Psihološka obzorja / Horizons of Psychology, 19, 1, 79-98 (2010)
© Društvo psihologov Slovenije 2010, ISSN 1318-187
Znanstveni teoretsko-pregledni prispevek

Neuropsychology of music – a rapidly growing branch of psychology

Katarina Habe[*]
Faculty of Education, University of Maribor

Abstract: Relationship between brain and music is of interest to musicians, psychologists and neuroscientists. In recent years no other area of psychology of music has seen as much advancement as neuropsychology of music. The aim of the article is to present some main issues in the neuropsychology of music abroad and in Slovenia, to classify research studies into larger categories and to predict the future development of this field.There are different levels of inquiry into the neuropsychology of music: (1) the analysis of normal and abnormal psychological and physiological functions to determine the principles and modes by which the human brain processes, codifies, stores, and produces music, and (2) a description of the clinical deficits in music perception or performance resulting from localized or diffuse damage to the nervous system. Main topics that occupy neuropsychology of music are neuropsychological models of musical processing, functional imaging of musical perception and cognition, and the use of music as a therapeutic and clinical tool. Although some important studies have already been conducted since the year 2003, in Slovenia we faced a "formal" turning point in acknowledging the importance of the connection between music, mind and brain with the Sinapsa's Week of the brain 2009 under the title Brain and music.

Key words: neuropsychology, music

Nevropsihologija glasbe – razvijajoče se področje psihologije

Katarina Habe
Pedagoška fakulteta, Univerza v Mariboru

Povzetek: Povezanost glasbe in možganov je predmet zanimanja psihologov, glasbenikov in nevroznanstvenikov. V zadnjih letih je to področje doseglo največji razcvet izmed vseh področij glasbene psihologije. Namen pričujočega članka je predstaviti poglavitna spoznanja številnih raziskav s področja glasbene nevropsihologije v tujini in v Sloveniji, klasificirati dosedanje raziskave s tega področja v večje kategorije in napovedati smernice nadaljnjega razvoja. Obstaja več nivojev raziskovanja na področju nevropsihologije glasbe: (1) analiza normalnih in abnormalnih psiholoških in fizioloških funkcij, ki determinirajo osnovne principe in načine, s katerimi človeški možgani predelujejo, kodirajo, skladiščijo in ustvarjajo glasbo ter (2) opis kliničnih deficitov v glasbeni percepciji, kogniciji in glasbenem ustvarjanju, ki izhajajo iz lokaliziranih ali difuznih okvar živčnega sistema. Poglavitne teme, s katerimi se ukvarja glasbena nevropsihologija so modeli glasbenega procesiranja, prirojene in pridobljene motnje glasbenega procesiranja, uporaba metod možganskega slikanja med glasbenim procesiranjem in uporaba glasbe kot kliničnega in terapevtskega sredstva. Čeprav so se

[*] Naslov / Address: asist. dr. Katarina Habe, Oddelek za temeljne pedagoške predmete, Pedagoška fakulteta, Univerza v Mariboru, 2000 Maribor, e-pošta: katarina.habe@uni-mb.si

v Sloveniji izvajale raziskave s tega področja od leta 2003 dalje, pa je bil ključni »formalni« korak v smeri prepoznavanja povezanosti možganov in glasbe narejen v letu 2009 v okviru Tedna možganov, v organizaciji društva Sinapsa.

Ključne besede: nevropsihologija, glasba

CC = 2520

Musical brain

An amusing, clear, but also highly professional introduction of the musical brain can be found in the two books of almost celebrity scientist and musician D. Levitin: This is your brain on music (2006) and The world in six songs (2008). Brain specialization for music refers to the possibility that human brain is equipped with neural networks that are dedicated to the processing of music. Finding support for the existence of such music-specific network suggests that music may have biological roots. There are numerous behavioral indications that music-specific networks are isolable in the brain (Peretz, 2000). Music-specific neural networks should correspond to a common core of musical abilities that is acquired by all normally developing individuals of the same culture.

Hodges (2000) introduces the concept of musical brain. The main postulates of his model are: (1) All human beings are born with a musical brain, (2)The human musical brain is different from other animal brains, (3) The musical brain is in operation in infancy, and perhaps even in the later fetal stages of development, (4) The musical brain consists of an extensive neural system involving widely distributed, but locally specialized, regions of the brain, (5) The musical brain has cognitive components, (6) The musical brain has affective components, (7) The musical brain has motor components, (8) The degree to which the musical brain is lateralized is still debated, (9) The musical brain is a very resilient system and (10) Early and ongoing musical training affects the organization of the musical brain.

The brain of musicians

Musicians are an ideal human model to investigate possible functional and structural neural changes due to the acquisition and continuous practice of complex perceptions and actions. Musicians perform complex physical and mental operations such as translating musical symbols into complex motor operations, performing independent movements of fingers and hands, remembering long musical phrases, improvising music, and identifying tones absolutely without a reference tone. The neural correlates of most of these musical operations are not fully understood yet. Many studies have provided evidence for functional and structural differences comparing musicians with non-musicians. Although self-selection for musicianship by individuals with innate functional and structural brain differences cannot be completely ruled out, there is now more and more evidence to support the notion that musical training will lead to changes in brain function and structure. Structural brain differences between musicians and non-musicians can mainly be seen in the structural changes in corpus callosum, motor cortex and cerebellum. Most pronounced functional differences between musicians and non-musicians have been found in perisylvian brain regions with various perceptual tasks ranging from listening to musical pieces, pitch discrimination and memory, harmony, melody and rhythm tasks (Altenmueller, 1986; Besson, Faita & Requit, 1994; Mazziota, Phelps, Carson & Kuhl, 1982; Pantev, Oostenveld, Engelien, Ross, Roberts & Hoke, 1998; Tervaniemi, Just, Koelsch, Widmann & Schröger, 2005). It appears from these studies that musicians and non-musicians process music in a different way, leading to more left hemispheric activation with increased musical sophistication. There may be aspects of music that will be processed more on the right hemisphere by both musicians and non-musicians (e.g., melodic contour tasks) while there are others that will be more processed on the left by both groups (e.g., rhythmic tasks). Gaser and Schlaug (2003) conducted a study using a voxel-by-voxel morphometric technique. They found gray matter volume differences in motor, auditory, and visual-spatial brain regions when comparing professional musicians (keyboard players) with a matched group of amateur musicians and non-musicians. The latest research of Gibson, Folley and Park (2009) shows that professionally trained musicians more effectively use both the left and the right sides of their frontal cortex more heavily than the average person. They report a greater bilateral frontal activity in musicians during divergent thinking compared with nonmusicians. Their results suggest that creative individuals are characterized by enhanced divergent thinking, which is supported by increased frontal cortical activity.

Developmental issues in music neuropsychology

Four concepts are central in explaining developmental issues in music neuropsychology: critical periods, optimal periods, windows of opportunity and plasticity. Critical period refers to the idea that there are time frames in which there will be no development if certain stimulation is not present. There are no identified critical periods in musical development. An optimal period is used to refer to those periods in which development will be faster or easier. Gordon (1979, 1990) advanced the idea of developmental music aptitude. He has found that children's scores on measures of musical aptitude do not change significantly after the age of approximately nine years. A few studies indicate optimal periods and point toward possible critical periods of music training (Elbert, Pantev, Wienbruch, Rockstrub & Taub, 1995; Nelson & Bloom, 1997; Schlaug, Jäncke, Huang, Steiger & Steinmetz, 1995). Windows of opportunity refers to the idea that there are general time frames in which optimal or critical development will take place. Bruer writes: "For most learning, particularly learning culturally transmitted skills and knowledge such as reading, mathematics, and music, the window of experience-dependent opportunity never close" (1999, p.187). Brain plasticity refers to the notion that the brain is very adaptable, fluid. Involvement in music may help keep the brain more fluid as opposed to no musical involvement throughout the human lifespan (Snowdon, 1997, 2001).

To conclude, developmental periods hint of a genetically-influenced mechanism that is mediated by environment. These developmental periods have received a great deal of attention also in music-making skills. Several recent works have suggested that music learning has a critical period, which if missed, closes the doors to future musical competence. This widely accepted fact is untrue – the brain does have some periods in which it is more sensitive to the active development of music, and it makes sense to engage learners during these times. However, it is not true that if you don't learn music as a youngster, you'll never learn it. It may take more time to reach proficiency if you learn it later in life, but it's possible.

Ways of conducting neuromusical research

Understanding of the cognitive and neurological bases for music processing has advanced greatly in recent decades (Peretz & Coltheart, 2003; Peretz & Zatorre, 2005; Koelsch & Siebel, 2005; Stewart, von Kriegstein, Warren, & Griffiths, 2006). Flohr and Hodges (2002) have divided strategies for conducting neuromusical research into six categories: animal research, fetal and infant research, research on brain-damaged individuals, hemispheric asymmetry research, brain imaging research, neuromotor research and affective research. I'm going to use these categories that Flohr and Hodges defined as a starting-point and a frame for explaining the main issues in neuropsychology of music. Many times the research studies could be classified into more than one category, so one must be aware of the arbitrary decisions.

Animal research

This line of research provides evidence of some of the neural mechanisms possess that allow human musicality and it's important in developing a theory of an evolutionary basis for music (Hodges, 1989, 1996, 2000; Patel, 2006; Patel & Iversen, 2006; Patel, Iversen, Bregman, & Schulz, 2009a; Patel, Iversen, Bregman, & Schulz, 2009b; Wallin, Merker & Brown, 2000). This research strategy informs two concerns of music psychologists: What are the evolutionary antecedents of human musicality and what extra cognitive structures and processes do humans possess beyond those of other animals that allow for the degree of musicality expressed in other cultures. Most animals have devices for detecting, analyzing, and responding to sounds. When humans listen to music, the process is similar in that we analyze the sound for meaning and that meaning shapes our responses. Humans are able to bring a number of cognitive and affective processes to bear that animals cannot; but the rudimentary structures may be much the same. Thus, the value of animal research is in providing us with knowledge of these basic structures. Most of these researches have been done with song-birds (Marler, 1991), with rats, monkeys, great apes and pigeons (D'Amato, 1988; Gillis, 1990; Hulse, 1990; Hulse, Takeuchi & Braaten, 1992). The main conclusion is that none of the animal studied so far are able to discriminate frequency contour and that all animal species utilize absolute frequency discrimination as a means of discriminating tonal patterns. Both humans and nonhumans use a hierarchy of perceptual strategies that begins with absolute pitch perceptions and then moves to relative pitch perception. However nonhuman animals stay on relaying on absolute pitch perception. This evolutionary approach is profoundly presented in two books: in a book by S. J. Mithen *The Singing Neanderthals: The Origins of Music, Language, Mind and Body (2005) and in a book* Music, language and the brain by A. D. Patel (2008).

Fetal and infant research

In the past few years there is a growing interest in studying fetal responses to music because in the last trimester before birth, the fetus is capable of responding to sounds in the womb. A very thorough and systematic introduction of the auditory development in fetus and infant can be found in the article of Graven and Brown (2008). There is abundant evidence showing that the human fetus is aware of and responsive to sounds, including music (Annis, 1978; Eccles & Robinson, 1985; Friedrich, 1983; Restak, 1983). Researchers can gauge fetal responses by monitoring heart rate and through bodily movements (Abrams & Gerhardt, 1997; Deliege & Sloboda, 1996). Almost immediately after birth, babies can orient toward sounds and soon after that can pick out the sounds of the mother's voice (Trehub, Schellenberg & Hill, 1997; Trehub & Trainor, 1993). "Motherese," a term psychologists have coined to refer to the type of a baby talk tipically spoken to infants, emphasizes pitch, timbre, dynamic inflections, and rhythm patterns in order to convey meaning (Dissayanake, 2000). Through that baby learns to interpret the emotional content and consequently to communicate by manipulating the same sonic elements to express basic emotions and needs. S. Trehub, one of the first and leading researchers in the field of developmental music perception and cognition, and her colleagues had established that human infants begin life with various musically relevant abilities, including fine-grained perception of pitch and rhythm patterns (Hannon & Trehub, 2005a; Trehub, 2000), preferences for consonant over dissonant intervals (Trainor, Chang & Cheung, 2002; Zentner & Kagan, 1996), cross-modal correspondences between sound and movement (Phillips-Silver, & Trainor, 2005) and heightened responsiveness to the expressively sung performances of mothers (Masataka, 1999; Nakata & Trehub, 2004; Shenfield, Trehub & Nakata, 2003; Trainor, 1996; Trehub

& Trainor, 1998). They have also learned that exposure to the music of their culture not only builds upon infants' initial biases but also reshapes them (Hanon & Trehub, 2005b; Trainor & Trehub, 1992; Trainor & Trehub, 1994). In a recent study Soley and Hanon (2010) concluded that infants' musical preferences appear to be driven by culture-specific experience and a culture-general preference for simplicity.

Research on brain-damaged individuals

Neuroscientists have found it very revealing to study brain-damaged patients as a means of understanding cognitive functioning (Aldridge, 2005; Dalla Bella, Kraus, Overy & Pantev, 2009; Gilbertson & Aldridge, 2008). A review of the literature on this matter was done in the article "Music and the brain: disorders of musical listening" by Stewart, von Kriegstein, Warren & Griffiths (2006). We can divide the brain-damaged individuals into three categories: (1) individuals who have suffered a tumor, stroke or lesions, (2) individuals with inherited cognitive limitations and (3) individuals who suffer from cognitive dementias due to aging. A common research approach is to ask brain-damaged subjects to do a variety of music-related tasks. Main conclusions from this research line are that music and language are represented, at least to a large degree, by separate neural system (Hodges, 1996b; Marin & Perry, 1999). Many brain regions are implicated in both language and music (Falk, 2000; Patell, 2008). The next important finding is that musical savants are cognitively impaired but capable of amazing musical feats (Miller, 1989). Especially individuals with Williams syndrome often have cognitive "peaks" and "valleys" and music appears to be something many of them can do quite well (Levitin & Bellugi, 1998). Concerning individuals with cognitive dementias due to aging it is evident that individual with prior musical backgrounds may retain procedural skills. Music is being recommended to elders as a means of staving off the ravages of Alzheimer's (Golden, 1994; Omar, Hailstone, Warren, Crutch, Warren, 2010). Dalla Bella, Giguère & Peretz (2009) conducted a study using an acoustic analyses that showed that amusics are, on average, substantially worse at singing familiar melodies than normals and that auditory perception and action streams may be distinct in some ways, dissociation between conscious perceptual and production abilities was further supported by reports that quarter-tone differences in pitch can evoke electrophysiological responses without perceptual awareness in amusics (Peretz, Brattico, Järvenpää & Tervaniemi, 2009).

Hemispheric asymmetry research

For a period of time, primarily during the 1970s, much was made of music being in the right side of the brain. Osborne and Gale (1976) found the left hemisphere more activated for words and arithmetic and the right hemisphere for music. Molfese, Freeman, and Palermo (1975) demonstrated that subjects had larger auditory evoked responses for nonspeech sounds (including music) in the right hemisphere. This oversimplification has since been modified. Music is not in the right side of the brain alone; both sides are involved. In fact, sophisticated musical processing most likely involves front-back, top-bottom, and left and right sides of the brain is widely distributed but locally specialized neural networks. The human brain appears to have highly specialized structures for music. It is believed that the elemental response to music falls into the lower parts of the brain (cerebellum, limbic system) and to the right hemisphere. The development of musical forms, sophisticated analysis and harmonic understanding lie in the left hemisphere. Pitch is a primary feature of all sounds and is necessary for auditory perception. Because pitch is a built-in property of the brain, then damage to the area responsible for processing impair it. And in cases of a right-hemisphere stroke or seizure, timbre is also typically impaired (Samson and Zatorre, 1994). The brain has a kind of frequency map where neighboring frequency areas are located close together. If you stimulate one part of the map with a frequency, an adjacent area of the cortex is activated, too (Zatorre, 1988). This suggests likelihood for built-in structures related to pitch, frequency, and tones. Another musical quality called melodic contour has interested researchers and specific brain cells are supposed to process it (Weinberger & McKenna, 1987). Other cells in the mammalian auditory cortex have been found to process specific harmonic relationships (Sutter & Schreiner, 1991). On the other hand rhythmic/temporal qualities have been linked to a specific group of neurons in the auditory cortex (Hose, Langner & Scheich, 1987).

Most of this research is conducted by studying brain damaged individuals, brain imaging and dichotic listening. Since the first two are going to be explained in other chapters, in this chapter we will focus on dichotic listening. Dichotic listening tasks have been widely used as a means of comparing one side of the brain's performance with other. Basically, the technique is to present conflicting signals to the right and left ears via headphones. Approximately 70% of the fibers in the auditory pathway are contralateral. Thus, although both sides receive all the information from each ear, signals from the right ear are more strongly represented in the left hemisphere, and vice versa (Kimura, 1961; Robinson & Solomon, 1974). Researchers obtained data show bilateral involvement, with the left hemisphere predominant, for notes and scales, but bilateral involvement with right hemisphere dominance for melody (Breitling, Guenther & Rondot, 1987). Referring to the literatures that suggest that right hemisphere might participate in the expression of music, namely singing and playing instrumentals, Masayuki Satoh, Katsuhiko Takeda, Shigeki Kuzuhara (2007) conducted the study using melodic intonation therapy (MIT). They predicted that MIT will utilize the compensational function of right hemisphere for damaged left hemisphere. They reported that mental singing improved the gait disturbance of patients with Parkinson's disease. Their conclusion was that music therapy is changing from a social science model based on the individual experiences to a neuroscience-guided model based on brain function and cognitive processing of the perception and expression of music.

Brain imaging research

Various brain imaging techniques (EEG and ERP, MEG and SQUID, MRI and fMRI, PET, TMS) are opening up new understanding about the brain in general and about music cognition specifically. The most rapid advancements are being made in this field. In this chapter the emphasis will be given to just those brain imaging techniques that are frequently used in studying music processing. Electroencephalography (EEG) concerning music neurology it's being employed to study music processing (Altenmüller, 1993; Barber, 1999; Faita & Besson, 1994). Many studies that are presented in other chapters have been conducted using EEG, so only some of them are going to be introduced here. EEG patterns have been examined while subjects engaged in a variety of musical activity. Rogers and Walter (1981) found alpha waves to be in synchrony with strongly rhythmic portions of a Mozart symphony. Osaka and Osaka (1992) also found that peak alpha frequency of EEG changes as the tempo of music changed. Wieser and Mazola (1986) demonstrated that EEG recordings made from depth electrodes implanted in the left hippocampus reflects a musical consonance/dissonance dichotomy. Numerous researchers have found that alpha production decreases during music listening conditions (Duffy, Bartels & Burchfield, 1981; Flohr & Miller, 1993; Furman, 1978; Inglis, 1980). It was also found, that musician produce more alpha activity that non-musicians in music listening conditions (Wagner, 1975a, 1975b; Wagner & Mantzel, 1977) and that musicians increased their alpha output during music while non-musicians decreased in alpha (Mc Elwain, 1979; Wagner & Mantzel, 1977). It was concluded that the incidence of alpha waves may vary according to a positive or negative reaction to the music. The evidences also reflect that musicians show alpha decrease with a stronger decrease in the left hemisphere involving the temporal region and invading the precentral, frontal, and parietal areas. Non-musicians exhibited a decrease in alpha restricted to the left midtemporal area (auditory cortex) (Petsche, Linder, Rappelsberger & Gruber, 1988). Concerning EEG coherence patterns it was concluded that musically trained subjects exhibit significantly higher coherence values both within and between hemispheres. These differences, found mainly in the upper and lower frequency bands and less so in alpha, may indicate specialized brain reorganization enhancing the ability to process ordered acoustical patterns.

Event-related potentials (ERP) examine the brain's immediate response to a stimulus in millisecond intervals. The P300 has been more frequently studied in relation to music (Cohen & Erez, 1991; Frisina, Walton, & Crummer, 1988). It has been found that the more difficult the pitch discrimination task, the larger the latency of P3 (Ford, Rooth & Kopell, 1976; Walton, Frisina, Swartz, Hantz, & Crummer, 1988). Musicians showed an inverse relationship between accuracy and P3 latency (Chuang, Frisina, Crummer & Walton, 1988; Levett and Martin, 1992). P3 was greatly reduced or absent altogether in subjects with absolute pitch (Hantz, Crummer, Wayman, Walton & Frisina, 1992). P3 was not different for musicians and nonmusicians for easier timbre discrimination, but musicians had shorter latencies than nonmusicians for more difficult timbre discrimination (Crummer, Walton, Wayman & Hantz, 1994). P3 was found to be useful technique for studying neural and cognitive responses to music in patients with senile dementia (Swartz, Walton, Crummer, Hantz & Frisina, 1992).

Magnetic resonance imaging (MRI) it has been used to show structural features of musician's brain (Amunts et al., 1997). Researchers used MRI data to document that the left planum temporal and corpus callosum of musicians are larger than those of nonmusicians (Schlaug, Jancke, Huang & Steinmetz, 1994). A subsequent study revealed that planum temporale is more strongly lateralized in the left hemisphere for musicians than nonmusicians and that the musicians with perfect pitch are more strongly lateralized to the left than musicians without perfect pitch (Schlaug, Jancke, Huang and Steinmetz, 1995). Keenan, Ven Thangaraj, Halpern and Schlaug (2001) had further established a significantly greater leftward PT (planum temporal) asymmetry and a significantly smaller right absolute PT size for the AP (absolute-pitch) musicians compared to the two control groups was found, while the left PT was only marginally larger in the AP group.

Positron emission topography (PET) it is often used for studying music processing (Parsons, Fox & Hodges, 1998; Zatorre, 1994; Zatorre, Evans, & Myer, 1994). From the results it can be concluded that there is greater activation of the right temporal and parietal lobe along with the right posterior, interior frontal area. PET data also showed the right temporal cortex to be active in perceptual analyses of melodies (Zatorre, 1994; Zatorre, Evans & Mayer, 1994).

Neuromotor research

This line of research can be divided into two categories: (1) Motor aspects of music making and (2) Effects of music on motor activity. The most profound review of the literature on this subject was made in the book Music, Motor Control and the Brain by Eckart Altenmüller, Jurg Kesselring, and Mario Wiesendanger (2006). This is the first book to explore the neural bases of musicians' motor actions, examining these functions across a range of instrumental types and performance situations. It presents state of the art research showing how long term involvement in music can affect the brain and explores the motor problems that frequently occur in later life amongst professional musicians, and possible therapies. Musical performance activates motor control areas in the brain to such a high degree that musicians may be considered small-muscle athletes (Wilson, 1986). Rhythmic timing embedded in music serves as a cue to motor system timing mechanism in the brain. Main conclusions from this research area are that motor systems in the brain are strongly activated during music performance (Parsons, 2001) and that motor cortex controlling particular instrument movements is increased in response to musical training, both actual and imagined (Pascual-Leone et al., 1995). Musicians frequently rely on the rapid execution of intricate patterns. According to Wilson (1986) the motor cortex acting alone is far too slow to allow for the necessary speed of these movements to be carried out in the tempo required. Accomplishing this feat demands the cooperation of the cerebellum. When a particular sequence of muscle movements is repeated frequently, the pattern of those movements is stored as a unit or program. The motor cortex, basal ganglia, and cerebellum work hand in hand to provide smooth, facile, musical performance. The results of several studies indicate that early musical training has long-term effect on brain organization (Elbert et al., 1995; Fox et al., 1995; Moore, 1988, 1992; Wilson, 1992). The results of studies may be useful in understanding not only the physiology of skill acquisitions, but also the pathophysiology of movement disorders in skilled performers.

On the other hand we must not neglect the effects of music listening on motor activity. Music elicits strong motor responses from listeners. Researchers are using music, particularly its rhythmic and tempo aspects, in a neurologic rehabilitation program. Rhythmic auditory stimulation has facilitated walking in stroke and Parkinson's patients (Thaut, McIntosh, Prassas & Rice, 1993; Thaut, McIntosh, & Rice, 1995).

Affective research

The emotional import of music experience is a strong component of music and music instruction (Leonard & House, 1972). It may be helpful to think of emotion in three ways (Buck, 1986): Emotion (1) involves homeostasis (maintenance of body stability) and adaptation and can be measured by monitoring physiological changes. Emotion (II) involves spontaneous expressive tendencies and can be measured by direct observation of external displays, such as postures and facial expressions. Emotions (III) involves the subjective experiences of a person and is often monitored by self-report. Concerning neurology the first two are of our interest.

Musical experiences can elicit a wide variety of physiological responses, including changes in heart rate, blood pressure, brain waves, and muscle contractions. It has been concluded that different brain regions are activated in response to positive and negative musical listening experiences (Blood, Zatorre, Bermudez & Evans, 1999). In particular, studies in psychoneuroimmunology are being used in music medicine to document the physiological effects that music has on body (Pratt & Spingte, 1996; Reilly, 1999). Fear and anxiety can be reduced in many clinical situations through the use of music. Blood, Zatorre, Bermudez & Evans (1999) suggest that music may recruit neural mechanisms similar to those previously associated with pleasant/unpleasant emotional states but different from those underlying other components of music perception and emotions such as fear.

Emotional experiences tend to elicit spontaneous expressions; these can often be seen in facial expressions, body movements, posture, and so on. Nearly all individuals can modulate the voice in terms of pitch, tone and rhythm to express emotion. Music is an extended version of the expression of emotion via sound across time. According to Langer (1953) music is the tonal analog of the emotive life. A series of experiments have been conducted to document the relationship between music and essentic form. The results show that each of several major composers, such as Bach, Mozart etc., has a distinctive essentic form and that the essentic forms produced by internationally famous musicians were consistent within each composer's music (Clynes, 1977). De Vries (1991) found out that sentograms for the same pieces of music were similar to different subjects.

Hunter, Schellenberg and Schimmack (2010) examined similarities and differences between (1) listeners' perceptions of emotions conveyed by 30 s pieces of music and (2) their emotional responses to the same pieces. Feeling and perception ratings were highly correlated but perception ratings were higher than feeling ratings, particularly for music with consistent cues to happiness (fast-major) or sadness (slow-minor), and for sad-sounding music in general. Associations between the music manipulations and listeners' feelings were mediated by their perceptions of the emotions conveyed by the music. Happiness ratings were elevated for fast-tempo and major-key stimuli, sadness ratings were elevated for slow-tempo and minor-key stimuli, and mixed emotional responses (higher happiness and sadness ratings) were elevated for music with mixed cues to happiness and sadness (fast-minor or slow-major). A lot of studies about affective responses to music have been made in the domain of music therapy (Aldridge, 2005; Baker, Wheeler, Tamplin & Kennelly, 2006;)

Neuropsychology of music in slovenia

Only a few studies in the research field of the neuropsychology of music have been conducted in Slovenia. We've started with the studies of Mozart effect using ERD/ERS (event related desynchronization/synchronization) and ERCoh (event related coherence) technology. In our first study (Jaušovec & Habe, 2003) we confirmed significant differences in induced event-related desynchronization between the 3 music clips, that differed in the level of their complex structure, induced mood, musical tempo and prominent frequency. The differences were only observed in the lower-1 alpha band which is related to attentional processes. A similar pattern was observed for the coherence measures. While respondents listened to the Mozart clip, coherence in the lower alpha bands increased more, whereas in the gamma band a less pronounced increase was observed as compared with the Brahms and Haydn clips. The clustering of the three clips based on EEG measures distinguished between the Mozart clip on the one hand, and the Haydn and Brahms clips on the other, even though the Haydn and Brahms clips were at the opposite extremes with regard to the mood they induced in listeners, musical tempo, and complexity of structure. This would suggest that Mozart's music - with no regard to the level of induced mood, musical tempo and complexity - influences the level arousal. In our second study (Jaušovec & Habe, 2004) twenty individuals solved a visual oddball task in two response conditions: while listening to the Mozart's sonata K. 448, and while listening to nothing. In the music response condition the ERP peak latencies on the left hemisphere increased, whereas on the right hemisphere a decrease of peak latencies as compared with the silence response condition was observed. In the theta, lower-1 alpha and gamma band increases in induced event-related coherences were observed while respondents solved the oddball task and listened to music, whereas a decoupling of brain areas in the gamma band was observed in the silence response condition. This study suggested that auditory background stimulation can influence visual brain activity, even if both stimuli are unrelated. Our third study (Jaušovec & Habe, 2005) investigated the influence of Mozart's music on respondent's brain activity while solving spatial rotation and numerical tasks. The method of induced event-related desynchronization/synchronization (ERD/ERS) and coherence (ERCoh) was used. The music condition had a beneficial influence on respondents' performance of spatial rotation tasks, and a slightly negative influence on the performance of numerical tasks as compared with the silence condition. On the psychophysiological level a general effect of Mozart's music on brain activity in the induced gamma band was observed, accompanied by a more specific effect in the induced lower-2 alpha band which was only present while respondents solved the numerical tasks. It was suggested that listening to Mozart's music increases the activity of specific brain areas and in that way facilitates the selection and "binding" together of pertinent aspects of sensory stimulus into a perceived whole. Jaušovec, Jaušovec & Gerlič (2006) investigated further the influence Mozart's music on brain activity in the process of learning. In Experiment 1 individuals were first trained in how to solve spatial rotation tasks, and then solved similar tasks. Fifty-six students were divided into 4 groups: a control one – CG, who prior to and after training relaxed, and three experimental groups: MM - who prior to and after training listened to music; MS - who prior to training listened to music and subsequently relaxed; and SM - who prior to training relaxed and afterward listened to music. The music used was the first movement of Mozart's sonata (K. 448). In Experiment 2, thirty-six respondents were divided into three groups: CG, MM (same procedure as in Experiment 1), and BM - who prior to and after training listened to Brahms' Hungarian dance No. 5. In both experiments the EEG data collected during problem solving were analyzed using the methods of event-related desynchronization/synchronization (ERD/ERS) and approximated entropy (ApEn). Results in the first experiment showed that the respondents of the MM, MS, and SM group showed a better task-performance than did the respondents of the CG group. Individuals of the MM group displayed less complex EEG patterns and more rx band synchronization than did respondents of the other three groups. In Experiment 2 individuals who listened to Mozart showed a better task performance than did the respondents of the CG and BM groups. They displayed less complex EEG patterns and more lower-1 x and y band synchronization than did the respondents of the BM group. Authors therefore concluded that Mozart's music, by activating task-relevant brain areas, enhances the learning of spatio-temporal rotation tasks.

Conclusion

The neuropsychology of music is nowadays growing so rapidly that all the new findings in this unique multidisciplinary science can hardly be followed. Since approximately 1970s, when the first significant studies occurred, a giant steps ahead have been made. More than 41 science books involving with music-neuropsychological matters have been published, not to mention all the research articles that are countless. Especially with brain imaging techniques music neuropsychology has gained several important facts in brain functioning and structure regarding to music. There are numerous research laboratories all over the world putting their effort in exploring the relationship between brain and music. In a few recent years the neuropsychology of music has made an important step towards the educational practice, trying to make all the empirical data more understandable and useful for the educators. Coming to this point the neuropsychology of music has become quite a popular science.

In Slovenia we have only just began exploring this science field with some interesting studies of Mozart effect using ERP technology. But the problem is that such a research field requires a lot of expensive equipment and a good multidisciplinary team that is in Slovenia not yet established.

What is the future of the neuropsychology of music? Probably the popularization of this science will become even greater, because there is always a large interest of the public to understand the phenomena that are kind of mysterious and not completely understandable to our mind, what the music will always remain. So the science will continue trying to reveal the secret behind the music. On the other hand, the music profession will become inevitable dependent on important findings of the neuropsychology of music for their practice.

References

Abrams, R. & Gerhardt, K. (1997). Some aspects of the fetal sound environment. In I. Deliege & J. Sloboda (Eds.), *Perception and cognition of music* (pp.83-101). East Sussex: Psychology Press.

Aldridge, D. (2005). *Music Therapy in Neurological Rehabilitation: Performing Health*. London: Jessica Kingsley Publishers.

Altenmueller, E. (1986). Electrophysiological correlates of music processing in the human brain. *European Archives Psychiatry Neurological Science, 253*, 342-354.

Altenmüller, E. (1993). Psychophysiology and EEG: In E. Niedermeyer & F. L. da Silva (Eds.), *Electroencephalography* (pp. 597-614). Baltimore: Williams & Wilkins.

Altenmüller, E., Kesselring, J. & Wiesendanger, M. (2006). *Music, Motor Control and the Brain.* Oxford: Oxford University Press

Amunts, K., Schlaug, G., Jancke, L., Steinmetz, H., Schleicher, A., Dabringhaus, A. … Zilles, K. (1997). Motor cortex and hand motor skills: structural compliance in the human brain. *Human brain mapping, 5,* 206-215.

Annis, L. (1978). *The child before birth*. Ithaca, NY: Cornell University Press.

Baker, F., Wheeler, B. L., Tamplin, J. & Kennelly, J. (2006). *Music Therapy Methods in Neurorehabilitation: A Clinician's Manual*. Jessica Kigsley Publishers.

Barber, B. (1999). An investigation of neural processes in music cognition using quantitative electroencephalography. *Unpublished doctoral dissertation*, University of Melburne, Melburne.

Besson, M., Faita, F. & Requit, J. (1994). Brain waves associated with musical incongruities differ for musicians and non-musicians. *Neuroscience letters, 168,* 101-105.

Blood, A., Zatorre, R., Bermudez, P. & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature neuroscience, 2*(4), 382-387.

Breitling, D., Guenther, W. & Rondot, P. (1987). Auditory perception of music measured by brain electrical activity mapping. *Neuropsychologia, 25*, 765-774.

Bruer, J. T. (1999). *The myth of the first three years*. New York: Free Press.

Buck, R. (1986). The psychology of emotion. In J. LeDoux and W. Hirsch (Eds.) *Brain and Mind: Dialogues between Cognitive Psychology and Neuroscience*. New York: Cambridge University Press.

Chuang, S., Frisina, R., Crummer, G. & Walton, J. (1988). Effects of varying chord progression on P3 event related potentials in musicians and nonmusicians. *Journal of the acoustical society of America, 83*(1), 13.

Clynes, M. (1977). *Sentics: The touch of emotions*. New York: Doubleday.

Cohen; D. & Erez, A. (1991). Event related potential measurements of cognitive components in response to pitch patterns. *Music perception, 8*(4), 405-430.

Crummer, G., Walton, J., Wayman, J. & Hantz, E. (1994). Neural processing of musical timbre by musicians, nonmusicians, and musicians possessing absolute pitch. *Journal of acoustical society of America, 95*(5), 2720-2727.

Dalla Bella, S., Giguère, J.-F., & Peretz, I. (**2009**). Singing in congenital amusia: An acoustical approach. *Journal of Acoustics Society of America, 126*, 414–424.

Dalla Bella, S., Kraus, N., Overy, K. & Pantev, C. (2009). The Neurosciences and Music III—Disorders and Plasticity. *Annals of the New York Academy of Sciences, 1169.*

D'Amato, M. (1988). A search for tonal pattern in cebus monkeys: Why monkeys can't hum a tune. *Music Perception, 5*(4), 453-480.

Deliege, I. & Sloboda, J. (1996). *Musical beginnings: Origins and development of music competence*. Oxford: Oxford University Press.

De Vries, B. (1991). Assesment of the affective response to music with Clynes's scentograf. *Psychology of music, 19*, 46-64.

Dissayanake, E. (2000). Antescendents of the temporal arts. In N. Wallin, B. Merker & S. Brown (Eds.). *The origins of music* (pp. 387-410). Cambridge, MA: MIT Press.

Duffy, F., Bartels, P. & Burchfield, J. (1981). Significance probability mapping: An aid in the topographic analysis of brain electrical activity. *Electroencephalography and Clinical Neurophysiology, 51*(5), 455-462.

Eccles, J. & Robinson, D. (1985). *The wonder of being human*. New York: McGraw-Hill.

Elbert,T., Pantev, C., Wienbruch, C., Rockstrub, B. & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270*(5234), 305-307.

Faita, F. & Besson, M. (1994). Electrophysiological index of musical expectancy: Is there a repetition effect on the event-related potentials associated with musical incongriuities? In I. Deliege (Ed.). *Proceedings of the third international conference for music perception and cognition* (pp.433-435). Liege: Centre de Recherche et de Formation Musicales de Wallonie.

Falk, D. (2000). Hominid brain evolution and the origins of music. In N. Wallin, B. Merker & S. Brown (Eds.). *The origins of music* (pp.197-216). Cambridge, MA: MIT Press.

Flohr, J. W. & Hodges, D. A. (2002). Music and neuroscience. In R. Colwell & C. Richardson (Eds.). *The new handbook of research on music teaching and learning* (pp. 991-1009). Oxford: Oxford University Press.

Flohr, J. & Miller, D. (1993). Quantitative EEG differences between baseline and psychomotor response to music. In R. A. Fiese & R. A. Duke (Eds.), *Texas Music Education Research 1993* (pp. 1-7). Austin, TX: Texas Music Educators Association.

Ford, J., Rooth, W. & Kopell, B. (1976). Auditory evoked potentials to unpredictable shifts in pitch. *Psychophysiology, 13*(19), 32-39.

Fox, P., Sergent, J., Hodges, D., Martin, C., Jerabek, T., Glass, T., …Lancaster, J. (1995). *Piano performance from memory: A PET study.* Paper presented at The human brain mapping conference, Paris.

Frisina, R., Walton, J. & Crummer, G. (1988). Neural basis for music cognition: *Neurophysiological foundations. Psychomusicology, 7*(2), 99-107.

Furman, C. (1978). The effects of musical stimuli of the brainwave production in children. *Journal of music therapy, 15*(3), 108-117.

Friedrich, O.(1983, August). What do babies know. *Time Magazine,* 122(7)*,* 52-59.

Gaser, C. & Schlaug, G. (2003). Brain Structures Differ between Musicians and Non-Musicians. *The Journal of Neuroscience, 23*(27), 9240-9245.

Gibson, C., Folley, B. S. & Park, S. (2009). Enhanced divergent thinking and creativity in musicians: A behavioral and near-infrared spectroscopy study. *Brain and cognition, 69*(1), 162-169.

Gilbertson, S. & Aldridge, D. (2008). *Music Therapy and Traumatic Brain Injury: A Light on a Dark Night*. London: Jessica Kingsley Publishers.

Gillis, A. (1990). What are birds hearing? *Bioscience, 40*(11), 810-816.

Golden, D. (1994, July). Building a better brain. *Life*, 62-70.

Gordon, E. (1979). *Primary measures of music audiation.* Chicago: GIA.

Gordon, E. (1990). The nature and description of developmental and stabilized music aptitudes: Implications for music learning. In F. Wilson (Ed.), *Child development* (pp.16-20). St.Louis, MO: MMB Music.

Graven, S. N. & Brown, J. V. (2008). Auditory development in fetus and infant. *Newborn and infant nursing reviews, 8*(4), 187-193.

Hannon, E. E. & Trehub, S. E. (2005a). Metrical categories in infancy and adulthood. *Psychological Science, 16,* 48–55.

Hannon, E. E. & Trehub, S. E. (2005b). Tuning in to musical rhythms: Infants learn more readily than adults. *Proceedings of the National Academy of Science, 102,* 12639–12643.

Hantz, E., Crummer, G., Wayman, J., Walton, J. & Frisina, R. (1992). Effects of musical training and absolute pitch on neural processing of melodic intervals: A P3 event-related potentials study. *Music perception, 10*(1), 25-42.

Hodges, D. (1989) Why are we musical? Speculations on the evolutionary plausibility of musical behavior. *Bulletin of the Council of Research in Music Education*, 99, 7-22.

Hodges, D. (1996a). Human musicality. In D. Hodges (Ed.). *Handbook of music psychology* (pp.29-68). University of Texas at San Antonio: IMR Press.

Hodges, D. (1996b). Neuromusical research: A review of the literature. In D. Hodges (Ed.). *Handbook of music psychology* (pp.197-284). San Antonio, TX: Institute for music research.

Hodges, D. (2000). Why are we musical? Support for an evolutionary theory of human musicality. In C. Woods, G. Luck, R. Brochard, F. Seddon, J. Sloboda (Eds.), *Proceedings of the sixth International conference on music perception and cognition*. Staffordshire: Keele University, Psychology Department.

Hose, B., Langner, G. & Scheich, H. (1987). Topographic representation of periodicities in the forebrain of a mynah bird: One map for pitch and rhythm? *Brain research, 422*, 367-373.

Hulse, S., Takeuschi, A., & Braaten, R. (1992). Perceptual invariances in the comparative psychology of music. *Music perception, 10*(2), 151-184.

Hunter, P. G., Schellenberg, G. E. & Schimmack, E. (2010). Feelings and Perceptions of Happiness

and Sadness Induced by Music: Similarities, Differences, and Mixed Emotions. *Psychology of Aesthetics, Creativity, and the Arts, 4*(1), 47-56.

Inglis, T. (1980). The effects of music on the electroencephalograms of secondary school music students and nonmusic students. *Bulletion of the council for research in music education, 62,* 45-47.

Jaušovec, N. & Habe, K. (2003) The “Mozart effect” : an electroencephalographic analysis employing the methods of induced event-related desynchronization/synchronization and event-related coherence. *Brain topography*, *16*(2), 73-84.

Jaušovec, N. & Habe, K. (2004). The influence of auditory background stimulation (Mozart’s sonata K. 448) on visual brain activity. *International journal of psychophysiology, 51*(3), 261-271.

Jaušovec, N. & Habe, K. (2005). The influence of Mozart’s Sonata K. 448 on brain activity during the performance of spatial rotation and numerical tasks. *Brain topography, 17*(4), 207-218.

Jaušovec, N., Jaušovec, K., Gerlič, I. (2006). The influence of Mozart’s music on brain activity in the process of learning. *Clinical neurophysiology, 117,* 2703-2714.

Keenan, J. P., Thangaraj, V., Halpern, A. R. & Schlaug, G. (2001). Absolute pitch in planum temporale. *NeuroImage, 14*(6), 1402-1408.

Kimura, D. (1961). Some effects of temporal-lobe damage on auditory perception. *Canadian Journal of Psychology, 15*, 156-65.

Koelsch, S. & Siebel, W. A. (2005). Towards a neural basis of music perception. *Trends of the Cognitive Science, 9,* 578–84.

Langer, S. (1953). *Feeling and form.* New York: Schribner.
Leonard, C. & House, R. (1972). *Foundations and principles of music education*. New York: McGraw-Hill.
Levett, C. & Martin, F. (1992). The relationship between complex music stimuli and the late components of the event-related potentials. *Psychomusicology, 11,* 125-140.
Levitin, D. J. (2006). *This Is Your Brain on Music: The Science of a Human Obsession.* New York: Dutton.
Levitin, D. J. (2008). *The World in Six Songs: How the Musical Brain Created Human Nature.* New York: Dutton.
Levitin, D. & Bellugi, U. (1998). Musical abilities in individuals with Williams syndrome. *Music perception, 15*(4), 357-389.
Marin, O. & Perry, D. (1999). Neurological aspects of music perception and performance. In D. Deutch (Ed.). *The psychology of music* (pp.653-724). New York: Academic Press.
Marler, P. (1991). Song-learning behavior: The interface with neuroethology. *Trends in neuroscience, 14*(5), 199-211.
Masayuki, S., Katsuhiko, T., Shigeki, K. (2007). Music therapy and neuropsychology: a proposal to music therapy based on the cognitive processing of music. *Rinshō shinkeigaku = Clinical neurology, 47*(11), 868-70.
Masataka, N. (1999). Preference for infant-directed singing in two-day-old hearing infants of deaf parents. *Developmental Psychology, 35,* 1001–1005.
Mazziota, J. C., Phelps, M. E., Carson. R. E., & Kuhl, D. E. (1982). Tomographic mapping of human cerebral metabolism: auditory stimulation. *Neurology, 32,* 921-937.
McElwain, J. (1979). The effect of spontaneous and analytical listening on the evoked cortical activity in the left and right hemispheres of musicians and nonmusicians. *Journal of music therapy, 16*(4), 180-189.
Miller, L. (1989). *Musical savants: Exceptional skills and mental retardation*. Hillsdale, NY: Earlbaum.
Mithen, S. J. (2005). *The Singing Neanderthals: The Origins of Music, Language, Mind and Body.* London: Weidenfeld & Nicolson.
Molfese, D., Freeman, R. & Palermo, D. (1975). The ontogeny of brain lateralization for speech and nonspeech stimuli. *Brain and language, 2*, 356-368.
Moore, G. (1988). A computer-based portable keyboard monitor for studying timing performance in pianists. *Annals of the New York Academy of sciences, 432*, 651-652.
Moore, G. (1992). Piano trills. *Music perception, 9,* 351-360.
Nakata, T. & Trehub, S. E. (2004). Infants' responsiveness to maternal speech and singing. *Infant Behavioral Development, 27,* 455–464.
Nelson, C. A. & Bloom, F. E. (1997). Child development and neuroscience. *Child development, 68*(5), 970-987.
Omar, R., Hailstone, J. C., Warren, J. E., Crutch, S. J. & Warren, J. D. (2010). The cognitive organization of music knowledge: a clinical analysis. *Brain. Advance online publication. doi:10.1093/brain/awp345*
Osaka, M. & Osaka, N. (1992, February). Effects of musical tempo upon reading performance. Paper presented at the *2nd International Conference on Music Perception and Cognition*. Los Angeles,University of California.

Osborne, K. & Gale, A. (1976). Bilateral EEG differentiation of stimuli. *Biological psychology, 4*(3). 184-196.

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L. E. & Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature, 392,* 811-814.

Parsons, L., Fox, P. & Hodges, D. (1998). Neural basis of the comprehension of musical melody, harmony and rhythm. *Paper presented at the Society for Nuroscience*, Los Angeles.

Parsons, L. (2001). Exploring the functional neuroanatomy of music performance, perception, and comprehension. *Annals of the New York Academy of Sciences*, *930*.

Pascual-Leone, A., Dang, N., Cohen, L., Brasil-Neto, J., Cammarota, A. & Hallet, M. (1995). Modulation of muscle responses evoked by transcranial magnetic stimulation during the acquisition of new fine motor skills. *Journal of neurophysiology, 74*(3), 1037-1045.

Patel, A. D. (2008). *Music, language and the brain.* New York: Oxford University Press.

Patel, A. D. (2006). Musical rhythm, linguistic rhythm, and human evolution. *Music Perception, 24,* 99-104.

Patel, A. D. & Iversen, J. R. (2006). A non-human animal can drum a steady beat on a musical instrument. In M. Baroni, A. R. Addessi, R. Caterina, & M. Costa (Eds.) *Proceedings of the 9th International Conference on Music Perception & Cognition* (p. 477). Bologna: University of Bologna.

Patel, A. D., Iversen, J. R. Bregman, M. R. & Schulz, I. (2009a). Studying synchronization to a musical beat in nonhuman animals. *Annals of the New York Academy of Sciences, 1169*, 459-469.

Patel, A. D., Iversen, J. R., Bregman, M. R., & Schulz, I. (2009b). Avian and human movement to music: Two further parallels. *Communicative and Integrative Biology, 2*(6): 1-4.

Peretz, I. (2000). Music perception and recognition. In B. Rapp (Ed.), *The handbook of cognitive neuropsychology* (pp.519-540). London: Psychology press.

Peretz, I., Brattico, E., Järvenpää, M. & Tervaniemi, M. (**2009).** The amusic brain: In tune but unaware, *Brain, 132,* 1277–1286.

Peretz, I. & Col**thea**rt, M. (2003). Modul**a**rity **of music** processing. *Nature Neuroscience, 6,* 688–91.

Peretz, I. & Z**a**torre, R. J. (2005). Br**a**in **organization** for **music** processing. *Annual Reviews of Psychology, 56,* 89–114.

Petsche, H., Linder, K., Rappelsberger, P. & Gruber, C. (1988). The EEG: an adequate method to concretize brain process elicited by music. *Music perception, 6*(2), 133-159.

Phillips – Silver, J. & Trainor, L. J. (2005). Feeling the beat: movement influences infant rhythm perception. *Science, 308,* 1430–1430.

Pratt, R. & Spingte, R. (1996). *Music medicine: Vol. 2.* St.Louis, MO: MMB Music.

Restak, R. (1983). Newborn knowledge. In I. K. Funk & A. W. Wagnalls (Eds.). *Science yearbook 1984* (pp. 48-52). New York: New illustrated encyclopedia.

Reilly, M. (1999). Music: A cognitive behavioral intervention for anxiety and acute pain control in the elderly cataract patient. *Dissertation Abstracts International, 60*(07b), 3195.

Robinson, G. & Solomon, D. (1974). Rhythm is processed by the speech hemisphere. *Journal of Experimental Psychology, 102*(3), 508-511.

Rogers. L. & Walter, D. (1981). Methods for finding single generators, with application to auditory driving of the human EEG by complex stimuli. *Journal of neuroscience methods, 4*(3), 257-265.

Samson, S. & Zatorre, R. (1994). Contribution of the right temporal lobe to musical timbre discrimination. *Neuropsychologia, 32,* 231-240.

Schlaug, G., Jancke, L., Huang, Y., & Steinmetz, H. (1994). In vivo morphometry on interhemispheric asymmetry and connectivity in musicians. In I. Deliege (Ed.). *Proceedings of the 3d international conference for music perception and cognition* (pp.417-418). Liege: Centre de Recherche et de Formation Musicales de Wallonie.

Schlaug, G., Jancke, L., Huang, Y. & Steinmetz, H. (1995). In vivo evidence of structural brain asymmetry in musicians. *Science, 267*(5198), 699-701.

Schlaug, G., Jäncke, L., Huang, Y., Steiger, J. & Steinmetz, H. (1995). Increased corpus callosum size in musicians. *Neuropsychologia, 33,* 1047-1055.

Shenfield, T., Trehub, S. E. & Nakata, T. (2003). Maternal singing modulates infant arousal. *Psychology of Music, 31,* 365–375.

Snowdon, D. A. (1997). Aging and Alzheimer's disease: Lessons from the nun study. *Gerontologist, 37*(2), 150-156.

Snowdon, D. (2001). *Aging with grace: What the nun study teaches us about leading longer, healthier, and more meaningful lives.* New York: Bantam Books.

Soley, G. & Hannon, E. E. (2010). Infants Prefer the Musical Meter of Their Own Culture: A Cross-Cultural Comparison. *Developmental psychology, 46*(1), 286-292.

Stewart, L., von Kriegstein, K., Warren, J. D. & Griffiths, T. D. (2006). Music and the brain: disorders of musical listening. *Brain, 129,* 2533–53

Sutter, M. L. & Schreiner, C. E. (1991). Physiology and topography of neurons with multipeaked tuning curves in cat primary auditory cortex. *Journal of neurophysiology, 65,* 1207-1226.

Swartz, K., Walton, J., Crummer, G., Hantz, E. & Frisina, R. (1992). P3 event related potentials and performance of healthy older and Alzheimer's dementia subjects for music perception tasks. *Psychomusicology, 11*, 96-118.

Tervaniemi, M., Just, V., Koelsch, S., Widmann, A. & Schröger, E. (2005). Pitch discrimination accuracy in musicians vs nonmusicians: an event-related potential and behavioral study. *Experimental brain research, 161*(1), 1-10.

Thaut, M., McIntosh, G., Prassas, S. & Rice, R. (1993). Effect of rhytmic cuing on temporal stride parameters and EMG patterns in hemipateric gait of stroke patients. *Journal of neurologic rehabilitation, 7,* 9-16.

Thaut, M., McIntosh, G., Prassas, S. & Rice, R.(1995). Rhythmic auditory stimulation as an entrainment and therapy technique in gain of stroke and Parkinson's patients. In R. Pratt & R. Spingte (Eds.). *Music medicine* (pp. 213-217). St.Louis: MMB Music.

Trainor, L.J. (1996). Infant preferences for infant-directed versus noninfant-directedplaysongs and lullabies. *Infant Behavioral Development, 19,* 83–92.

Trainor, L.J. & Trehub, S.E. (1992). A comparison of infants' and adults' sensitivity toWestern musical structure. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 394–402.

Trainor, L. J. & Trehub, S. E. (1994). Key membership and implied harmony in Western tonal music:developmental perspectives. *Perception and Psychophycs, 56,* 125–132.

Trainor, L. J., Tsang, C. D. & Cheung, V. H.W. (2002). Preference for sensory consonance in two- and four-month-old infants. *Music Perception, 20,* 187–194.

Trehub, S. E. (2000). Human processing predispositions and musical universals. In N. L. Wallin, B. Merker & S. Brown (Eds.), *The Origins of Music* (pp. 427-448). Cambridge, MA: MIT Press.

Trehub, S., Schellenberg, E. & Hill, D. (1997). The origins of music perception and cognition: A developmental perspective. In I. Deliege & J. Sloboda (Eds.). *Perception and cognition of music* (pp.103-128). East Sussex: Psychology Press.

Trehub, S. & Trainor, L. (1993). Listening strategies in infancy: The roots of language and musical development. In S. McAdams & E. Bigand (Eds,), *Thinking in sound: cognitive perspectives of human audition* (pp.278-327). New York: Oxford University Press.

Trehub, S. & Trainor, L. (1998). Singing to infants: lullabies and play songs. *Advanced Infancy Research, 12,* 43–77.

Wagner, M. (1975a). Brainwaves and biofeedback: A brief history-implications for music research. *Journal of music therapy, 12*(2), 46-58.

Wagner, M. (1975b). Effects of music and biofeedback on alpha braiwaves rhythm and attentiveness . *Journal of research in music education, 23*(1), 3-13.

Wagner, M., Mentzel, M. (1977). The effect of music listening and attentiveness training on the EEG's of musicians and nonmusicians. *Journal of music therapy, 14,* 151-164.

Wallin, N., Merker, B., & Brown, S. (Eds). (2000). *The origins of music*. Cambridge: MA: MIT Press.

Walton, J., Frisina, R., Swartz, K., Hantz, E. & Crummer, G. (1988). Neural basis for music cognition: Future directions and biomedical implications. *Psychomusicology, 7*(2), 127-138.

Weinberger, N. & McKenna, T. M. (1987). Sensitivity of single neurons in auditory cortex to contour: Toward a neurophysiology of music perception. *Music perception, 5,* 355-390.

Wieser, H. & Mazola, G. (1986). Musical consonances and dissonances: Are they distinguished independently by the right and left hippocampi? *Neuropsychologia, 24*(6), 805-812.

Wilson, F. (1986). *Tone deaf and all thumbs?* New York: Viking.

Wilson, F. (1992). Digitizing digital dexterity: A novel application for MIDI recordings of keyboard performance: *Psychomusicology, 11,* 79-95.

Zatorre, R. (1988). Pitch perception of complex tones and human temporal lobe function. *Journal of acoustical society of America, 84*, 566-572.

Zatorre, R. (1994). Musical processing in the nonmusician's brain: Evidence for specialized neural networks. In I. Deliege (Ed.).*Proceedings of the 3d international conference for music perception and cognition* (pp.39-40). Liege: Centre de Recherche et de Formation Musicales de Wallonil.

Zatorre, R., Evans, A. & Meyer, E. (1994). Neural mechanisms underlying melodic perception and memory for pitch. *Journal of neuroscience, 14*(4), 1908-1919.

Zentner, M. R. & Kagan, J. (1996). Perception of music by infants. *Nature, 383***,** 29.

Prispelo: 16.11.2009
Sprejeto: 21.03.2010