internalised movement, the body and its motor activities become prominent modes and models in education. Especially in early childhood education, it is necessary to enable children to develop mental representations of the musical phenomena they are exposed to. And this process is best supported by the involvement of the entire body. The understanding of different modes of musical thinking in children and adults should affect the teaching of pitch and time (rhythm) through weight and flow. A better knowledge of the mental processes of music perception and cognition, then, will promote the embodied cognition of musical parameters which do not completely correspond to notated music. Therefore, in Western societies, children must learn how the Western conventions of musical notation are represented in notational symbols. Otherwise they will never understand the phenomenal correspondence of sound and sign. Besides the evolutionary roots of embodiment (Llinás, 2001), which supports the integration of movement into the learning process, two different types of listening (holistic versus spectral sound representation) should be considered to address the individual needs of students regarding their sound representation.

However, a detailed knowledge of the psychological and physiological processing of music as well as the most sophisticated neuromusical research cannot immediately lead to explicit methodical and didactical applications, but we can and should base didactic decisions on relevant empirical facts. With regard to this, further research could include more intervention studies that investigate the effect of neuroscientifically recommended methods on the quality of learning. There is also a desideratum of comparative studies of the learning in different cultures, traditions and social practices that reflect the activated mechanisms of music perception, cognition and practice.

Reflective questions

1. Is there an educational need or possibility to apply results from cognitive psychology and/or neuroscience to music pedagogy?
2. To what extent does neuromusical research account for music pedagogy?
3. Is there a particular domain in music pedagogy that is strongly based on the knowledge coming from neuromusical research?
4. According to individual teaching experiences, are there didactic aspects that are strongly related to the reported findings?
5. How and in which domain is educational and neuropsychological research related to the actual challenges for music pedagogy?

Suggestions for further reading

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