Abdominal draw-in maneuver changes neuromuscular responses to sudden release from trunk loading in patients with non-specific chronic low back pain

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Conflicts of interest

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ABSTRACT

Background: Abdominal draw-in maneuver (ADIM) has been recommended to achieve appropriate trunk muscle response for patients with non-specific chronic low back pain (CLBP). However, it has remained unclear whether the intervention with ADIM could change the trunk muscle response to sudden release from loading, which is considered to contribute mechanical circumstances to low back pain. The purpose of the present study was to investigate the effects of the intervention with ADIM on electromyography (EMG) activities of trunk muscles following sudden release from loading.

Methods: Seventeen subjects with non-specific CLBP participated. Subjects resisted trunk flexion or extension loading in semi-seated position, and then the loading was suddenly released. EMG recordings of 6 trunk muscles were acquired using a wireless surface EMG system. Onset and offset times were calculated from the EMG data. The intervention with ADIM was provided for 4 weeks in the subjects with non-specific CLBP.

Results: At the post-intervention, the onset of trunk flexors following release from trunk flexion loading became significantly earlier than pre-intervention ($P = 0.028$). The offset of flexors following release from trunk extension loading of post-intervention was significantly earlier than that of pre-intervention ($P = 0.001$).

Conclusions: We showed that the intervention with ADIM changed the EMG activity of trunk muscles in response to sudden release from loading. These results suggest a possibility that

ADIM might be effective to improve the neuromuscular control of trunk flexors for the treatment of young patients with non-specific CLBP.

1. Introduction

Low back pain is typically classified as being 'non-specific' or 'specific'. The majority of patients (up to 90%) were labelled as having non-specific low back pain, which was defined as back pain without known underlying pathology [1]. Chronic low back pain (CLBP) is defined as low back pain persisting for at least 3 months [2] and approximately 40 % of patients with non-specific low back pain will develop non-specific CLBP [3].

Lack of spinal stability in trunk muscle response by neuromuscular control is one of the possible causes of developing non-specific CLBP [4]. Previous studies reported that patients with non-specific CLBP had significantly longer latencies in the offset of agonistic as well as in the onset of antagonistic trunk muscles in response to sudden release from trunk loading [5, 6]. Radebold et al. [5] reported that patients with non-specific CLBP seemed to maintain agonistic muscle contraction while their antagonistic muscles became concurrently activated. In the long term, the altered trunk muscle response may have negative consequences. Patients with low back pain have been shown to expose their spine to higher compression and share forces due to co-contraction of trunk muscles than healthy subjects [7]. In addition, Cholewicki et al. [8] found that delayed offset of abdominal muscle activity following sudden release from trunk extension loading was associated with a risk for development or recurrence of low back pain. This highlights the important role of trunk muscle response for sudden release from trunk loading in the chronicity of low back pain.

Abdominal draw-in maneuver (ADIM) was one method to develop to restore co-ordination and control of trunk muscles [9, 10]. The aim of ADIM was to acquire appropriate trunk muscle response through the isolated contraction of transversus abdominis [9]. After the ADIM, the onset times of transversus abdominis in patients with non-specific CLBP during rapid upper limb movement were significantly earlier than that of pre-intervention [11, 12]. Additionally, a previous study reported electromyography (EMG) activity of lumbar erector spinae after the ADIM was decreased compared to that of pre-intervention [13]. ADIM changed EMG activity of both abdominal and back muscles during active-motion in patients with non-specific CLBP [11, 12, 13]. However, it remains unclear whether the ADIM can change trunk muscle response to external loading such as release from trunk loading. In addition, a previous study has reported a significant association between perceptions of pain and response time of deep trunk muscle [14]. ADIM may improve intensity of low back pain through change of trunk muscle response for sudden release from trunk loading. The purpose of the present study was to investigate the effects of the intervention with ADIM on trunk muscle response to sudden release from trunk loading in patients with non-specific CLBP.

2. Methods

2.1 Participants

Seventeen subjects with non-specific CLBP including 5 females participated in the present study. All subjects were recruited from our University thorough advertisement. The subjects had age of 21.8 ± 1.1 years (mean ± SD), height of 172.0 ± 8.1 cm and body weight of 66.9 ± 10.5 kg. CLBP is defined as pain and discomfort, localized from the lower margin of the twelfth ribs to the lower gluteal folds at least 3 months [15, 16]. In addition, subjects with non-specific CLBP were excluded if they had been suspected or confirmed a serious underlying condition (such as cancer, infection, or cauda equina syndrome), spinal stenosis or radiculopathy, or another specific spinal case (such as vertebral compression fracture or ankylosing spondylitis) [17]. The duration of symptom was 27 ± 23 months (median ± quartile deviation). All subjects completed the Oswestry disability index (ODI) and visual analogue scale (VAS) to characterize their low back pain. This research has been approved by the Institutional Review Board of the authors' affiliated institutions and all subjects provided written informed consent before participation.

2.2 Exercise intervention for CLBP group

The aim of ADIM involved achieving isolated voluntary contraction of deep trunk muscles. The principle underlying the teaching of the contraction was to instruct the subjects to draw in the abdominal wall in the way which produced the contraction of transversus abdominis in isolation from other abdominal muscles [9]. Subjects with non-specific CLBP were instructed as 'draw in your abdominal wall without moving your spine or pelvis and hold for 10 seconds while breathing normally' [9]. We set 4 weeks of the intervention because a previous study reported that the onset of transversus abdominis activity during upper limb elevation were significantly earlier after 4 weeks of ADIM [11]. The exercise was supervised by a physical therapist in the initial session and the 2 weeks later from the initial session. In these sessions, a physical therapist provided a real-time feedback with ultrasound imaging to observe thickening and shortening of transversus abdominis [9, 18, 19]. Ultrasound imaging is noninvasive and can represent a change in the shape of even deep trunk muscles [18]. Subjects were instructed to train 3 sets of ten repetitions, twice a day [11]. Exercise compliance was evaluated with an exercise diary.

2.3 Experimental procedure

Subjects sat upright in a semi-seated position with restrained hip and pelvic motions (Fig. 1). The semi-seated position allowed the subjects to assume their most comfortable lumbar spine geometry before their pelvis was secured [8]. It also excluded any postural adjustments through other joints than the spine. A cable held with an electromagnet and a force sensor was attached to their chest at approximately T9. Trunk loading was applied via the cable by 2 directions: trunk extension or flexion (Fig. 1) [5]. The applied force as a trunk loading was adjusted to approximately 20% of body weight for each subject [20]. The applied force as a trunk loading was suddenly released using an electromagnet at random time intervals. This sudden release test was carried out before and after 4 weeks intervention in non-specific CLBP group. Each participant performed 5 trials after 8 practice trials [21].

2.4 Data collection

EMG recordings of 6 trunk muscles of right side were acquired using a wireless surface EMG system (WEB-1000; NIHON KOHDEN Corporation, Tokyo, Japan) with surface-type electrode telemeters that were sampled at 1000 Hz. We recorded EMG activity of trunk flexors including internal oblique/transversus abdominis, external oblique and rectus abdominis. Also, we recoded EMG activity of trunk extensors including latissimus dorsi, thoracic erector spinae and lumbar erector spinae. Surface electrodes were placed in parallel with muscle fibers: internal oblique/transversus abdominis (20 mm medial and inferior to the anterior superior iliac spine), external oblique (approximately 15 cm lateral to the umbilicus), rectus abdominis (3 cm lateral to the umbilicus), latissimus dorsi (lateral to T9 over the muscle belly), thoracic erector spinae (5 cm lateral to T9 spinous process), and lumbar erector spinae (3 cm lateral to L3 spinous process) [5, 22].

2.5 Data analysis

The raw EMG signals were band-pass filtered at 20-500 Hz, full-wave rectified, and filtered using a fourth-order Butterworth low-pass filter with a cut off of 10 Hz. To identify the onset and the offset of muscle activity from EMG signals, MATLAB software (The MathWorks, Natick, MA, USA) was used. When the amplitudes increased by 2 SD from the baseline activity and lasted for at least 25 msec, the muscle onsets were detected. Muscle offsets were defined as EMG amplitudes decreased 2 SD from the baseline activity and lasted for at least 25 msec. The baseline activity was defined as the average of the 80 msec period preceding the release from the loading. In addition, each onset of EMG signal was confirmed visually [23]. The onset and offset times of muscle activity were expressed relative to the release from loading (Fig. 2). Following the release from the loading of trunk flexion, extensors acted as the agonists group and flexors acted as the antagonists. In release from trunk extension loading, flexors acted as agonists and extensors as antagonists. The onset and offset time were averaged for each muscle group (flexor and extensor) and for each load direction (flexion and extension).

2.6 Statistical analysis

A priori power analysis was performed in G*power 3.1 (University of Dusseldorf, Dusseldorf, Germany) [24]. The sample size was estimated from the pilot study that we carried out with 4 subjects with non-specific CLBP, for a calculated effect size of *Cohen's d* = 0.798. We performed the power analysis using paired t-test model of G*Power 3.1. Fifteen subjects with non-specific CLBP were deemed to be sufficient to detect significant differences in the offset of trunk flexors following release from trunk extension loading between pre- and post-intervention with a power (1-β) of 0.8. If the exercise compliance of a subject was lower 30 %, the subject was excluded in this study.

Statistical analyses were performed using IBM SPSS Statistics 22 software (IBM, Chicago, IL, USA). Paired t-tests or Wilcoxon signed rank test were used to examine differences in onset and offset times, ODI score and VAS score between pre- and post-intervention in non-specific CLBP group. A statistical significance level was set at $\alpha = 0.05$. In addition, the value of Cohen's d was calculated as effect size.

3. Results

None of the subjects dropped out of the intervention. Exercise compliance was 75.9 ± 13.5 % (mean ± SD) from exercise diary of each subject.

All subjects reported minimal or no pain throughout testing. Figure 3 and 4 show EMG onset and offset times of trunk muscles relative to release from trunk flexion and extension loading. The onset of trunk flexors following release from trunk flexion loading in non-specific CLBP group became significantly earlier at the post-intervention ($P = 0.028$, [$d = 0.620$]) (Fig. 3a, Table 1). Additionally, the offset of trunk flexors following release from trunk extension loading became significantly earlier at the post-intervention ($P = 0.001$, [$d = 1.062$]) (Fig. 4a, Table 1). On the other hand, there were no significant differences of the offset and onset times of trunk extensors between pre- and post-intervention. (*P* = 0.063, 0.163, [*d* = 0.527, 0.328], respectively) (Fig. 3b, 4b, Table 1).

At the post-intervention, ODI score was significantly lower than that of pre-intervention (*P* = 0.034, [*d* = 0.515]). For subscale analysis, the score of section 9 of ODI at post-intervention was significantly lower compared to that of pre-intervention (*P* = 0.009, [*d* = 0.846]) (Table 2). However, there was no significant difference in VAS score at the post-intervention compared to the pre-intervention (*P* = 0.209, [*d* = 0.378]). The VAS score of pre- and post-intervention were 25.9 ± 16.2 (min: 4, max: 58) and 20.7 ± 8.8 (min: 8, max: 37), respectively.

4. Discussion

This study demonstrated for the first time that the responses of abdominal muscle activity to sudden release from trunk loading could be changed with ADIM. In addition, the results showed that ODI score of post-intervention was decreased but the pain intensity evaluated by VAS was not changed. These findings suggest that the disability due to non-specific CLBP could be improved with ADIM.

In the present study, we showed that the responses of abdominal muscles to sudden release from loading at the post-intervention with ADIM were induced earlier than that of pre-intervention. The findings suggest that ADIM can induce the changes in abdominal muscle responses to unexpected external loading. The aim of ADIM is an independent contraction of transversus abdominis as a deep abdominal muscle [9]. Therefore, the effect of ADIM would be specific in the response of abdominal muscles. Lee et al. [13] reported the EMG activity of lumbar erector spinae after the ADIM was decreased compared to that of pre-intervention. However, we could not detect significant differences in the onset or the offset of back muscles between pre- and post-intervention. Richardson et al. [9] suggested a training focused on multifidus as training of a deep back muscle. Therefore, the intervention adding other training focused on back muscle has been needed to detect significant differences of back muscle responses. These findings are consistent with the existing literatures that reported improvements in the dysfunction of the trunk muscle activities during active-motion through the intervention including ADIM [11, 12]. Tsao et al. [25] reported adaptive changes in motor cortical organization of patients with non-specific recurrent low back pain, which were linked to altered motor coordination. Tsao et al. [12] also observed that the intervention with ADIM induced both its motor cortical reorganization and improvement in deep abdominal muscle activities but walking exercise for non-specific CLBP did not induce these changes. Previous reports found that cortical plasticity was induced from training intervention with conscious attention and skill [26, 27], but repetitive movement without precision or skill does not cause motor cortical reorganization [27]. The ADIM is a skilled maneuver and needs an attention to perform appropriately. Therefore, in this study, there was a possibility that the improvements in trunk flexor activities were related to changes in motor coordination. However, the mechanisms underlying this relationship between ADIM intervention and changes in motor coordination remain unclear and this requires further investigations. On the other hand, Boucher et al. [28] found improvements in proprioception through exercises focused on ADIM. Furthermore, Radebold et al. [6] also reported poor balance performance related to proprioception deficits in subjects with non-specific CLBP and balance performance correlated with onset of trunk muscles activity during a sudden release test. Therefore, it is expected that the changes in the flexor muscle response was due to the improvement in proprioception and balance performance through the intervention with ADIM. It may be more effective to put sensory training together for ADIM, and future study is needed to investigate the effects of combined these trainings.

We found an improvement in ODI score at the post-intervention with ADIM. For subscale analysis, the scores of section 9 in ODI was significantly improved after ADIM. The score of section 9 in ODI evaluate the effects of low back pain on social life. In this study, the disability of daily living would be mainly improved in social life. These findings are partially consistent with the existing literatures. Previous studies reported scores of ODI were significantly decreased after the intervention including ADIM in patients with non-specific CLBP [11, 12, 22, 29]. There is a possibility that the effect of low back pain on subjects' daily living was decreased through ADIM.

This study has four limitations. First, we did not include non-specific CLBP group without exercise or with other exercises. Future studies are needed to investigate the effects of ADIM compared to non-specific CLBP group without exercise or with other exercises. Second, we have to take attention that the subjects in this study were only 20s. Therefore, the present findings may be a character of young patients with non-specific CLBP. Third, although the aim of ADIM is prevention of chronicity of non-specific low back pain, we didn't observe long-term effects of ADIM for pain. Future research should investigate whether improvements in trunk muscle response by ADIM result in a decreased risk of chronicity of non-specific low back pain. Fourth, a duration of intervention in this study may be relatively short. Tsao et al. [11] reported the onset of transversus abdominis activity during upper limb elevation was changed after 4 weeks of ADIM, while the VAS pain was not changed. On the other hand, Brooks et al. [29] reported significant improvements in self-rated pain scores of non-specific CLBP subjects after the interventions with specific trunk exercises including ADIM for 8 weeks. Therefore, more improvements in self-rated pain might be provided by longer intervention period.

5. Conclusion

ADIM changed earlier the trunk flexor responses at the sudden release from trunk loading in patients with non-specific CLBP. These results suggest a possibility that ADIM might be effective to improve the neuromuscular control of trunk flexors for the treatment of young patients with non-specific CLBP.

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Figure captions

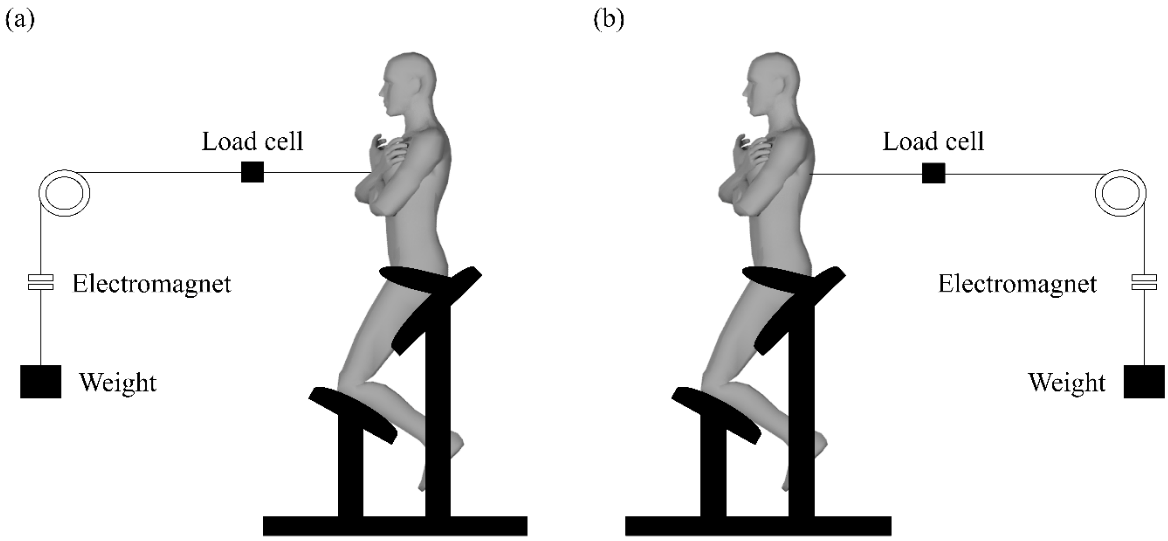
Fig.1 Experimental set-up for sudden release from (a) trunk flexion loading and (b) trunk extension loading. All subjects were placed in a semi-seated position with pelvis restrained from any motion. The weight was adjusted to generate the resisted force for 20 % of body weight.

Fig.2 An example of (a) force in direction of trunk extension, (b) activity of internal oblique/transversus abdominis and (c) activity of lumbar erector spinae. The vertical solid line means the onset of internal oblique/transversus abdominis and the offset of lumbar erector spinae.

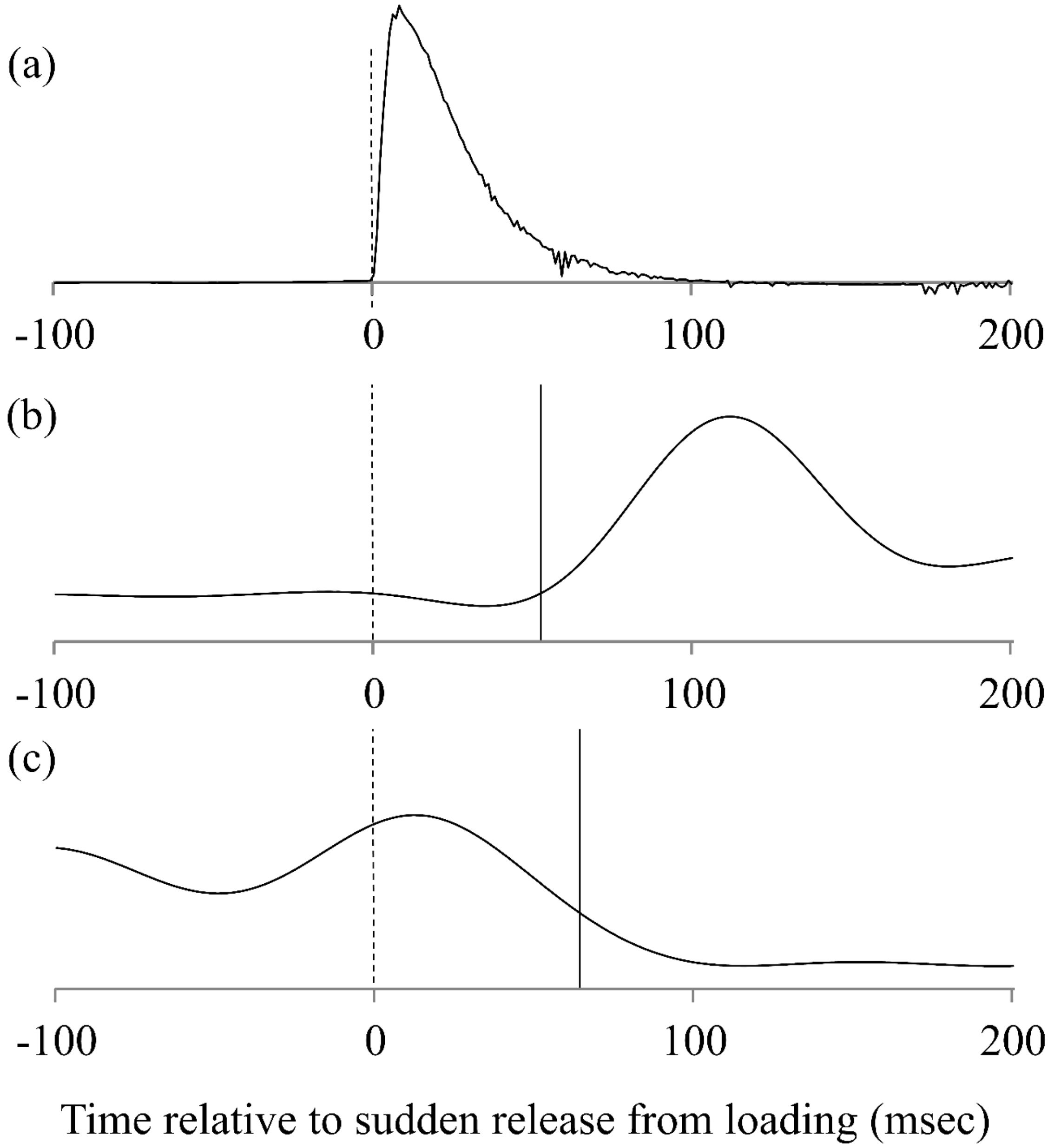
Fig.3 The mean timings of trunk muscle response to release from trunk flexion loading. Mean timings of (a) onset from all trunk flexor muscles and (b) offset from all trunk extensor muscles.

Fig.4 The mean timings of trunk muscle response to release from trunk extension loading. Mean timings of (a) offset from all trunk flexor muscles and (b) onset from all trunk extensor muscles.

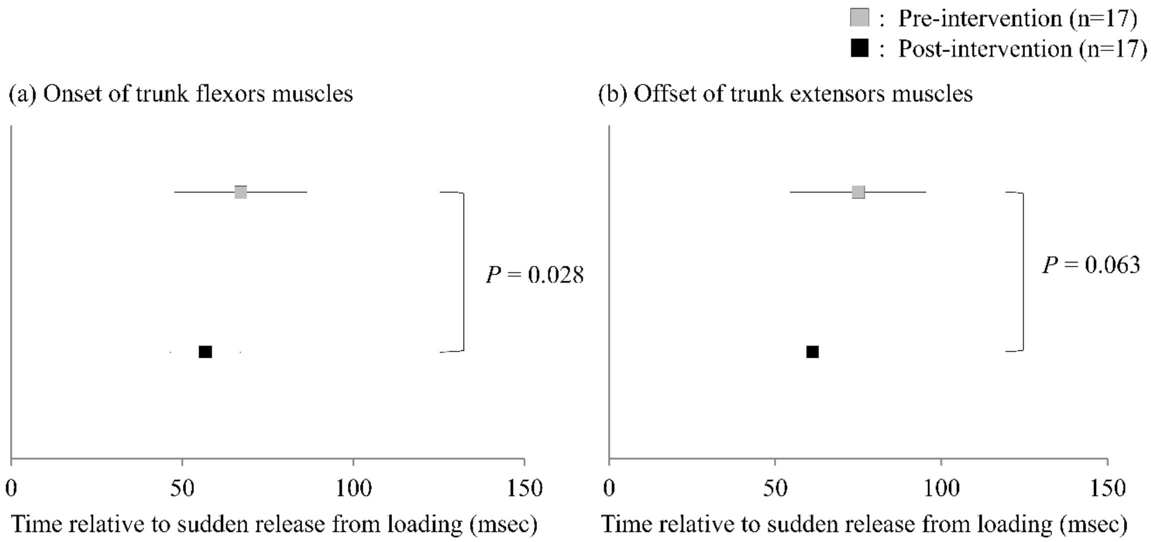
Figures



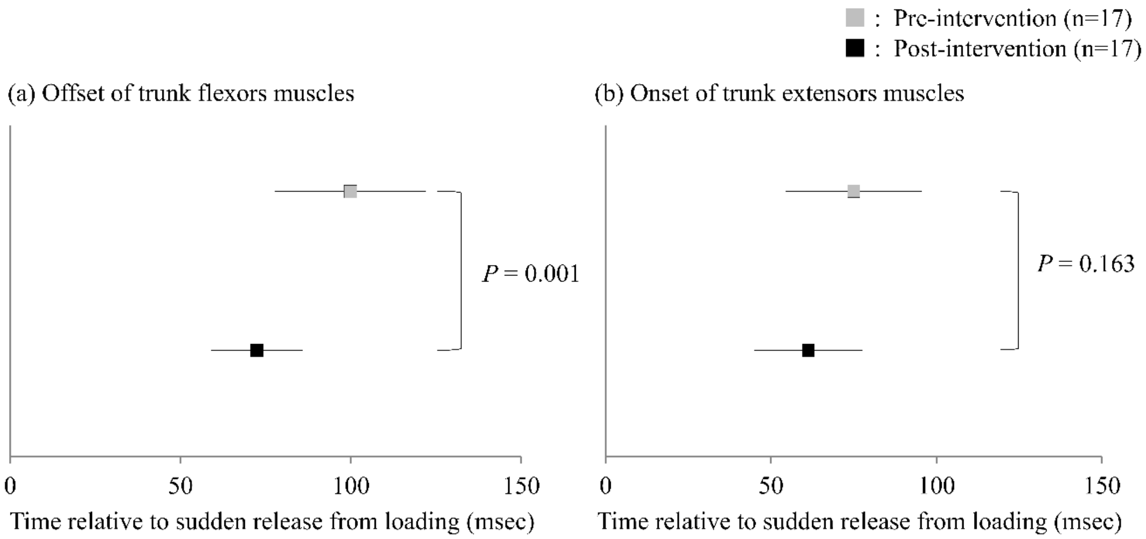
(a)
Load cell
Electromagnet
Weight
(b)
Load cell
Electromagnet
Weight


(a)
-100
0
100
200
(b)
-100
0
100
200
(c)
-100
0
100
200
Time relative to sudden release from loading (msec)

363



: Pre-intervention (n=17)
: Post-intervention (n=17)
(a) Onset of trunk flexors muscles
(b) Offset of trunk extensors muscles
P = 0.028
P = 0.063
0
50
100
150
Time relative to sudden release from loading (msec)
Time relative to sudden release from loading (msec)


: Pre-intervention (n=17)
: Post-intervention (n=17)
(a) Offset of trunk flexors muscles
P = 0.001
0
50
100
150
Time relative to sudden release from loading (msec)
(b) Onset of trunk extensors muscles
P = 0.163
0
50
100
150
Time relative to sudden release from loading (msec)

Tables

Table 1. Muscle reaction times to sudden loading

		Pre-intervention	Post-intervention	*P* value
Sudden release from trunk flexion loading	Onset of trunk flexor muscles (msec)	67.1 (19.3)	56.8 (10.2)	0.028
	Offset of trunk extensor muscles (msec)	75.0 (20.4)	61.3 (16.2)	0.063
Sudden release from trunk extension loading	Offset of trunk flexor muscles (msec)	99.8 (22.1)	72.3 (13.4)	0.001
	Onset of trunk extensor muscles (msec)	66.7 (28.2)	56.8 (10.1)	0.163

Values expressed as mean (standard deviation)

Table 2. Mean scores (standard deviation) in each section of Oswestry disability index (ODI).

	Pre-intervention	Post-intervention	*P* value
Total score	14.5 (5.81)	11.5 (5.89)	0.034
Section 1_Pain intensity	2.35 (1.06)	2.00 (1.00)	0.366
Section 2_Personal care	0.71 (0.98)	0.94 (1.03)	0.317
Section 3_Lifting	0.71 (0.98)	1.53 (0.87)	1.000
Section 4_Walking	1.52 (0.87)	0.47 (0.87)	1.000
Section 5_Sitting	0.47 (0.87)	2.12 (1.11)	0.180
Section 6_Standing	2.47 (0.87)	1.76 (1.39)	0.739
Section 7_Sleeping	0.00 (0.00)	0.00 (0.00)	1.000
Section 8_Sex life	0.24 (0.66)	0.12 (0.49)	0.317
Section 9_Social life	2.59 (1.70)	1.06 (1.75)	0.009
Section 10_Traveling	2.24 (1.56)	1.53 (1.81)	0.084

Total score is up to 100 and subscores of each section are up to 10. A higher score indicates more severe symptoms.