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The Effects of Abdominal Hollowing in Lower-limb PNF Pattern Training on the Activation of Contralateral Muscles

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Abstract. [Purpose] The purpose of this study was to determine the effects of abdominal hollowing during lower-limb proprioceptive neuromuscular facilitation (PNF) training on the activation of contralateral muscles. [Subjects] Twenty male college students without symptoms or signs of muscular or nervous disease participated in this experiment after signing a consent form. [Methods] All the subjects were measured with electromyography (EMG) in a muscle activation test before and after abdominal hollowing. In the PNF program, the lower-limb pattern of PNF training, was maintained for 5 seconds, followed by a 2-minute break. This was repeated three times. The resting time between sets was 30 minutes. Surface EMG (Keypoint, Medtronic Inc., USA) was used for the measurements, and the highest value of three measurements was used in the analysis. [Result] The results revealed a significant change in the muscular activation of the opposite-side lower limbs. The muscular activations of the vastus lateralis, tibialis anterior, semitendinosus and gastrocnemius were increased significantly after the abdominal hollowing. [Conclusion] The findings suggest that abdominal hollowing in PNF pattern training can be effective at promoting muscular activation of the contralateral muscles. To promote muscular activation of the opposite side in lower-limb PNF pattern training, abdominal hollowing should be considered to improve the effect of PNF pattern training.
Key words: PNF pattern, Abdominal hollowing, Contralateral muscle activation

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INTRODUCTION

Proprioceptive neuromuscular facilitation (PNF) is a treatment method that can be applied in a specific diagonal pattern, to facilitate the ability to promote function[1)]. PNF is known to increase muscle coordination and to elicit the maximum response from motor units[2)].

Generally, in neurological PNF treatment, the treatment is applied directly to the affected side with the aim of functional improvement of that side. However, many recent studies have shown that the indirect PNF treatment method, which focuses on the unaffected side, is effective at improving the recovery of the affected side. The indirect treatment method strengthens the weak side by increasing the resistance to the strong side in a process known as irradiation[2)]. Although the mechanism underlying the effect of irradiation is unclear, if continuous training of the ipsilateral limb is performed, it also affects the contralateral limb via cross-training or the contralateral effect[3)]. In PNF, proprioception is recovered by facilitating muscle activation through resistance training at the unaffected side[4)]. The contralateral effect is frequently used to promote muscular strength and motor function, and it has been reported to have positive effects[5)].

In a meta-analysis of the effect of ipsilateral training, Munn et al.[4)] stated that cross-training was effective at increasing contralateral muscular strength. Kim[6)] determined muscle activation after applying PNF flexion, abduction and external rotation upper-limb patterns, and bilateral upper-lifting patterns. One study found that PNF patterns applied to the ipsilateral upper-limb noticeably increased the muscle activation of the contralateral lower limb. Zhou[7)] reviewed a number of studies of the effect of cross-training, and found that the muscular strength of the contralateral limb could be promoted, depending on the intensity of the exercise. Thus, the literature suggests that resistance training applied to an ipsilateral extremity is effective at promoting muscular strength. However, these previous studies did not consider an essential prerequisite for the effectiveness of cross-training, the stabilization of the core muscles.

The core muscles are responsible for all the power and the mobility of the human body. They control balance every time the human body moves, and they protect muscle

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and bone by properly maintaining musculoskeletal structure. Furthermore, core muscles are tonic muscles, which play an important role in trunk stability and postural control during whole body training[8]. Among the core muscles, physical therapists have focused in particular on the role of the transversus abdominis muscle in stability[9]. In particular, the activities of the transversus abdominis increase the tension of the lumbar facial structure and contribute to stability through variation of intra-abdominal pressure[10]. Therefore, to maximize the effects of cross-training resistance exercises during PNF and to enhance core stabilization, the activities of the transversus abdominis should be facilitated. There have been few studies of the stabilization of core muscles during PNF cross-training with resistance, either in South Korea or elsewhere. In particular, few studies have investigated the influence of core stabilization on the effect of cross-training on the co-activation of the transversus abdominis. Therefore, this study aimed to determine the influence of the coactivation of the transversus abdominis on the muscle activation of the contralateral lower limb in PNF lower-limb pattern training.

SUBJECTS AND METHODS

The research participants were selected from students of S university in Busan, Republic of Korea. The subjects could control independent weight bearing of the lower limbs on both sides and had no abnormalities in the muscular or nervous systems. Twenty male students participated in the experiment. They participated in the experiment after being informed of the procedures of the experiment. The ethical committee of Silla University approved this study, and written informed consent was received from each participant.

At the start of the exercise, the subjects lay in a supine position, with the sole of the foot pressed against the surface of a wall, the lateral malleolus and fibular head at a normal level, and the hip joint flexed at an angle of 40 degrees In the lower-limb PNF exercises, flexion/adduction and external rotation patterns were applied to the right lower limb to facilitate the contralateral effect. The increase in muscle activation was measured and approximated while the ankle joint was held and maximally dorsiflexed in the mid-range of the lower-limb patterns,

For the analysis, the highest value of three surface electromyogram (EMG) (Keypoint, Medtronic Inc., USA) measurements was used. Following Jung[11], the electrodes were attached to the muscle belly of the vastus lateralis, the semitendinosus, the tibialis anterior, and the gastrocnemius. To reduce measurement error, the locations where the electrodes were placed were shaved and cleansed with alcohol. The electrodes were firmly attached to the skin to prevent noise resulting from their movement during the PNF pattern training. They were attached 10–15 cm from the upper part and 6 cm from the lateral part of the upper edge of the patella on the vastus lateralis. The semitendinosus was monitored by attaching another electrode at a point halfway between the ischial tuberosity and the medial condyle of the tibia. Another electrode was attached to the upper 75% area of the tibialis anterior, linking the lateral condyle to the lateral malleolus and the knee joint. At the medial head of the gastrocnemius, an electrode was attached to the upper 35%, linking the medial condyle to the lateral calcaneus of the knee joint[12]. The ground electrode was attached just below the fibular head. The maximal voluntary isometric contraction (MVIC) was measured for 5 seconds, and the highest value of three trials, excluding the first second, was used as the MVIC. The duration of the contractions (5 seconds) was strictly controlled during the measurement, after which the subjects had a 5-minute rest. Measurements with or without abdominal hollowing were also made for 5 seconds, and the first second of data was discarded. When applying the PNF lower-limb patterns, a 2-minute rest was given after every trial to prevent muscle fatigue, and sufficient rest was also given after every measurement. The measurements were conducted three times, and the highest value of the trials was used in the analysis.

Table 1. The general characteristics of the study subjects (Unit)

Age (year)	Height (cm)	Weight (kg)
21.1 ± 1.4[a]	174.7 ± 4.5	68.4 ± 8.2

[a]Mean ± SD

For the EMG analysis, EMG was normalized to MVIC as follows: NorEMG (MVIC%) = EMGm/EMGmax × 100%. Here, NorEMG represents the normalized EMG value of each muscle, EMGm indicates the EMG value of each muscle measured during the training, and EMGmax stands for the EMG value of the maximum MVIC of each muscle.

The Shapiro-Wilk test was conducted to verify the normality of the data, which were collected from only a small number of subjects. The test result was satisfactory, and parametric tests were conducted accordingly. To examine the effect of abdominal hollowing on muscular activation, the paired sample t-test was conducted to compare the muscular activation before and after the abdominal hollowing. SPSS WIN (ver. 20.0) was used for statistical analysis, with a significance level of $\alpha=0.05$.

RESULTS

The 20 male subjects had an average age of 21.1 years, an average height of 174.6 cm, and an average weight was 68.35 kg (Table 1). Comparison of the muscle activations in the contralateral lower limb, according to the presence or absence of abdominal hollowing following the application of the PNF patterns, showed that the vastus lateralis remarkably increased from 41.5% MVIC to 54.3% MVIC ($p<0.05$), the semitendinosus increased from 59.7% MVIC to 73.4% MVIC ($p<0.05$), the tibialis anterior increased from 47.5% MVIC to 61.8% MVIC ($p<0.05$), and the gastrocnemius increased from 51.8% MVIC to 62.6% MVIC ($p<0.05$) with abdominal hollowing (Table 2).

DISCUSSION

Recent clinical trials have described the indirect treatment approach in cross-training using the contralateral effect, and their results reveal that training the unaffected

Table 2. Comparison of muscle activations in the contralateral lower-limb, according to presence or absence of abdominal hollowing, in PNF patterns (Unit: %MVIC)

Muscles	absence	presence
Vastus lateralis*	41.5 ± 16.2[a]	54.3 ± 19.9
Semitendinosus*	59.7 ± 16.9	73.4 ± 18.8
Tibialis anterior*	47.5 ± 15.6	61.8 ± 14.5
Gastrocnemius*	51.8 ± 20.3	62.6 ± 22.8

[a] Mean ± SD *: $p<0.05$

side affects the function of the affected side[13]. For this reason, PNF focuses on strengthening the weak side through exercises of the strong side using an approach known as irradiation[2]. Many studies have reported that interlateral transfer is enabled by cross-training exercise, with resulting improvements in muscular strength, function, and endurance of the untrained contralateral limb[14]. Furthermore, improvements in motor function have also been reported[15].

Shima et al.[16] reported that ipsilateral resistance training improved contralateral muscular strength according to EMG measurements. Bemben and Murphy[17] indicated that the muscular strength of the untrained contralateral limb also increased after temporary ipsilateral resistance training. Kim et al.[18] showed that isokinetic exercise for the hip joint improved the balance of the contralateral lower limb while standing on one leg. Similarly, this kind of effect has been observed in PNF. In a study of healthy people, Nikolaos et al.[19] showed that application of the lower-limb pattern to the ipsilateral lower limb increased the knee extensor strength of the untrained contralateral limb. Lee et al.[20] reported that lower-limb patterns applied to the unaffected side of stroke patients triggered irradiation, which indirectly increased the muscle activation of the upper limb, regardless of all articular elements. According to Hortobagyi et al.[21], this cross-training effect is controlled at the cortical level. Lagerquist et al.[22] suggested that the cross-training effect is generated at a level higher than the spinal cord level. Hortobagyi et al.[21] stated that the effect occurred after the activation of the contralateral and ipsilateral sensorimotor cortexes. Munn et al.[23] reported that ipsilateral weight training increased contralateral muscular strength because of an increase in the firing rate and the recruitment of motor units in the central nervous system.

However, most recent research studies did not consider the stabilization of the core muscles. Such stabilization is an essential prerequisite for the effectiveness of cross-training, in particular, the stabilization of the core muscles in the center of the body. To increase muscle strength, the limb and trunk muscles must be recruited. Among these muscles, the activity of the transversus abdominis is important. Abdominal hollowing is a core stabilization exercise that can facilitate the activity of the transversus abdominis[24]. The transversus abdominis is involved in postural control, and it contracts first at the moment when any movement starts, or when the body is loaded. The transversus abdominis of a healthy individual contracts 30 to 100 ms earlier before the movement of the upper or lower limbs[25]. Oh et al.[26] reported that the muscle activation of the gluteus maximus and the medial hamstring was increased after hip extension exercise with abdominal hollowing. In a study of the effect of bridging exercise including abdominal hollowing, measured with a pressure biofeedback unit, Kim et al.[27] reported that the muscle activation of the lateral hamstring was remarkably increased. Thus, unilateral application of PNF patterns appears to increase muscle activation on the contralateral side, and core stabilization through coactivation seems to be effective at increasing muscle activation. In the present study, when the PNF lower-limb patterns were applied with abdominal hollowing, the muscle activation of the vastus lateralis, semitendinosus, tibialis anterior, and gastrocnemius increased noticeably. We think this is due to local activation of the transversus abdominis during the abdominal hollowing exercise. In essence, the activation of the transversus abdominis through abdominal hollowing contributed to stability by increasing the tension of the thoracolumbar facia, as a function of the local system, and providing proprioceptor feedback during the abdominal hollowing. The activation of the transversus abdominis may also increase the intra-abdominal pressure, solidify articular stiffness, more firmly fix the spine and the pelvic girdle, and facilitate postural balance, thereby making core stabilization possible.

The results of this study show that the activation of the transversus abdominis makes anticipatory postural control and core stabilization possible, in addition to contributing to the stability of the lower limb and facilitating smoother and more complete movement. All the power and the mobility of the body are generated from the core muscles. When the core of the body becomes unstable, the limbs are used to stabilize the core, resulting in poor functioning. Thus, core stabilization is the main factor in every movement. As a result, it is important to combine abdominal hollowing with PNF patterns.

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REFERENCES

1) Klein D, Stone W, Phillips W, et al.: PNF training and physical function in assisted-living older adults. J Aging Phys Act, 2002, 10: 476–488.
2) Knott M, Voss DE: Proprioceptive Neuromuscular Facilitation: Patterns and Techniques, 3rd ed. New York: Harper and Row, 1968.
3) Munn J, Herbert RD, Gandevia SC: Contralateral effects of unilateral resistance training: a meta-analysis. J Appl Physiol, 2004, 96: 1861–1866. [CrossRef] [Medline]
4) Adler S, Beckers D, Buck M: PNF in practice, 3rd ed. Berlin: Springer, 2008.
5) Fujiwara T, Hara Y, Chino N: The influence of non-paretic leg movement on muscle action in paretic leg of hemiplegic patients. Scand J Rehabil Med, 1999, 31: 174–177. [CrossRef] [Medline]
6) Kim KH: Effect of Proprioceptive Neuromuscular Facilitation applied to the unilateral upper extremity on the muscle activation of contralrteral lower extremity. Eulji University, Master thesis, 2005.
7) Zhou S: Chronic neural adaptations to unilateral exercise: mechanisms of cross education. Exerc Sport Sci Rev, 2000, 28: 177–184. [Medline]
8) Marshall PW, Murhpy BA: Core stability exercise on and off a Swiss ball. Arch Phys Med Rehabil, 2005, 86: 242–249. [CrossRef] [Medline]

9) Hodges PW: Core stability exercise in chronic low back pain. Orthop Clin North Am, 2003, 34: 245–254. [CrossRef] [Medline]
10) Hodges PW, Eriksson AE, Shirley D, et al.: Intra-abdominal pressure increases stiffness of the lumbar spine. J Biomech, 2005, 38: 1873–1880. [CrossRef] [Medline]
11) Jung HS: A study of muscle activities and gait analysis between young adults and elderly people according to gait speed in level walking. Daegu University, Dissertation of Doctorate Degree, 2009.
12) Cram JR, Kasman GS, Holtz J: Introduction to surface electromyography. Maryland: Aspen Pub, 1998.
13) Hortobágyi T, Scott K, Lambert J, et al.: Cross-education of muscle strength is greater with stimulated than voluntary contractions. Motor Control, 1999, 3: 205–219. [Medline]
14) Farthing JP, Borowsky R, Chilibeck PD, et al.: Neurophysiological adaptations associated with cross-education of strength. Brain Topogr, 2007, 20: 77–88. [CrossRef] [Medline]
15) Stromberg BV: Contralateral therapy in upper extremity rehabilitation. Am J Phys Med, 1986, 65: 135–143. [Medline]
16) Shima N, Ishida K, Katayama K, et al.: Cross education of muscular strength during unilateral resistance training and detraining. Eur J Appl Physiol, 2002, 86: 287–294. [CrossRef] [Medline]
17) Bemben MG, Murphy RE: Age related neural adaptation following short term resistance training in women. J Sports Med Phys Fitness, 2001, 41: 291–299. [Medline]
18) Kim K, Cha YJ, Fell DW: The effect of contralateral training: influence of unilateral isokinetic exercise on one-legged standing balance of the contralateral lower extremity in adults. Gait Posture, 2011, 34: 103–106. [CrossRef] [Medline]
19) Nikolaos D, Kofotolis N, Kellis E: Cross-training effects of a proprioceptive neuromuscular facilitation exercise programme on knee musculature. Phys Ther Sport, 2007, 8: 109–116. [CrossRef]
20) Lee MK, Kim JM, Kim WH: The effects of proprioceptive neuromuscular facilitation leg patterns on the muscle activation of biceps and triceps in stroke patients. J Korean Soc Phys Ther, 2009, 54: 1–7. [CrossRef]
21) Hortobágyi T, Taylor JL, Petersen NT, et al.: Changes in segmental and motor cortical output with contralateral muscle contractions and altered sensory inputs in humans. J Neurophysiol, 2003, 90: 2451–2459. [CrossRef] [Medline]
22) Lagerquist O, Zehr EP, Docherty D: Increased spinal reflex excitability is not associated with neural plasticity underlying the cross-education effect. J Appl Physiol, 2006, 100: 83–90. [CrossRef] [Medline]
23) Munn J, Herbert RD, Hancock MJ, et al.: Training with unilateral resistance exercise increases contralateral strength. J Appl Physiol, 2005, 99: 1880–1884. [CrossRef] [Medline]
24) Springer BA, Mielcar BJ, Nesfield TK, et al.: Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance. J Orthop Sports Phys Ther, 2006, 36: 289–297. [Medline]
25) Hodges PW, Richardson CA: Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther, 1997, 77: 132–142. [Medline]
26) Oh JS, Cynn HS, Won JH, et al.: Effects of performing an abdominal drawing-in maneuver during prone hip extension exercises on hipand back extensor muscle activity and amount of anterior pelvic tilt. J Orthop Sports Phys Ther, 2007, 37: 320–324. [Medline]
27) Kim EO, Kim TH, Roh JS, et al.: The influence of abdominal drawing-in maneuver on lumbar lordosis and trunk and lower extremity muscle activity during bridging exercise. J Korean Acad Univ Trained Phys Therapists, 2009, 39: 1–9. [CrossRef]