J. Phys. Ther. Sci. 28: 2560–2564, 2016

The Journal of Physical Therapy Science

Original Article

The effect of intervention according to muscle contraction type on the cerebral cortex of the elderly

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Abstract. [Purpose] Here we investigated the activity of the cerebral cortex after resistance training in the elderly. We evaluated the clinical neuropsychological basis of 2 contractile types, and determined the usefulness of a movement-related cortical potential (MRCP) from an electroencephalography (EEG). [Subjects and Methods] The subjects were 11 females and 11 males aged between 65 and 70 years. The subjects were randomly assigned into a group that performed an eccentric contraction exercise (experimental group I, n=11) and a group that performed a concentric contraction exercise (experimental group II, n=11). We measured activities of the rectus femoris, vastus medialis, and vastus lateralis in the non-dominant lower extremity by using surface electromyography (EMG), and measured brain activity using EEG before conducting an intervention. An intervention was conducted 40 minutes per session, once a day, 3 times a week for 4 weeks. [Results] After the intervention, activity in C4, the Cz area and rectus femoris were significantly different. [Conclusion] Our results demonstrate that MRCP from an EEG has the advantage of being non-invasive and cost-effective. Nonetheless, prospective studies are needed to reveal the specific mechanism underlying eccentric contraction exercise, which can provide baseline data for research related to aging and neural plasticity.

Key words: Aging, Eccentric contraction, Movement related cortical potential

(This article was submitted Mar. 4, 2016, and was accepted May 26, 2016)

INTRODUCTION

Aging affects all species, particularly in terms of the quality and activities of life. Nonetheless, questions about aging remain unanswered[1]. Isaac et al. reported that the loss of muscle strength and power that are related to human aging are partially caused by a change in the skeletal muscle structure and a volume reduction in skeletal muscle[2–5]. Clearly, aging decreases the cross sectional area of the skeletal muscles and the volume of the contractile tissue on the cross sectional area. Such changes alter muscle function, such as the characteristics of motor unit firing, the aerobic capacity of the skeletal muscles, decreasing the function and productivity of power[6]. In addition, aging changes the nervous system. For example, aging leads to broad and quantitative changes in both white and gray matter. Such changes can occur in the sensorimotor area of the brain[7].

A decrease in nervous system function commonly leads to a change in the contractile ability of the skeletal muscles; however, eccentric contraction is less affected than concentric contraction[8, 9]. Voluntary eccentric contraction and concentric contraction show a unique activation pattern in the brain[10]. Because of the differences in the muscular actions of these 2 contraction types, various exercise programs for patients have used in clinical care. However, the mechanisms that regulate these 2 contraction types are still unclear[11]. Exercise programs that successfully improved the functional ability and muscle

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*Corresponding author. Hyun Choi (E-mail: pelvic@hanmail.net) strength of elderly patients using resistance training[12]. Moreover, muscle adaptation through eccentric contraction training can be beneficial for preventing damage due to intense exercise[13] and the functional loss of skeletal muscles due to aging[14].

Various tools have been used to investigate the effect of resistance training on the nervous system and the regulatory mechanisms of contraction types. In particular, the cortical potential related to movement measuring activity of neurons in the cerebral cortex has been used as electrophysiological evidence for distinguishing hypofunction of the nervous system[15, 16]. A movement-related cortical potential (MRCP) using electroencephalography (EEG) describes the brain potential from an EEG that is related to voluntary movement[17]. A MRCP can record the activity of the cerebral cortex that is related to active movement and voluntary impulse[18]. Notably, the techniques for measuring a MRCP are cost-effective in the clinic[19]. Thus, here we investigated the activity of the cerebral cortex after resistance training based on 2 contractile types in the elderly. We also evaluated the clinical neuropsychological basis of 2 contractile types and the usefulness of an MRCP from an EEG.

SUBJECTS AND METHODS

This study received the approval of the Bioethics Committee of the Sehan University Center (IRB) (Approval number: 2015-11). The study subjects were 11 females and 11 males aged between 65 and 70 years with a right-side predominance (Table 1). The subjects did not present with pathological neuromuscular skeletal system findings. The subjects consistently had no training for muscle strength for a year and had not consistently taken medicine. The subjects were randomly assigned to either a group performing an eccentric contraction (n=11) or a group performing a concentric contraction (n=11). Experimental group I performed the eccentric contraction exercise and experimental group II performed the concentric contraction exercise. The subjects understood the purpose of this study and voluntarily agreed to participate, as documented with the written informed consent of each subject.

We measured activities of the rectus femoris, vastus medialis, and vastus lateralis in the non-dominant lower extremity by using a surface EMG, and measured brain activity by using an EEG before conducting an intervention. The intervention was performed 40 minutes per session, once a day, 3 times a week for 4 weeks. We used the MP 150 System (Biopac System Inc., Goleta, CA, USA) and EEG100C (Biopac System Inc.) to measure MRCP based on voluntary contraction of knee extensor muscles on the non-dominant side. The sampling rate for signal collection was set to 200 Hz, and the frequency band filter was set at 1 to 35 Hz. The Acqknowledge 3.8 software program (Biopac System Inc.) was used to analyze the PP (positive potential) of the MRCP in the collected signal.

The one-rep-max (1RM) for the concentric contraction training group was measured based on the maximum weight that the subjects could maintain from flexing their knee at a 90-degree angle to extending their knee at a 180-degree angle for 5 seconds. The 1RM for the eccentric contraction training group was measured based on the maximum weight that the subjects could maintain from extending their knee at a 180-degree angle to flexing their knee at a 90-degree angle for 5 seconds. The measurement was performed in triplicate, and sufficient resting time was provided to prevent muscle fatigue in the subjects. The MP 150 System (Biopac System Inc.) was used as a surface EMG, the sampling rate for signal collection was 200 Hz, and the frequency band filter was set to 1 to 35 Hz. The Acqknowledge 4.2.2 software program (Biopac System Inc.) was used to analyze the collected signal. The rectus femoris is located at the center of the anterior surface of the thigh, and approximately half the distance between the knee and iliac spine. The 2 active electrodes were placed 2 cm apart and parallel to the muscle fiber. The electrodes for the vastus medialis oblique were placed with 2 cm spacing and at an oblique angle (55 degrees), 2 cm medially from the superior rim of the patella. The vastus lateralis activity was measured using 2 active electrodes that were placed 2 cm apart and were approximately 3 to 5 cm above the patella at an oblique angle just from lateral to mid line. During extension of the knee the muscles was palpated. Standing posture as a standards action was set in an EMG signal, and the root mean square (RMS) was measured for 10 seconds. The RMS was collected during the maximal voluntary isometric contraction of the knee extensor in a sitting posture using the manual muscle test as suggested by Kendall[20] and are expressed as percentages. The RMS was normalized as %MVIC (maximum voluntary isometric contraction). All of the measurements were performed in triplicate and the mean value was used. Each measurement was taken repeatedly after a sufficient interval of resting time to prevent muscle fatigue.

Measuring the posture of a cerebral cortex neuron was similar to measuring the posture of the 1RM. signals of the brain waves that were collected sequentially and repeated 30 times with a 30% 1RM weight. An assistant aided the subjects in performing either a concentric contraction or an eccentric contraction. Next, among signals of collected EMGs, we selected and averaged the brain wave signal at 2 seconds before initiating an EMG signal starting action and the signal a second after initiating an EMG signal starting action. The MP 150 System (Biopac, USA) and EEG100C (Biopac, USA) were used, and the sampling rate for signal collection was set to 200 Hz with a frequency band filter of 1 to 35 Hz. Active electrodes were placed in CZ, C3, C4, and FZ based on the International 10–20 System, and CZ was placed at the central part of the scalp of motor area. An electrode for C3 and C4 was placed on the left and right scalp of the M1 area. The FZ electrode was placed at the central part of the prefrontal cortex. The ground electrode and reference electrode (i.e., A1 and A2, respectively) were placed in the mastoid process. The Acqknowledge 4.2.2 software program (Biopac System Inc.) was used to analyze the negative potential (NP) of the MRCP in the collected signals, and Brain MAP-3D Software (Laxtha, Korea) was used to analyze the brain mapping of brain wave before and after conducting the intervention. The NP from the channel attached in each area was averaged per group. Amplitudes of these values were expressed in colors and overlapped with the standardized

Table 1. General subject characteristics

	Experimental group I (n=11)	Experimental group II (n=11)
Age (years)	67.1 ± 1.8[a]	68.2 ± 1.4
Height (cm)	162.8 ± 5.3	159.0 ± 4.9
Weight (kg)	63.5 ± 8.1	61.1 ± 8.0
Gender (M/F)	6/5	5/6

[a]Mean ± SD, Shapiro-Wilk.
Experimental group I: eccentric contraction exercise group
Experimental group II: concentric contraction exercise group

Table 2. Comparison of the difference in the cerebral cortex area between groups

	Group	Pre	Post
Fz	Experimental group I	1.4 ± 0.4[a]	1.6 ± 0.4
	Experimental group II	1.3 ± 0.6	1.4 ± 0.6
C3	Experimental group I	2.0 ± 0.9	2.2 ± 0.7
	Experimental group II	1.6 ± 0.8	1.7 ± 0.6
Cz	Experimental group I	1.9 ± 0.8	2.4 ± 0.7*
	Experimental group II	1.4 ± 0.5	1.6 ± 0.6
C4	Experimental group I	1.5 ± 0.8	1.9 ± 0.4*
	Experimental group II	1.0 ± 0.3	1.1 ± 0.3

*$p<0.05$.
[a]Mean ± SD, ANCOVA.
Experimental group I: eccentric contraction exercise group
Experimental group II: concentric contraction exercise group
Fz: prefrontal area, C3: primary motor area (left), Cz: supplementary motor area, C4: primary motor area (right)

three-dimensional scalp image. Weight for training was set to 70% of the 1RM to determine the exercise weight of the subjects based on the measured 1RM. The eccentric contraction group maintained a full extension of the knee extensor muscles of the non-dominant side for a second on the NK table and then flexed their knee for 5 seconds, adjusting to the metronome. When the subject in the eccentric contraction group returned to the starting position, an assistant instructed them to flex their knee joints passively. The concentric contraction group flexed their knee extensor muscle of the non-dominant knee joint at a 90-degree angle for a second on the NK table and then fully extended their knee for 5 seconds, adjusting to metronome. When the subject in this group returned to the starting position, an assistant instructed them to extend their knee joints passively. The intervention was performed 10 times per set for 3 sets, three times a week for 4 weeks. Two weeks later, 1RM was re-measured and training began again for 2 weeks, increasing the weight for training to 70% of the increased weight. The subjects rested for 5 minutes after each set to prevent muscle fatigue, and another exercise training was performed 48 hours after the session.

SPSS version 18.0 was used to analyze data, and Shapiro-Wilk test was used to analyze data normality distribution. An ANCOVA was used to analyze differences between the experimental groups at a significance level of 0.05.

RESULTS

1) The data followed a normal distribution indicating that there were no distinct characteristics between the groups (Table 1).
2) There was a statistically meaningful difference between the C4 area and Cz area ($p<0.05$) (Table 2).
3) There was a statistically meaningful difference for the activity of the rectus femoris ($p<0.05$) (Table 3).

DISCUSSION

The sensorimotor area of the cerebral cortex is consistently changing by experience21), and reversibility of cortex related-aging that is associated with a decrease in physical ability is related to broad neurochemical and neurophysiological changes22). Pellicciari et al.23) reported that normal aging is associated with hypoexcitability of inhibitor circuits that exist in the cerebral cortex and the loss of synapse connection. Lee et al.24) reported that morphological changes in the peripheral nervous system, namely, abnormal myelination or loss of axons, results in functional changes, including the loss of sensory receptors and a decrease of innervated tissues. However, despite such changes, progressive resistance exercise can drive changes in musculoskeletal system and accompanying changes in the nervous system in older adults25). Smith et al.26) emphasized that the improvement of competence after training both hands for a short period of time appeared to decrease reaction times, namely because of a decrease in the latency of the Bereitschaftspotential (BP) and amplitude, These results indicate that the activity of neurons in the cerebral cortex increase after training. We note that active and voluntary movements are needed to generate effective cortical activation. Yang et al.27) investigated differences in the activities of spinal neurons based on muscle contraction types and cerebral cortical neuron potential, and reported that the peak values in Cz, C3 and Fz during eccentric contraction are higher than those during concentric contraction. Falvo et al.28) insisted that MRCP after intervention, but not before, has an earlier onset (by as much as 28%) in 11 normal subjects who had been trained with resistance exercise of the knee extensor muscles for 3 weeks. Moreover, neural adaptation in cortex increased. That is, C4 and Cz in the motor area had a higher positive potential (PP) mean value after performing an eccentric contraction exercise. Eccentric resistance training resulted in higher activities in the primary motor area, and thus contributes to an increase in the excitability of the cerebral

Table 3. Comparison of the muscle activity between groups

Items	Groups	Pre-test	Post-test
Rectus femoris (%)	Experi-group I	104.8 ± 13.2[a]	127.7 ± 13.6*
	Experi-group II	106.8 ± 18.2	114.1 ± 15.7
Vastus medialis obliqus (%)	Experi-group I	98.8 ± 14.8	107.3 ± 16.3
	Experi-group II	95.7 ± 15.3	103.2 ± 13.8
Vastus lateralis (%)	Experi-group I	100.6 ± 13.8	109.2 ± 14.2
	Experi-group II	99.9 ± 14.8	105.4 ± 15.2

*$p<0.05$.
[a]Mean ± SD, ANCOVA.
Experi-group I: eccentric contraction exercise group
Experi-group II: concentric contraction exercise group

cortex. These results suggest that sensory feedback occurs more during an eccentric contraction compared to a concentric contraction as a result of having plans in the cerebral cortex about additional movements or have to deal with problems specific to eccentric contraction16). Generally, increasing voluntary muscle strength occurs through 2 main mechanisms, neural adaptation and myohypertrophia, and increasing muscle strength requires changes to the nervous system at the beginning of a training program.29) Many advanced meta-analysis that Gault and Willems performed showed that eccentric contraction training, but not concentric contraction training, could improve muscle strength in both the young and old when performing reinforcement training of a single joint through concentric, eccentric, and isokinetic contraction30). In particular, Gault and Willems suggest that knee extensor muscles are an important factor in the elderly. Roige et al.31) suggested that the average conservation rate of an eccentric contraction is 21.6%, and ranges from 2% to 48%, based on their comparison of studies of concentric contraction and eccentric contraction in the elderly. These studies support the clinical significance of low intensity eccentric contraction exercise in the elderly, indicating that it could be useful for early and rehabilitative resistance training. LaStayo et al.32) suggest that the neural adaptation of eccentric resistance exercise at a high intensity is beneficial for muscle strengthening or injury prevention in athletes, and that this approach has many advantages for the rehabilitation of the elderly. Our results support the research of others, showing that an increase in the muscle activity of the rectus femoris after eccentric contraction training. The muscle activities of the vastus medilis and vastus lateralis increased in both eccentric and concentric training groups, with no meaningful difference between them. The most significant effect of exercise occurred in the rectus femoris because it takes a neutral posture in the ankle joint and a training posture in the hip joint, and thus has the greatest load.

In summary, our results demonstrate that a MRCP based on an EEG has the advantage in rehabilitative research of being both non-invasive and cost-effective. We found that eccentric contraction was associated with overall higher neural activity, and there was a statically meaningful difference for the activity in C4, Cz, and the primary motor area. Similar to previous studies, we found more complex and higher activity in cerebral cortex after eccentric contraction training. We found that eccentric contraction in older adults is a more effective exercise through stimulation of the nervous system and musculoskeletal system, supporting the use of eccentric contraction training for preventing falls and rehabilitation exercise training in the elderly. However, we did not control for the daily life activities of all of the subjects. Moreover, the results of our study need to be verified using a longer experimental period. Furthermore, prospective studies are needed to clarify the mechanism of eccentric contraction exercise, which will be useful for research related to aging and neural plasticity.

ACKNOWLEDGEMENT

This paper was supported by the Sehan University Research Fund in 2016.

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