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ORIGINAL ARTICLE

Intensive unilateral neuromuscular training on non-dominant side of low back improves balanced muscle response and spinal stability

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Abstract Effective stabilization is important to increase sports performance. Imbalanced spinal muscle responses between the left and right sides increase the risk of spinal buckling and microtrauma at the intervertebral joints. The purpose of this study was to confirm whether intensive unilateral neuromuscular training (IUNT) focusing on the non-dominant side of the low back improves balanced muscle responses and spinal stability. The IUNT group ($n = 8$) performed side bridge and quadruped exercises using their non-dominant trunk muscles for 8 weeks, while the control group ($n = 8$) performed their regular training. Before and after the training, motion-capture cameras measured trunk angular displacement, and electromyography recorded the activities of both multifidus muscles (L4–5) during unexpected sudden forward perturbation. After the training in the IUNT group, the difference in onset time between both sides decreased to approximately 120 % compared with that before the training. The asymmetry of muscle activities also decreased from 56 to 23 %. Moreover, the angular displacement on the sagittal plane decreased to approximately 35 % after the training. We expect that IUNT focused on the non-dominant side of the low back will be useful to improve balanced back muscle responses and spinal stability during sudden trunk perturbation.

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Keywords Electromyography · Lumbar region · Skeletal muscle · Motion · Exercise movement techniques

Abbreviations

EMG Electromyographic
IUNT Intensive unilateral neuromuscular training

Introduction

Spinal stability determines the magnitude of trunk disturbance during sudden trunk perturbation. Moreover, spinal stability can affect disturbances in limb movement (Bazrgari et al. 2009; Hodges et al. 1999; Hodges and Richardson 1997). Thus, to improve spinal stability, experts in the field of rehabilitation and athletic training have studied the activation pattern of back muscles during trunk stabilization.

When the activation pattern of the back muscles is imbalanced between the left and right sides during sudden perturbation, spinal decoupling forces increase the risk of back pain (Grabiner et al. 1992; Hodges and Richardson 1996). The spinal decoupling forces between the left and right sides can induce abnormal joint torque caused by errors in motor control over a short time period, namely spinal bucking (Cholewicki and McGill 1996). Because spinal buckling produces frictional force between the intervertebral joints and damages the surrounding tissues, balanced force production between the left and right sides is important to prevent low back pain (Millner and Dickson 1996; Stokes and Iatridis 2004). Furthermore, if spinal buckling accompanies the production of joint compression forces, the damage to the surrounding tissues increases (Gardner-Morse and Stokes 1998; Stokes and Iatridis 2004;

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Vera-Garcia et al. 2006). In fact, a number of studies reported that the trunk muscles, especially the multifidus (L4–5) muscles, were imbalanced in sports athletes with back pain (Hides et al. 2008a, b; McGregor et al. 2002; Reeves et al. 2006; Renkawitz et al. 2006).

In terms of biomechanics, a decrease in the imbalanced muscle response between the left and right trunk muscles may decrease trunk disturbances and improve spinal stability. Among the trunk muscles, the multifidus muscles play an important role in providing segmental stiffness (Panjabi 1992a; Wilke et al. 1995) and control of the spinal neutral zone (Panjabi et al. 1989; Panjabi 1992b) as a local stabilizer (Bergmark 1989). However, it is still unclear whether a decrease in the imbalanced muscle response in both multifidus muscles improves spinal stability.

The current study investigated the effects of intensive unilateral neuromuscular training (IUNT) on decreasing the imbalanced response between the left and right multifidus muscles and increasing spinal stability. The first hypothesis in this study was that IUNT decreases the difference in muscle onset time and activities between both multifidus muscles (L4–5) during unexpected sudden forward perturbation. The second hypothesis was that IUNT increases spinal stability against unexpected sudden perturbation.

To decrease the imbalanced response of the multifidus, we applied IUNT to the non-dominant side of the multifidus. A previous study demonstrated decreased imbalance by specific home-based training for tennis players (Renkawitz et al. 2007). However, which specific exercises reduced the imbalance was unclear. Recently, unilateral neuromuscular training has received attention in terms of providing counterbalance that can diminish the resultant asymmetrical contractile force of the axial muscles (Behm et al. 2010). Above all, the quadruped and side bridge exercises are typical asymmetrical exercises targeting the back and abdominal muscles. The quadruped exercise is considered to elicit great electromyographic (EMG) activities of the erector spinae and gluteus maximus unilaterally (Souza et al. 2001). The side bridge exercise specifically activates the ipsilateral abdominal and erector spinae muscles (Behm et al. 2005; Okubo et al. 2010). Thus, we speculated that these unilateral neuromuscular training exercises focusing on the non-dominant side of the trunk would effectively decrease the imbalanced response of the multifidus during trunk stabilization.

Methods

Subjects

Sixteen healthy female adolescent basketball players (14–16 years of age) participated in this study. All subjects were right-handed and available to attend periodic basketball training. No subjects had a previous history of orthopedic or neurological surgeries or balance disorders. Eight of the 16 subjects were randomly assigned to the IUNT group, and the remaining 8 subjects were assigned to the control group. The characteristics of the two groups are presented in Table 1. All experimental procedures were conducted after obtaining informed consent from the subjects and their legal guardians. All experimental protocols were approved by the Institutional Review Board of Korea University.

Table 1 Anthropometric characteristics of the subjects

Variable	IUNT group	Control group	*t*	*P*
Number of subjects	8	8		
Age (years)	14.8 (0.9)	14.0 (0.9)	1.655	0.120
Height (cm)	163.0 (7.6)	168.8 (5.3)	−1.722	0.098
Weight (kg)	55.1 (9.0)	59.6 (7.0)	−1.124	0.280

Values are presented as mean (SD). *t* and *P* values refer to *t* tests for independent samples

IUNT intensive unilateral neuromuscular training

Apparatus

The trunk must first be destabilized to allow for observation of the stabilizing phase. For this purpose, an unexpected, suddenly released forward perturbation was applied to the upper trunk. The apparatus used to induce the trunk perturbation is shown in Fig. 1. The subjects were instructed to cross their arms on their chest and sit on a bench tilted at 45° with their knees placed on a 30° inclined wedge. A Velcro strap fixed the proximal femur to minimize movement of the lower extremities, and the feet were allowed to be placed naturally. A load of 8 kg was connected using a cable through two electromagnets. One electromagnet was connected at the mid-T9–10 level, and the other was connected to the load that was suspended through a pulley. The current flow of the electromagnet set was operated by a switch. When the current was turned off, forward perturbation occurred as soon as the two adhered electromagnets were separated.

At the beginning of the perturbation, the solenoid switch was connected, and the subjects were instructed to maintain an upright sitting posture against the backward pulling force by the external load. The load was then suddenly released without any warning or expectation. As a result, the subjects' trunk was suddenly moved in a forward direction. Assessments were performed before and after the training periods. Three trials were conducted, and the resting time between trials was 10–15 s.

Electromyography

A surface EMG device (MES 9000; FA Myotronics Noromed Inc., Seattle, WA, USA) was used to identify the

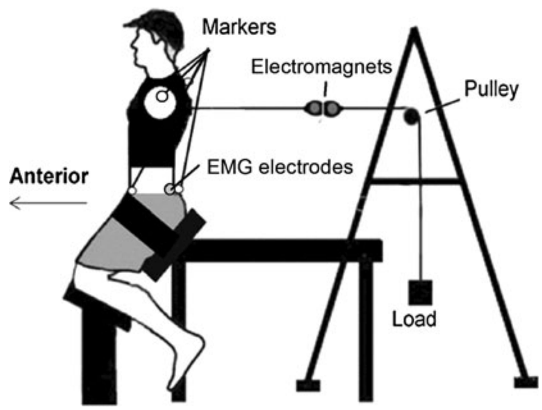

Fig. 1 Equipment for sudden-release trunk perturbation in the forward direction. An external load was attached to the upper trunk at an angle of 90° from the midline. The subjects performed an isometric trunk contraction against an external load while seated on a bench. When the load was subsequently released, the movements of the markers were traced and quantified with a three-dimensional motion-capture system, and the muscle responses of the multifidus (L4–5) were recorded

non-dominant side of the trunk during the unilateral neuromuscular exercises and to measure the imbalanced response during the trunk perturbation.

The skin was prepared by rubbing alcohol prep pads (Kendall Co., Mansfield, MA) saturated with 70 % isopropyl alcohol to reduce impedance. Ag/AgCl bipolar electrodes (Norotrode 20TM; FA Myotronics Noromed Inc., Seattle, WA, USA) with an interelectrode distance of 2 cm were placed over the targeted muscle sites and aligned with the muscle fibers. The electrodes were placed 2 cm laterally from the fourth and fifth lumbar spinous processes to measure the muscle activities of the multifidus (Callaghan et al. 1998).

Before the trunk perturbation, the subjects performed submaximal voluntary isometric contraction of the trunk extensor muscles in the Biering–Sorensen position to determine the individual reference EMG (Vera-Garcia et al. 2006). The measurement position was held for 3 s. After obtaining the reference measurements, EMG signals were recorded from 5 s before the perturbation to 5 s after it. These procedures were performed before and after the training periods.

Angular displacement

Angular displacement of the trunk induced by the sudden perturbation was measured as an index of trunk stability. Motion analysis (Motion Analysis Corporation System, Santa Rosa, CA, USA) was performed to detect the angular displacement in three dimensions. Six cameras were used for motion analysis, and the signals were sampled at 60 Hz. The motion-capture sensors were attached at the bilateral acromions, T1 spinous processes, anterior superior iliac spines, and S2 spinous processes (Fig. 1).

Training procedures

IUNT comprised side bridge and quadruped exercises focusing on the non-dominant side of the trunk. The criterion of the non-dominant side was the side with a root-mean-square EMG normalised to the EMG of submaximal voluntary isometric contraction, which was lower than that of the other side while performing the quadruped and side bridge exercises and alternating between the left and right sides. The training was performed on a Swiss ball as documented previously (Behm et al. 2005; Souza et al. 2001). For the side bride exercise, subjects lay on the non-dominant side with the legs straight and elevated on the Swiss ball (Fig. 2a-1). The subjects then elevated their pelvis until their whole body was straight and 45° to the floor (Fig. 2a-2). For the quadruped exercise, the subjects were initially asked to posture a four-point stance characterized by 90° flexion of the shoulders, hips, and knees (Fig. 2b-1). The non-dominant leg and contralateral arm were then simultaneously extended until both were parallel (Fig. 2b-2). Each exercise comprised 3 sets of 15 trials. The same physical therapist instructed the training group each time. The training lasted for 30 min and was performed twice a week for 8 weeks. The resting time between the sets was 1 min. The IUNT group performed additional side bridge and quadruped exercises along with their routine training; the control group received no specific training other than their routine training.

Data analysis

The muscle balance level between the right and left sides was calculated for measured values during the trunk perturbation (Fig. 3). The onset time was determined when the signal increased to more than the threshold of the average plus three standard deviations of the pre-perturbation baseline (Hodges and Bui 1996). To calculate the muscle activities, the root-mean-square value of sampled EMG amplitudes was computed for 100 ms after the muscle onset time. The root-mean-square value was then divided by the peak root-mean-square amplitude that was measured in the Biering–Sorensen position. The time window for calculating the root-mean-square was 12.5 ms. The balance ratio of the muscle activities was calculated with the following asymmetry index equation:

$$\text{Asymmetry index}(\%) = \left|\frac{R-L}{{}^{1}\!/_{2}(R+L)}\right| \times 100$$

where R and L indicate the right and left sides of the multifidus (L4–5). A higher asymmetry index value

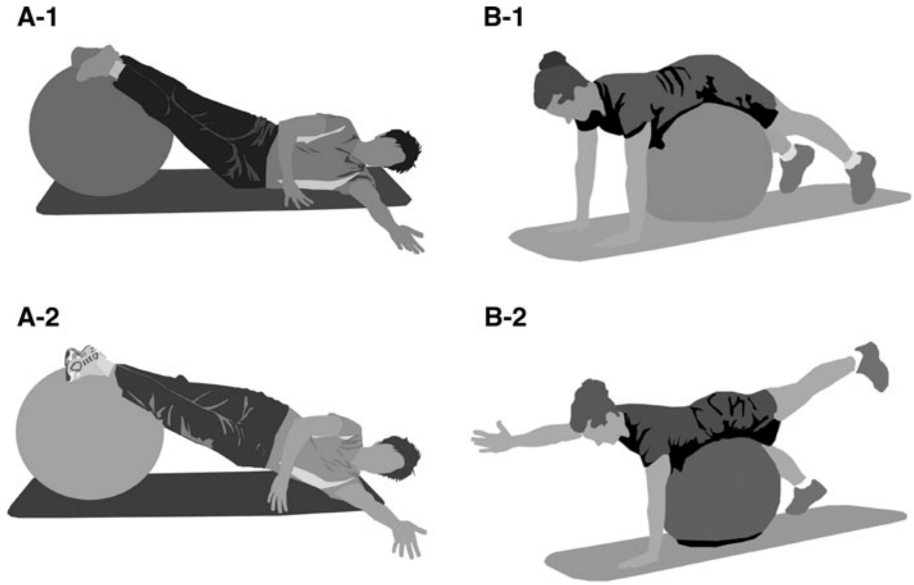

Fig. 2 Intensive unilateral neuromuscular training comprised the side bridge exercise (**a**) and quadruped exercise (**b**)

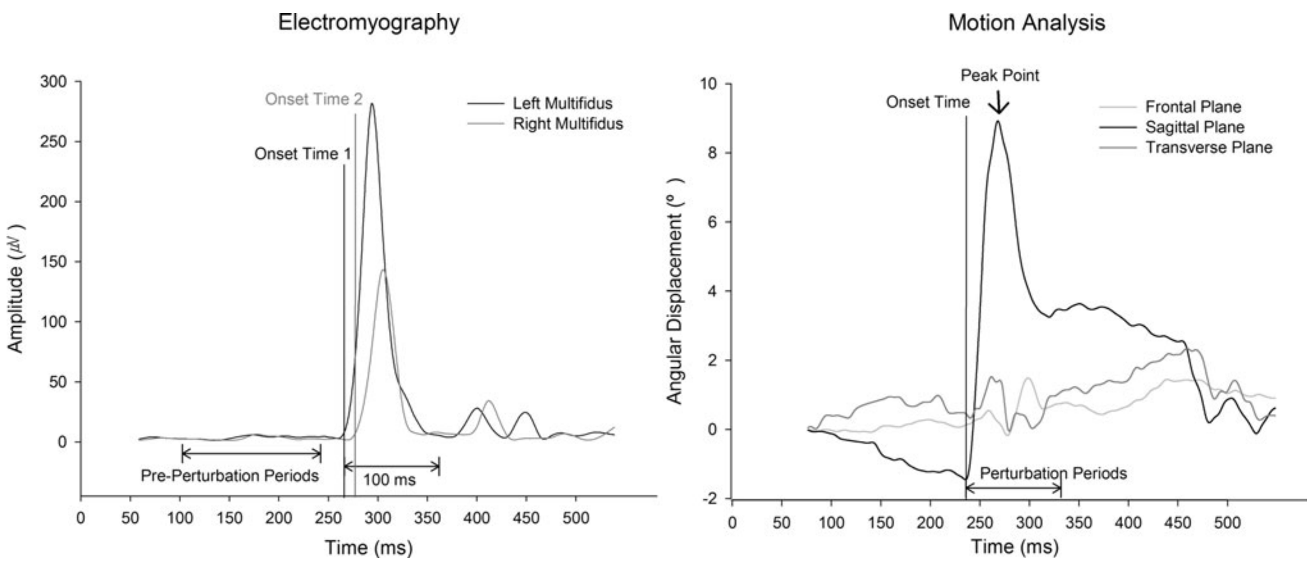

Fig. 3 Electromyography (*left*) and angular displacement (*right*) curve illustrating the measured data. The onset times were determined when muscle activities were higher than the average plus three standard deviations of the pre-perturbation baseline. After the onset time, the average values of the root-mean-square amplitude for 100 ms were calculated to analyze the asymmetry of muscle activities. The peak point represents the maximum amplitude of trunk angular displacement. The angular displacement as a result of the perturbation was calculated by subtracting the angular displacement at the onset time from that at the peak point for each plane

indicates higher muscle imbalance between the left and right sides. MATLAB (MathWorks Inc.,) was used to analyze the onset time and muscle activities from the EMG data.

The level of trunk stability was analyzed by angular displacement of the trunk segment using CORTEX 1.0 software (Motion Analysis Corporation, Santa Rosa, CA, USA). The trunk segment was defined by the connection of two points: the center of both acromions and the spinous process of T1, and the center of both anterior superior iliac supines and the spinous process of S2. The reference position of angular displacement was determined as that immediately before perturbation. The angular displacement was calculated in the sagittal, frontal, and horizontal planes when the trunk segment was maximally moved by the sudden perturbation.

Statistical analysis

A *t* test for independent samples was conducted to compare the mean age, height, and weight between the IUNT and control groups. Because the EMG data did not show a normal distribution based on the Kolmogorov–Smirnov test, Wilcoxon's signed-rank test was used to compare the asymmetry index and the difference between the left and right onset times between pre- and post-training. To detect the change in trunk stability in three dimensions, angular displacements were analyzed using two-way repeated measures ANOVA with the following factors: training (pre- and post-training) × plane of angular displacement (sagittal, frontal, and transverse planes). Within-group comparison was conducted to analyze the training effects. Bonferroni correction was used as a post hoc test. The data were analyzed by SPSS 12.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at $\alpha = 0.05$.

Results

The difference in muscle onset time between the left and right sides and the asymmetry index of muscle activities were analyzed as representative values for muscle balance. The difference in onset time decreased to approximately 120 % compared with that before the training ($z = -2.325$, $P = 0.020$). No significant changes were found in the control group for 8 weeks. The overall ranges of the differences in onset time were 0–58 ms during the trunk perturbation (Fig. 4a). A change in the asymmetry index occurred in the IUNT group only. The asymmetry index decreased from 56 % before the training to 23 % after the training ($z = -2.240$, $P = 0.025$). The changes in the asymmetry index in the two groups are presented in Fig. 4b.

Before and after the training, changes in the angular displacement during forward perturbation were analyzed in the three planes as the index of spinal stability. An interaction effect between before/after training and the three planes was observed ($F = 5.694$, $P = 0.020$). The post hoc analysis indicated that IUNT decreased the angular displacement in the sagittal plane to approximately 35 % after the training ($P = 0.025$). The angular displacements of the control group remained stable before and after training (Fig. 5).

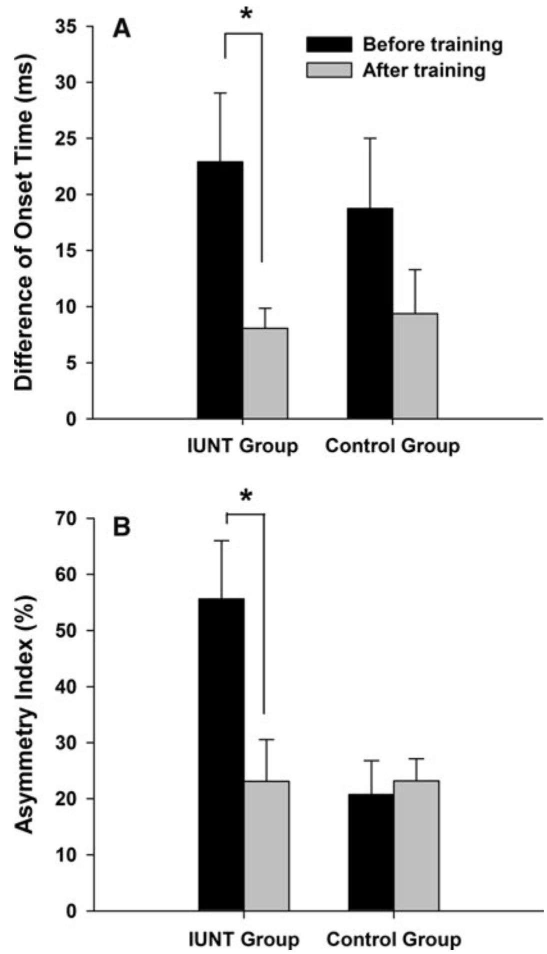

Fig. 4 **a** Difference in muscle onset time between the left and right multifidus (L4–5) muscle during perturbation. **b** Asymmetry index of normalized electromyography amplitudes between both multifidus muscles (L4–5) during perturbation. After the intensive unilateral neuromuscular training (IUNT; *gray bar*), the differences in the onset time between both sides and the asymmetry index were reduced compared with those before the training (*dark bar*). All values are presented as the mean and standard error. *Asterisk* denotes a significant statistical difference appeared between pre- and post-training sessions ($P < 0.05$)

Discussion

The purpose of this study was to identify whether IUNT on the non-dominant side of the low back reduces the imbalanced response of both multifidus muscles (L4–5) and improves trunk stability. In this study, we provided evidence that IUNT significantly reduces the imbalanced response of both multifidus muscles (L4–5) based on differences in muscle onset time and the asymmetry index. In addition, the angular displacement indicates that the trunk stability was improved in the sagittal plane after the training.

The difference in muscle onset time between both multifidus muscles (L4–5) was decreased by practicing IUNT for 8 weeks. This indicates that the muscle onset time can be controlled separately on the left and right sides. To reduce the muscle onset time after sudden trunk perturbation, previous studies implemented specific training. One previous study implemented home-based training to identify a reduced muscle onset time of the lumbar erector muscles in healthy individuals. Although they did not individually compare the muscle onset time between the left and right sides, the difference in the average values between both sides decreased from baseline values to

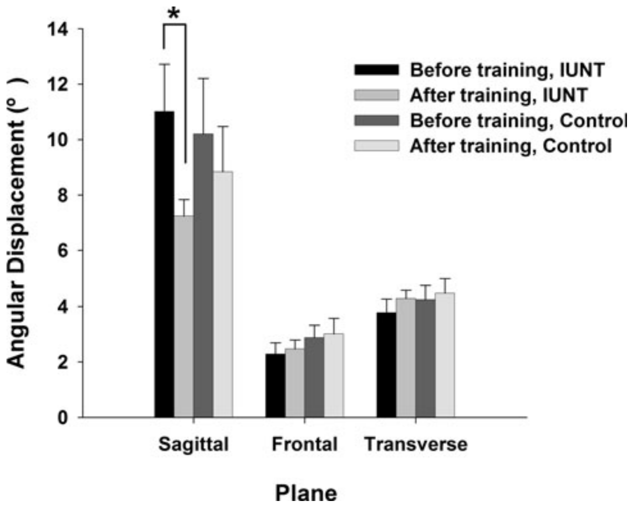

Fig. 5 Perturbation-induced trunk angular displacements in the intensive unilateral neuromuscular training (IUNT) group and in the control group. The angular displacements were calculated in each of the sagittal, frontal, and horizontal planes. All values are presented as the mean and standard error. *Asterisk* denotes a significant difference appeared between the pre- and post-training values ($P < 0.05$)

approximately 10 ms after the training (Pedersen et al. 2007). Another study also reported that the difference in muscle onset time decreased after their 2-week rehabilitation program (Magnusson et al. 1996). However, direct comparison was difficult with this study because their subjects were patients with low back pain. This study supports that neuromuscular training can be used as intervention to reduce the muscle onset time. In particular, we expected that IUNT would be useful to selectively decrease the muscle onset time of both sides.

In this study, the difference in the left and right onset times was higher than that in previous studies. Generally, normal subjects show a high level of co-contraction between both sides, <10 ms in unexpected sudden perturbation (Strutton et al. 2009), which would be an optimum level for daily activities. However, the difference between both sides in this study was nearly twice that of previous results. Considering their repeated asymmetrical movements, we speculate that this high difference is a characteristic shown in adolescent female basketball players. Our speculation was also generated from one previous study in which the risk of muscular asymmetry between the left and right trunk was higher in adolescent athletes participating in basketball (Boldori et al. 1999). Therefore, the usually low imbalance in low back muscle onset time should be emphasized in adolescent female basketball players.

In addition to the decreased difference in the muscle onset time, the asymmetry index, presented as the amount of imbalanced muscle activity during sudden perturbation, was also reduced after IUNT. We speculated that the quadruped exercise was the main contributor for the decrease in the asymmetry index. During measurement of the dominant and non-dominant sides of the multifidus (L4–5) in the quadruped exercise, we more clearly identified the difference in EMG amplitude between the two sides. For example, when the dominant leg was extended, only the dominant multifidus (L4–5) was activated. However, in the non-dominant leg, the dominant multifidus (L4–5) was still activated, but the activated level of dominant side was lower than that of the non-dominant side. This pattern indicates that the muscle activation of the non-dominant side was not separated. A similar pattern was presented in a previous EMG study. When the multifidus (L4–5) activities were measured during the quadruped exercise while alternating both sides, the muscle activities of the dominant multifidus (L4–5) were still relatively high despite the alternations in the arms and legs (Okubo et al. 2010). In our subjects, the dominant side of the multifidus (L4–5) was mostly the right side. In these cases, we intensively trained the left (non-dominant) multifidus muscle by lifting the left leg and right arm to increase and separate non-dominant muscle activation. Fortunately, this method decreased the asymmetry index during the sudden perturbation. These results may indicate a decrease in the risk of the resultant asymmetrical force at the intervertebral joints.

The results of this study indicate that IUNT can change the muscle response of the local system. To interpret our results, it is necessary to consider the classification of trunk muscles. The trunk muscles are divided into local and global systems in terms of their functional aspects in spinal stabilization (Bergmark 1989). Functionally, it is hypothesized that the multifidus muscles play a role in maintaining a neutral posture using a high level of co-contraction in the local system (Bergmark 1989). Our results demonstrate that the level of muscle imbalance in the local system can be changed after IUNT. To the best of our knowledge, there is no existing evidence showing why an imbalanced muscle response in the local system decreases after specific training. However, we speculate that a decrease in the imbalanced response might be affected by contralateral crossing over of monosynaptic neurons. Neuromuscular training provokes a facilitated neural net in the sensorimotor pathways for postural control (Borghuis et al. 2008). In particular, these facilitating effects might induce excitation not only on the ipsilateral side but also on the contralateral side (Beith and Harrison 2004; Mullington et al. 2009; Myriknas et al. 2000). That is, IUNT can achieve increased muscle activities on both sides.

With regard to the second hypothesis, we found that the angular displacement induced by the unexpected sudden loading was reduced only in the IUNT group. These findings support the second hypothesis that IUNT improves trunk stability. The angular displacement decreased only in the sagittal plane, but was unchanged in the frontal and transverse planes. Because the direction of the trunk perturbation was anterior and posterior, the amounts of angular displacement in the sagittal plane must be considered as representative values for the index of spinal stability. We presume that the unchanged angular displacements in the frontal and transverse planes were because of the floor effect. Unfortunately, because this study was not designed to investigate the mechanisms by which trunk stability improves, it has a limitation in that it is difficult to explain these exact mechanisms. One may speculate that the effect of crossed monosynaptic neurons, which increase the muscle activities of the contralateral side despite exercising only one side, would be a main mechanism regarding why IUNT increases spinal stability. The increase in spinal stability has an important meaning in terms of athletic performance. Hence, we expect that IUNT will effectively and rapidly increase postural control in athletes.

This study has a limitation in its ability to provide direct and definite evidence of a relationship between an imbalanced muscle response and spinal stability. Whether spinal stability increases with a decreased imbalanced response or increase in back muscle forces must be determined. Unexpectedly, the baseline of the asymmetry index between the two groups was too different (mean difference, training group: 55 % vs. control group: 21 %). We speculate that this difference was caused by the fact that the position of basketball athletes was not considered in the randomization for group assignments. A previous study, which reported different leg strength following playing position and left–right side (Köklü et al. 2011), supports this speculation. Hence, further study will have to consider the playing position in group assignment. However, based on our results, IUNT may be suitable to increase trunk stability in patients with scoliosis and an imbalanced muscle response. More extensive research is necessary in terms of clinical applications.

Conclusion

The aim of this study was to understand the effects of IUNT in decreasing imbalanced muscle responses and increasing spinal stability. After the 8-week training period, the IUNT group showed a decreased imbalanced muscle response and an increased spinal stability. Thus, we presume that IUNT is useful as specific training to improve imbalanced trunk muscle responses and spinal stability.

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Conflict of interest There are no conflicts of interest to declare.

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