# Hemispheric Music Processing and Learning Efficiency Improvement in Children with ADHD and Healthy During Working Aural Musical Memory Training at its Optimal Maturity Age

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**ABSTRACT—** ***Working memory training has influence on the learning efficiency processing with near and far transfers effects. The music is the matter of bilateral stimulation during its listening or music working memory training stimulation, with respecting of memory span limitation during training processing. The aim of the present experimental-correlation study, on the children aged 12$^{th}$ healthy and with ADHD inattentive pattern, was experimental verification of: I. influence of the working aural musical memory training stimulation, as dynamical part-time brain condition during aural music perception, with duration of 3 months (35 training sessions at three times per week for 1,5 h), as near transfer effect, on the outcome cognitive learning efficiency improvement - in mathematics or language development and in the time abridgement for school homework (working memory efficiency) inflicted in the educational process, with additional income condition of cognitive maturity level in school grades' average indicator; II. relation between working aural musical memory laterality (income functional condition with outcome dynamical change tendency) and cognitive learning efficiency indicators in both groups during working aural musical memory training stimulation. Income and outcome measure was through with working aural musical memory psychology measurement, with additional learning efficiency data obtained from 80 subjects. Results suggest that working aural musical training influences the learning efficiency process, with its musical hemispheric specification processing, without differing health and ADHD empiric groups. Working memory training by music stimulation may be important in learning efficiency development in ADHD as well as in healthy children with forming up bilateralism condition and better interhemispheric processing in cognitive and learning functions. Future implications for research are discussed.***

**Keywords —** working aural musical memory training, language and mathematics learning efficiency, ADHD, hemispheric music processing.

## 1. INTRODUCTION

The aim of the present experimental-correlation study, on the children healthy and with ADHD inattentive pattern, was experimental verification of:

I. influence of the working aural musical memory *(WAMM)* training stimulation, as dynamical part-time brain condition during aural music perception, with duration of three months (35 training sessions at three times per week for 1,5 h), as near transfer effect, on the outcome cognitive learning efficiency improvement (in mathematics or language development and in the time abridgement for school homework (working memory *(WM)* efficiency) inflicted in the educational process, with additional income condition of cognitive maturity level in school grades' average indicator);

II. relation between WAMM laterality (income functional condition with outcome dynamical change tendency) and cognitive learning efficiency indicators in both groups during WAMM training stimulation.

The learning efficiency, for the aim of present research, is defined as cognitive learning condition with income cognitive maturity statement in school grades' mean indicator, with outcome improvement syndromes during influence of working aural musical memory training stimulation such as time abridgment for school's homework processing, with improvements in mathematics and language learning process by obtained higher school grades during three months training period. Independent causal scientific evidences of its changes might be found during decreasing level of asymmetric statement of aural musical memory brain condition at the post-test measurement as the working memory training stimulation influence.

### *Connection between working memory and ADHD*

The Working memory (*WM*) is the cognitive function responsible for the temporary storage and manipulation of information, crucial for maintaining focused behavior in practical situations (Kane et al. 2007a), which supports active maintenance of task-relevant information during the performance of a cognitive task (Baddeley, 1992). WM is most important when searching for memory representations which reside outside of one's immediate awareness (Unsworth et al. 2007b). The performance on WM tests is under a high correlation with IQ scores (Fry et al. 1996; Kyllonen et al. 1990) including such WM tests as digit span test, reasoning test and problem solving test. Tasks rely on deliberate WM processes in that they require multiple processing steps and temporary storage of intermediate results, going back and forth between different tasks, as well as resisting distracting information. WM allows individuals to store, manipulate and retrieve task-relevant information in the presence of irrelevant distraction with the ability to resist distraction from irrelevant stimuli (Unsworth et al. 2007a). It is the ability to retain information during a delay and then to make a response based on that internal representation, underlying other executive functions such as control of attention with reasoning ability (Engle et al. 1999b), several cognitive abilities including logical reasoning, reading, arithmetic and problem solving (Hulme et al. 1995; Klingberg, 2000; Swanson et al. 2007; 2008; Shah et al. 1999), and school-relevant tasks such as mathematics and reading comprehension (de Jonge et al. 1996; Gathercole et al. 2006b; Passolunghi et al. 2001).

Working memory capacity (*WMC*) is the ability to retain and manipulate information during a short period of time (Goldman-Rakic, 1987), it depends at the neurobiological level on the dorsolateral prefrontal circuit function (Barbey et al. 2013; Fuster, 2008), in the prefrontal and parietal lobe (Gray et al. 2003), predicts storage and later retrieval of information (Alloway et al. 2009a). People vary in how much information they can hold in WMC (Jonides et al. 2008). Memory span is meant by the ability to reproduce immediately the list of stimuli in their original order after one presentation in fresh memorizing of an unknown material (Blankenship, A. B. 1938). The difference with WMC concerns of memorizing type in memory span with passive memorizing, while in working memory capacity is connected with storing, processing and manipulation of information during guide decision-making and behavior (Diamond, 2013; Malenka et al. 2009), however they both are limited by focus of attention, with limited range increasing gradually over childhood (Gathercole et al. 2004) and declining in elder age (Levin, 2011), with holding up to four of the activated representations in the fresh empirical evidence principle (Cowan, 2001; Andrews et al. 2002). The nature of WMC limitation involves three background cases – of limited cognitive resources needed to keep information active available for processing (Just et al. 1992), of memory trace decay in a few seconds after fresh perception unless refreshed through rehearsal processing including its limited speed (Towse et al. 2000), and of interference of representations with each other (Waugh et al. 1965). WMC is also crucial for our ability to acquire new knowledge and skills in daily life (Pickering, 2006), and has been linked to academic success, since it is the best predictor of future scholastic success (Alloway, 2009), better than intelligence, especially in young children (Alloway et al. 2010).

WM is a strong predictor of reading abilities (Swanson et al. 2004) and mathematical skills over time (Gathercole et al. 2005; Mazzocco et al. 2007; Toll et al. 2011). Children with reading disabilities, as well as children with mathematical disabilities experience problems particularly with the verbal domain of WM (Swanson et al. 2009; Friso-van den Bos et al. 2013), while children with severe disabilities in mathematics have also deficits in spatial WM (Passolunghi et al. 2012). Poor WM capacity is the serious risk factors for learning disabilities and academic failure (Gathercole et al. 2000; 2006a; Rogers et al. 2011), and may play an important role in the development of neurodevelopmental ADHD disorder and learning disabilities (Aronen et al. 2005; Denckla, 1996). WMC and attention are certainly highly related concepts (Kane et al. 2007b,) and it does seem plausible that the adaptive-span training may be shown to be effective as a method of attention training. Repeated activation and stimulation of attentional systems can facilitate changes in cognitive capacity that presumably reflects underlying changes in neuronal activity (Kerns et al. 1999). The WM Adaptive-span training affects relatively general mechanisms of cognitive control such as the ability to maintain and manipulate information over short periods (Holmes et al. 2010), the processing capacity of domain-free attention (Chein et al. 2010), or acquisition-and-retrieval of new information (Alloway et al. 2009a), with evidence of improvement in humans with stroke (Sohlberg et al. 2000), in elderly people (Ball et al. 2002), and in people with traumatic brain injury (Salazar et al. 2000). The effect of WM training also transfers to non-trained executive tasks, thus it explains how WM training can generalize to reasoning. WM training provides accompanying physiological and cognitive changes (Dahlin et al. 2008a), with neuroimaging studies indicated a significant impact on neural activity in the middle frontal gyrus and superior and parietal cortices (Westerberg et al. 2007), with revealing increased prefrontal and parietal activity (Hempel et al. 2004; Jolles et al. 2010). Such results got evidence after 5 weeks of WM cognitive training (Thorell et al. 2009; Brehmer et al. 2012), with additional improvement in fluid intelligence (Jaeggi et al. 2008) or non-verbal reasoning (Mackey et al. 2011), where research of McNab et al. (2009) revealed in fMRI and positron emission tomography indicated effect of WM training on dopamine receptor D1 in selected regions of right ventrolateral prefrontal, right dorsolateral prefrontal and left and right posterior cortices.

Although in research of Dahlin et al. (2008b) with WM adaptive-span training the computation-span task, which requires participants to solve arithmetic problems while keeping the final digit of each problem in memory for later recall, didn't demonstrate transfer effects, what might be the evidence of WMC limitations.

The WM capacity (i.e. WM span) in cognitive research got evidence for the optimal maturity improvement in around 11th - 12th age (Cowan et al. 2008; Salthouse, 1994), with biological limitations of impossibility to its increasing during working memory training, with no significant span difference for music between musicians and non-musicians (Baddeley et al. 2010), also for gender factor (Zatorre et al. 2001). WM tasks are based on attention process (Cowan, 1995) because they do require monitoring and manipulation of information from fresh perceived material as the part of completing goal-directed actions in the setting of interfering processes and distractions, which permit interim integration, processing, disposal, and retrieval of information (Baddeley, 2003). Additionally Oberauer (2002) in attention research noted attentional selecting one of the units for processing, belonging to WM span, and then attention is focusing to the next unit, continuing processing until all units would be processed, in the example of numbering mathematical functioning manipulation. The performing of WM trials with adapting the difficulty level typically leads only to faster reaction times, without significant evidence for WM capacity increase (Kristofferson, 1972; Philips et al. 1984).

ADHD is defined by the DSM-V (Diagnostic and Statistical Manual of Mental Disorders) as a neurodevelopmental disorder, presented for at least 6 months, with persistent pattern of the inattention with / or hyperactivity-impulsivity behavior condition, interfered human development with the direct negative impact on cognitive, educational, social and occupational functioning, with symptoms presented at different activities such as work, education, home and social space, with symptoms of difficulties with restlessness, inattention or poor planning, presented before present prior to 12th age and compared to 7th age (with no clinical differences between children identified by 7 years versus later in terms of ADHD symptoms), with scientific evidence that a substantial proportion of children remain relatively impaired into adulthood continuation (Biederman et al. 2000; Rasumssen et al. 2000), where ADHD does not fade at a specific age (American Psychiatric Association, 2013). This behavioral disorder is manifested by developmentally inappropriate degrees of: inattentiveness – such as short attention span, distract-ability, inability to complete tasks, difficulty in following directions; impulsiveness – such as acting without due reflection; and hyperactivity – such as restlessness, fidgeting, squirming, excessive loquacity (*ADHD /* Partner Medical Dictionary, 2012). Additionally ADHD manifests itself as excessive movement, irritability, immaturity, and an inability to concentrate or control impulses, with affecting learning and skill acquisition (*ADHD /* Mosby's Medical Dictionary, 2009). Inattentive ADHD symptoms include: - failing to pay close attention to details with disliking doing things which require sustained focus attention or sustained thinking; - failing to follow through on instructions and to finish work or task; - problems with getting organized and sustaining attention with presence of not listening when spoken to directly and in easily distraction by other duties or things; - forgetting and loosing things frequently (American Psychiatric Association, 2013). The attentional system can be broken down into three responsible EEG networks represented in distinct anatomical areas (Posner et al. 1990): a – for maintaining a state of alertness (in right frontal and parietal regions), b – for control the selection of information from sensory input (in superior parietal lobe, temporal parietal junction), c – for resolving conflicts among responses (in midline frontal areas and lateral prefrontal cortex). Poor WM affects attention and WMC decrease (Fukuda et al. 2009), thus low attention causes low working memory. In medical clinical evidences humans' brains with ADHD symptoms may have: - slightly smaller anterior frontal cortices, right caudate, and globous pallidus; - greater temporal blood flow; - lower glucose metabolism in the premotor cortex and superior prefrontal cortex (brain regions involved in control of attention and motor activity). The vulnerability to ADHD symptoms may be due to multi-genetic effect linked to dopamine receptors or serotonin products, since ADHD patients often do have a blunted response to dopamine signals and less inhibited behavior due to a defect in the D4 dopamine receptor gene (DRD4), as the so-called novelty-seeking gene (*ADHD /* Segen's Medical Dictionary, 2012). Children with neurodevelopmental disorders (ADHD) show abnormalities in the prefrontal cortex (Lazar et al. 1998; Arnsten et al. 2012) with an impaired function of the frontal lobe (Zametkin et al. 1990; Rubia et al. 1999; Schweitzer et al. 2000).

WM impairment is central deficit of ADHD importance (Barkley, 1997; Castellanos et al. 2002; 2006; Rapport et al. 2000; Kuntsi et al. 2001; Martinussen et al. 2005; 2006; Alloway et al. 2009b; Deary et al. 2007; Kasper et al. 2012; Karatekin, 2004; Schachar et al. 1993), most commonly measured with the verbal and visual digit span test (Karatekin et al. 1998; Korkman et al. 1994; Mariani et al. 1997; Pennington et al. 1996; Shue et al. 1992; Engelhardt et al. 2008). Chilren with ADHD also receive low grades in academic achievements (academic subjects), and low scores on standard measures of verbal fluency, reading, spelling, written language (Pineda et al. 1998; Barkley et al. 1990) and mathematics (Minear et al. 2006). WM is crucial for maintaining the prioritization of test-specific information and thereby reducing distractions from irrelevant stimuli (de Fockert et al. 2001). This describes how WM deficits could lead to greater distractibility in ADHD. In empiric research evidence systematic WM training in children with ADHD might result in positive near transfer effect on WM capacity (Hovik et al. 2013) and in far transfer effects on ADHD deficits (Bigorra et al. 2015). WM tasks can also enhance executive functioning including response inhibition and reasoning (Klingberg et al. 2002a).

Treatment for moderate to severe ADHD constitutes psycho-stimulants combined with behavioral therapy (Atkinson et al. 2010). WM functioning is dependent on dopamine (Williams et al. 1995), which is consistent with the association of ADHD with atypical dopaminergic transmission (Cook et al. 1995). In stimulant medical treatment the methylphenidate has been shown to increase dopamine levels in normal subjects (Solanto, 2002; Volkow et al. 2001), it does reduce the symptoms in ADHD (Whalen et al. 1987), facilitate dopaminergic transmission (Volkow et al. 1995), improve WM (Luciana et al. 1992; Mehta et al. 2004; Ostberg et al. 2012), it has also been reported to improve performance on a number of school-related activities (Douglas et al. 1986). However the evidence of treatment's limitation is being increasingly recognized (Antshel et al. 2008; Chacko et al. 2010, 2014; Halperin et al. 2011) for suggestions for novel interventions to improve outcomes for ADHD children, since in the Goldman et al. (1998) research evidence a significant minority of youth with ADHD, near 30 %, does not respond to stimulant medication, while the effects of stimulant medication are presented only during its taking. Although behavioral intervention may be less effective than medical stimulation for ADHD core symptoms, research of Krain et al. (2055) revealed that up to 58 % of parents refuse stimulant medication for their child with ADHD. However some significant evidences of behavioral intervention of WM training for cognitive functions are increasingly recognized, especially for ADHD remediation with additional medication. Two studies of Barnett et al. (2001) and of Kempton et al. (1999) have reported improvements with using of methylphenidate on WM tasks, comparing children treated with methylphenidate to normal controls found no difference in WM tasks performance between medicated group and control group. Other studies have directly compared the WM performance of children with ADHD, both taking and not taking medication, and revealed better performance for medicated ADHD group on measures of verbal WM (Tannock et al. 1995), visual-spatial WM (Bedard et al. 2004), focused and sustained attention (Konrad et al. 2004), and task switching (Kramer et al. 2001). Another research of Olesen et al. (2004) was evaluated the effect of WM training on brain activity in young healthy adults with functional magnetic resonance imaging during performing a WM task before and after WM training, where WM training improved the subjects' WM performance and resulted in increased brain activity in the dorsolateral prefrontal and parietal association cortices, indicating plasticity of the neural system underlying WM. In addition these cortical areas partly overlap with the prefrontal regions implicated in ADHD pathology (Castellanos et al. 1996; Filipek at al., 1997) that provides the neuroanatomical background rationale for undertaking WM training in children with ADHD as the form of behavioral treatment for ADHD remediation.

***Connection between music and cognitive functions***

Working aural musical (WAM) memory and laterality condition of the aural music perception are cognitive features based on musical audiation as inborn, innate cognitive musical resource which has normal distribution in population and is presented in each healthy human brain (Gordon, 1997), with maturity stabilization around $9^{th}$ age, while amusia is aural perception disorder of musical sound attributes (such as pitch, rhythm, timbre) with the neuropsychological background (Peretz, 2002). Music processing occurs bilaterally in the brain and the laterality of the aural music perception is due to hemispheric specialization difference of music sound's attributes processing. The right auditory cortex is processing the height pitch analysis and the left auditory cortex is processing the temporal rhythm analysis (Tramo, 2001; Hall et al. 2002; Cuddy et al. 2005), where simultaneous activation of the two hemispheres responsible for the aural music perception processing, form up different laterality condition of musical brain for the aural music perception and therefore WAM memory. Lateral differences exist in the temporal and spectral resolving power between corresponding cortical fields in the two hemispheres (Samson et al. 2001; Platel et al.1997), also due to pitch or rhythm attitudes as competing cues (Hamaoui et al. 2010), with possible lateralization for aural music perception and WAM memory: of rhythm-dominance 'left lateralized musical brain'), of pitch-dominance ('right lateralized musical brain'), or with no dominance ('homogenous musical brain'). The dominance presence is conditioning higher development of selected WAM memory type, while the dominance absence is conditioned equal development of two basic WAM memory types (Springer et al. 2001). Scientific data of lateralized brain networks in Nielsen et al. (2013) research revealed the evidence of stable condition, with very weak, if any, changes from childhood and difference in gender factor.

Musical intelligence has been posited in the Gardner theory of multiple intelligences, where the music is considered as an autonomous intellectual realm with music audiation abilities to perceive and to understand the structural components of music such as rhythm, pitch, timbre and harmony with the appreciation of the form of musical expression (Gardner, 1983, 1985; Gardner et al. 1989). Additionally, in early childhood the music plays a special role in the primary system of knowledge, which contributes to the development of spatial thinking, activation of visual perception and attention with the short-term memory, with a causal influence of music on cognitive ability demonstrated in measures of processing speed with working memory tasks (Bugos et al. 2007), with significant scientific evidences for that all children are born with a high potential of musical perception, allowing them to feel and understand the language of music (Bridger, 1961; Stanley et al. 1990; Trehub et al. 1990; Zentner et al. 1996). Therefore although in Gardner's statement linguistic, musical and mathematical-logical intelligences are defined as independent modules, they also may share common thinking processes and activate the same brain resources, what cause opposite scientific evidences for dependence vs. independence of these functions (Gardner, 1999).

Research of Bergman-Nutley et al. (2014) got evidence for the Gardner statement on independence of music, linguistic and mathematic intelligences, with no significant effect of music activity level on the development of processing math or reading performance. However they noted also a positive significant association between aural musical training and math performance, but not with reading comprehension, therefore it might be the evidence for interhemispheric stimulation importance in aural musical training influence on the math learning. Independent Park et al. (2013) research revealed the functional connectivity between the right parietal seed region and the left sensorimotor cortex based on math task-resolving, also between the right parietal seed region and both the left parietal and right parietal cortex during subtraction process, with relation of functional connectivity to behavioral performance across individual participants. They noted that mathematic processing depends on crosstalk between and within the parietal cortex effective neural communication, with inefficient neural communication between the hemispheres as the case of dyscalculia syndrome. Thus aural musical training might enhance logical thinking, especially due importance to hemispheric communication during aural music processing and mathematics processing. As for the Gardner statement evidence, no transfer effects of musical training to math skills or to general cognitive intelligence were noted in the research of Schlaug et al. (2005), Vaughn (2000) and Forgeard et al. (2008), neither increased musicality among mathematicians (Haimson et al. 2011). Although children aged 9 to 11 with musical training scored higher on the vocabulary subtest on the Wechsler Intelligence Scale for children, what was suggested by Schlaug et al. (2005) that far transfer to linguistic abilities may be the most robust one that might be observable already after a relatively short period of aural musical training.

Independent scientific evidences for aural musical training transfer to language related skills (Chandrasekaran et al. 2010; Strait et al. 2013) are caused by that music and language share common auditory substrates, thus indicated training of responsible brain mechanisms with sounds from one domain can enhance the ability of these mechanisms to acquire sound categories in the other domain (Patel, 2008; Patel et al. 2007). Patel (2011, 2014) noted that there is an overlap of common brain networks between speech and music, thus aural musical training benefit and far transfer effects can be found in task of auditory perception such as Gordon's Intermediate Measures of Music Audiation (Schlaug et al. 2005), or in verbal fluency and verbal memory (Chan et al. 1998; Ho et al. 2003; Jakobson et al. 2003). Especially it was noted in second language acquisition with reading abilities (Besson et al. 2011), with independent evidence in Sleve et al. (2006) research on adults about prediction of aural musical ability for linguistic and phonological skills in the second language learning and in reading (Butzlaff, 2000), with transfer effect from musical pitch (Anvari et al. 2002) or musical rhythm (Tierney et al. 2013), since temporal orienting of attention during listening to music is an ability required also in the reading process. Furthermore there is a close link between language and reading skills and the ability to perceive and to produce the rhythm, with widely evidences in studies of children presenting rhythmic difficulties with syndromes of dyslexia (Huss et al. 2011; Goswami, 2012), or of attention deficits as ADHD (Ben-Pazi et al. 2003). The most clear scientific evidences for the influence of the aural music stimulation on the cognitive processing are obtained in neuropsychological research. Listening to music requires the certain perceptual abilities, including pitch discrimination, auditory memory and selective attention to perceive the temporal and harmonic structure of the music as well as its affective components, and engages a distributed network of brain structures (Peretz et al. 2005). Music, like all sounds, unfolds over time. The auditory cognitive system is depending on working memory mechanisms that allow a stimulus to be maintained on-line to be able to relate one element in a sequence to another one that occurs later.

Unlike speech, music is not linked with a fixed semantic system, although it may convey meaning through such systems as associative memories (Dalla Bella et al. 2003). Research of Ohman (1979) has shown, that cognitive effort is reflected as an increase in frontal interhemispheric coherence during listening to music what requires a cognitive process occurring in response to the musical information such as pitch, harmony and rhythm (Cohen et al. 1991; Janata et al. 1993). Additional research of Tucker et al. (1992) revealed that the frontal area might influence motivated attention, thus increase in the frontal coherence during listening to music may relate to the positive attention to music as its impact. Listening to music as a complex process is activating simultaneously the functions of both hemispheres, with possibility to change the EEG brain state throughout its sounding, after which its effect calms down (Leeds, 2001). According to the principle of music physiology, the influence occurs only during the presence of music stimulation and in very short period after ending of its sounding. Alpha mental statement was found as optimal for effective learning process at an elevated mental attention focus, it dominates mostly in the music of Mozart (Mozart effect / Segen's Medical Dictionary, 2011) and of later baroque period (Bragdon et al. 2003) with psychophysiological evidences for increasing the dopamine release in the human brain. This EEG brain condition with alpha rhythms waves is a natural auto-synchronization of both hemispheres in the range of 8 to 12 or 13 Hz, with significant increasing in the concentration of attention and with improving the memory efficiency in the mental perception of new information, such as accelerated learning process, also with inspiration of the creativity.

An increase of elicited alpha band activity (8-12 Hz) in the electroencephalogram (EEG) has been shown to be implicated in and related to aspects of aural music processing in research of Gunther et al. (1991) with using 8 to 13.5 Hz band to healthy subjects, which revealed that alpha increases with musical complexity in music listening with stable test-retest results, including attentional mechanisms; it was also reported for musicians and nonmusicians alike in research of Ruiz et al. (2009). For brain localization the results on music perception mostly showed alpha effects in the right hemisphere (Breitling et al. 1987), with reported frontal effect by Cooper et al. (2003). Additionally left occipital-parietal alpha increase was also reported for auditory working memory (Dijk et al. 2010), also alpha synchronization has been noted to be related to the auditory attention (Fu et al. 2001).

Inter-hemispheric synchronization is arising from the association of analysis (left brain) and of synthesis (right hemisphere) in information processing (Palisca, 2001). The complexity of music contributes to the preservation of the memory at the neuronal functional level, and the memorizing strategies development (Calvert et al. 1998; Cross, 2007). In Besson et al. (2007) research children aged 8$^{th}$ after aural musical training on classical music with duration of 6 months demonstrated electroencephalographic signature of increased amplitude of the N300. Listening to that type of classical music has the same moderate positive influence on cognitive functions for both healthy individuals and for patients with dementia (Witzke et al. 2008), with activation of the connection between the behavior and the neurological processes of the human brain at the level of hemispheric affection. Such music at the level of auditory influence does stimulate different types of memory and has an influence supporting the cognitive functions in patients with dementia, as well as performs a preventive role in reducing and deterring senile age-related changes in human cognitive sphere area. Medical research of Mammarella et al. (2007) got evidence, that listening to Four Seasons cycle of Vivaldi exerted a positive impact on the cognitive tasks performance by elderly people with the better working memory memorization after listening to this music than in conditions of silence or white noise. Additionally positive influence of Vivaldi music was noted in autobiographical memory by elderly patients with Alzheimer's disease (Irish et al. 2006; Thompson et al. 2005). In the auditory processing of music both hemispheres are involved and their simultaneous cortical reactions are integrating partially the modified and the healthy areas of the human brain, what leads to rehabilitation and recovery of cognitive processes in the brain afflicted with dementia in the interchangeable brain substrates. Subcortical structures are spared out of the progressive destruction of the cortical tissue, thus they perform a correctional and rehabilitative role during listening to music. Sound stimuli perceived by the ear during listening to music are transformed into neural impulses in the auditory nervous system, forming up the synchronization of neural impulses in the cerebral cortex, aligning their frequency, what corrects memory and attention, reduces muscle tension and fatigue syndromes, and additionally improves the coordination of movements furtherly (Drake et al. 2000; Kilgour et al. 2000). Iwaki et. al (1997) studied the relationship between listening to music and brain activities by investigating the stimulating effects of music perception with using EEG channels recorded on during sounding periods of stimulating and calming music. In their data the amplitude of alpha-2 band increased during both periods of stimulating and calm music, while the frontal interhemispheric coherence values (F7-F8) of the alpha-2 band increased only during the stimulating music session and the coherence values did not change during the calm music period. These findings implied close relationships between the interhemispheric transmission of information in the frontal areas and positive attention to stimulating music, close by construction to the classical music. Thus listening to music activates interhemispheric transmission of information at the frontal area, where the neuropsychological function of the frontal lobe and in particular the anterior-temporal function is responsible for intellectual activity and self-control (Roland, 1984; Roland et al. 1985).

## METHODOLOGY

### *Subjects*

The present cognitive study was done at public elementary schools with double measurement before and after the WM training, on children aged 12$^{th}$ (WM optimal cognitive maturity age), with research procedure approved by psychological ethical committee, with final selection included empirical data (analyzed by the Statistica software) from 80 subjects into two equal samples (healthy children and with ADHD inattentive type) with no grouping on gender and musical activity factors. Inclusion criteria were: 1) – diagnosis of ADHD inattentive type from specialists to the guidelines of the DSM-V established at study intake in the ADHD group. None of the children had any ADHD stimulant treatment during the period of WM training, although all of them went through early medical treatment; 2) – age 12$^{th}$ with personal willingness of participants, with theirs and parents' written informed consent for the WAMM training participation, with income information of cognitive learning maturity level in school grades' mean indicator; 3) – presence in all training sessions with possible late completion absent sessions in the period between the forward training sessions (the nearest possible time period after skipped session with latest time in two weeks after finished training program);

4) – complete the WAMM test versions before and after training to evaluate the training influence, with the transfer of the additional information from participants and parents about their cognitive learning efficiency improvement condition (in mathematics or language development, also in the time abridgement for school homework) at the final training meeting.

### *Methods*

The psychological WM data were collected through aural paper - test survey, with natural piano sound presence on CD and the fulfillment of basic psychometric requirement, without pre-selection for diagnosis of musical audiation presence, where the participants of musical audiation very low skill were expected to unsubscribe, they could voluntarily resign at any moment of the measurement and during the WM training. The WAMM test, with 2 versions for 10 aural tasks of unknown music solfeggio material and 2 trail tasks, is based on the behavioral reaction on the acoustic stimuli perception (music one-voice melodies) during the serial recall method, with tasks required multi-alternative forced choice final answer decision in the recognition of the repeated original version among three reproductions. Where one is correct and two have separate changes in pitch or in rhythm, i.e. once presented all 4 task versions. Each musical melody is characterized by four independent quantitative musical indicators: ambitus, octave register, tonality and meter. Behavioral income and outcome WM measurement included the WAMM test with WM subscales - memory for pitch, memory for rhythm, common memory with the function (memory for pitch + memory for rhythm - 10), laterality state with asymmetry of memory income indicator with the function (memory for pitch – memory for rhythm) with three variants: of pitch dominance (right-lateral aural musical memory brain), of rhythm dominance (left-lateral aural musical memory brain) or of dominance absence (homogenous bilateral aural musical memory brain), and outcome asymmetry dynamic change tendency in pitch – rhythm normalized scale, as WAM memory training stimulation influence, in three combinations of single attributes (i.e. pitch and rhythm): 1) of both single attributes' equal change duration (↑|↑or↔|↔) i.e. absence of asymmetry of pitch-rhythm change tendency level; 2) of different single attribute change duration with stable unchanged level of accompanied single attribute (↔|↑↓or↑↓|↔) i.e. low level of asymmetry of pitch-rhythm change tendency level; 3) of both single attributes' different change duration (↑|↓or↓|↑) i.e. high level of asymmetry of pitch-rhythm change tendency level.

Verification of scientific background of neuropsychological organization of aural music perception, so of aural working musical memory, has got positive functional adaptation to the test's construction in earlier psychometrics research (Dymnikowa, 2015). The exploratory factor analysis structure of the test scales on early empirical study with 907 subjects aged $12^{th}$ based on the central method application of factors' selection, with the normalized equamax factorial rotation and variables' eigenvalues ≥ 1 for the factor loading by Kaiser rule, revealed 2-factory model structure, with total eigenvalue at the level 3,98 explained with 99,6 % of total variance. [$1^{st}$ factor content – single test-scales with factor's commonality = 61,32 % , with eigenvalue level at 2,45 and with selective factor loadings: Pitch memory = 0,872; Rhythm memory = -0,887; Asymmetry of memory = 0,997; $2^{nd}$ factor content – complex test-scale, i.e. Common memory, with factor's commonality = 32,28 % , with eigenvalue level at 1,53 and factor loading = 0,998.] The assess of consistency measure by test-retest reliability was done on 108 subjects with $1^{st}$ version of WAMM test in 1 week space with obtained significant ($p < 0.05$) correlation Pearson indices for 3 test-scales at the level > 0.8. [Pitch memory = 0,893; Rhythm memory = 0,874; Common memory = 0.842].

Estimation of musical brain types for working aural musical memory laterality types' frequency (*f*) of observed empirical sample volume (*n*) data of healthy subject aged $12^{th}$ into population parameter with 99% probability, i.e. confidence interval for proportion, was identified with using "correction for continuity" of normal distribution, as continuous distribution, for improving the approximation of lower limit (endpoint) and of upper limit (endpoint) ranges in population, including 99 % two sided confidence interval level 2.576 (Field, 2013), on the function for big (*n>100*) sample: $f \pm \{2 .576 * ( \sqrt{} [ ( f * (1 – f ) / n] ) + 0.5 / n \}$ (Smithson, 2002). While estimation of the functional asymmetry level of music perception of determinacy values and Pearson correlation (*c*) of the pitch memory and rhythm memory point scores in normalized musical memory asymmetry level scale ranges of observed sample volume (*n*) data of healthy subject aged $12^{th}$ into population parameter with 99 % probability. (i.e. confidence interval for correlation coefficient, was identified on the function for big (*n>100*) sample: $c \pm \{ 2.576 * [ (1 - c^{2}) / \sqrt{} (n - 1) ] \}$, Moinester et al. 2014). The confidence population interval with 99 % probability for bilateral homogenous musical brain condition of working aural musical memory varies in the range of 38 % - 46 % frequency distribution, for left-laterality musical brain condition of working aural musical memory (with rhythm perception dominance) varies in the range of 24 % - 32 % frequency distribution, for right-laterality musical brain condition of working aural musical memory (with pitch perception dominance) varies in the range of 26 % - 34 % frequency distribution.

The confidence population interval with 99 % probability for working aural musical pitch - rhythm memory relation: in norm range with high level of musical memory asymmetry) varies in the range of 90 % - 96,6 % determinacy distribution with correlation range (-0,949; -0,983), in norm range with middle level of musical memory asymmetry varies in the range of 67 % - 76,5 % determinacy distribution with correlation range (-0,819; -0,875), in norm range with low level of musical memory asymmetry varies in the range of 54 % - 76,2 % determinacy distribution with correlation range (-0,735;-0,873), in the range of left-right laterality musical brain condition presence varies in the range of 45,3 % - 60 % determinacy distribution with correlation range (-0,775; -0,673), in the range of bilateral homogenous musical brain condition presence varies in the range of 22,3 % - 42,5 % determinacy distribution with correlation range (0,472; 0,652).

Test revealed the content validity verification during correlation study on 51 subjects aged 19-20, with using the background of hemispheric emotion processing lateralization in projection method with biographic past and future events estimation with individual value from 1 to 5 points for each important positive and negative personal fate event in open personal choice. In scientific neuropsychology evidences the left hemisphere is dominant and specialized, primarily processing and regulates positive emotions, whereas the right hemisphere is dominant and specialized, primarily processing and regulates negative emotions (Sackeim et al., 1978; 1982; Hirschman et al., 1982; Ross, 1984; Robinson et al., 1989; Davidson, 1992; Gur et al., 1994; Meadows et al., 1994; Borod, 1997). When subjects were primed with positive stimuli before hearing a consonant, the left hemisphere was more active than the right hemisphere, whereas when subjects were primed with negative stimulus before hearing a consonant, the right hemisphere was more active than the left hemisphere (Alfano et al. 2008). Research revealed significant correlation Pearson indices between aural working musical memory laterality [-1 with rhythm dominance, 0 with bilateral statement, +1 with pitch dominance] and point sum value of: negative events ($r$ = –0.48; $p$ = 0.01) and positive events ($r$ = 0.41; $p$ = 0.03). These results suggest the evidence that aural working music memory laterality condition is in moderate (medium) opposite relation to hemispheric emotion processing lateralization and needs further study for the case indication of that statement, which certify that subjective estimation value tendency of past and future fate events of positive-negative direction content is opposite to biological condition of hemispheric emotion processing laterality. However, the presence of significant correlation values certifies the evidence of laterality background measurement in working aural musical memory test.

The WAMM training, with natural piano sound, has its basis on forming up the "memory trace continuity" i.e. consolidation of the memory trace with differences in the range of stimulating aural musical solfeggio material, which is presented once or twice and repeated by several techniques for aural recognition of the material memorized early. The continuity is possible to form up with using the melody which has prolonged structure unlike selective units of musical tones or rhythmic patterns. The WM training included 35 sessions has been done in separate ADHD and healthy children groups with similar training program versions, was completed in 12 weeks (3 times per week including final outcome meeting), with each session lasting approximately 1,5 h with 2 training sessions for around 30 minutes for healthy children and 40 minutes for participants with ADHD in case of their delayed and slower WM training tasks resolving, with simple internal brake in groups for half an hour with passive listening to stimulated music on the basis of therapeutic influence for cognitive condition (with compositions from late baroque period). During internal brake participants could talk quietly to each other without disturbing the silent children, making physical exercises or preparing assigned school homework. Each session included 6 - 7 trials of possible WM exercises.

WM training tasks included directed and selected attention on the basis of the attention inhibition with perceptual skipping in selected encoding, with variants of stimuli material presentation manipulation at the encoding and at the recognition levels in memorizing process, designed for aural musical stimulation material, with the procedure of paper-written feedback answer decision, included the numbers used of numerical aural material presented for memorizing. The WAMM training program included simultaneous processing and storing information mechanisms, with forward and backward technique of WM span tasks for selected acoustic music stimulus, also counting the aural sounds presented by melody or by one-sound rhythmic phrase. The duration of single memorized aural units, i.e. music stimulation material, was ranged from three longer 1-2- bar musical motives (structural part of melodies) till six simple shorter single pitch or rhythm attributes, i.e. with volume belonged to WM span (capacity). The backward tasks were done only with a single pitch or rhythm attributes in the range from 4 to 6 elements, with the same encoding and reproduction methods. While musical motives and melodies were presented only forward, with once or twice presentation of stimuli material in a specific sequence and then reproduced in different variants (order change or type change), with free or selected encoding, with three recall types: 1) on the estimation yes – no in reproduction with the change of some elements; 2) on recognition the order - change reproduction; 3) on the estimation of which elements were incorrect (and why) in serial and order-change reproduction. Advanced methods were based on the changed structure between encoding and reproduction, as encoded single pitches reproduced in rhythmized motive, or encoded melodies reproduced in clear plane rhythm or pitch, with the reproduction change of octave register (pitch modulation) and meter (rhythm modulation) differences (separate and mixed).

The training included an algorithm that continually increased or decreased the difficulty of each exercise according to the child's memory performance, by including memory span limitation. Therefore participants were always working at their WM capacity, where each training session finished by control task performance for the trainer's cognitive evidence of WM training processing.

### *Statistical Analysis*

The methodological establishment of empirical cognitive and behavioral psychological data evaluation (Cohen, 1988) concerned: 1) verification of positive influence of the WAMM training stimulation on cognitive learning efficiency improvement of outcome data of frequency distribution of obtained tendencies and of mean indicators of outcome homework's time abridgement and income school grades', also analyses of difference of pre- post- measure scores of WAMM subscales' mean values with comparison between two experimental samples, according to distribution type of empirical results, and effect size estimation. The frequency specific characteristic of selected empirical variables for the combined groups was set at the minimum 70% acceptance level. 2) verification of correlation analysis, with additional path analyses, between the income WAMM laterality with dynamical change tendency, in pre- and post- scores, additionally with cognitive learning efficiency indicators in experimental samples with additional analyses of frequencies distribution of laterality change tendency of each group. According to small empirical samples (for 40 subjects in each healthy and ADHD group), the verification of normal distribution of musical variables is expected to have the equal level of mean, median and mode values, with the skewness indices in the range [–0.5; +0.5], with excluding kurtosis indices as variants of normal flattening distribution when presented [ where the values in the range {–0.5; +0.5} tend to the central type, values <0.5 tend to the platykurtic type, and values >0.5 tend to the leptokurtic type ]. The effect size estimation of difference of two means' values from independent groups was obtained by Cohen's (1988) index with the function included *t* student value and degrees of freedom (*df*): $2\ t\ /\ \sqrt{df}$ or with sample (*n*) volume $t * \sqrt{[\{(n^1 + n^2) / (n^1 * n^2)\} * \{(n^1 + n^2) / (n^1 + n^2 - 2)\}]}$, with the range thresholds interpretation for means' difference *d*: $d < 0.2$ as no effect size (trivial in size), $0.2 < d < 0.5$ as small effect size, $0.5 < d < 0.8$ as medium (intermediate) effect size; $d > 0.8$ as large effect size. The correlation analysis of Pearson value for parametric musical data and binary learning data was used for the analysis of relation between learning and musical variables (with separate comparison of pitch-rhythm pre-post point scores) for partial correlations in 10 groups of 4 categories [empiric - health and ADHD; learning improvement - mathematic and language; laterality – rhythm dominance or pitch dominance or bilateral WAMM statement; dynamic change direction in pitch-rhythm normalized scale – asymmetry absence (↑|↑ or ↔|↔), low asymmetry (↔|↑↓ or ↑↓|↔) and high asymmetry (↑|↓ or ↓|↑) of pitch-rhythm norm change level] with the range thresholds interpretation: 0.0-0.1 as trivial, very small, tiny, insubstantial or practically zero; 0.1-0.3 as low, small or minor; 0.3-0.5 as moderate or medium; 0.5-0.7 as high, large or major; 0.7-0.9 as very high, very large or huge; 0.9-1 as practically perfect, nearly perfect or almost perfect.

## RESULTS WITH DISCUSSION

Descriptive normalized statistics of median, mode, modal and skewness indices for the WAMM scales distribution obtained in research are represented by the normal distribution requirements in both test versions of the basic test scales, with the data in table 1.

Table 1. Descriptive normalized statistics for the WAMM scales distribution

| Pre-test (pre-training) measure | | | | | |
|---|---|---|---|---|---|
| Scale | Group | Mean | Median | Modal | Skewness |
| Pitch memory | Healthy | 6.46 | 6 | 6 | 0.1 |
| | ADHD | 6.8 | 7 | 7 | - 0.5 |
| Rhythm memory | Healthy | 7 | 7 | 7 | - 0.1 |
| | ADHD | 6.8 | 7 | 7 | - 0.5 |
| Common memory | Healthy | 3.53 | 4 | 4 | - 0.3 |
| | ADHD | 3.6 | 4 | 4 | 0.2 |
| Asymmetry of memory | Healthy | -0.6 | -1 | -1 | 0.1 |
| | ADHD | 0 | 0 | 0 | 0.1 |
| Post-test (post-training) measure | | | | | |
| Scale | Group | Mean | Median | Modal | Skewness |
| Pitch memory | Healthy | 8.35 | 8 | 8 | - 0.1 |
| | ADHD | 7.22 | 7 | 7 | - 0.4 |
| Rhythm memory | Healthy | 6.67 | 7 | 7 | 0.2 |
| | ADHD | 7.27 | 7 | 7 | - 0.3 |
| Common memory | Healthy | 5 | 5 | 5 | 0.1 |
| | ADHD | 4.5 | 5 | 5 | - 0.1 |
| Asymmetry of memory | Healthy | 1 | 1 | 1 | - 0.3 |
| | ADHD | 0 | 0 | 0 | 0.2 |

The pitch-rhythm combinations tendency changes in the norm scale also represent symmetrical two-size normal distribution type [ two size asymmetry tendency (↑|↓ or ↓|↑) for 26,25 % of the whole empirical sample (n=21) as „asymmetry below the norm" ; one size asymmetry tendency (↔|↑↓ or ↑↓|↔) for 47,5 % of the whole empirical sample (n=38) as „asymmetry in the norm" ; symmetric tendency (↔|↔ or ↑|↑) for 26,25 % of the whole empirical sample (n=21) as „asymmetry up from the norm – i.e. asymmetry absence" ], with additional quite equaled distribution of the lateral types in whole sample [ I. Pitch dominance = 30% (n=24); II. Rhythm dominance = 36,25 % (n=29); III. Bilateral condition = 33,75 % (n=27); *2-tailed p*: I–II = 0,401; I–III = 0,61; II–III= 0,74]. No significant difference was noted in mean values for the school homework time abridgement in both empirical groups [$_{HEALTHY}$ = 33.57; $_{SD}$ = 38.66; $_{ADHD}$ = 24.72; $_{SD}$ = 28.72; *2-tailed p* = 0,248], therefore the presence of ADHD inattentive type doesn't change significantly the time abridgement for the school homework in comparison with healthy subjects, what might be the evidence for possible thinking processes involved in that learning procedure, what wasn't included in the present empirical study. Another possibility might be related to individual differences in that learning processes duty, what is the aim of future research with this learning efficiency variable.

Four significant two-tailed differences of means between the health group and the ADHD group were revealed with intermediate size of difference, with the higher value in the health group:

I. at the level of $p < 0.01$ ($t_{critical\ value}$ = 2.640 for $df$ = 78) for two variables:

1) – the school grades' average index ($t_{78}$ = 3,087; *2-tailed p*=0,003; *means of groups:* $_{HEALTHY}$ =4.66; $_{ADHD}$ = 4.18 ) with *Cohen* effect size (0,69). The present result is confirmed evidence of the earlier empirical data from the research of Pineda et al. (1998), Barkley et al. (1990) and Minear et al. (2006). The school grades' average value is additionally related to the bilateral tendency during WAMM training influence, described by bilateral condition in 17% - 39 %, observed in two factor groups: 1 – of pitch-rhythm norm change tendency in the group with one size asymmetry tendency (↔|↑↓ or ↑↓|↔), with moderate Pearson value 0.412 ($p$<0.05; determinacy index = 17 %) to common memory change in norm scale at outcome level; 2 - of pitch dominance (low level of the rhythm memory at income level), i.e. mainly represented by the health group, where the common memory improvement is directed by the rhythm memory increase, with two significant high Pearson values 0.627 ($p$<0.05; determinacy index = 39,3 %) for outcome rhythm point scale, and 0.543 ($p$<0.05; determinacy index = 29,5 %) for rhythm change pre-post tendency point scale.

2) – the pitch memory score in the outcome level ($t_{78}$ = 3,105; *2-tailed p*=0,003) with *Cohen* effect size (0,7). The present result is conditioned by different distribution of the WAMM brain condition on both empirical groups at the income level, with the low level of participants with pitch dominance laterality in the healthy group in comparison to rhythm dominance laterality frequency index, i.e. left-sized (I – R>P; II – R=P; III – P>R) normal distribution type, what was significantly dynamically changed during the WAMM training stimulation influence. [*Health group*: Left-laterality rhythm dominance WAMM brain statement = 32,5%; Homogenous bilateral WAMM brain statement = 42,5 %; Right-laterality rhythm dominance WAMM brain statement = 25 %; *ADHD group*: Left-laterality rhythm dominance WAMM brain statement = 22,5 %; Homogenous bilateral WAMM brain statement = 55 %; Right-laterality rhythm dominance WAMM brain statement = 22,5 %].

This income laterality distribution is the cause of the additional accompanying differential frequency distribution specification of the WAMM change tendency during training influential effect in both empirical groups, with direction tendency (↑|↑ or ↔|↔) of both features improvement or stability in dynamical change tendency to 32,5 % of healthy participants. While with the direction tendency (↓|↑) of one feature improvement with the accompanying feature decrease in 37,5 % of ADHD participants, with holding the rule of the normal distribution of cognitive feature's development, including no significant frequency difference in dominated dynamical change tendency in both empirical groups (↑|↔) of a feature improvement with accompanying stable non changed feature [$_{HEALTHY}$ = 50 %; $_{ADHD}$ = 45 %; *2-tailed p* = 0,654].

II. at the level of $p < 0.05$ ($t_{critical\ value}$ = 1.991 for $df$ = 78) for two variables:

1) – the asymmetry of memory scale score with the pitch-dominance tendency in outcome level ($t_{78}$ = 2,509; *2-tailed p*=0,015) with *Cohen* effect size (0,56). This statement is also described by the increased pitch memory score in the outcome level, since asymmetry of memory is the function of difference between pitch and rhythm memory scores.

2) – the tendency change in the development of common memory in point scale score in the outcome level ($t_{78}$ = 2,287; *2-tailed p*=0,026) with *Cohen* effect size (0,51). The frequency of the common memory change for health group was obtained at the level of 77,5 % with range decrease from 1 to 4 points, while for ADHD group with significantly lower frequency at the level of 55 % with range of decrease from 1 to 2 points [*2-tailed p* = 0,033]. Also the frequency of non-change and improvement of common memory score at the outcome level in norm scale is significantly different between the empirical groups for bigger value of non-change common memory in ADHD group [stable condition: $_{ADHD}$ = 82,5 %; $_{HEALTHY}$ = 50 %; *2-tailed p* = 0,002; decrease condition: $_{ADHD}$ = 17,5 %; $_{HEALTHY}$ = 50 %; *2-tailed p* = 0,002].

The present result is conditioned by different distribution of the common memory in normalized scale with bigger frequencies of norm-range scores for ADHD group in both pre-post measurements [$_{ADHD\ GROUP}$ pre-measure: <norm = 12,5 %; norm = 82,5 %; >norm = 5 %; Post-measure: <norm = 5 %; norm = 82,5 %; >norm = 12,5 %; $_{HEALTHY\ GROUP}$ pre-measure: <norm = 22,5 %; norm = 77,5 %; Post-measure: norm = 67,5 %; >norm = 32,5 %], with additional improvement of the bilateral condition in the 3$^{rd}$ norm-range (>nom) for both groups, with statistical significant difference for the frequency of health group [$_{ADHD}$ = 12,5 %; $_{HEALTHY}$ = 32,5 %; *2-tailed p* = 0,032]. Therefore the WAMM training influence got evidence in forming up the bilateral WAMM condition (totally 95 % of ADHD participants and 100 % of healthy participants in norm and >norm range) at the outcome measurement, what is caused by the music stimulation specification. Since the WAMM scales of memory for pitch and for rhythm are including the part of common memory, with additional one-size lateral answers which are causing the left-right-laterality state (pitch-dominance or rhythm-dominance in the case of difference between memory of pitch and of rhythm with the higher level from 1 point, what belongs to the asymmetry of WAMM function, with homogenous bilateral WAMM statement with the scores of 0 or 1 point in normalized scale).

Analysis of relation between the pitch and the rhythm memory point scores at the pre- and post - measurements, presented in table 2, revealed asymmetric tendency basic principle of aural perception of music with significant (p <0.01) mostly large and very high Pearson negative values in all empirical groups, as the evidence of neuropsychological principle due to hemispheric specialization of the aural music processing, without two-tailed significant difference between correlation indices in all 10 partial factor groups (in separate pre- and post- values) and inside of 7 groups (between pre- and post-values), with the range of pre-score results [-0.639: -0.855] with determinacy value between 40,8% and 73,1 %, and with the range of post-score results [-0.483: -0.791] with determinacy value between 23,3% and 62,5 %. All children participated in WAMM training noted improvement presence in mathematics or language school subjects. The health group demonstrated bigger frequency of learning efficiency in language improvement (60 % of empirical sample, N = 24), while the ADHD group demonstrated bigger frequency of learning efficiency in mathematics improvement (65 % of empirical sample, N = 26), however these tendencies are not significantly different (*p*>0,05) between the groups (*p*=0,644).

Table 2. Pearson indices of the pitch-rhythm point scales with significance p <0.01

<table>
<tr><td>Score-type</td><td colspan="35">Group specifications: I - ADHD (n=40); II - Health (n=40);<br>Improvement: III - Math (n=42); IV - Language (n=38);<br>Pitch – rhythm norm change tendency:<br>V:(↑|↓or↓|↑) (n=21); VI: (–|↑↓ or ↑↓|–) (n=38); VII: (–|– or ↑|↑) (n=21);<br>Laterality condition: VIII: Rhythm dominance (n=29);<br>IX: Bilateral (n=27); X: Pitch dominance (n=24);</td></tr>
<tr><td rowspan="3">Pre-score</td><td colspan="35">Group number - Pearson value</td></tr>
<tr><td colspan="5">I</td><td colspan="5">II</td><td colspan="5">III</td><td colspan="5">IV</td><td colspan="5">V</td><td colspan="5">VI</td><td colspan="5">VII</td></tr>
<tr><td colspan="5">-0.761</td><td colspan="5">-0.715</td><td colspan="5">-0.707</td><td colspan="5">-0.773</td><td colspan="5">-0.855</td><td colspan="5">-0.639</td><td colspan="5">-0.7</td></tr>
<tr><td rowspan="5">Post-score</td><td colspan="35">Group number - Pearson value</td></tr>
<tr><td colspan="7">I</td><td colspan="7">II</td><td colspan="7">III</td><td colspan="7">IV</td><td colspan="7">V</td></tr>
<tr><td colspan="7">-0.665</td><td colspan="7">-0.548</td><td colspan="7">-0.569</td><td colspan="7">-0.672</td><td colspan="7">-0.791</td></tr>
<tr><td colspan="7">VI</td><td colspan="7">VII</td><td colspan="7">VIII</td><td colspan="7">IX</td><td colspan="7">X</td></tr>
<tr><td colspan="7">-0.483</td><td colspan="7">-0.78</td><td colspan="7">-0.698</td><td colspan="7">-0.695</td><td colspan="7">-0.535</td></tr>
</table>

Additional analyses of frequency distribution of musical variables allowed finding common specifications of language and math improvement for both empirical groups, what suggested that WAMM training had equal influence on both samples and did not differ in the conditions of learning efficiency effects between healthy and ADHD groups. This condition also concern of no significant difference between mean indices of the learning efficiency groups for average of grades' [ $_{LANGUAGE\ IMPROVEMENT}$ = 4,44; $_{MATHEMATICS\ IMPROVEMENT}$ = 4,36; *2-tailed p* = 0,637] and for the homework time abridgement [$_{LANGUAGE\ IMPROVEMENT}$ = 22,17; $_{MATHEMATICS\ IMPROVEMENT}$ = 27,8; *2-tailed p*=0,594]. The language improvement is mainly conditioned by outcome common memory at the normal range (75 % in healthy group, 87,5 % in ADHD group), with additional rhythm memory improvement at the outcome level (72,5 % of participants in ADHD group; 52,5 % of participants in healthy group). The lower frequency index in the healthy group is conditioned by its laterality specification as the group of pitch-dominance laterality (62,5 % of participants), with additionally characteristic of the rhythm memory increase accompanied with the pitch memory decrease in outcome significant (*p*<0.05) two-tailed correlation evidence with determinacy value around 30 % [high Pearson values for pitch norm scale –0.522 (determinacy index = 27,2 %) and for rhythm norm scale 0.554 (determinacy index = 30,7 %)], where the first condition defines the cause of the second tendency for making up the homogenous WAMM brain condition at the outcome level, with another empirical evidence of bilateral condition for the asymmetry difference between pitch memory and rhythm memory at the level 0-1 point in 75 % of participants of ADHD group.

The mathematics improvement is mainly conditioned by both income and outcome common memory at the normal range, over 70 %, with additional characteristic for healthy group in distribution pitch-rhythm change tendency (72,5%) with the stable norm level of one attribute (pitch) accompanied with change in the other attribute (rhythm), in case of its pitch-dominance laterality specification tendency, with outcome significant ($p$<0.05) two-tailed medium Pearson correlation evidence 0.402 for the rhythm improvement in norm scale (determinacy index = 16,1 %). Homogenous bilateral WAMM brain statement is thus important for math learning efficiency, in accordance with the neuropsychological study of Park et al. (2013) concerning importance of the bilateralism in math processing, while the rhythm improvement is important for language learning efficiency improvement in case of the same left hemisphere functional specialization in rhythm and language processing (Tramo, 2001; Hall et al. 2002; Cuddy et al. 2005), and of the overlap of common brain networks between speech and music (Patel 2011, 2014), where aural musical training can influence with transfer effect on the auditory perception. Therefore hemispheric functional specialization of learning processing of selected subjects is related to music processing and might be improved during WAMM training stimulation influence.

## CONCLUSION

The WM is a fundamental cognitive function closely related to controlled attention. They do rely on the same mechanisms of sustained neural activity and top-down excitation. Therefore WM training might mediate improvements in attention, where the WM capacity is subject to training-induced improvements (Green et al. 2012) and the size of the transfer effects are linearly related to practice time (Bergman-Nutley et al. 2011) in spacing and frequency of WM training (Cepeda et al. 2008). WMC measures are strongly related to the performance of reading comprehension, mathematics, problem solving and to general cognitive IQ indicator (Conway et al. 2003). WM improvement is the major driving force of cognitive development (Pascual-Leone, 1970; Case, 1985), while WMC is the strong predictor of cognitive abilities in childhood (Jarrold et al. 2007), with longitudinal study evidence that WMC at young age is the predictor of reasoning ability in the later age (Kail, 2007), with reflecting the efficiency of executive functions (Engle et al. 1999a).

WM training requires hard work and engagement from both participants and researchers in order to be effective, with two general principles for successful training - such as the length of training and adaptability of difficulty (Klingberg et al. 2002a). A potential approach to maximize long-term transfer effect retention is to continue training activity after training completion (Ball et al. 2002), where WM training might be indeed a valuable endeavor to facilitate learning, with daily training time limited to as little as 10 - 20 min a day (Jaeggi et al. 2011). Strengthening WM skills can lead to performance improvements in tasks that rely on the functioning of the WM system. Training WM skills can be beneficial not only to improve WM skills themselves, but also to improve skills that rely on the integrity of WM functions, such as: attentional control, language-related abilities enhance with reading comprehension (Loosli et al. 2012; Dahlin, 2010; Egeland et al. 2013), mathematical reasoning (Klingberg et al. 2005) with mathematical problem solving (Holmes et al. 2009), fluid intelligence - with near transfer effect to non-trained executive control (Jonides et al. 2012) and to the scholastic achievement measures in an applied school setting (Holmes, 2014; Melby-Lervag et al. 2013). WM training is effective in special-needs people with pre-existing WM deficits - a central cognitive mechanism underlying the symptoms in ADHD (Willcutt et al. 2005), since by this not only WM might be improved but also attention, inhibition and problem solving skills in children with ADHD. Every academic task requires the efficient functioning of attentional systems and attention deficit is the primary cause for poor academic performance in children with ADHD (Zentall, 1993). WM training might indeed reduce attention and memory problems, learning difficulties and academic achievement problems, and it suggests plasticity of the brain in children with neurodevelopmental problems across a wide age range (Klingberg, 2010). WM and the reasoning processing rely on the same cortical areas, i.e. prefrontal cortex (Duncan et al. 2000; Klingberg et al. 2002b; Prabhakaran et al. 1997) - an area that shows deficits in humans with ADHD (Shaw et al. 2007). A topic for conclusive further research is clear understanding and set of expectancies for how WM training processing is accomplished in the brain, with the use of neuroimaging techniques for demonstrating and measuring the effects of WM training interventions on neural activity.

Intensive and adaptive WM training gradually increases the amount of information that humans can keep in their WM. The improvement from WAMM training was evident for both empirical groups of healthy and with ADHD inattentive type children. Additionally the improvement in the learning efficiency is a clear evidence for that the training effect is generalized to non-practiced and non-trained tasks requiring WM, as the transfer effect, since the present training did not include any problem solving or reasoning exercises of cognitive learning process at all. Therefore the WM might be improved by practice and might be useful in other conditions in which WM deficits are prominent, such as those after traumatic brain injury and stroke affecting the frontal lobe. However the significant efficacy of WM training far transfer needs to demonstrate observable, practical and clinically meaningful behavior change in children both healthy and with ADHD, in further research, to define which change certify that WM training do provide better complete learning academic tasks and do improve on objective academic measures except higher grades and time abridgement for school homework processing.

The right hemisphere is adept for nonlinear processing information, while the left hemisphere is adept for sequential linear processing information (Williams, 1986). The music is one of the few activities that stimulate both sides of the brain. Listening to music impacts the brain stimulating in hemispheres, affecting a child overall cognitive development and possibly increasing a child overall intellectual capacity with creative and abstract thinking more than any other activity affecting the brain bilaterism (Yoon, 2000). If causality can be established between listening to therapeutic music for cognitive functioning (as the aural musical training stimulation form), and its association with cognitive and academic benefits, then aural musical training with WAMM training should perhaps be considered a type of cognitive training. Additionally music processing typically engages the functioning of both cerebral hemispheres so it occurs bilaterally in the brain and determines the metaplasticity state, which occurs when the activity of the brain regulates the expression of future plasticity at the level of both individual neuronal connections and connections between brain regions (Abraham, 2008). Therefore the aural working memory training by music can enhance neural and cognitive functions, also can influence learning in other fields, providing a potential mechanism for 'near transfer' effects, and the broader cognitive with behavioral benefits of engaging the brain in music (i.e. aural music perception and listening to music).

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