Neural differences between strength trained athletes and skill trained musicians

Neural Specificity of Training: Neural Differences Between Strength Trained Athletes and Skill Trained Musicians

The human body is a system that must constantly adapt over time according to the stresses it undergoes. Neuroplasticity is the concept in which the brain is able to adapt, modify itself, or be altered by the external environment, be that through normal development, learning, or pathological processes (Moreno & Bidelman, 2013; Chieffo et al., 2016). When individuals learn new tasks, there is an association with immediate and long lasting plastic changes in the sensorimotor cortex and in several associated areas in the brain (Chieffo et al., 2016). However, the specificity of different types of training affect neurological adaptations in different ways. For example, musical training offers neural plastic changes related to auditory, motor, visual, and memory related processes (Moreno & Bidelman, 2013). Musical training also offers functional changes in human behavior, enhancements in the auditory system related to basic sound processing, listening skills, and speech comprehension, and also influences cognitive functions of language, intelligence, attention, and memory (Moreno & Bidelman, 2013). There is also some suggestion that music training promotes neuroplastic changes that enhance brain function and may improve music performance and learning (Vaquero et al., 2016). Most studies relating to neural adaptations in strength trained athletes do not discuss cognitive changes, but rather adaptations in the skeletal muscle as well as mechanisms regarding neuromuscular adaptations to strength training. This paper will seek to describe the effects of skill training and resistance training on neural factors including areas in the brain activation areas related to training, brain matter differences, early onset vs late onset of skill training, and motor skills related to training.

Relating to structures in the brain affected by specificity of training, a variety of areas in the brain indicate changes that occur due to training effects. In skill training, brain matter is significantly different in individuals who participate in musical training. For example, the right putamen, hippocampus, amygdala, basal ganglia, corpus callosum, all exhibit structural changes after participating in musical training for years (Vaquero et al., 2016; Herholz & Zatorre, 2012; Chieffo et al., 2016; Schlaug, 2001). The putamen is an area in the brain that has been linked to motor skill training and long-term storage of learned motor skills (Vaquero et al., 2016). Musicians have been well-documented to have increased grey matter volume in the bilateral putamen compared to non-musicians, but interestingly enough, as skill-level increases in pianists, the volume of the right putamen actually decreases due to optimization and efficiency in the area, in essence " pruning" unnecessary synapses (Vaquero et al., 2016). Comparatively, there is limited evidence that the putamen is affected in strength trained individuals, though Hanggi et al. showed decreases in gray matter volume in dancers compared with nondancers, which may include the putamen and Palmer et al. found that a 4-week unilateral strength training program in adults decreased putamen volumes (Hanggi et al., 2010; Palmer et al., 2013). The corpus callosum is an area in the brain that allows for communication between the two hemispheres of the brain; it has been found in previous studies that when piano players began training before age 7, they have a significantly larger anterior portion of the corpus callosum

(Chieffo et al., 2016). In the first ten years of life, the corpus callosum goes through development, and bimanual training may allow for plastic changes in the area's fibers which can lead to long term changes in functional connections of the corpus callosum (Chieffo et al., 2016). In a study by Howatson et al., when strength training is performed by doing a unilateral motor task with a mirror, it is believed that corpus callosum fibers may also be involved by mediating effects between frontal motor areas that are involved in mirror training (Howatson et al., 2013). The hippocampus and amygdala are tied to emotional learning and memory consolidation in individuals (Vaquero et al., 2016). Specifically with regards to the anterior hippocampus, this area is involved with novelty detection and associative learning, reward or goal-directed functions, emotional memory, pitch processing, and consonance/dissonance detection (Vaquero et al., 2016). The amygdala is not restricted solely to processing emotional or fear related stimuli, but may also be involved in emotional processing of musical content and detecting stimuli that may be important in the music learning process (Vaquero et al., 2016). In individuals with musical training, there is an understandable connection between these areas in the brain and with musical performance comparatively to those without musical training (Vaquero et al., 2016). A study by Groussard et al. showed that there are grey matter increases in the anterior part of the hippocampus comparing expert musicians to non-musicians, suggesting that musicians construct specific memories of musical experiences with this area of the brain in more detailed, vivid, and emotional ways (Groussard et al., 2014). Few studies have analyzed the effects of resistance training on the hippocampus and amygdala, though one study by Lin et al. examined the effects of learning and memory performance during a treadmill run and wheel run, finding that specific adaptations in the brain may be induced by various levels of stress or intensity during different types of exercises, which may indicate changes in both the hippocampus and amygdala regions (Lin et al., 2012). Furthermore, relating to areas of change in the brain over time specifically relating to skill training, a study by Groussard et al. examined the effects of musical training on structural regions in the brain. The authors found that specific brain regions were affected or modified by musical practice; specifically, the right middle and superior frontal regions, left hippocampus, left superior temporal, posterior cingulate, and right supplementary motor areas appeared to have significant differences when compared between novice and expert musicians and their nonmusical counterparts (Groussard et al., 2014). The left superior temporal gyrus may be attributed to musical expertise in the fact that this area helps to decode features in tunes and memorize them in order to create a unique representation during each musical encounter one may have (Groussard et al., 2014). The left posterior cingulate cortex helps to integrate sensory information and emotional content and may be involved with musical memory by associating memories with specific musical excerpts (Groussard et al., 2014). The right insular cortex is thought to reflect emotional aspects of music processing, specifically relating to the ability to perceive emotional content and be able to communicate that emotion to the audience during a performance (Groussard et al., 2014). An increase in grey matter in the right supplementary motor area is only visible on an fMRI after 15 or more years in expert musicians, with a possible involvement with pitch and timing repetition during listening and performance tasks (Groussard et al., 2014).

The right superior and middle frontal gyri are related to musical ensemble performance and synchronization with other instruments during performances (Groussard et al., 2014). The left anterior hippocampus is noted to increase in grey matter over time and may be related to constructing specific memories relating to musical experiences (Groussard et al., 2014). White matter connections in the brains of musicians have also been found to be more anatomically well-organized in comparison to non-musicians (Herholz et al., 2012). Overall, many changes in grey and white matter in the brain are noticeable with differing types of training.

During different activities, brain activity varies in terms of the level of activity in different regions and results in changes in grey matter over time. In a study by Flanagan et al., cortical activity was measured in individuals completing resistance exercises by using EEG during activity, and they determined that there were increases in functional cortical regions indicated by large increases in motor and sensory activity during a fatiguing volume protocol more so than in a power or magnitude protocol, suggesting that there is a strong relationship between fatigue and cortical activity (Flanagan et al., 2012). In pianists, areas of largest cortical stimulation during activity are combinations of the auditory, motor, and sensorimotor areas (Vaquero et al., 2016). Herholz and Zatorre also reported that M1 and premotor cortices are highly important in motor sequence learning and information storage, and thus are important during piano playing and learning to play instruments (Herholz & Zatorre, 2012). They go on to discuss fMRI results in untrained non-musicians learning to play piano, reporting that there was increased activity in the motor network including the ventral and dorsal premotor and parietal areas (Herholz & Zatorre, 2012). The ventral premotor cortex showed decreased activity over time with training, indicating its role with initial learning during new motor sequences, while the dorsal premotor cortex was only active after participants learned to successfully play a melody, indicating the dorsal area's role in sound mapping and sensorimotor associations (Herholz & Zatorre, 2012). They concluded that there was a very strong role and association between the auditory and motor areas in the brain while performing musical tasks or training (Herholz & Zatorre, 2012). In another study by Chieffo et al., fMRI data showed that ipsilateral motor cortex activation was lower during unilateral movement, and during bimanual coordination, recruitment of motor association areas was decreased in areas such as the premotor cortex, cerebellum, prefrontal, and basal ganglia (Chieffo et al., 2016). Overall, these studies indicate the integration of multiple areas in the brain during skill or resistance training tasks.

Motor control is important with doing tasks, most especially while doing fine motor tasks as that of a musician or collaborating motor function in multiple joints during movement or resistance training. Musical practice helps to develop fine motor skills, bimanual coordination, audio-motor integration, and processes involved with memory, attention, and executive function (Vaquero et al., 2016). During musical training, the changes in grey matter of the brain over time explain the motor skills and effects developed over time; as grey matter density increases in higher-order cognitive processes and decreases in sensorimotor regions, it can be presumed that as skill levels increase, motor skills become more automatic over time as efficiency in multi-sensory motor pathways increases (Vaquero et al., 2016). Further, fMRI studies have revealed decreased cortical activation after long-term training in pianists, which may indicate the increased efficiency of the motor system with a smaller number of active neurons performing specific movements (Furuya & Yakota, 2018; Vaquero et al., 2016). Motor training in piano players also leads to increases in hand dexterity bilaterally, more symmetric motor performance, and improved left-hand motor tasks compared to right-handed tasks (Chieffo et al., 2016). Musicians are also better at controlling hand movement, have increased anatomical skill symmetry in the distal hand and finger during motor skills, and have more symmetric motor performances than when compared to nonmusical counterparts (Chieffo et al., 2016). Regarding motor pathways, different dimensions of musical information and skill are processed in different areas of the brain, meaning that different pathways are used in relaying peripheral signals to the primary sensory cortex during tasks (Tanaka & Kirino, 2017). Musicians have organized thalamocortical systems in which they are used to connect with cortical midline structures to aid with performance by its role in sensitivity to sound, integrating mental imagery with sound, and controlling information related to the performance (Tanaka et al., 2017). The corticothalamocortical network is involved in musical performance as the network is able to regulate afferent input or sound, mediate integration of multimodal information related to the performance to other areas of the brain, and control skilled performance (Tanaka & Kirino, 2017). Relating to adaptations of musical training on synapses in the nervous system, existing synapses are strengthened, new synapses are formed, and cortical tissue that was not previously recruited may be recruited all in combination with each other (Schlaug, 2001). An increase in synapses per neuron is also found after motor skill learning and during long term stimulation of thalamic afferents to the motor cortex (Schlaug, 2001). In an article by Lai et al., it was suggested that, rather than " power training," piano playing could be considered as more endurance training due to the nature of musical performing being for longer periods of time instead of in short bouts (Lai et al., 2008). Further, in their study of pianists performing isometric exercises in the hands, it was found that there are training-induced changes in metabolic adaptation, motor unit recruitment, possibly muscle fiber composition, and improvement in coordination and central drive of motor control, indicated by higher firing rates with shorter duration and higher amplitude during evaluation of EMG data during the study (Lai et al., 2008). Overall, all of these different motor skill adaptations occur during skill trained musicians in accord with each other and over time with training.

Motor training in resistance trained individuals runs at a slightly different pattern than skill trained individuals. Evidence shows that there is a role for a neural drive increase caused by corticospinal tract excitability increases which may be related to changes in the primary motor cortex (Palmer et al., 2013). During strength training, adaptive changes in the primary motor cortex can play a role in strength development in the early stages of training (Kidgell et al., 2017). The excitability of corticospinal neurons, motor neurons in the spinal cord, neuromuscular junction, and in the muscle itself, and interneurons projecting within the M1 area in the brain are all related to the motor threshold in the body; this threshold represents the minimum intensity of a stimulation in order to evoke a MEP in the target muscle when a stimulus is applied (Kidgell et al., 2017). When performing motor skill training, motor threshold has been reported to be reduced over time (Kidgell et al., 2017). Corticospinal excitability and inhibition in relation to strength training interventions has been analyzed, indicating that there is no change at rest, but there is a significant decrease in excitability when 50% of the MVC is evoked (Kidgell et al., 2017). Increases in myelination in the central nervous system leads to white matter plasticity over time with training as well, which is another adaptation to strength training as it is important to fire motor units strongly and quickly to improve power or strength (Palmer et al., 2013). These changes can occur rapidly, even after just one session of strength training (Palmer et al., 2013). In addition, most large increases in muscle strength at the beginning of strength training interventions is related to neural adaptations as the body learns to increase EMG amplitude, discharge rate, reduce antagonist coactivation, and adjust to other neural changes elicited through strength training or new movements (Kidgell et al., 2017). These changes in motor skills during resistance training are only a few of the wide variety of changes that accompany resistance training skills.

Interestingly, early and late onset of musical training can greatly affect the cortical adaptations related to musicians. By starting to play an instrument early in life, there are advantages for the individual to have improved auditory, motor, cognitive, and associative systems than when compared to non-musicians or those who begin playing instruments later in life (Vaquero et al., 2016). Regarding brain structures, grey and white matter differences are present in skill tasks, performance, timing skills, and other abilities (Vaquero et al., 2016). Early onset musicians are reported to have better performance in musical ability and motor learning tasks when compared to late onset musicians; additionally, there are differences in auditory-motor processing abilities, noted by enhanced timing skills in a finger tapping task and in synchronization tasks (Vaquero et al., 2016). When individuals begin musical training before the age of 7, changes in white matter connectivity and the amount of practice they undergo has a relevant impact on the individual’s brain structure as a child and throughout their adult life; additionally, they are noted to have larger anterior corpus callosum size in piano players if they begin training before the age of 7 (Chieffo et al., 2016). There is also evidence to show an improvement in connectivity in the posterior isthmus in the corpus callosum wen an individual begins to be musically trained at an earlier age (Cheiffo et al., 2016; Schlaug, 2001). Another study by Groussard et al. reflected that 15 months of instrumental musical training during childhood was enough to show that the auditory and motor cortices in the child’s brain increased in volume (Groussard et al., 2014). Thus, there is a strong relationship between the age of musical training onset and with brain modifications related to musical training, specifically in that of the premotor cortex and in the corpus callosum, indicating that there may be a sensitive period in which the onset of musical training may have an increased effect (Groussard et al., 2014).

Resistance training can begin at any age for individuals, but it must be done so in a safe and effective manner. In children, resistance training may help strengthen muscles and reduce risk of injury due to the increase in joint stability and postural sway that may occur without the strength in lower extremity muscles (Granacher et al., 2011). Additionally, children can improve motor fitness skills and reduce injury in sports if they are able to perform strength training tasks if performed in a safe and feasible manner (Granacher et al., 2011). By performing resistance training, strength gains can be increased and attributed to improved intermuscular coordination and, to a larger degree, neural adaptions including motor neuron recruitment, motor unit activation, and during muscle contractions (AAP, 2007; Granacher et al., 2011). However, it is to be well noted that explosive and rapid lifting should not be included in resistance training for children due to its intense and abrupt stress on body tissues during the movements (AAP, 2007). Resistance training is great for individuals throughout any area in life due to its benefits for health, fitness, and for motor and neurological changes resulting from training, though there is no benefit of starting at a younger age similar to that of skill training in musicians, and there may be a ceiling effect in training as well as a loss of training adaptations if more than 6 weeks are taken off from training (Granacher et al., 2011).

Overall, neural adaptations resulting from specificity of training yields varying, yet similar changes. There are definite areas in the brain that are more or less stimulated due to training regimens, motor adaptations due to training, and the age of training onset. Skill training yields more cognitive changes in neural adaptations, including changes in the size of grey matter for varying areas in the brain, increased white matter connectivity at the corpus callosum, improvements motor symmetry in bilateral and unilateral tasks, and when skill training such as that of piano playing is initiated at an early enough age, neural adaptations begin early and will follow individuals throughout their entire life, benefiting them in terms of cognitive, auditory, and motor functions. Strength training also induces changes in neural structuring, though research does not often discuss brain adaptations over time compared to sedentary controls or indicate benefits of early-onset strength training rather than that of injury prevention due to improved postural control and strength during movements (AAP, 2007). Motor unit recruitment and synchronization is improved and becomes more efficient with strength training as well (Kidgell et al., 2017; Palmer et al., 2013). Overall, it would be beneficial for individuals to partake in various types of training regimens so as not to miss out on the benefits that the other training can provide, be that cardiorespiratory effects of endurance training, strength of resistance training, or cognitive and fine motor changes of skill training.

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