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The effect of core stability exercise on the reaction time of deep trunk muscles

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Abstract: This study aimed to clarify the immediate effect that trunk muscle exercise has on muscle reaction time, and to clarify the effect of 2-week exercise on muscle reaction time. The study showed that as for immediate effects, the muscle reaction time was significantly shortened in the TrA/OI (transversus abdominis muscle/obliquus internus muscle) of two exercise groups. However, the immediate effect seen before the 2-week trunk muscle exercise intervention disappeared after the intervention. In addition, trunk muscle exercise intervention for 2 weeks significantly shortened the muscle reaction time of TrA/OI in one exercise group. Furthermore, shortening of the muscle reaction time was also observed in the MF (multifidus muscle) of both exercise groups. The factors affecting the muscle reaction time of TrA observed in this study were considered to be an improvement of neuromuscular function by the central nervous system. It was also considered that 2-week exercise intervention has a lower value after 2 weeks due to an improvement of neuromuscular function by the central nervous system, and an immediate effect could not be obtained with the same exercise as at the time of intervention.

Key words: Local muscles, exercise intervention, surface EMG, core stability exercise, feedforward.

1. Introduction

Segmental stability of lumbar spine has been a focus of attention because the lumbar spine is kinetically unstable. Segmental stability of the lumbar spine is achieved by the trunk muscles. Bergmark [1] categorized the trunk muscle group as local muscles and global muscles based on the muscles' origin, insertion, and function (Table 1). Local muscles, excluding the psoas major, have their origin or insertion directly attached to a lumbar vertebra. Global muscles are not directly attached to a lumbar vertebra. The local muscles are mainly located deep within the body and control the segmental stability of the lumbar spine. The global muscles are mainly located on the surface of the body and control the position of, and equilibrium in, the lumbar spine [2]. Cholewicki and McGill [3] reported that the action of the global muscles alone does not increase segmental stability. Maintaining segmental stability of the lumbar spine requires co-contraction of the local and global muscles because the function of trunk muscles differs between the surface and deep muscles [2, 4, 5].

Hodges et al. [6, 7] describe the timing of muscle contraction with an index of muscle reaction time, which is time to start muscle activity when instantaneously causing articulation to light or sound stimulus, and evaluate the stability of trunk. When rapid upper or lower limb movement is performed (such as flexion, abduction, and extension of the shoulder or flexion, abduction, and extension of the hip), they reported the existence of a feedforward mechanism in which the transversus abdominis muscle (TrA) contracts preceding the agonist muscles such as

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Table 1 Local muscles and global muscles.

Local muscles	Global muscles
・Transversus abdominis	・Rectus abdominis
・Obliquus internus (fibre insertion into thoracolumbar fascia)	・Obliquus externus
・Quadratus lumborum (medial fibres)	・Obliquus internus
・Multifidus	・Quadratus lumborum (lateral fibres)
・Lognissimus (lumbar portion)	・Lognissimus (thoracic portion)
・Iliocostalis (lumbar portion)	・Iliocostalis (thracic portion)
・Intertransversarii	
・Interspinales	

the deltoid muscle, rectus femoris muscle, thigh muscle tension tendon muscle, gluteus maximus muscle, etc. [6, 7]. Those with chronic low back pain and those with a history of low back pain had delayed muscle reaction time of TrA compared with healthy subjects, and this delay was possibility due to the dysfunction of stabilization of the spinal column due to lack of motor control and muscle [8, 9]. That is, it is considered that the segmental stability of the lumbar vertebrae is secured by this feedforward mechanism, and the muscle reaction time of the trunk muscles is considered to be an important index for evaluating the stability of the trunk from the muscle function.

In sports, trunk muscle exercises are being conducted with the aim of securing the stability of the trunk, which is considered necessary for improving performance and sports injuries prevention. Previous studies have examined trunk muscle activity [10, 11] and the relation between trunk muscle exercise and athletic performance [12-14]. In sports, it is necessary to move according to the movements of balls and opponent players, and stabilization of the trunk by contracting the trunk muscles in accordance with those stimuli is required. However, few studies have evaluated the stability of the trunk to the stimulus needed during actual sports activity. Previous studies have examined the improvement of the muscle reaction time for persons with low back pain who have delayed muscle reaction time (decrease in trunk stability) in TrA [15-18], but the effect of the muscle reaction time for healthy individuals is not clear. In addition, relatively low exercise intensity was set in many cases, and it is expected that it is not the same load as trunk muscle exercise which is actually done in sports-related training because individuals had low back pain. Therefore, the effect of trunk muscle exercise should be examined by using exercises which are actually done in sports-related training, such as Elbow-toe with contralateral arm and leg lift, which has been reported to be an exercise that results in the greatest increase in the muscle activity of the TrA [10]. In addition, trunk muscle exercises are sometimes performed in a warm-up before a practice or game, but the immediate effect is not clear.

The objective of this study was to clarify the immediate effect that trunk muscle exercise gives to muscle reaction time, and to clarify the effect of 2 weeks' exercise on the muscle reaction time.

2. Methods

2.1 Subjects

The subjects were 21 healthy adult men who did not engage in regular exercise. They were randomly assigned to a Core stability exercise group, a Draw-in exercise group, or a Control group, with seven subjects in each group. There were no significant differences in physical characteristics between the subjects in each group (Table 2).

The subjects were provided with full explanations of the objectives and details of this study and each of them was provided written consent to participate. The study

Table 2 Physical characteristics of each group.

Group	Age	Height(cm)	Weight(kg)
Core stability	23.9±0.9	173.3±5.9	62.4±5.7
Draw-in	24.1±2.6	172.3±7.0	64.7±7.3
Control	24.4±1.7	174.7±4.0	68.9±7.0

(mean±SD)

was approved by the ethics committee of the Graduate School of Comprehensive Human Sciences, Tsukuba University (approval no. 22-129).

2.2 Experimental Protocol

Fig. 1 shows the experimental protocol. The experiment was conducted over 15 days. This included an exercise period comprising 7 sessions over a 13-day period, i.e., long-term period, and the measurements were obtained on Days 1 and 15. On Day 1, we measured trunk muscle response times before and after exercise (“pre” and “post”; Fig. 1 ①). After the 13-day intervention period, the response times were measured in the same manner before and after the exercise on Day 15 (“2w-pre” and “2w-post”; Fig. 1 ②). We also compared the pre and 2w-pre values to examine the effect that the 2-week intervention had on muscle reaction time (Fig. 1 ③).

2.3 Intervention

Each of the three exercise groups (Core stability, Draw-in, and Control) performed different types of exercises.

2.3.1 Core stability Exercise Group

For the core stability exercise, the subjects maintained elbow–toe postures with the right arm and left leg raised (Fig. 2a) and the left arm and right leg raised (Fig. 2b) for 30 s each with 45 s intervals. Two sets were performed with a 90-s interval between. Assistance was provided to subjects who found it difficult to maintain the posture. The exercises were performed 4 days per week for a total of 2 weeks (including the exercise on Day 1). The exercise on Day 15 was performed once. All exercises were performed under the supervision of the same tester.

2.3.2 Draw-in Exercise Group

For the Draw-in exercise, the subjects lay in a supine position and flexed their hip joints at a 45-degree angle and knee joints at a 90-degree angle, drawing their legs into their abdomens, and held the posture for 10–20 s. This was repeated over a 5-min period. The exercises were performed 4 days per week for a total of 2 weeks (including the exercise on Day 1). The exercise on Day 15 was performed once. TrA contraction during the exercises on Days 1 and 15 was confirmed using diagnostic ultrasound, and feedback was provided using both images and spoken words.

2.3.3 Control Group

No specified exercises were performed by the subjects in this group.

2.4 Movement Task

With reference to previous study [6, 8, 9], the movement task of the shoulder joint flexion was taken as the motion task. A miniature light bulb was synchronized to the subjects’ electromyogram. In response to the light stimulus provided by the light, the subjects flexed the shoulder on their dominant side while in a standing posture, and their muscle reaction time was measured (Fig. 3). The subjects were instructed to perform the lifting movement as fast as possible, five times.

2.5 Target Muscles and Electrode Placement

Electromyogram measurements of the TrA/OI, MF, OE, and AD muscles on the dominant hand side were obtained. The TrA/OI electrodes were placed within 2 cm below the anterior superior iliac spine, the MF

Fig. 1 Experimental protocol.
※Ex. 1 = Exercise 1.
① Effect of trunk muscle exercise before the intervention.
② Effect of trunk muscle exercise after the 2-week intervention.
③ Effect of the 2-week trunk muscle exercise intervention.

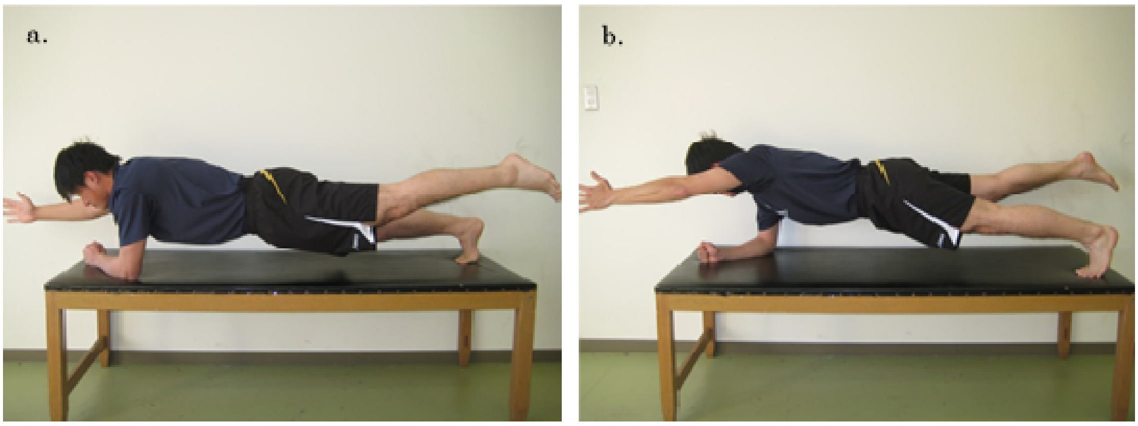

Fig. 2 Core stability exercise.
a. Elbow-toe with right arm and left leg lift; b. Elbow-toe with left arm and right leg lift.

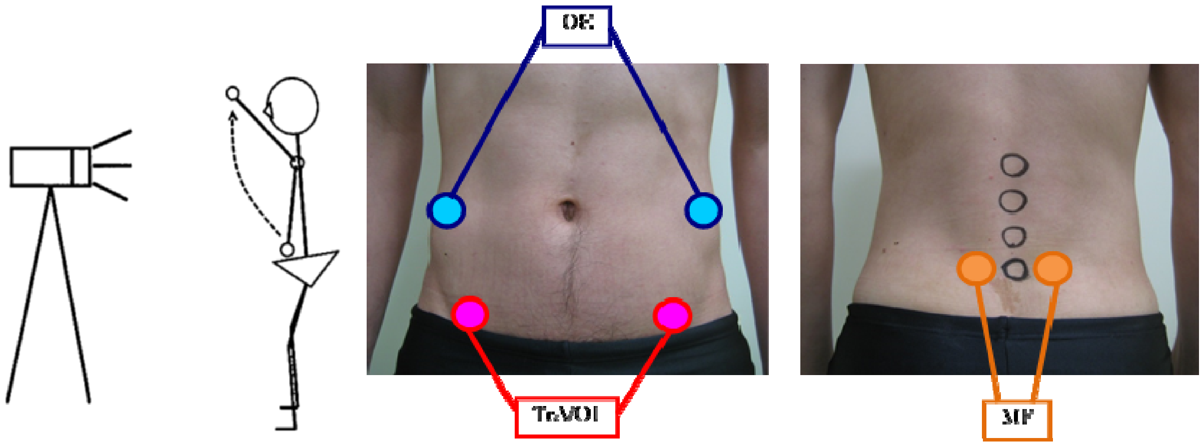

Fig. 3 Movement task and electrode placement.
The left figure shows the movement task and the right figure shows electrode placement.
TrA/OI: transversus abdominis/obliquus internus, MF: multifidus, OE: obliquus externus.

electrodes were placed 2 cm lateral to the L5 spinous process, the OE electrodes were placed 15 cm lateral to the superior navel, and the AD electrodes were placed 3 finger widths from the anterior margin of the acromion (Fig. 3).

Prior to attaching the electrodes, skin resistance was decreased to 2 kΩ or below by removing the cuticle using either a skin abrasive or an alcohol-impregnated degreasing cotton. Bipolar surface electrodes (F Vitrode disposable electrodes, Nihon Kohden) were used. The electrodes were attached parallel to the muscle fiber orientation of each muscle, with a distance of 10 mm between the electrodes.

2.6 Data Analysis

Electrode measurements and analyses were performed using a Vital Recorder2 (KISSEI COMTEC). We amplified the myogenic potential using an amplifier (MEG-6116, JB-640J, Nihon Kohden) and converted data from analog to digital at a sampling frequency of 2,000 Hz.

The measured myogenic potential was subjected to 10–1,000 Hz band-pass filtering to remove motion artifacts, and full-wave rectification was performed. Next, we calculated the mean muscle activity level every 10 ms and identified the initiation of muscle activity from the point at which muscle activity exceeded the mean rest value + 2 standard deviations (SD). The rest value was the 100-ms mean value prior to light stimulus. The muscle reaction time was calculated by subtracting the time of initiation of the AD muscle activity from the time of initiation of activity in the TrA/OI, MF, and OE muscles. Muscle reaction times are presented as the mean ± SD of five repetitions of the tasks. Fig. 4 shows a typical example of the electromyography data at shoulder flexion.

2.7 Statistical Analysis

To investigate the effect of the various types of intervention on the reaction time of all target muscles, we performed two-way analysis of variance (ANOVA) for groups (Core stability, Draw-in, and Control) and intervention (pre and post). In cases in which a significant difference was found in the main effect or interaction, we performed a post-hoc test using the Bonferroni correction. Statistical analysis was performed using the statistical software Dr. SPSS II for Windows. The standard of significance for all tests was set at under 5%. Significant trends were at values between 5% and 10%.

3. Results

3.1 Immediate Effect of Trunk Muscle Exercise

Table 3a shows the reaction time of all of the target muscles on the subjects' flexion and non-flexion sides (pre and post). On the flexion side, TrA/OI did not show a significant interaction in the ANOVA analysis, but there was a significant simple main effect of intervention. In the Core stability exercise group, the post value (14.6 ± 26.9 ms) was significantly lower than the pre value (35.1 ± 13.1 ms; $p < 0.05$). In the Draw-in exercise group, the post value (3.8 ± 20.3 ms) was significantly lower than the pre value (22.0 ± 19.8 ms; $p < 0.05$). On the non-flexion side, a significant interaction as well as a simple main effect of intervention was observed. In the Core stability exercise group, the post value (10.0 ± 22.4 ms) was significantly higher than the pre-value (−14.9 ± 22.0 ms;

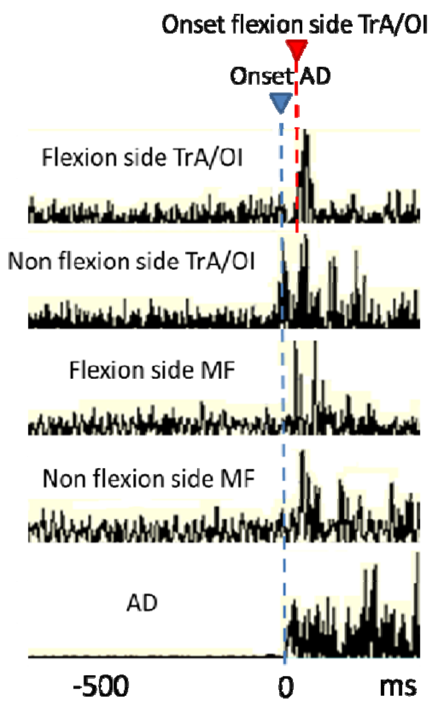

Fig. 4 Example of electromyography data in shoulder flexion.

Table 3 Reaction time of all of the target muscles on the subjects' flexion and non-flexion sides, a: before the intervention (pre and post), b: after the 2 week intervention (2w-pre and 2w-post), c: before and after the 2 week intervention (pre and 2w-pre).

a

Group	Muscle	TrA/OI		MF		OE	
	Side	flexion side	non flexion side	flexion side	non flexion side	flexion side	non flexion side
Core stability exercise	pre	35.1 ± 13.1	-14.9 ± 22.0	2.0 ± 11.4	-4.0 ± 13.4	52.3 ± 26.4	22.6 ± 46.8
	post	14.6 ± 26.9 *	10.0 ± 22.4 *	-5.8 ± 29.5	-8.4 ± 19.9	51.8 ± 30.7	28.2 ± 16.4
Draw-in exercise	pre	22.0 ± 19.8	0.9 ± 13.4	-3.7 ± 15.9	-10.9 ± 10.6	38.3 ± 23.3	9.5 ± 22.8
	post	3.8 ± 20.3 *	11.6 ± 11.4	-12.2 ± 18.3	-15.6 ± 16.0	52.3 ± 38.1	15.1 ± 34.1
Control	pre	24.0 ± 9.9	-8.9 ± 15.1	6.6 ± 13.2	-1.1 ± 5.3	18.8 ± 10.4	8.6 ± 24.0
	post	28.1 ± 17.6	-10.4 ± 14.8	10.5 ± 15.7	1.8 ± 11.7	17.6 ± 22.7	16.6 ± 26.0

(ms: mean±SD)

* vs. pre ($p < 0.05$)

b

Group	Muscle	TrA/OI		MF		OE	
	Side	flexion side	non flexion side	flexion side	non flexion side	flexion side	non flexion side
Core stability exercise	2w-pre	3.7 ± 38.1	-15.0 ± 16.1	-15.6 ± 29.1	-13.3 ± 20.2	57.1 ± 25.1	20.6 ± 27.5
	2w-post	-1.1 ± 42.1	-18.4 ± 12.9	-16.6 ± 28.3	-24.5 ± 28.6	55.8 ± 36.0	12.7 ± 21.3
Draw-in exercise	2w-pre	7.4 ± 13.5	-18.5 ± 29.9	-13.0 ± 19.4	-21.5 ± 11.4	30.9 ± 36.2	6.5 ± 25.7
	2w-post	1.4 ± 24.4	-22.2 ± 26.6	-11.7 ± 16.3	-21.0 ± 11.7	27.5 ± 32.4	-0.8 ± 22.1
Control	2w-pre	24.5 ± 12.1	-12.6 ± 14.3	9.5 ± 22.3	0.2 ± 8.7	21.2 ± 19.9	0.0 ± 21.8
	2w-post	22.2 ± 12.8	-12.2 ± 20.4	6.3 ± 16.2	3.3 ± 9.0	14.0 ± 24.4	-5.7 ± 25.6

(ms: mean±SD)

c

Group	Muscle	TrA/OI		MF		OE	
	Side	flexion side	non flexion side	flexion side	non flexion side	flexion side	non flexion side
Core stability exercise	pre	35.1 ± 13.1	-14.9 ± 22.0	2.0 ± 11.4	-4.0 ± 13.4	52.3 ± 26.4	22.6 ± 46.8
	2w-pre	3.7 ± 38.1 *	-15.0 ± 16.1	-15.6 ± 29.1	-13.3 ± 20.2 #	57.1 ± 25.1	20.6 ± 27.5
Draw-in exercise	pre	22.0 ± 19.8	0.9 ± 13.4	-3.7 ± 15.9	-10.9 ± 10.6	38.3 ± 23.3	9.5 ± 22.8
	2w-pre	7.4 ± 13.5	-18.5 ± 29.9	-13.0 ± 19.4	-21.5 ± 11.4 *	30.9 ± 36.2	6.5 ± 25.7
Control	pre	24.0 ± 9.9	-8.9 ± 15.1	6.6 ± 13.2	-1.1 ± 5.3	18.8 ± 10.4	8.6 ± 24.0
	2w-pre	24.5 ± 12.1	-12.6 ± 14.3	9.5 ± 22.3	0.2 ± 8.7	21.2 ± 19.9	0.0 ± 21.8

(ms: mean±SD)

* vs. pre ($p < 0.05$), # vs. pre ($p < 0.10$)

TrA/OI: transversus abdominis/obliquus internus, MF: multifidus, OE: obliquus externus.

$p < 0.05$). We detected no significant differences for MF or OE on either the flexion or the non-flexion side in any of the groups.

Table 3b shows the 2w-pre and 2w-post reaction time for all muscles on the flexion and non-flexion sides. We detected no significant differences for any muscles in any of the groups on either the flexion or the non-flexion side.

3.2 Effect of the 2-Week Trunk Muscle Exercise Intervention

Table 3c shows the reaction times for all the trunk muscles on the flexion and non-flexion sides prior to exercise before and after the 2 weeks' intervention (pre and 2w-pre values). The TrA/OI on the flexion side did not show a significant interaction, but a simple main effect of intervention was detected. In the Core stability exercise group, the post value (3.7 ± 38.1 ms) was significantly lower than the pre value (35.1 ± 13.1 ms; $p < 0.05$). However, on the non-flexion side, no significant differences were detected. In the Draw-in exercise and Control groups, no significant differences were detected on either the flexion or the non-flexion side. We detected no significant differences in any of the groups for MF on the flexion side. On the non-flexion side, we detected no significant interaction, but we detected a significant simple main effect of intervention, and in the Core stability exercise group, the post value (−13.3 ± 20.2 ms) tended to be significantly lower than the pre value (−4.0 ± 13.4 ms; $p < 0.10$). In the Draw-in exercise group, the post value (−21.5 ± 11.4 ms) was significantly lower than the pre value (−10.9 ± 10.6 ms; $p < 0.05$). In the Control group, there were no significant differences. We detected no significant differences in any of the groups for OE on either the flexion or the non-flexion side.

4. Discussion

In the examination of the immediate effect of the trunk muscle exercise, the muscle reaction time of TrA/OI was significantly shortened on the flexion side in the Core stability exercise group and the flexion side in the Draw-in exercise group. In addition, in the study of the effect of trunk exercise intervention for 2 weeks, the muscle reaction time was significantly shortened in the flexion side TrA/OI in the Core stability exercise group. It is widely believed that changes in muscle reaction time are due to neuromuscular function. Although the specific mechanism underlying the changes in neuromuscular function remains unknown, it is thought that the central nervous system, reflexive control, and transmission speed of motor neurons are some of the factors that contribute to this mechanism. Of these, reflexive control and transmission speed of motor neurons are a decrease in the excitability of motor neurons [19] caused by damage such as joints and peripheral nerves, and decrease in conduction velocity. Therefore, we believe that one factor affecting muscle reaction time in this study is an improvement of neuromuscular function by the central nervous system. In general, the short-term effect of training is an improvement in neuromuscular function by which training stimulation increases the recruitment and firing rate of the motor units [20]. Changes in excitability of motor neurons and motor cortex occur by repeated voluntary contractions [21]. Human sensory cortex and motor cortex have been shown to maintain plasticity change by training [22] and these changes have been shown to occur rapidly within minutes to hours after training [21, 23]. Therefore, the Elbow-toe with right arm and the left leg lift and the Draw-in exercise carried out in this study are specific exercises for TrA, and by performing these exercises, TrA is stimulated and muscle reaction time of TrA/OI is shortened.

In this study, the immediate effect of the shortening of the muscle reaction time seen before intervention of the trunk muscle exercise was not significant in either the Core stability exercise group or the Draw-in exercise group after the trunk muscle exercise intervention for 2 weeks. It has been reported that changes in reaction times with exercise were readily decreased when pre values were higher but were difficult to reduce when the values were lower [17]. Therefore, we believe that 2-week exercise intervention lowers the value of 2w-pre due to improvement of neuromuscular function by the central nervous system, and an immediate effect could not be obtained with the same exercise as at the time of intervention. It was considered that it is necessary to incrementally raise the load by implementing ingenuity in order for an athlete who continuously performs trunk muscle exercise to obtain immediate effect, that is, according to the principle of training, regularly changing to a high amount of muscle activity, increasing frequency, lengthening time.

In this study, the muscle reaction time of the flexion side and the non-flexion side was measured, respectively. This was done because there are few symmetrical behaviors in sport movements and it is considered that trunk muscles do not act simultaneously on both sides at the same time. In previous studies it has been reported that the muscle reaction time of the trunk muscles shows different responses between the flexion side and the non-flexion side [24, 25]. As a result of immediate effect, the muscle reaction time of the flexion TrA/OI was significantly shortened in both the Core stability exercise group and the Draw-in exercise group, and the non-flexion side TrA/OI was significantly prolonged in the Core stability exercise group, but there was no significant difference in the Draw-in exercise group. These results are new findings showing bilateral changes due to trunk muscle exercise. In previous studies, it was reported that the non-flexion side acts faster than the flexion side when flexing the shoulder joints [24, 25]. The reason for this is considered to be that precursory attendant posture adjustment that adjusts the posture is caused by the action of the central nervous system in order to minimize the oscillation of the center of gravity due to the movement of the upper limbs [26]. In this study, muscle reaction time on the non-flexion side in the Core stability exercise group was significantly delayed. Although no statistical comparison was made, the post value of the non-flexion side (10.0 ± 22.4 ms) was active before the flexion side (14.6 ± 26.9 ms), which was the same result as the previous study. Since there is a report that muscle reaction time is delayed by muscle fatigue [27], it is considered that muscle fatigue is caused by first performing and a core stability exercise with high muscle activity amount may be an influence. In addition, the non-flexion side in the Core stability exercise group possibly may be not further shortened because the pre value was low (-14.9 ± 22.0 ms).

As a result of intervention of trunk muscles exercise for 2 weeks, shortening of the muscle reaction time was also observed in MF. The core stability exercises and draw-in exercises result in selective and specific contractions of TrA, so MF muscle activity is low [10]. Thus, it is difficult to believe that these exercises directly act on the MF. However, when TrA contractions simultaneously occur with MF contractions, the thoracolumbar fascia tenses and the function of the muscle-fascia corset, which is formed between the TrA, MF, and thoracolumbar fascia, improves the stability of the spinal–pelvic region [28]. When the back muscle groups contract, the TrA is the most active among the abdominal muscles [29]. Therefore, we believe that the functions of the TrA and MF are closely related and that their activities may influence each other.

5. Conclusions

This study aimed to clarify the immediate effect that trunk muscle exercise has on muscle reaction time, and to clarify the effect of this 2-week exercise on the muscle reaction time. The study showed that in the immediate effect, the muscle reaction time was significantly shortened in the TrA/OI of the Core stability exercise group and the Draw-in exercise group. However, the immediate effect seen before the 2-week trunk muscle exercise intervention disappeared after 2 weeks' intervention. In addition, trunk muscle exercise intervention for 2 weeks significantly shortened the muscle reaction time of TrA/OI in the Core stability exercise group. Furthermore, shortening of the muscle reaction time was also observed in the MF of the Core stability exercise group and Draw-in exercise group.

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