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A Rationale for Instrumental Music Playing for Upper Extremity Rehabilitation in Subacute Stroke*

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Upper extremity dysfunction is a common consequence following stroke. Spontaneous recovery during the first six months post-stroke is rigorous and considered as a significant indicator of potential long-term progress. Various approaches have been utilized to regain functional upper limb movement necessary for independent living; however, conventional therapy approaches have failed to prove consistency, especially for subacute stroke patients. There is, thus, a need for innovative therapeutic strategies that motivate stroke survivors to facilitate neural and functional recovery during the critical window immediately following stroke. The effect of music on physical enhancement has been frequently reported in the field of medicine as well as neurorehabilitation. The efficacy of rhythm on lower extremity deficits has been well established. Yet, the rationale for using instrumental music making enhancing subacute upper extremities rehabilitation is not clearly described to date. Based on the key mechanism of music as sensori-motor movement facilitator, this paper reviews previous empirical research that utilized music-based interventions for upper extremity rehabilitation for stroke patients, either in the form of receptive or expressive activity. This paper, further, focuses on the current research trends in subacute stroke upper limb rehabilitation and provides applicable rationale of using instrumental music playing.

Keywords : Music intervention, Subacute stroke, Upper extremity rehabilitation, Instrumental music playing

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아급성 뇌졸중 환자의 상지재활을 위한 악기 연주의 임상적 활용 근거 연구*

정은주**

상지의 운동기능 장애는 뇌졸중 환자에게서 빈번히 보고되는 증상 중의 하나이다. 뇌졸중의 원인인 신경학적 손상의 회복은 발병 초기인 6개월 동안 가장 활발히 일어나며, 이 시기의 회복은 이후 기능회복에 결정적 영향을 미친다. 독립적인 일상생활 수행과 상지 운동기능의 재활을 위하여 다양한 재활치료 접근이 적용되어 왔으나 그 효과성에 있어서 일관성이 결여된 결과가 보고되어 왔다. 따라서 뇌졸중 환자의 신경학적, 기능적 상지 운동 기능의 재활을 촉진할 수 있는 보다 효과적인 치료 방안 마련이 시급하다고 할 수 있다. 재활의학 분야의 연구에서 음악은 운동기능의 향상에 긍정적인 영향을 미치고 있으며, 특히 하지 운동기능 향상에 있어서 리듬 적용의 근거 및 그 효과성이 입증되고 있다. 하지만, 음악연주를 활용한 뇌졸중 환자의 상지 운동기능 재활에 대한 근거는 아직 확립되어 있지 않으며, 적용 대상 또한 만성 뇌졸중 환자에 제한되어 있는 실정이다. 본 연구에서는 운동기능을 촉진하는 음악의 역할을 근거로, 뇌졸중 환자의 상지 운동기능 재활을 위하여 다양한 음악활동을 사용한 선행 연구를 고찰 및 분석하였다. 이를 바탕으로 아급성 뇌졸중 환자의 상지 운동기능의 재활을 도모하기 위한 악기연주 활용 방안에 대한 근거를 마련하고자 하였다.

핵심어 : 음악중재, 아급성 뇌졸중, 상지재활, 악기연주

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Ⅰ. Introduction

Stroke is a leading cause of adult disability in South Korea (Im et al., 2011). Stroke is "a focal or global cerebral dysfunction of presumed vascular origin lasting more than 24 hours"(Calafiore et al., 2002, p. 1388). This dysfunction in the vascular system results in a variety of neuropsychological and behavioral difficulties that negatively impact activities of daily living. Sensorimotor deficits and restriction of physical mobility are the most common symptoms after stroke (Gresham et al., 1995). In particular, approximately 80% of individuals experience upper limb dysfunction after stroke, which is characterized by paresis, loss of dexterity, and movement abnormalities (van Delden et al., 2009; Morris, Wijck, Joice, Ogston, Cole, & MacWalter, 2008). About 20 to 80% of stroke patients regain spontaneously some degree of upper limb function within six months (Morris et al., 2008), depending on etiology and lesion location of initial impairment (Shelton & Reding, 2001). The upper extremities are closely related to daily living skills such as getting dressed, bathing, and eating, so rehabilitation of impaired functioning in upper extremity movement is critical.

Due to recent medical advances, survival rates from stroke have dramatically increased leading to more need for rehabilitation. Given the high incidence and relatively low recovery rate of motor impairment following stroke, there is a great need for symptom-specific intervention techniques in neuromotor rehabilitation with this population. Several conventional therapies for upper extremity rehabilitation currently available include Brunnstrom, Bobath (or neurodevelopmental treatment, NDT), and proprioceptive neuromuscular facilitation (PNF). More recent interventions include constraint-induced therapy (CIT) (Bowman et al., 2006; Lin, Wu, Wei, Lee, & Liu, 2007; Winstein et al., 2003) and bilateral arm training with rhythmic auditory cueing (BATRAC; Luft et al., 2004; Richards, Senesac, Davis, Woodbury, & Nadeau, 2008; Senesac, Davis, & Richards, 2010) and reported controversial outcomes in treating upper limb paresis.

Longitudinal studies on stroke recovery show that neurological and functional improvements occur most rapidly during the first one to three months following stroke (Kelly-Hayes, Wolf, Kase, Gresham, Kannell, & D'Agostino 1989; Skilbeck, Wade, Hewer, & Wood, 1983). Improvement in motor function continues until six months post-stroke at which point progress decelerates. Thus, the critical period for therapeutic intervention is considered two weeks post-stroke until six months post-stroke, referred as "subacute post stroke" (Ferrucci et al., 1993). Intensifying rehabilitation treatment during the subacute stroke stage maximizes the potential for upper extremity function recovery (Oujamaa, Relave, Froger, Mottet, & Pelissier, 2009). However, these approaches are mainly targeting chronic stroke patients and their effectiveness on treating the upper limb dysfunctions in subacute stroke (i.e., after two weeks until six months) has been rarely investigated (Morris et al., 2008, Richards et al., 2008). To date, the effective treatment strategy for subacute stroke is still developing (Oujamaa et al., 2009).

There is a need to effective treatment that challenges subacute stroke patients engaged to comply with intensive treatment during the subacute stage. Music as a vehicle to facilitate motor movement has been well recognized. Especially, the effect of listening to rhythm on enhancement of lower extremity movement, such as gait, has been proven with healthy adults (Miller, Thaut, McIntosh, & Rice, 1996; Thaut, Mclntosh, Prassas, & Rice, 1992; Thaut, Miller, Mezza, Rice, & McIntosh, 1995) as well as patients with neurological impairments (Hurt, Rice, McIntosh, & Thaut, 1998; Kim, Cho, Oh, & Kwak, 2010; Schauer & Mauritz, 2003; Thaut, McIntosh, Prassas, & Rice, 1993). Research studies targeting upper extremity rehabilitation using music have recently increased. However, target population was mainly chronic patients and those focused on subacute stroke rehabilitation were sparse (Bowman et al., 2006; Luft et al., 2004; Richards, Senesac, Davis, Woodbury, & Nadeau, 2008; Rojo, Amengual, Juncadella, Rubio, & Camara, 2011; Whitall, Waller, Silver, & Macko, 2000; Wolf, Lecraw, Barton, & Jann, 1989; Yoo, 2009). Considering the critical window of treatment (i.e., less than six months post-stroke), the impact of initial severity can be lessened with effective rehabilitation during the first 6 months post-stroke. It is, thus, necessary to establish therapeutic rationale of using music as upper extremity rehabilitation tool for subacute stroke patients and design effective therapeutic strategy beyond the rationale. The purpose of this paper is to review the empirical literature pertaining to music and motor movement and to provide a theoretical rationale for using music as sensory-motor experience facilitating learning and exercising through playing a musical instrument for subacute stroke upper limb rehabilitation.

Ⅱ. Establishing a Rationale

1. Neuropathology of Upper Extremity Dysfunction Post-stroke

Symptoms and recovery progress in motor function post-stroke are specific to etiology (i.e., ischemic, hemorrhage) and lesion location (i.e., cortical area only, cortical and subcortical areas, subcortical areas only; Arima et al., 2006; Shelton, & Reding, 2001; Schneider, Schönle, Altenmüller, & Münte 2007). Various regions of the brain are known to control motor functions, such as the primary motor cortex as well as pre- and supplementary-motor cortex, centrum semiovale, genu, anterior and posterior limbs of the internal capsule, basal ganglia, thalamus, and cerebellum. The majority of upper extremity dysfunction following stroke is associated with infarct or hemorrhage in the territory of the superior division of the middle cerebral artery (MCA; Shelton & Reding, 2001). Also, either complete or incomplete lesions in the primary-, supplementary, and pre-motor areas affect isolated or synergistic voluntary movement of upper limbs through pyramidal as well as extra-pyramidal pathways (Shelton & Reding, 2001). As lesion locations and types are believed to predict upper limb mobility recovery, cortical stroke is generally associated with better outcomes than mixed stroke followed by subcortical stroke (Feys, Hetebrij, Wilms, Dom, & De Weerdt, 2000; Shelton & Reding, 2001; Wenzelburger et al., 2005).

Aforementioned neuropathology causes muscle weakness and abnormal muscle tone, which further leads to difficulties in temporal sequencing of muscle contractions, impaired regulation of force control, abnormal synergistic organization of movements, and loss of range of motion (Gresham et al., 1995). Recently, several research studies characterized abnormal muscle coactivation patterns in the arm movement after stroke (Bourbonnais, Vanden Noven, Carey, & Rymer, 1989; Levin, 1996; Tang & Rymer, 1981). The findings obtained from electromyograms (EMGs) of elbow and shoulder movement revealed muscle flaccidity and spasticity as well as ineffectiveness in muscle co-activation. Such alterations in muscle activation patterns post-stroke are attributable to the following three mechanisms: (1) interruption of monosynaptic cortico motor neuronal connections to proximal muscles, (2) reversion to control by descending brain stem pathways, and (3) changes in segmental reflex circuits (Krakauer, 2005).

Spastic muscles around the joints of the shoulder, elbow, and wrist not only lead to stiffness of upper limb movement, but affect lower limb movement, such as gait, by producing ineffective control of body postures (Nashner & Forssberg, 1986). Also, instability in upper limbs is associated with additional physical risks. Given that approximately 24% of stroke patients fall during rehabilitation exercises, and most falls occur while walking or shifting from sitting to standing, repetitive exercises for enhancing strength and endurance in the upper limbs are indeed crucial (Chun, Choi, & Chun, 1999). Therefore, upper extremity rehabilitation post-stroke must include exercises that enhance patients' physical balance by improving optimized upper limb movements.

Planning and execution of upper limb movement, such as reaching, are modulated by complex mechanisms (Morasso, 1981; Shadmehr & Wise, 2005). The nature of voluntary arm movement involves kinematic and inertial properties of multi-jointed limbs, with the latter including dependence on multi-directional force and rotational interaction among joints (Hogan, 1985; Hollerbach & Flash, 1982; Gordon, Ghilardi, Cooper, & Ghez, 1994; Krakauer, 2005).

Upper limb movement lacking of synergies has been frequently reported in the stroke-related literature (Shelton & Redings, 2001) and considered attributable to stereotypic patterns of muscle co-activation that limits independent control of single joints. Patients with hemiparesis chronic stroke showed abnormalities in shoulder-elbow excursions as well as arm flexion and extension, indicating deficits in executing upper limb movement through a joint angle sequence. Such idiosyncrasy in dynamics of multi-joint arm movements following stroke was reported due to deficit in modulating acceleration and/or deceleration by communicating and compensating for interaction torques (Beer, Dewald, & Rymer, 2000).

The NDT approach suggested by Bobath theory has been widely utilized for upper extremity rehabilitation post-stroke (Luke, Dodd, & Brock, 2004; Paci, 2003). This approach aims to restore posture and movement functions by replacing abnormal with functional patterns in a controlled manner (Veličković & Perat, 2005). However, previous research studies based on the NDT approach reported non significant results as compared to either physiotherapy or CIT (Langhammer & Stanghelle, 2000; van der Lee, 2001; Woldag & Hummelsheim, 2002). A more recent intervention, CIT, utilizes "intensive mass practice approach" and shapes functional movements with a gradual increases in task difficulty involving functional tasks (Nonuse, 2001). The outcome has been reported relatively positive (Winstein et al., 2003). However, given that main characterist of CIT, repetition of functional movement in affected limbs often combined with inhibition on intact extremity, a more rewarding and effective strategy that motivates post-stroke patients, and thus, facilitate neural recovery of upper extremity function is needed.

2. Music and Auditory-Motor Facilitation

Music is ubiquitous and widely recognized as a vehicle to facilitate motor functioning. Enhancement in motor movements via music experience is well explained by two mechanisms: oscillator-coupling mechanism and auditory-spinal facilitation (Pal'tsev & El'ner, 1967; Rossignol & Jones, 1976). In a very early study, but providing the most fundamental rationale of using sound, Pal'tsev and El'ner (1967) examined the effect of patterned sound stimuli on the knee reflex and femoral quadriceps. The EMG finding revealed that the amplitude of knee reflex was enhanced with increase in sound intensity and, then, maximized at 120-140ms after the initial stimulation. The latency of the the femoral quadriceps was inverse to increase in sound intensity. The findings indicated prominent influence of sound pattern and intensity on voluntary as well as involuntary muscle movement.

Rossignol and Jones (1976) explored the possibility of using sound for muscle facilitation. The purpose of the study was to investigate immediate activation and habituation of H-reflex responses to auditory stimuli and the synchronization of motor responses to musical stimuli during hopping. Participants first heard metronome beats with a certain pitch at 110dB and the H-reflex from the medial or lateral head of the gastrocnemius muscle was electrically recorded. In the second condition, participants were instructed to hop on one leg in synchrony with beat. The results obtained from the EMG responses showed the effectiveness of using patterned auditory rhythm in increasing excitability of gastrocnemius muscle immediately and maintaining the audio-spinal potentiation through the auditory-startle pathway. A decrease in EMG amplitude after repeated exposure to sound over time was observed, indicating habituation of motor movement to sounds. Also, the periods in excitability of motor neurons was synchronized to a cycle of the on beat, enhancing motor movement.

Moreover, acoustic startle responses are induced upon exposure to music. The periods of central pattern generator (CPG) at the brain stem are entrained to that of rhythmic patterns and, in turn, lead to immediate motor synchronization (Molinari, Leggio, De Martin, Cerasa, & Thaut, 2003). Motor entrainment to music occurs in response to changes even below the perceptual threshold, suggesting the effect of rhythm at a subconscious level (Stephan et al., 2002; Tecchio, Salustri, Thaut, Pasqualetti, & Rossini, 2000; Thaut, Tian, & Azimi-Sadjadi, 1998). Also, music provides spatiotemporal as well as where to start and end information, which is necessary to produce an accurate and smooth movement trajectory (Kenyon & Thaut, 2003).

Aforementioned effect of rhythm on motor movement execution has been rigorously applied to lower extremity movement. Numerous research studies have reported that auditory rhythmic cueing significantly increased lower limb movement, such as gait, not only for typical adults (Miller et al., 1996; Thaut et al., 1995; Thaut et al.,1992), but also for individuals with neurological impairments (Thaut, Hoemberg, Hurt, & Kenyon, 1998; Kim et al., 2010; Schauer & Mauritz, 2003; Thaut et al., 1993).

3. Music and Upper Limb Movement

There has been reported a relatively small number of research studies examining muscle activation in upper extremities. In a relatively early stage of research, Safranek, Koshland, and Raymond (1982) examined the effect of auditory rhythm on co-contraction in antagonist muscles. Participants performed a motor task involving elbow flexion and extension while hearing either even or uneven rhythmic patterns, or silence. In general, the EMG response showed that the biceps were activated reciprocally with triceps. Activation in the biceps maintained after the target contact for additional elbow extension. Collectively, upon exposure to even rhythmic patterns, the elbow movement yielded more efficient and increased consistent co-contraction patterns.

Thaut, Schleiffers, and Davis (1991) investigated muscle activation during arm flexion and extension. Participants performed a motor task with/without rhythmic auditory stimuli and in either matched to personally preferred tempo or 30% slower than personal tempo. In general, triceps were activated with biceps being deactivated during arm extension; pattern of muscle activation occurred inversely as attempted arm flexion. While being presented with rhythmic auditory stimuli, the biceps were activated earlier and activation was maintained over longer time as compared to the non-rhythm condition. This was more prominent especially in the slower tempo condition, leading to co-contraction between the biceps and triceps before and after the target contact. Variability of the tricep decreased with auditory rhythm presented in personally preferred tempo. This finding indicated that rhythmic auditory stimuli contributed to a more accurate and consistent arm flexion and extension.

Enhancement in muscle co-activation contributes to optimized movement in the upper extremities. Thaut, Brown, Benjamin, and Cooke (1996) examined the effects of rhythmic auditory cueing on the spatiotemporal organization of four sequential movements. Participants were asked to reach five different target points aligned to various distances using both arms alternatively, either with internalized auditory sounds or external auditory. Results showed evenly-timed movement over varied target distance with external auditory cueing.

A recent study examined whether complexity in rhythm induced a difference in temporal and spatial properties of movement (Krasovsky, Berman, & Liebermann, 2010). Participants performed a visually guided point-to-point reaching task while listening to either regular or irregular rhythmic patterns. The spatial as well as temporal parameter analysis showed an increased velocity and motor path optimization. Rhythmic patterns (i.e., triple) when being presented with relatively slow tempo were likely to induce shortened movement path, indicating interaction between tempo and pattern. Complex rhythmic patterns, on the other hand, revealed disturbed patterns in spatiotemporal parameters, indicating challenges in movement control.

Contrast to the effects of external sounds on motor function, relatively less evidence has been reported while performing tasks in the form of expressive behaviors. Two early studies examined the nature of wrist and finger movement while playing the string instrument (Guettler, 1992; Thiem, Green, Prassas, & Thaut, 1994). As measured surface EMG, the left trazepius was activated when holding the instrument and maintaining the position. The right teres major and teres minor were found to involve playing the double bass. Especially, coordination between the two muscles as observed in co-contraction patterns was an indicator of being capable of appropriate vibrato technique (Guettler 1992).

The effect of rhythm on arm, hand, and finger movement while playing the cello was examined (Thiem et al., 1994). A specific technique of the cello performance with rhythmic cueing was utilized to facilitate a shoulder abduction/adduction and forearm pronation/supination movement pattern supporting the 4-finger succession. Two groups of musicians practiced daily the technique with different levels of exposure over two weeks. The results showed that the external beat entrained the first finger movement, leading to greater peak EMG amplitude followed by a gradual decrease in the rest of the other fingers. Changes in movement patterns at the glenohumeral and radioulnar joints were accompanied; however, it was questionable that pronation of the forearm facilitated relieving the stress of the joint of the fingers and, thus, enhanced positioning the first finger in a successive movement.

4. Rhythm Perception as Post-stroke Upper Extremity Rehabilitation

Previous research exploring the possibility of using music for post-stroke upper extremity utilized a form of receptive music behavior (i.e., listening to auditory rhythmic patterns). Researchers utilized rhythm patterns presented in a variety of tempi, including participants' preferred tempo, and deviated (i.e., either decreased or increased tempo) from their neutral states, while asking participants to perform spontaneous motor-related tasks. This approach emphasized the role of rhythm as a vehicle to facilitate motor recovery. In other words, rhythm is being used "in therapy" as rhythm enhances muscle activation (i.e., muscle strength, endurance and coordination) and cue initiation and continuation of functional movements.

In a study that utilized rhythm to cue arm movement (Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002), stroke patients performed a motor task involving elbow flexion and extension while listening to metronome beats. Upon exposure to the metronome, variability of timing and movement trajectory decreased, indicating optimized contours of arm movement. Reduction in the movement parameters was apparent even in the first few trials, indicating the immediate effect of rhythmic cueing. With the significant increase in elbow motion range, the findings collectively suggest rhythmic cueing as supplement stimuli for upper extremity rehabilitation post-stroke.

A similar study (Kenyon & Thaut, 2003) employed metronome beat presented in a tempo matched with preferred movement frequency. Stroke patients were asked to alternate between two target points and to make contact to each of two using their paretic arms. The results were similar to Thaut et al. (2002), suggesting rhythmic cueing is an effective medium to enhance temporal as well as spatial aspects of upper extremity movement.

Malcolm, Massie, and Thaut (2009) extended the effect of rhythmic auditory stimulation, which was characteristically applied to facilitate recovery process of lower limb movement, to upper limb movement rehabilitation. Post-acute stroke patients (average time since stroke was 9.5 months) received a two-week music therapy program using rhythmic auditory cueing. Participants performed a motor task asking them to reach the affected arm in various directions (i.e., frontal, sagittal, diagonal) and to make contact with targets at varying distances while listening to auditory rhythmic patterns. Motor movement and functional outcome were measured using kinematic motion analysis and extensive batteries. Results obtained from kinematic motion analysis showed that maladaptive trunk movement decreased significantly. Positive motor movement, such as shoulder flexion and elbow extension, increased significantly. Also, time and velocity of the movements improved significantly. Additionally, functional outcomes as measured by the Wolf Motor Function Test, Motor Activity Log, and Fugl-Meyer Assessment showed significant increase, collectively supporting the role of rhythmic cueing in enhancing upper limb movement. The research outcomes were positive when targeting chronic stroke patients, so the effective strategy of using music for subacute patients is still in need to develop.

5. Instrumental Music Playing as Subacute Stroke Upper Extremity Rehabilitation

More recently, researchers began to explore the potential of instrumental music playing, rather than solely listening to repetitive rhythm patterns, as immediate rehabilitation strategy for subacute stroke patients. Different forms of expressive music behavior are designed and utilized depending on functional target movements. The types of musical instruments are carefully selected with considerations on the underlying mechanisms involving music playing. For example, when aiming to enhanced fine motor function, a therapist provides practice involving finger flexion and extension by utilizing a keyboard playing. In order to improve upper limb movements, playing the percussive instruments is more appropriate to involve arm and shoulder flexion and extension.

In a very initial study that used the MIDI instrument to measure improvement in hand function, Fjare (2001) examined the effect of keyboard exercise on hand function of stroke patients. Two participants received three sessions (i.e., 40 minute session) per week for 3.5 weeks. As obtained results from the MIDI scores as well as occupational assessment measurement instruments (i.e., the Fugl-Meyer Test, Jebsen Hand Function Test) showed a tendency of increased velocity due to decreased variability. Despite limitations in the case study method, Fjare's (2001) study provided important evidence for using a MIDI instrument as a tool in rehabilitation as well as for assessment.

Schneider et al. (2007) examined the effect of playing a musical instrument on inpatient stroke rehabilitation. Forty stroke patients received fifteen, 30 minute, either music-supported therapy combined with conventional therapy or conventional therapy over three weeks. Music-supported training sessions consisted of instrumental playing (MIDI keyboard or electronic drum pads tuned with a certain pitch) of which task challenged gradually, while conventional therapy sessions included traditional occupational and physical therapy. The results showed that finger tapping performance increased significantly in music-supported training as measured by strength, dexterity, and evenness. The pre-posttest scores obtained from occupational assessment instruments (i.e., Action Research Arm Test, Arm Paresis Score, Box and Block Test, and Nine Hole Pegboard Test) were significantly different in the music-supported training group. Overall, music therapy focusing on instrumental playing when combined with conventional therapy was effective for upper extremity rehabilitation for subacute stroke patients.

The effect of music-supported training was compared with that of constraint-induced therapy (CIT) and conventional physiotherapy (Schneider, Münte, Rodriguez-Fornells, Sailer, & Altemüller 2010). A total of 77 stroke patients at inpatient care received (1) music-supported training combined with conventional therapy (n = 32), (2) CIT combined with conventional physiotherapy (n = 15), or (3) conventional physiotherapy only (n = 30) over three weeks, with a total of fifteen sessions for each group. Music-supported training utilized the same MIDI instruments used in Schneider et al. (2007). Results showed that patients trained with music-supported therapy performed finger tapping, hand tapping, supination, and target movement tasks significantly better than those who received conventional therapy and CIT. Also, changes in functional movement of upper extremities as measured by extensive occupational assessment batteries (i.e., Box and Block Test, Nine Hole Pegboard Test, Action Research Arm Test, Arm Paresis Score) showed significant improvement in arm and hand functions in music-supported group as compared to those in conventional therapy and CIT groups.

By extending Schneider et al. (2007), Altenmüller, Marco-Pallares, Münte, and Schneider (2009) investigated the effect of a music-supported therapy on neural reorganization and functional recovery after stroke. Subacute stroke patients in rehabilitation hospital received either a three week music-supported therapy that aimed to rehabilitate fine as well as gross motor movement or a conventional therapy. Results obtained from electrophysiology (EEG) responses showed significantly decreased power of beta bands in participants who received the music therapy group, particularly with the affected limb, indicating an increased activity of motor regions. Coherence of electronic activation among brain regions was more pronounced in the music therapy group, particularly with drum pads playing, indicating inter-communication among brain regions and, further, neural reorganization post-stroke. All functional outcome measures proved significant except wrist supination/pronation with a moderate to small effect size.

A neurophysiological study conducted by Fujioka, Ween, Jamali, Stuss, and Ross (2012) supported the findings of Altenmüller et al. (2009). Fujioka et al. emphasized the role of music instrument playing in upper limb rehabilitation for stroke patients via improved auditory-motor interaction. Participants received a music supported therapy program (MST) (Schneider et al., 2007) consisting of an instrumental music performance task of which level of difficulty gradually increased. Before and after the MST intervention, participants tapped their index finger while being guided by rhythmic auditory cueing and magnetoencephalography (MEG) was recorded. The findings from the MEG revealed that the magnitude of the beta band frequency decreased significantly with rhythmic auditory cueing and the decrease was more prominent after the MST training. Functional outcomes measures showed consistency with the MEG findings, indicating that active music making using electronic instruments facilitates neural plasticity of stroke patients even in chronic stages. Such findings, further, suggest the solid rationale of using instrumental playing as an effective medium for upper extremity rehabilitation for subacute stroke patients.

Ⅲ. Conclusions

The paper explored the potential of using instrumental music playing for upper extremity rehabilitation in subacute stroke. The basic mechanism in terms of how music perception enhances motor function was briefly described and the efficacy of rhythm-driven lower extremity rehabilitation was introduced. Specific to upper limb rehabilitation post-stroke, two different approaches were summarized with an emphasis on instrumental music playing. As compared to music listening and other type of therapy, instrumental music playing can be more effective for upper limb rehabilitation during subacute stroke. The followings point out essential aspects of instrumental music playing and delineate rationales for using instrumental music playing for upper extremity rehabilitation in subacute stroke.

1. Auditory-motor integration

In general, rhythmic components of music contribute to recruiting more motor neurons and increase excitability. Enhanced activities at the motor neuron level lead to increases in muscle strength, endurance, and co-activation. When exposed to recurrent rhythm patterns, repetitive motor movements are entrained to their periodicity. Also, beat as well as phase information delivered through rhythm patterns cue starting as well as ending points of movement (Thaut, 2005). Such information also contributes to guiding efficient movement trajectory and spontaneously decreases unnecessary, compensatory movements.

Specific to instrumental music playing, a number of recent empirical studies have reported auditory-motor facilitation and auditory-motor integration. Listening to rhythm facilitated auditory motor coordination in terms of timing processing as evidence by neural beta-band oscillations (15-30Hz) (Fujioka, Trainor, Large, & Ross, 2009). In a later study, Fujioka et al (2012) reported that neuromagnetic beta-band activity was similar during listening to rhythm patterns and during finger tapping with/without auditory guidance, suggesting a shared neural mechanism between rhythm perception and motor movement. Further, Bangert and Altenmüller (2003) suggested the role of playing the musical instruments in auditory-motor integration as evidenced by electroencephalogram mapping. After a 5-week music training, the activation patterns in EEG were similar during playing required melodic patterns on the piano without auditory feedback and during listening to the melodic patterns. The finding indicated a learned auditory-motor coupling after training using instrumental music instruments. Such auditory-motor integration during instrumental music playing may lead to enhancement in motor facilitation for upper extremity rehabilitation in subacute stroke.

2. Auditory feedback

Auditory feedback experienced through instrumental music playing, including rhythm, melody, tempo, and dynamics, provides immediate auditory feedback and enables to control the precise timing of movements. Sensory feedback involves motor adjustment, such as planning and executing movement sequence (Zatorre, Chen, & Penhune, 2007). With delayed or distorted auditory feedback, motor performance was not timely and precisely executed (Pfordresher & Palmer, 2006). Patients with stroke have often experience movement errors (Dancause, Ptito, & Levin, 2002) due to difficulties updating the internal representations during movement (Mercier, Bertrand, & Bourbonnais, 2004). Auditory feedback during instrumental music playing, therefore, aids upper extremity rehabilitation for subacute stroke.

3. Visual target points

The use of various sensory stimuli as anticipatory cue as well as consequent reinforcement provides a multisensory guideline for motor exercise for upper extremity rehabilitation post-stroke. Musical instruments provide visual target recognition that aid actual start and ending point of movements. Also, the arrangement of musical instruments creates possibly the environment to enhance motor performance. Therefore, visually guided exercise during instrumental music playing may facilitate complex motor movements of upper limbs in subacure stroke.

4. Stepwise shaping

Upper extremity movements consist of a series of complex functional movements and a stepwise approach to shape functional improvements is, thus, needed. Structured exercises throughout instrumental music playing may promote upper limb movements of subacute stroke. Music patterns given in a movement task, speed and timing of movement, and movement trajectory can be effectively designed according to complexity of functional movement and individual progress. For example, tempo of movement patterns can be shaped based on perceptual threshold. When planning to facilitate arm flexion and extension movement using the drum, music patterns can be provided in a patient's subjective tempo (e.g., 60 beat per minute) and increases gradually to 63 beat per minute (i.e., 5% increased tempo from the patient's subjective tempo). Also, arrangement of musical instruments can be adjusted in accordance with kinematic and dynamic trajectory of desired movement and, then, the range of movement can be gradually increased (e.g., increases in joint angel).

5. Enhanced affective-cognitive functions, and motivation to exercise

According to previous empirical as well as conceptual studies, music listening as well as music playing lead to positive affect (Menon & Levintin, 2005). Positive affect s, in turn, leads to enhance in various cognitive functions through dopaminergic systems (Ashby & Isen, 1999). A recent study conducted by Särkämö and colleagues (2008), music listening activates a wide regions of the brain that are known to modulate motor, emotional as well as cognitive functions (i.e., attention, memory).

Such integrative enhancement in the brain may be associated with increases in motivation as reported in Schneider et al. (2007)'s study. Patients with stroke who received rehabilitation training program using instrumental music playing stated that it was highly enjoyable and motivated them to maintain involvement to a 3-week music exercise where the difficulty of given tasks gradually increased. Thus, diverse sensory rewards, enhanced mood and cognitive functions, as well as pleasure of exercising and learning through active music making may contribute to motivate patients' maintenance of simple but intensive exercise, yielding a maximized outcome for upper extremity rehabilitation in subacute stroke.

In conclusion, with the necessity of early intervention immediately following stroke due to the limited critical period of neural recovery, instrumental music playing, therefore, can be innovative alternatives for upper extremity rehabilitation in subacute stroke. Future research studies will be undertaken in order to obtain empirical evidence that confirms the effect of using instrumental music playing in improving upper limb functions of patients with subacute stroke.

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