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An Evaluation of an Innovative Exercise to Relieve Chronic Low Back Pain in Sedentary Workers

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INTRODUCTION

Low back pain (LBP) is a common musculoskeletal problem among the working age population. In Thailand, the estimated prevalence of LBP in workers of various occupations is up to 83% (Keawduangdee et al., 2015; Sitthipornvorakul et al., 2015). Sedentary call center operators in Thailand report recurring LBP, and 63% report that their LBP was aggravated by sitting during working hours (Montakarn & Nuttika, 2016). Chronic low back pain (CLBP) has an international prevalence of 11%–23% among people that suffer from LBP (Balagué et al., 2012; Jiménez-Sánchez et al., 2012). The economic impact of CLBP stems from prolonged loss of function that consequently results in loss of work productivity and medical costs (Manchikanti et al., 2014; Olafsson et al., 2017).

Sedentary workers experience increased levels of inactivity, with a high proportion accrued in unbroken bouts of prolonged sitting (≥ 30 min; Hadgraft et al., 2016; Parry & Straker, 2013). Previous studies report that continuous contraction of trunk muscles in seated postures can cause trunk muscle fatigue during prolonged sitting (Areeudomwong, Puntumetakul, Kaber, et al., 2012; Waongenngarm et al., 2016). Deep trunk muscle fatigue reduces the muscular support to the spine, causing impairment of motor coordination as well as increased stress on ligaments and intervertebral discs, resulting in disc height loss (Areeudomwong, Puntumetakul, Kaber, et al., 2012; Waongenngarm et al., 2016). Therefore, prolonged sitting postures may influence lumbar spine stability, ultimately leading to LBP (Gregory et al., 2006; Holmes et al., 2015; Waongenngarm et al., 2016).

Trunk muscles have an essential role in contributing to spinal stability (Grenier & McGill, 2007; Kavcic et al., 2004; Panjabi, 2003). There are two trunk muscle systems: superficial and deep (Bergmark, 1989; Faries & Greenwood, 2007; Kavcic et al., 2004). The internal oblique (IO), transversus abdominis (TrA), and lumbar multifidus (LM) muscles make up the deep muscle system (Kavcic et al., 2004; Panjabi, 2003). Reduced activity of the deep trunk muscles and concurrent increased activity of the large superficial trunk muscles are argued to change spinal loading, which may contribute to the recurrence of LBP symptoms (Hodges & Moseley, 2003; Rodacki et al., 2003; Tsao et al., 2010). These changes in trunk muscle activation may increase spinal compression and lead to changes in stature (Lewis & Fowler, 2009; Schmidt et al., 2016) and delayed stature recovery (Healey et al., 2005; Rodacki et al., 2003).

Reduction in disc height could increase compressive stress on structures in the lumbar spine—that is, intervertebral discs, segmental nerve roots, and interspinous ligaments—and may stimulate nociceptor activity leading to pain (Adams et al., 1990; Fryer et al., 2010). Ergonomists have used stature change to evaluate spinal loads related to different sitting postures (Pape et al., 2018; Puntumetakul et al., 2009; Vergroesen et al., 2016). Previous

research has reported that continuous sitting (total duration of 48 min) could lead to stature reduction (Phimphasak et al., 2016). However, when the spine is subsequently unloaded, these processes are reversed, leading to elastic return the annulus fibrosis, water inflow, and stature recovery (Schmidt et al., 2016; Vergroesen et al., 2016).

The current study is the first study to investigate the supported dynamic lumbar extension with an abdominal drawing-in maneuver (ADIM) technique on stature recovery in CLBP participants. Fryer et al. (2010) demonstrated a supported dynamic lumbar extension exercise, whereby the lumbar spine was extended with upper limb support for 5 s, then repositioned to a neutral position for 3 s, and repeated for four cycles. This exercise has been shown to restore disc height as confirmed by magnetic resonance imaging measurement in healthy participants (Fryer et al., 2010). In addition, activation of deep trunk muscles using the ADIM technique appears to effectively reduce lumbar spinal load, thereby improving stature recovery from compressive forces to the spine, as reported in CLBP patients (Saiklang et al., 2020). Therefore, the supported dynamic lumbar extension with the ADIM technique might be an effective exercise to improve stature recovery in people with CLBP.

It was hypothesized that after a period of prolonged sitting, there would be improved stature recovery, less trunk muscle fatigue, and a reduction in pain intensity in the group who performed the intervention as compared to the group without any exercise.

METHOD

Study Design

The study was a randomized crossover study and was conducted at the research center in the Back, Neck, Other Joint Pain and Human Performance (BNOJPH) Laboratory at the Khon Kaen University, Thailand. Ethical approval was granted by the Human Research Ethics Committee (HE612220) of Khon Kaen University. The study was registered at clinicaltrials. in. th (registration number: TCTR20180823004).

Participants

Thirty participants—15 males, 15 females—aged 20–39 years were recruited via posters displayed around Khon Kaen University. Participants were included if they had CLBP lasting more than 3 months, demonstrated low to moderate pain levels on the numeric rating scale (NRS; ≤ 7 score; Boonstra et al., 2016), and reported sitting for at least 2 hr at work on any working day either continuous or not (Waongenngarm et al., 2016). Participants were excluded if they had previous spinal surgery, were presently using medication known to alter imbibition of water in the discs, had been identified with a medical condition that affected spinal soft tissues, or were pregnant (Lewis et al., 2014; Phimphasak et al., 2016). The sample size was calculated after preliminary data collection from 12 participants (six males and six females), assuming 90% power and 15% attrition rate.

Figure 1 - here

Experimental Apparatus

Stadiometer. Stature change response was measured using a seated stadiometer device (certified Thai petty-patent No. 5607; Figure 1). The digimetic indicator shows real-time Data on display and records data up to 5 Hertz (Hz; ID-C 150, 1050 Digimetic Indicator, Manual No. 3061, Series No. 543, Mitutoyo, Kawasaki, Japan). This device is used to identify variations in stature change; in laboratory tests, it has been shown to have a resolution of ± 0.006 millimeter (mm), but when applied in human trials, measurements to the nearest mm are recorded (Saiklang et al., 2019). The digimetic indicator was mounted in a rigid but adjustable structure that was positioned at the top of the stadiometer. This permitted the digimetic indicator to rest directly at the vertex of the head. The position of digimetic indicator was recorded by a waterproof pen, which controlled the head position to ensure positioning every time participants were repositioned. During each measurement, the digimetic indicator made direct contact with the participant's skull via a thin probe, which reduced the influence of hair thickness (Healey et al., 2011). Maintaining the head position with eye level was facilitated by coaching participants to concentrate on a visual cue, presented opposite them at eye level (Kanlayanaphotporn et al., 2003; Phimphasak et al., 2016).

Spinal alignment was controlled by sensors placed on the spinous processes of vertebrae: cervical (C4), thoracic (T4), thoracic (T12), and lumbar (L3; Kanlayanaphotporn et al., 2003; Phimphasak et al., 2016). These sensors connected with a light diode that was located in a position opposite the seated participant. The light diode was used as feedback to confirm that the participant maintained the same posture during the measurement period. Throughout the measurements, the related footrest and the wooden seat were adjustable so that the participant's ankle, knee, and hip joints were positioned at 90°. The sacral support was adjustable to accommodate the participant's spinal posture. A pillow was placed on the participant's lap to support their forearms at 90° to their upper arms.

Muscle Fatigue Measurement

Eight pairs of Ag-AgCl disposable surface electromyography (sEMG) electrodes (EL 503) with electrical contact surface areas of 1 cm² and a centre-to-center spacing of 2.5 cm were attached bilaterally, parallel to: rectus abdominis (RA; Imai et al., 2010), internal oblique and transversus abdominis (IO&TrA; Marshall & Murphy, 2003), iliocostalis lumborum pars thoracis (ICLT; Danneels et al., 2001), and the lumbar multifidus (LM; Areeudomwong, Puntumetakul, Jirarattanaphochai, et al., 2012) after skin abrasion and cleaning with alcohol. EMG data were recorded at 2000 Hz using the Wireless Bipolar Cometa Mini Wave Plus 16-channel EMG system (Cometa, Bareggio, Italy), online band-pass filter (10–500 Hz), and 60 Hz notch filter (power line in Thailand). The raw EMG signal was first visually checked for electro cardiac artifacts. The raw EMG signal was processed with the Fast Fourier transformation to determine the median frequency (MDF) value (Hz). Decrease in the MDF of the EMG signals was taken as an indirect measure of muscle fatigue (Roldán Jiménez et al., 2019).

Muscle Activity Measurement

Participants performed the required condition (control or intervention) for 1 min. The conditions were repeated three times (at 12–13, 25–26, and 38–39 min) throughout the 41-min prolonged sitting time. The values for average, muscle activity were taken from the middle 30-s sample of the 1-min period for each condition. Raw sEMG signals were full-wave rectified and represented as root mean square (RMS) values.

To gain submaximal voluntary isometric contraction (sub-MVIC) measurements of each participant, participants performed three trials. A rest period of 2 min was given between the tests to avoid muscle fatigue (Areeudomwong, Puntumetakul, Jirarattanaphochai, et al., 2012; Ng et al., 2002). The crook lying double leg raise, during which the participant laid down with the hips and knees flexed to 45° and 90°, respectively, before raising both legs 1 cm from the bed for a 5-s hold (Dankaerts et al., 2004), was used to measure sub-MVIC for the TrA&IO muscles. The RMS values of the middle 3 s of the 5-s testing period were analyzed.

Pain Measurement

Subjective measures of pain were obtained from a 0–10 NRS, employed to assess pain over a 24-h period on a scale ranging from (0) no pain to (10) worst possible pain. Boonstra et al. (2016) reported that NRS scores ≤ 5 correspond to mild pain, scores of 6–7 to moderate pain and scores ≥ 8 to severe pain.

Procedure

This study was conducted according to the flowchart presented in Figure 2. Thirty-three participants responded to the recruitment advertisements, and after screening, 30 eligible participants entered the study. Three participants were excluded due to experiencing LBP >7 on the NRS. Participants meeting the inclusion criteria were asked to visit the research laboratory on three consecutive days.

On the first day, participants were familiarized with the experimental protocol and outcome measurement tests. A physical therapist instructed all participants thoroughly on how to co-contract trunk muscles and body movements while breathing normally without blocking their airway by closing the glottis. To ensure consistency, the same physical therapist instructed participants throughout the study. The participants were trained in this intervention until they achieved good rhythm in sitting conditions. A pressure biofeedback device (Chattanooga Australia Pty Ltd, Brisbane, QLD, Australia) was used to provide feedback and facilitate correct ADIM performance during training in the prone position (Park & Lee, 2013). The pressure biofeedback device was placed under the lower abdomen with the lower edge in line with the anterior-superior iliac spine and inflated to 70 mm of mercury. Optimal performance of the ADIM technique reduces the pressure by approximately 4–10 mm of mercury (Lee et al., 2015; Richardson & Jull, 1995). This session aimed to reduce variations due to postural positioning over repeated measurements. It also involved participants practicing stepping in and out of the stadiometer until a standard deviation (SD) of $<.5$ mm was achieved over 10 repeated stature measurements (Healey et al., 2008; Kanlayanaphotporn et al., 2003).

Participants were randomly allocated to one of two groups (group A or B). On the second day, group A performed the control condition, while group B performed the intervention condition followed by a 24-h washout period (Healey et al., 2008; Phimphasak et al., 2016). On the third day, participants crossed over and performed the other condition (Figure 2).

Figure 2 here

Conditions

Control condition. For the control condition, participants were asked to sit without exercise during the 41-min testing period.

Intervention condition. For the intervention condition, participants were asked to assume a neutral sitting posture for 27 s (Figure 3, position A). At the 28th second, participants were instructed to straighten their lower back and gently draw in their lower abdomen and extend their lumbar spine with their upper limbs supported to transfer the spinal load to the upper limbs, with their chest up slightly and chin in for 5 s (position B). Participants then repositioned to a neutral position and relaxed their lower abdomen for 3 s (position C). A set of conditions (B to C) was referred to as one cycle. This condition required the participant to complete four consecutive cycles in 1 min. This was repeated at 12–13, 25–26, and 38–39 min during the 41-min sitting period. The rhythm of the conditioning cycle was controlled by video feedback.

Figure 3 here

Experiment

On the second and third days, all participants were required to attend at the same time of day between 8 and 10 am (Healey et al., 2008; Saiklang et al., 2019) within an hour of the participant waking. They were requested to sleep at least 8 hr each night before the experimental days (Healey et al., 2011). The researchers asked participants to confirm their sleep duration before the experiment. They were asked to undertake normal activities of daily living, refrain from alcohol consumption, and vigorous physical activities for 24 h before experimental sessions (Fowler et al., 2005; Healey et al., 2008). It was essential to start test trials within 2 hr after participants arose from the bed to avoid stature loss occurring before the test trial.

An overview of the experimental procedure along with time points and their outcome measurement is shown in Figure 4. After the application of the sEMG electrodes, all participants were asked to attain and maintain Fowler's position for 20 min to eliminate any abnormal spinal loading that may have preceded arrival at the laboratory (Fowler et al., 2005; Rodacki et al., 2003). Then, participants sat in the seated stadiometer, according to conditions described above, and a baseline stature measurement was recorded (T₀). During the test trials, the participants remained in a freestyle sitting position, for which a straight back was not required, without a backrest for 10 min. Participants were measured for stature change and pain perception in the lower back (T_{sit}). Following this, participants were asked to perform the condition, according to the group they were assigned to

on the first day, for 1 min at 12–13, 25–26, and 38–39 min throughout the trial. Trunk muscle activity was captured simultaneously. Stature change and pain intensity were measured at the end of each condition (T1 = 13 min; T2 = 26 min; T3 = 39 min). For the trunk muscle fatigue, the sEMG data were retrieved (at 0–10, 15–25, and 28–38 min) from the 41-min sitting period for analysis. Participants were not allowed to stand up during the test trials.

Figure 4 here

Outcome Measurements

All outcomes were measured at the same time point for both conditions. Each measurement set, consisting of 75 data points (sampled over 15 s; Phimphasak et al., 2016; Saiklang et al., 2019), was considered at time 0 and at the end of a 2-min interval; this reduced the effect of breathing patterns and uncontrolled movements (Healey et al., 2011; Phimphasak et al., 2016). The raw stature change data were visually checked for breathing patterns and uncontrolled movement artifacts. This confirmed the quality of the data and all data were included in the analysis.

For trunk muscle fatigue, the raw sEMG signal was processed with the triangle-Bartlett method of Fast Fourier transformation to determine the MDF value. The trunk muscle activation of the TrA&IO muscles were measured with the sEMG. The middle 30-s sample of the three 1-min periods for each condition (at 12–13, 25–26, and 38–39 min) were retrieved for analysis. All the normalized RMS values achieved during each condition were expressed as a percentage of sub-MVIC (%sub-MVIC).

Statistical Analysis

All analyses were performed using SPSS version 19.0 software (SPSS Inc., Chicago, IL, USA). The Shapiro–Wilk test was performed to check the distribution of data. The mean and SD were used to assess participants' demographics. Stature at each time of measurement was calculated from the reference point of Tsit. A mixed analysis of variance (ANOVA) was performed for an interaction between the condition and time. Differences in stature within a condition were assessed using a one-way repeated measure ANOVA for time effect (T1, T2, and T3) with the Bonferroni post-hoc analysis (significant at $p < .017$; $.05/3$). Paired t-tests were used to compare between conditions at each time of measurement.

The differences in trunk muscle fatigue and pain intensity within groups for nonnormally distribution data were analyzed using the Friedman test; the post-hoc tests used the Wilcoxon signed-rank tests. Differences in trunk muscle fatigue, trunk muscle activity, and pain intensity between groups were analyzed using the Wilcoxon signed-rank test. A significance level was set at $p < .05$ for trunk muscle fatigue, trunk muscle activity, and pain intensity.

Table 1 here

Table 2 here

RESULTS

All participants achieved the necessary level of repeatability for the stature change measurements ($SD \leq 5$ mm). Characteristics of the participant are presented in Table 1.

The result of stature change after sitting for 10 min (T_{sit}) showed no significant differences between conditions ($p = .429$; Table 2). This result indicates that T_{sit} between conditions was comparable and could therefore be used as a reference point for stature change calculation at T1, T2, and T3. Descriptive data of stature change at four measurement times for each condition during the 41-min test are presented in Table 2.

The results demonstrated no interaction between the condition and time ($F(2, 58) = 2.067$; $p = .131$). The control condition showed a significant reduction in stature due to time (T1, T2, and T3; $p < .001$). Conversely, the intervention condition demonstrated no significant difference in stature change across time. Comparison between the conditions indicated that the first (T1), second (T2), and third (T3) occasion of the control condition demonstrated significant deterioration in stature change (T1, T2, and T3; $p < .001$).

The MDF at each measurement time for the two conditions is shown in Table 3. The Friedman test revealed a significant deterioration in MDF value in TrA&IO muscles bilaterally at each time of measurement within the control condition. The control condition demonstrated significantly reduced MDF in the TrA&IO bilaterally for the second and third time of measurements (15th–25th and 28th–38th min) when compared with the first time of measurement.

The control condition demonstrated significantly reduced MDF in the TrA&IO bilaterally for the second and third time of measurements (15th–25th and 28th–38th min) and decreased significant MDF in the LM bilaterally for the third time of measurement (28th–38th min) when compared with the intervention condition.

Trunk muscle activity at each measurement time for the two conditions is shown in Table 4. The intervention demonstrated significantly higher muscle activity than the control in TrA&IO muscles bilaterally at each time ($p \leq .05$).

Pain intensity at each measurement time for the two conditions is shown in Table 5. The Friedman test revealed a significant worsening in pain intensity in the control condition. Furthermore, the control condition shows a significant worsening in pain intensity between the times of measurement as follows: (a) pain intensity of T1 increased significantly from T_{sit} and (b) pain intensity of T2 and T3 increased significantly from T_{sit} and T1. Moreover, the control condition resulted in a significant increase in pain intensity compared with the intervention at T1, T2, and T3.

Table 3

Table 4

Table 5

DISCUSSION

This study is the first to examine the effectiveness of a novel supported dynamic lumbar extension with the ADIM technique on stature change, deep trunk muscle activity, trunk muscle fatigue, and pain intensity during prolonged sitting in CLBP participants.

The intervention condition significantly reduced stature loss after the first occasion (mean difference 3.1 mm; T1; Table 2), the second occasion (mean difference 3.0 mm; T2), and the third occasion (mean difference 4.3 mm; T3), as compared with the control condition. It should be noted that a mean difference in stature change between conditions of 3 mm or greater is considered clinically significant (Kanlayanaphotporn et al., 2003). This intervention was a combination of supported dynamic lumbar extension, which can share the load between the posterior aspects of the motion segment and the gleno-humeral-scapular complex to reduce the pressure on the intervertebral discs (Fryer et al., 2010), and the ADIM technique, which appears to activate the TrA&IO muscles (Saiklang et al., 2020; Watanabe et al., 2014). The intervention condition demonstrated significantly higher activation of the TrA&IO than the control (Table 4). Tayashiki et al. (2016) investigated the magnitude of intra-abdominal pressure (IAP) during the ADIM technique. Participants performing the ADIM technique increased activity of the IO muscle by approximately .329 mV and IAP by approximately 11.3 mmHg. Moreover, Tayashiki et al. (2016) reported that the relationship between IO muscle activity and IAP was significant in all participants (IO: $r = .845-.994$, $p < .01$). The current study proposed that the intervention condition can increase IAP by activating the TrA&IO muscles. IAP has been recommended as an important component in unloading the spine (Stokes et al., 2010). Increased IAP may partially reduce the compressive forces produced during prolonged sitting. Moreover, this combined intervention appears to improve stature recovery better than when participants performed only the ADIM technique (Saiklang et al., 2020).

There are two possible explanations for why the second and third occasions of the intervention condition did not show recovery as expected. First, change in stature occurs in two phases (fast and slow); stature quickly decreases after applying load to the spine (fast phase) and slowly reduces afterwards (slow phase; Schmidt et al., 2016; Vergroesen et al., 2016). This phenomenon is due to intervertebral discs being stiffer in the slow phase, in which the discs contain lower concentrations of water (Healey et al., 2011). This might affect stature recovery mechanisms, which could require more time for recovery, consequently leading to a lesser stature recovery in T2 and T3. Second, O'Connell et al. (2011) also reported that stature recovers in two phases: (a) immediate recovery from elastic recoil of spinal structures and (b) recovery from the disc rehydration mechanism. Therefore, the failure of stature recovery over time might be due to insufficient duration of the unloaded position of the intervention for rehydration mechanisms to occur.

The result of the current study found that bilaterally TrA&IO muscle fatigue occurred earlier during sitting (approximately 15th–25th min after sitting; see Table 3) in the control condition. A direct comparison is possible only with the research conducted by Waongenngarm et al. (2016). In that study, the investigators examined the characteristics of trunk muscle fatigue during sitting. The MDF value of the EMG signal of RA, ICLT, and LM

muscles was unchanged over time in sitting postures. Only the TrA&IO was significantly associated with decreased MDF over time. However, the values of MDF were more than in the current study. The results of the current study are supported by previous research by Talebian et al. (2011), who reported MDF values in participants with CLBP lower than healthy participants. During prolonged sitting, the LM is passively stretched, resulting in the TrA&IO muscles increasing co-contraction activity to balance spinal muscle forces. However, the intervention condition reported no muscle fatigue over the 41-min testing period (Table 3). The intervention condition induces body movement and frequent changes in position while sitting. So, this intervention can reduce the static posture, which is associated with disc compression (Fryer et al., 2010; Phimphasak et al., 2016) and prolonged contraction of deep trunk muscles (Areeudomwong, Puntumetakul, Kaber, et al., 2012; Waongenngarm et al., 2016). Furthermore, the ADIM technique appears to be sufficient to activate deep trunk muscles. The deep trunk muscles have a crucial stabilizing role in the lumbo-pelvic region and in reducing stress on spinal structures of this area (Tsao et al., 2010; Waongenngarm et al., 2016). The findings from this study suggest that the intervention condition might be appropriate during sitting to prevent deep trunk muscle fatigue in individuals who usually spend an extended period sitting.

The intervention can induce dynamic lumbar movement and maintain activation of deep trunk muscle during prolonged sitting. The suggested mechanisms for not seeing an increase in LBP are via reduced compression load on the spinal structures (Cannon et al., 2016; Wang et al., 2007) and deep trunk muscle activation to support the lumbar spine (Panjabi, 2003; Tsao et al., 2010). In the control condition, pain intensity increased significantly over the 41-min testing period. Previous studies have reported that static loading of the lumbar spine during prolonged sitting is associated with spinal structure compression (Billy et al., 2014; Fryer et al., 2010). If loading is sustained, it increases stress in the spinal structures (Billy et al., 2014; Fryer et al., 2010), reduces local nutrition (Wang et al., 2007), and may increase LBP (Fryer et al., 2010; Søndergaard et al., 2010). However, this finding should be treated with some caution as a difference of 0.5 on the NRS, whilst statistically significant, is not considered a clinically significant difference. According to Ostelo et al. (2005), they highlight that the MCIC for the NRS is 2.5.

The current study has limitations. First, the investigation was of young participants with CLBP participants in a narrow age range in a laboratory rather than a workplace setting. Therefore, the findings of this study might not apply to other age groups and may have limited ecological validity. Further research is required to investigate the impact of the intervention in other age groups and in workplace settings. Second, collecting instrumented rather than self-reported activity data across the entire 24-hr day should be considered in future investigations. This will give investigators increased confidence that they understand participants' activities that could affect the results. Third, there is currently no consensus regarding the optimum method of controlling head position. This study used the methods described by Kanlayanaphotporn et al. (2003). However, more recently, Fryer et al. (2010) used glasses with a site level, and this is an area worthy of further study. Fourth, future studies should control the participants' position during the intervention, as the exact location on the wooden seat may have varied. Finally, the current study was limited to the immediate effects of the intervention. Future studies should investigate the long-term

effect of the intervention in workplace settings. Moreover, further study should develop the exercise application to enable delivery via phone/app or wearable bio feedback device.

CONCLUSION

The intervention aimed at improving stature recovery in people with CLBP during prolonged sitting, using a combination of supported dynamic lumbar extension with the ADIM technique. It has been shown to provide, under controlled conditions in a laboratory with young and otherwise healthy participants, a protective effect on detrimental reductions in stature change and deep trunk muscle fatigue. It also prevented increases in pain intensity during prolonged sitting.

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REFERENCES

- Adams, M. A., Dolan, P., Hutton, W. C., & Porter, R. W. (1990). Diurnal changes in spinal mechanics and their clinical significance. *The Journal of Bone and Joint Surgery*, *72*, 266–270. <https://doi.org/10.1302/0301-620X.72B2.2138156>
- Areudomwong, P., Puntumetakul, R., Jirattanaphochai, K., Wanpen, S., Kanpittaya, J., Chatchawan, U., & Yamauchi, J. (2012). Core stabilization exercise improves pain intensity, functional disability and trunk muscle activity of patients with clinical lumbar instability: A pilot randomized controlled study. *Journal of Physical Therapy Science*, *24*, 1007–1012. <https://doi.org/10.1589/jpts.24.1007>
- Areudomwong, P., Puntumetakul, R., Kaber, D. B., Wanpen, S., Leelayuwat, N., & Chatchawan, U. (2012). Effects of handicraft sitting postures on lower trunk muscle fatigue. *Ergonomics*, *55*, 693–703. <https://doi.org/10.1080/00140139.2012.658086>
- Balagué, F., Mannion, A. F., Pellisé, F., & Cedraschi, C. (2012). Non-specific low back pain. *Lancet*, *379*, 482–491. [https://doi.org/10.1016/S0140-6736\(11\)60610-7](https://doi.org/10.1016/S0140-6736(11)60610-7)
- Bergmark, A. (1989). Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthopaedica Scandinavica*, *60*, 1–54.
- Billy, G. G., Lemieux, S. K., & Chow, M. X. (2014). Changes in lumbar disk morphology associated with prolonged sitting assessed by magnetic resonance imaging. *PM&R*, *6*, 790–795. <https://doi.org/10.1016/j.pmrj.2014.02.014>
- Boonstra, A. M., Stewart, R. E., Köke, A. J. A., Oosterwijk, R. F. A., Swaan, J. L., Schreurs, K. M. G., & Schiphorst Preuper, H. R. (2016). Cut-off points for mild, moderate, and severe pain on the numeric rating scale for pain in patients with chronic musculoskeletal pain: Variability and influence of sex and catastrophizing. *Frontiers in Psychology*, *7*, 1466. <https://doi.org/10.3389/fpsyg.2016.01466>
- Cannon, J., Emond, D., & McGill, S. M. (2016). Evidence on the ability of a pneumatic decompression belt to restore spinal height following an acute bout of exercise. *Journal of Manipulative and Physiological Therapeutics*, *39*, 304–310. <https://doi.org/10.1016/j.jmpt.2016.03.004>

Dankaerts, W., O'Sullivan, P. B., Burnett, A. F., Straker, L. M., & Danneels, L. A. (2004). Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. *Journal of Electromyography and Kinesiology*, 14, 333–342. <https://doi.org/10.1016/j.jelekin.2003.07.001>

Danneels, L. A., Cagnie, B. J., Cools, A. M., Vanderstraeten, G. G., Cambier, D. C., Witvrouw, E. E., & De Cuyper, H. J. (2001). Intra-operator and inter-operator reliability of surface electromyography in the clinical evaluation of back muscles. *Manual Therapy*, 6, 145–153. <https://doi.org/10.1054/math.2001.0396>

Faries, M. D., & Greenwood, M. (2007). Core training: Stabilizing the confusion. *Strength and Conditioning Journal*, 29, 10–25.

Fowler, N. E., Rodacki, C. D., & Rodacki, A. L. (2005). Spinal shrinkage and recovery in women with and without low back pain. *Archives of Physical Medicine and Rehabilitation*, 86, 505–511. <https://doi.org/10.1016/j.apmr.2004.07.352>

Fryer, J. C. J., Quon, J. A., & Smith, F. W. (2010). Magnetic resonance imaging and stadiometric assessment of the lumbar discs after sitting and chair-care decompression exercise: A pilot study. *The Spine Journal*, 10, 297–305. <https://doi.org/10.1016/j.spinee.2010.01.009>

Gregory, D. E., Dunk, N. M., & Callaghan, J. P. (2006). Stability ball versus office chair: Comparison of muscle activation and lumbar spine posture during prolonged sitting. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 48, 142–153. <https://doi.org/10.1518/001872006776412243>

Grenier, S. G., & McGill, S. M. (2007). Quantification of lumbar stability by using 2 different abdominal activation strategies. *Archives of Physical Medicine and Rehabilitation*, 88, 54–62. <https://doi.org/10.1016/j.apmr.2006.10.014>

Hadgraft, N. T., Healy, G. N., Owen, N., Winkler, E. A. H., Lynch, B. M., Sethi, P., Eakin, E. G., Moodie, M., LaMontagne, A. D., Wiesner, G., Willenberg, L., & Dunstan, D. W. (2016). Office workers' objectively assessed total and prolonged sitting time: Individual-level correlates and worksite variations. *Preventive Medicine Reports*, 4, 184–191. <https://doi.org/10.1016/j.pmedr.2016.06.011>

Healey, E. L., Burden, A. M., McEwan, I. M., & Fowler, N. E. (2008). Stature loss and recovery following a period of loading: Effect of time of day and presence or absence of low back pain. *Clinical Biomechanics*, 23, 721–726. <https://doi.org/10.1016/j.clinbiomech.2008.02.011>

Healey, E. L., Burden, A. M., McEwan, I. M., & Fowler, N. E. (2011). Diurnal variation in stature: Do those with chronic low-back Pain differ from asymptomatic controls? *Clinical Biomechanics*, 26, 331–336. <https://doi.org/10.1016/j.clinbiomech.2010.11.017>

Healey, E. L., Fowler, N. E., Burden, A. M., & McEwan, I. M. (2005). Raised paraspinal muscle activity reduces rate of stature recovery after loaded exercise in individuals with chronic low back pain. *Archives of Physical Medicine and Rehabilitation*, 86, 710–715. <https://doi.org/10.1016/j.apmr.2004.10.026>

Hodges, P. W., & Moseley, G. L. (2003). Pain and motor control of the lumbopelvic region: Effect and possible mechanisms. *Journal of Electromyography and Kinesiology*, 13, 361–370. [https://doi.org/10.1016/S1050-6411\(03\)00042-7](https://doi.org/10.1016/S1050-6411(03)00042-7)

Holmes, M. W. R., De Carvalho, D. E., Karakolis, T., & Callaghan, J. P. (2015). Evaluating abdominal and lower-back muscle activity while performing core exercises on a stability ball and a dynamic office chair. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 57, 1149–1161. <https://doi.org/10.1177/0018720815593184>

- Imai, A., Kaneoka, K., Okubo, Y., Shiina, I., Tatsumura, M., Izumi, S., & Shiraki, H. (2010). Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. *Journal of Orthopaedic & Sports Physical Therapy*, 40, 369–375. <https://doi.org/10.2519/jospt.2010.3211>
- Jiménez-Sánchez, S., Fernández-de-Las-Peñas, C., Carrasco-Garrido, P., Hernández-Barrera, V., Alonso-Blanco, C., Palacios-Ceña, D., & Jiménez-García, R. (2012). Prevalence of chronic head, neck and low back pain and associated factors in women residing in the autonomous region of Madrid (Spain). *Gaceta Sanitaria*, 26, 534–540. <https://doi.org/10.1016/j.gaceta.2011.10.012>
- Kanlayanaphotporn, R., Trott, P., Williams, M., & Fulton, I. (2003). Effects of chronic low back pain, age and gender on vertical spinal creep. *Ergonomics*, 46, 561–573. <https://doi.org/10.1080/0014013031000066500>
- Kavcic, N., Grenier, S., & McGill, S. M. (2004). Determining the stabilizing role of individual torso muscles during rehabilitation exercises. *Spine*, 29, 1254–1265. <https://doi.org/10.1097/00007632-200406010-00016>
- Keawduangdee, P., Puntumetakul, R., Swangnetr, M., Laohasiriwong, W., Settheetham, D., Yamauchi, J., & Boucaut, R. (2015). Prevalence of low back pain and associated factors among farmers during the rice transplanting process. *Journal of Physical Therapy Science*, 27, 2239–2245. <https://doi.org/10.1589/jpts.27.2239>
- Lee, N. G., You, Joshua (Sung) H., Kim, T. H., & Choi, B. S. (2015). Intensive abdominal Drawing-in maneuver after Unipedal postural stability in nonathletes with core instability. *Journal of Athletic Training*, 50, 147–155. <https://doi.org/10.4085/1062-6050-49.3.91>
- Lewis, S., Holmes, P., Woby, S., Hindle, J., & Fowler, N. (2014). Changes in muscle activity and stature recovery after active rehabilitation for chronic low back pain. *Manual Therapy*, 19, 178–183. <https://doi.org/10.1016/j.math.2014.01.008>
- Lewis, S. E., & Fowler, N. E. (2009). Changes in intervertebral disk dimensions after a loading task and the relationship with stature change measurements. *Archives of Physical Medicine and Rehabilitation*, 90, 1795–1799. <https://doi.org/10.1016/j.apmr.2009.04.017>
- Manchikanti, L., Singh, V., Falco, F. J. E., Benyamin, R. M., & Hirsch, J. A. (2014). Epidemiology of low back pain in adults. *Neuromodulation: Technology at the Neural Interface*, 17, 3–10. <https://doi.org/10.1111/ner.12018>
- Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology*, 13, 477–489. [https://doi.org/10.1016/S1050-6411\(03\)00027-0](https://doi.org/10.1016/S1050-6411(03)00027-0)
- Montakarn, C., & Nuttika, N. (2016). Physical activity levels and prevalence of low back pain in Thai call-center operators. *Indian Journal of Occupational and Environmental Medicine*, 20, 125. <https://doi.org/10.4103/0019-5278.203136>
- Ng, J. K. F., Richardson, C. A., Parnianpour, M., & Kippers, V. (2002). EMG activity of trunk muscles and torque output during isometric axial rotation exertion: A comparison between back pain patients and matched controls. *Journal of Orthopaedic Research*, 20, 112–121. [https://doi.org/10.1016/S0736-0266\(01\)00067-5](https://doi.org/10.1016/S0736-0266(01)00067-5)
- O'Connell, G. D., Jacobs, N. T., Sen, S., Vresilovic, E. J., & Elliott, D. M. (2011). Axial creep loading and unloaded recovery of the human intervertebral disc and the effect of degeneration. *Journal of the Mechanical Behavior of Biomedical Materials*, 4, 933–942. <https://doi.org/10.1016/j.jmbm.2011.07.001>

jmbbm. 2011. 02. 002

Olafsson, G., Jonsson, E., Fritzell, P., Hägg, O., & Borgström, F. (2017). A health economic lifetime treatment pathway model for low back pain in Sweden. *Journal of Medical Economics*, 20, 1281–1289. <https://doi.org/10.1080/13696998.2017.1372252>

Ostelo, R. W. J. G., & de Vet, H. C. W., Ostelo, W. R., & de Vet, C. H. (2005). Clinically important outcomes in low back pain. *Best Practice & Research Clinical Rheumatology*, 19, 593–607. <https://doi.org/10.1016/j.berh.2005.03.003>

Panjabi, M. M. (2003). Clinical spinal instability and low back pain. *Journal of Electromyography and Kinesiology*, 13, 371–379. [https://doi.org/10.1016/S1050-6411\(03\)00044-0](https://doi.org/10.1016/S1050-6411(03)00044-0)

Pape, J. L., Brismée, J.-M., Sizer, P. S., Matthijs, O. C., Browne, K. L., Dewan, B. M., & Sobczak, S. (2018). Increased spinal height using propped slouched sitting postures: Innovative ways to rehydrate intervertebral discs. *Applied Ergonomics*, 66, 9–17. <https://doi.org/10.1016/j.apergo.2017.07.016>

Park, D.-J., & Lee, S.-K. (2013). What is a suitable pressure for the abdominal drawing-in maneuver in the supine position using a pressure biofeedback unit? *Journal of Physical Therapy Science*, 25, 527–530. <https://doi.org/10.1589/jpts.25.527>

Parry, S., & Straker, L. (2013). The contribution of office work to sedentary behaviour associated risk. *BMC Public Health*, 13, 296. <https://doi.org/10.1186/1471-2458-13-296>

Phimphasak, C., Swangnetr, M., Puntumetakul, R., Chatchawan, U., & Boucaut, R. (2016). Effects of seated lumbar extension postures on spinal height and lumbar range of motion during prolonged sitting. *Ergonomics*, 59, 112–120. <https://doi.org/10.1080/00140139.2015.1052570>

Puntumetakul, R., Trott, P., Williams, M., & Fulton, I. (2009). Effect of time of day on the vertical spinal creep response. *Applied Ergonomics*, 40, 33–38. <https://doi.org/10.1016/j.apergo.2008.01.016>

Richardson, C. A., & Jull, G. A. (1995). Muscle control-pain control. What exercises would you prescribe? *Manual Therapy*, 1, 2–10. <https://doi.org/10.1054/math.1995.0243>

Rodacki, C. L., Fowler, N. E., Rodacki, A. L., & Birch, K. (2003). Stature loss and recovery in pregnant women with and without low back pain. *Archives of Physical Medicine and Rehabilitation*, 84, 507–512. <https://doi.org/10.1053/apmr.2003.50119>

Roldán Jiménez, C., Bennett, P., Ortiz García, A., & Cuesta Vargas, A. I., Jiménez, R., García, O., & Vargas, C. (2019). Fatigue detection during sit-to-stand test based on surface electromyography and acceleration: A case study. *Sensors*, 19, 4202. <https://doi.org/10.3390/s19194202>

Saiklang, P., Puntumetakul, R., Swangnetr Neubert, M., & Boucaut, R. (2019). Effect of time of day on height loss response variability in asymptomatic participants on two consecutive days. *Ergonomics*, 62, 1542–1550. <https://doi.org/10.1080/00140139.2019.1663941>

Saiklang, P., Puntumetakul, R., Swangnetr Neubert, M., & Boucaut, R. (2020). The immediate effect of the abdominal drawing-in maneuver technique on stature change in seated sedentary workers with chronic low back pain. *Ergonomics*, 1–14. <https://doi.org/10.1080/00140139.2020.1810326>

Schmidt, H., Reitmaier, S., Graichen, F., & Shirazi-Adl, A. (2016). Review of the fluid flow within intervertebral discs-how

could in vitro measurements replicate in vivo? *Journal of Biomechanics*, 49, 3133–3146. <https://doi.org/10.1016/j.jbiomech.2016.09.007>

Sitthipornvorakul, E., Janwantanakul, P., & Lohsoonthorn, V. (2015). The effect of daily walking steps on preventing neck and low back pain in sedentary workers: A 1-year prospective cohort study. *European Spine Journal*, 24, 417–424. <https://doi.org/10.1007/s00586-014-3577-3>

Stokes, I. A. F., Gardner-Morse, M. G., & Henry, S. M. (2010). Intra-abdominal pressure and abdominal wall muscular function: Spinal unloading mechanism. *Clinical Biomechanics*, 25, 859–866. <https://doi.org/10.1016/j.clinbiomech.2010.06.018>

Søndergaard, K. H. E., Olesen, C. G., Søndergaard, E. K., de Zee, M., & Madeleine, P. (2010). The variability and complexity of sitting postural control are associated with discomfort. *Journal of Biomechanics*, 43, 1997–2001. <https://doi.org/10.1016/j.jbiomech.2010.03.009>

Talebian, S., Hosseini, M., Bagheri, H., Olyaei, G. R., & Rezasoltani, A. (2011). Trunk muscle fatigue in subjects with a history of low back pain and a group of healthy controls measured by similarity index. *Journal of Back and Musculoskeletal Rehabilitation*, 24, 17–22. <https://doi.org/10.3233/BMR-2011-0270>

Tayashiki, K., Takai, Y., Maeo, S., & Kanehisa, H. (2016). Intra-abdominal pressure and trunk muscular activities during abdominal bracing and hollowing. *International Journal of Sports Medicine*, 37, 134–143. <https://doi.org/10.1055/s-0035-1559771>

Tsao, H., Druitt, T. R., Schollum, T. M., & Hodges, P. W. (2010). Motor training of the lumbar paraspinal muscles induces immediate changes in motor coordination in patients with recurrent low back pain. *The Journal of Pain*, 11, 1120–1128. <https://doi.org/10.1016/j.jpain.2010.02.004>

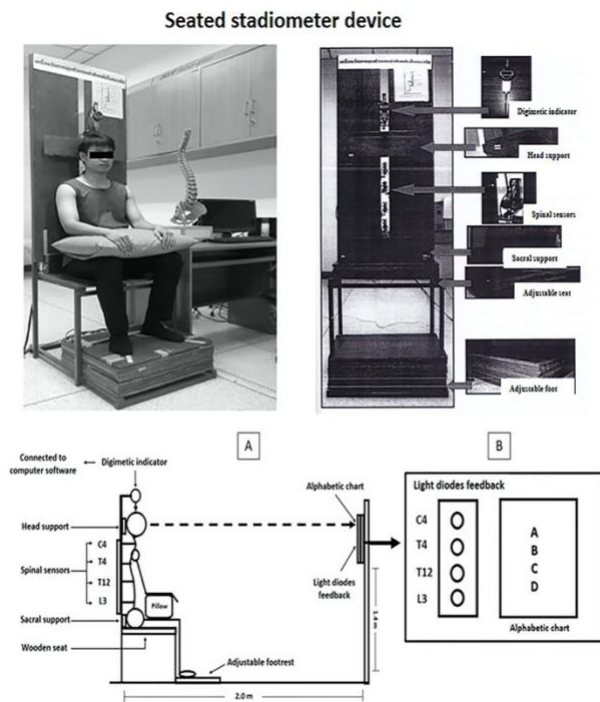
Vergroesen, P.-P. A., van der Veen, A. J., Emanuel, K. S., van Dieën, J. H., & Smit, T. H. (2016). The poro-elastic behaviour of the intervertebral disc: A new perspective on diurnal fluid flow. *Journal of Biomechanics*, 49, 857–863. <https://doi.org/10.1016/j.jbiomech.2015.11.041>

Wang, D.-L., Jiang, S.-D., & Dai, L.-Y. (2007). Biologic response of the intervertebral disc to static and dynamic compression in vitro. *Spine*, 32, 2521–2528. <https://doi.org/10.1097/BRS.0b013e318158cb61>

Waongenngarm, P., Rajaratnam, B. S., & Janwantanakul, P. (2016). Internal oblique and transversus abdominis muscle fatigue induced by slumped sitting posture after 1 hour of sitting in office workers. *Safety and Health at Work*, 7, 49–54. <https://doi.org/10.1016/j.shaw.2015.08.001>

Watanabe, S., Kobara, K., Yoshimura, Y., Osaka, H., & Ishida, H. (2014). Influence of trunk muscle co-contraction on spinal curvature during sitting. *Journal of Back and Musculoskeletal Rehabilitation*, 27, 55–61. <https://doi.org/10.3233/BMR-130419>

Figure 1 The device settings



Note. (A) participant position in the seated stadiometry device and (B) light diode feedback and alphabetic letter

Figure 2 The study flowchart

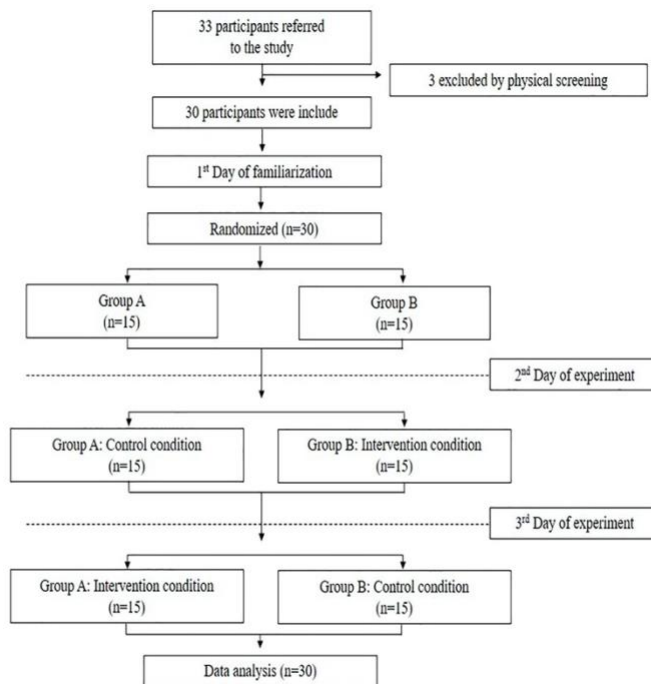


Figure 3 The intervention procedure

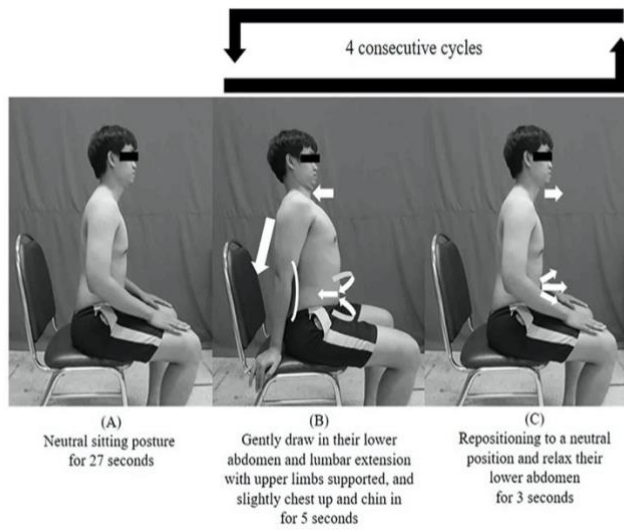


Figure 4 Overview of the experimental procedure

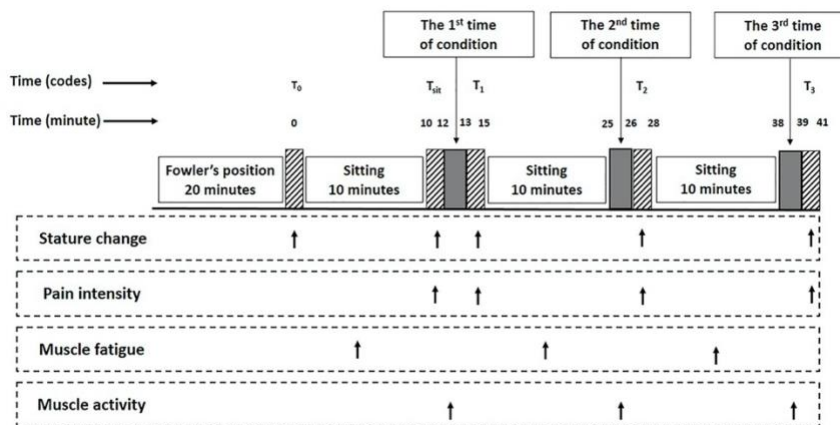


Table 1 Participant characteristics

	Combined (N=30) Mean ± SD	Male (N=15) Mean ± SD	Female (N=15) Mean ± SD
Age (years)	25.87 ± 3.31	25.67 ± 3.35	26.07 ± 3.37
Sitting height (cm)	86.22 ± 4.75	87.93 ± 5.38	84.50 ± 3.39
Standing height (cm)	164.23 ± 7.45	169.80 ± 5.16	158.67 ± 4.70
Body mass (Kg)	58.37 ± 8.59	63.93 ± 7.94	52.80 ± 4.84
Body Mass Index (kg/m ²)	21.53 ± 1.70	22.11 ± 1.90	20.95 ± 1.28
Pain duration (months)	10.6 ± 5.3	10.7 ± 6.2	10.5 ± 4.6
Perceived Pain (score)	4.4 ± 1.3	4.3 ± 1.3	4.5 ± 1.4
Smoking status	no	no	no

Note. SD = standard deviation, cm = centimetre, Kg = kilogram, m² = square metre. Body Mass Index = kg/m², where kg is a person's weight in kilograms and m² is their height in metres squared.

Table 2

Descriptive data of stature change at four measurement times

Conditions		Stature change after sitting for 10 minutes (T _{sit} ; millimetre)	Mean change from (T _{sit} ; millimetre)		
			T ₁	T ₂	T ₃
Intervention	Mean ± SD (95%CI)	-4.8 ± 2.7 (-5.8 to -3.7)	0.1 ± 4.4 (-1.4 to 1.8)	-1.5 ± 3.2 (-2.7 to -0.3)	-2.0 ± 3.3 (-3.2 to -0.7)
Control	Mean ± SD (95%CI)	-4.2 ± 2.2 (-5.0 to -3.4)	-2.9 ± 1.7 (-3.6 to -2.2) b**, c**	-4.6 ± 2.7 (-5.6 to -3.6) a**	-6.4 ± 3.6 (-7.7 to -5.0) a**, b**
Intervention vs. Control Mean difference ± SD (95%CI)		-0.5 ± 3.6 (-1.9 to 0.8)	3.1 ± 4.5 (1.4 to 4.7)	3.0 ± 3.3 (1.8 to 4.3)	4.3 ± 4.4 (2.7 to 6.0)
p-value		0.429	0.001**	0.001**	0.001**

Table 3 The differences in MDF each of the time between and within conditions

Muscles	Conditions	Right				Left			
		0th-10th min	15th -25th min	28th -38th min	p-value within condition	0th -10th min	15th -25th min	28th -38th min	p-value within condition
RA (Hz)	Control	15.71 (15.70 – 15.72)	15.69 (8.17 – 15.72)	15.71 (15.70– 15.72)	0.400	15.72 (15.70– 15.73)	15.73 (15.72 – 17.34)	15.71 (15.70 – 19.15)	0.443
	Intervention	15.71 (14.99 – 15.72)	15.70 (13.47– 15.71)	15.70 (14.18– 15.71)	0.733	15.72 (15.70– 15.73)	15.72 (15.70 – 17.07)	15.72 (15.70 – 19.22)	0.837
p-value between condition		0.304	0.247	0.144		0.854	0.829	0.682	
TrA& IO (Hz)	Control	15.70 (9.60 – 15.79) b**c*	7.79 (3.00 – 8.00) a**	7.65 (6.45 – 15.71) a*	0.004*	15.71 (14.61– 15.73) b**c*	7.39 (6.56 – 13.55) a**	5.95 (5.95 – 15.70) a**	0.001**
	Intervention	15.72 (15.30 – 15.99)	15.72 (12.15– 19.22)	15.71 (10.36– 19.05)	0.871	15.72 (15.70– 15.72)	15.74 (15.70 – 18.13)	15.72 (15.70 – 16.28)	0.093
p-value between condition		0.636	0.001**	0.032*		0.411	0.001**	0.001**	
ICLT (Hz)	Control	15.71 (15.70 – 15.73)	15.71 (15.48– 15.79)	15.71 (15.48– 15.72)	0.895	15.71 (15.68– 15.72)	15.70 (15.68 – 15.72)	15.70 (15.68 – 15.72)	0.491
	Intervention	15.72 (15.70 – 15.72)	15.71 (15.69– 15.85)	15.71 (15.70– 15.72)	0.279	15.71 (15.30– 15.72)	15.70 (15.14 – 15.78)	15.71 (15.60 – 15.72)	0.653
p-value between condition		0.713	0.382	0.918		0.341	0.370	0.999	
LM (Hz)	Control	15.72 (15.70 – 19.94)	15.72 (15.70– 17.43)	15.72 (15.70– 15.72)	0.455	15.71 (15.71– 16.658)	15.71 (15.70– 15.73)	15.71 (15.70– 15.72)	0.215
	Intervention	15.72 (15.71 - 25.39)	15.73 (15.71– 26.51)	15.73 (15.71– 28.80)	0.639	15.72 (15.70– 15.87)	15.72 (15.70 – 23.83)	15.72 (15.70 – 22.98)	0.227
p-value between condition		0.428	0.344	0.045*		0.805	0.092	0.001**	

Note. Data presented as Median (interquartile range) of the MDF, *p*-value from the Wilcoxon signed-rank test, ** significant difference at $p < 0.001$, * significant difference at $p < 0.05$. a = significant difference from 0th-10th, b = significant difference from 15th-25th, c = significant difference from 28th-38th. Abbreviations: RA, rectus abdominis; TrA, transversus abdominis; IO, internal oblique; ICLT, iliocostalis lumborum pars thoracis; LM, lumbar multifidus. Abbreviations: RA, rectus abdominis; TrA, transversus abdominis; IO, internal oblique; ICLT, iliocostalis lumborum pars thoracis; LM, lumbar multifidus.

Table 4*Trunk muscle activity at each time of measurement between conditions*

Muscles	Conditions	Muscle activity (%sub-MVIC)					
		Right			Left		
		12th-13th minute	25th-26th minute	38th-39th minute	12th-13th minute	25th-26th minute	38th-39th minute
TrA&IO	Control	30.14 (17.83–46.44)	29.20 (17.13 – 53.71)	31.54 (17.58 – 67.44)	32.82 (17.81 – 51.14)	35.61 (21.04 – 56.48)	36.87 (22.86 – 64.36)
	Intervention	59.13 (31.28–92.47)	52.81 (28.07–88.39)	54.27 (30.84 – 89.31)	50.22 (34.41 – 88.83)	62.31 (32.57 – 88.39)	59.62 (33.42 – 89.52)
p-value		0.001**	0.001**	0.009*	0.001**	0.001**	0.004*

Note. Data presented as Median (interquartile range) of muscle activity, *p*-value from the Wilcoxon signed-rank test, ** significant difference at $p < 0.001$, * significant difference at $p < 0.05$. Abbreviations: TrA, transversus abdominis; IO, internal oblique.

Table 5*The differences in pain intensity each of the time between and within condition*

Conditions	Times				<i>p</i> -value within condition
	T _{sit}	T ₁	T ₂	T ₃	
Control	3.0 (2.0 – 5.0) b*c**d**	3.0 (3.0 – 5.0) a*c*d*	3.5 (3.0 – 6.0) a**b*	3.5 (3.0 – 6.0) a**b*	0.001**
Intervention	3.0 (2.0 – 4.3)	3.0 (2.0 – 4.0)	3.0 (2.0 – 4.0)	3.0 (2.0 – 4.0)	0.097
<i>p</i>-value between condition	0.475	0.003*	0.001**	0.001**	