Title
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Journal
Safety and Health at Work, 7(1)

ISSN
2093-7911

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Publication Date
2016-03-01

DOI
10.1016/j.shaw.2015.08.001

Peer reviewed

Safety and Health at Work 7 (2016) 49–54

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Internal Oblique and Transversus Abdominis Muscle Fatigue Induced by Slumped Sitting Posture after 1 Hour of Sitting in Office Workers

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A R T I C L E I N F O

Article history:
Received 9 April 2015
Received in revised form
10 August 2015
Accepted 11 August 2015
Available online 21 August 2015

Keywords:
electromyography
musculoskeletal disorder
pain

A B S T R A C T

Background: Prolonged sitting leads to low back discomfort and lumbopelvic muscle fatigue. This study examined the characteristics of body perceived discomfort and trunk muscle fatigue during 1 hour of sitting in three postures in office workers.

Methods: Thirty workers sat for 1 hour in one of three sitting postures (i.e., upright, slumped, and forward leaning postures). Body discomfort was assessed using the Body Perceived Discomfort scale at the beginning and after 1 hour of sitting. Electromyographic (EMG) signals were recorded from superficial lumbar multifidus, iliocostalis lumborum pars thoracis, internal oblique (IO)/transversus abdominis (TrA), and rectus abdominis muscles during 1 hour of sitting. The median frequency (MDF) of the EMG power spectrum was calculated.

Results: Regardless of the sitting posture, the Body Perceived Discomfort scores in the neck, shoulder, upper back, low back, and buttock significantly increased after 1 hour of sitting compared with baseline values ($t_{(9)} = -11.97$ to -2.69, $p < 0.05$). The MDF value of the EMG signal of rectus abdominis, iliocostalis lumborum pars thoracis, and multifidus muscles was unchanged over time in all three sitting postures. Only the right and left IO/TrA in the slumped sitting posture was significantly associated with decreased MDF over time ($p = 0.019$ to 0.041).

Conclusion: Prolonged sitting led to increased body discomfort in the neck, shoulder, upper back, low back, and buttock. No sign of trunk muscle fatigue was detected over 1 hour of sitting in the upright and forward leaning postures. Prolonged slumped sitting may relate to IO/TrA muscle fatigue, which may compromise the stability of the spine, making it susceptible to injury.

1. Introduction

Low back pain (LBP) is a major problem for office workers, affecting 34% to 51% of them annually [1,2]. Between 14% and 23% of office workers reported a new onset of LBP during the 1-year follow up [3,4]. The annual prevalence of chronic LBP has been reported to range from 15% to 45%, with a point prevalence of 30% [5]. LBP is often the cause of significant physical and psychological health impairments. It also affects work performance and social responsibilities. As a result, LBP can be a great burden on patients and the society at large [6]. Its total socioeconomic burden in the United States in 2006 exceeded US$100 billion [7], whereas in the Netherlands the total cost of LBP in 2007 was estimated at €3.5 billion [8].

Office work is sedentary work, which mainly involves computer use, participation in meetings, giving presentations, reading, and phoning. Thus, office workers are usually required to sit for long hours in front of a computer. Many individuals experience musculoskeletal discomforts particularly at the buttock and low back regions during prolonged sitting [9]. Evidence suggests that signs of body perceived discomfort, such as tension, soreness, or tremors, are predictors of LBP [10]. Increased discomfort from prolonged sitting has been partly attributed to muscle fatigue from sustained contraction of back muscles in seated postures [11]. Poor back muscle endurance was an independent predictor of LBP in a working population [12,13]. Occupational groups exposed to poor postures (lordosed or kyphosed, or slumped) while sitting have a considerably increased risk of experiencing LBP [14].

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2093-7911/$ – see front matter
http://dx.doi.org/10.1016/j.shaw.2015.08.001

Three sitting postures commonly used by office workers are upright, slumped, and forward leaning sitting postures. The local and global muscles of the lumbopelvic region can be preferentially facilitated in different sitting postures [15]. To date, no studies have investigated characteristics of trunk muscle fatigue, including rectus abdominis (RA), internal oblique/transversus abdominis (IO/TrA), iliocostalis par thoracis (ICL), and superficial lumbar multifidus muscle (MF), and the relationship between muscle fatigue and body perceived discomfort during 1 hour of sitting in these sitting postures. TrA and MF muscles represent a local system for counterbalancing compressive forces on the upper lumbar segment of the spine and to increase lumbar stability [16], and contraction of transversus abdominis was found to be significantly delayed in patients with LBP [17]. Paraspinal muscle fatigue also reduces the muscular support to the spine, causing impairment of motor coordination and control as well as increased mechanical stress to ligament and intervertebral disks [18,19]. Thus, the purpose of this study was to examine the characteristics of body perceived discomfort and trunk muscle fatigue during three common sitting postures for an hour in office workers. Such information would provide a clue on how prolonged sitting is associated with LBP, which can be useful to develop an effective intervention to prevent and reduce the occurrence of LBP in office workers.

2. Materials and methods

2.1. Participants

Thirty healthy office workers were recruited for the study. Individuals were included if their job involved office work, if they had at least 1 year experience in their current position, and if their work required them to sit for at least 2 hours on a working day. Exclusion criteria were neck and back pain in the preceding 12 months, current or past history of known spinal disorders, sign of neurological deficit (i.e., muscle weakness or loss/disturbance of sensation), osteoarthritis, rheumatoid arthritis, gout, kidney diseases, open wound or contusion at the buttocks and posterior thigh region, hemorrhoids, and pregnancy. Those with body mass index < 18.5 kg/m^2 or > 23 kg/m^2 or skin fold thickness in the abdominal and suprailiac area > 20 mm [to reduce electromyography (EMG) artifact due to interposed adipose tissue between the surface electrode and the target muscles] were also excluded [20]. All participants were given information about the study and were asked to sign a consent form prior to their participation. Their anthropometric values are listed in Table 1. This study was approved by the Projects Committee of the School of Health Sciences (Allied Health) at Nanyang Polytechnic, Singapore (SHS/2013/PG/AH-Bala).

Table 1
Characteristics of the study population ($N = 30$)

Characteristics	Mean (SD)			p
	Group 1 ($n = 10$)	Group 2 ($n = 10$)	Group 3 ($n = 10$)	
Age (y)	21.3 (1.1)	21.5 (1.7)	22.2 (1.5)	0.369
Sex (female)	7	8	8	
Height (cm)	168.3 (8.4)	164.9 (8.9)	161.4 (6.1)	0.174
Weight (kg)	59.8 (6.8)	56.3 (5.8)	52.7 (7.1)	0.071
Body mass index (kg/m^2)	21.1 (1.4)	20.7 (1.7)	20.2 (1.7)	0.422
Skin fold thickness (mm)				
Abdominal area	15.9 (2.3)	15.3 (4.8)	16.0 (4.4)	0.915
Suprailiac area	15.7 (2.8)	14.5 (3.8)	14.5 (4.0)	0.695

Group 1, upright sitting; Group 2, slumped sitting; Group 3, forward leaning sitting; SD, standard deviation.

2.2. Equipment

The Body Perceived Discomfort (BPD) scale, a measuring tool of postural discomfort, determined the participant's level of discomfort during prolonged sitting. The participant indicated the level of discomfort at the neck, shoulder, upper back, low back, hip/thigh, and knee based on a scale of 0–10 (where 0 denotes no discomfort and 10 denotes extreme discomfort) [21].

Surface EMG, which is a noninvasive muscle activity measurement method, was used to objectively assess muscle fatigue [22]. The EMG signal of trunk muscles, including, RA, IO/TrA, ICL, and MF, was recorded using the preamplified, bipolar integral dry reusable surface electrodes with an interelectrode distance of 20 mm (Type NOS SX230 EMG sensor; Biometrics Ltd., Newport, UK) and an electrical contact surface area of 1 cm^2. Prior to electrode placement, the skin was prepared to reduce skin impedance below 5 kΩ by cleaning the area with an alcohol swab. Electrodes were placed parallel to the stated muscles on both sides of the body as recommended by the European Recommendations for Surface Electromyography (SENIAM): RA (1 cm above the umbilicus and 2 cm lateral to midline); IO/TrA (1 cm medial to the anterior superior iliac spine); ICL (level of L1 spinous process, midway between the midline and lateral aspect of the participant's body); and MF (L5 level, 2 cm from the spinous process) [23–25]. The reference earth electrode was placed over the right iliac crest. All electrodes were anchored securely by double-sided tape to avoid excessive movement of the leads and to ensure that they remained in place throughout the session.

The EMG signal was recorded using the PS900 portable system (Biometrics Ltd.). The EMG signal was sampled at 1,000 Hz band pass-filtered between 20 and 450 Hz, and amplified (analog differential amplifier, common mode rejection ratio > 96 dB at 60 Hz, total gain 1,000); the data were stored in a personal computer for later analysis.

The EMG signals were processed and analyzed with Biometrics DataLog 8.0 software. The raw EMG signal was first visually checked for electrocardiac artifacts. The raw EMG signal was processed with the triangle-Bartlett method of fast Fourier transformation to determine the median frequency (MDF) value at a sample rate of 1,024 per second. Changes in the MDF of the EMG signal were taken as an indirect measure of muscle fatigue.

We retrieved every 10-minute block of EMG data from the 60-minute sitting period (at 0–10, 10–20, 20–30, 30–40, 40–50, and 50–60 minutes) for analysis.

2.3. Experimental procedure

The participants were asked to sit using one of three sitting positions for a period of 1 hour. The individual's baseline BPD score of six body regions (i.e., the neck, shoulder, upper back, low back, hip/thigh, and knee) were recorded. After the application of surface electrodes, the participants sat on a stool with their hips and knees at 90°, their feet positioned shoulder width apart, and their arms relaxed at the side of their body. Each participant was asked to sit for an hour, during which time the EMG signals of RA, IO/TrA, ICL, and MF were collected. After the completion of the 1-hour sitting period, the participant was asked to record the BPD score again.

Three common sitting postures were investigated in the present study: upright, slumped, and forward leaning sitting postures [26]. The sitting posture for each participant was randomly selected using a random number table. The measurement outcomes were BPD and trunk muscles MDF value during the sitting period. The upright sitting posture consisted of sitting with anterior rotation of the pelvis, thoracolumbar spine extended, and shoulder blades slightly retracted [15]. In the slumped sitting posture, the pelvis is in posterior rotation, with the thoracolumbar spine relaxed while the participants looks straight ahead [15]. With the forward leaning sitting posture, the pelvis is in anterior rotation, with the thoracolumbar spine extended and bent forward by more than 10° [19]. In the forward leaning sitting posture, the participants were asked to cross their arms to prevent them from using their arms to support their body weight (Fig. 1).

To control the alignment of sitting postures during the study, two adjustable alignment boards were developed and attached to the right side of a regular stool (size 30 × 45 × 45 cm; Fig. 2). Two infrared sensors (Infrared Analog Distance Sensor; GP2Y0A21YK0F; Sharp Ltd., Osaka, Japan) were inserted into the vertical board at T1 level and T10 level [27]. Once the participant deviated from the selected sitting posture, an auditory feedback signal from the sensors is heard, reminding them to return to the proper sitting posture.

2.4. Statistical analysis

Shapiro–Wilk test was performed to check the distribution of data. Characteristics of the study participants were described using means. Comparisons of participant characteristics among groups were conducted using one-way analysis of variance (ANOVA). The paired-sample *t* test compared the BPD scores prior to and after 1 hour of sitting in each sitting posture. One-way ANOVA determined the effect of time on the MDF of the EMG signal of trunk muscles. The least significant difference *post hoc* comparison was used to determine whether two selected means were significantly different from each other. All statistical analyses were performed using the SPSS statistical software, version 17.0 (SPSS Inc., Chicago, IL, USA). The level of significance was set at 0.05 for all statistical analyses.

3. Results

Regardless of sitting posture, the BPD scores in all body regions (i.e., neck, shoulder, upper back, low back, hip/thigh, and knee) after 1 hour of sitting were significantly greater than those at the beginning ($t_{(9)} = -11.97$ to -2.69, $p < 0.05$; Table 2).

One-way ANOVA indicated no significant effect of time ($F_{(5,45)} = 0.301$ to 2.193, $p > 0.05$) for RA, ICL, and MF MDF of the EMG signal in all sitting postures, except for both sides of IO/TrA in the slumped sitting ($F_{(5,45)} = 4.488$, $p = 0.002$ for the right side; $F_{(5,45)} = 3.822$, $p = 0.006$ for the left side; Fig. 3). The least significant difference *post hoc* comparison revealed that Rt. IO/TrA MDF of

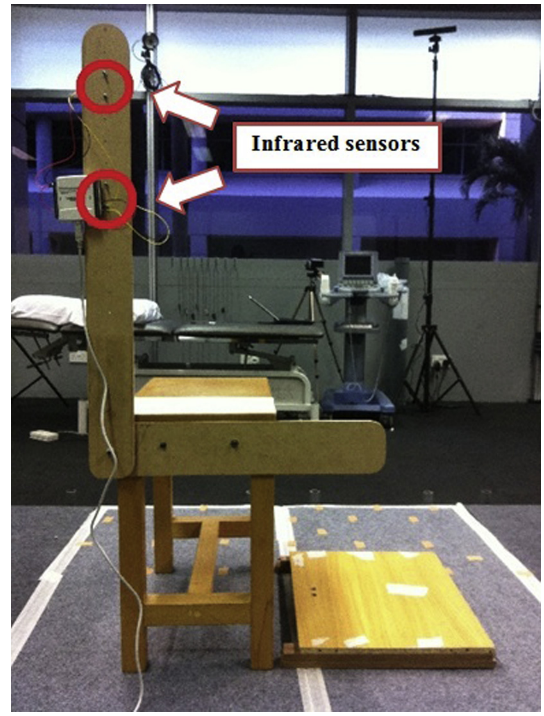

Fig. 2. The stool with infrared sensors.

the EMG signal in the slumped sitting posture at 0–10 minutes was significantly greater than that in slumped sitting posture at 10–20, 20–30, 30–40, 40–50, and 50–60 minutes ($p = 0.032$ to 0.041). Similar findings were also found for Lt. IO/TrA MDF of the EMG signal in the slumped sitting posture ($p = 0.019$ to 0.038).

4. Discussion

The results of this study revealed that 1 hour of sitting in upright, slumped, or forward leaning sitting postures led to increased discomfort at the neck, shoulder, upper back, low back, and buttock. No sign of trunk muscle fatigue was detected over 1 hour of sitting in the upright or forward leaning postures. However, the slumped sitting posture was associated with the right and left IO/TrA muscle fatigue after 1 hour of sitting. We also found that muscle

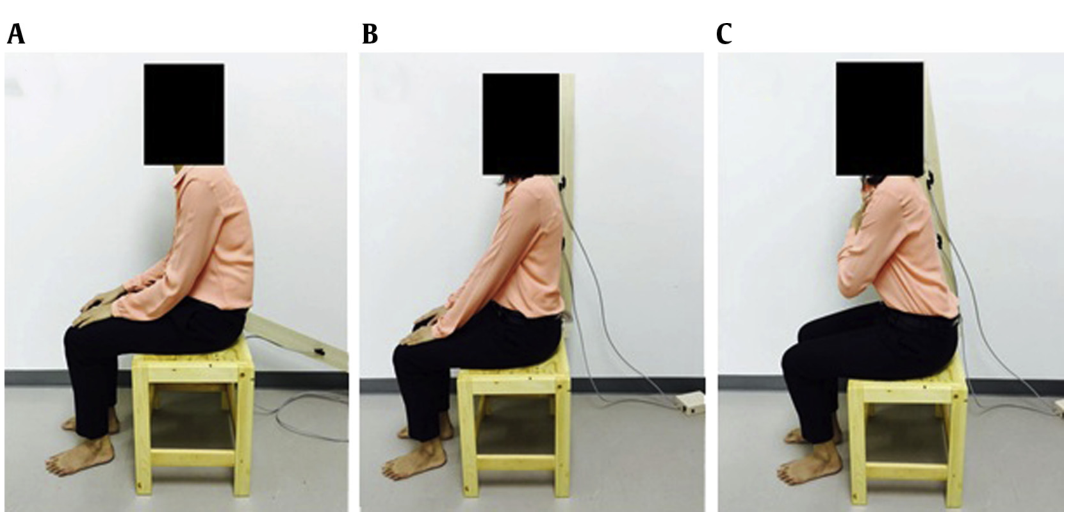

Fig. 1. Sitting postures. (A) Slumped sitting. (B) Upright sitting. (C) Forward leaning sitting.

Table 2
BPD scores at the beginning and after 1 hour of sitting in six body regions

Body region	Mean of BPD scores/10								
	Upright sitting			Slumped sitting			Forward leaning sitting		
	Before	After	t (p)	Before	After	t (p)	Before	After	t (p)
Neck	1.600	3.000	−2.69 (0.025*)	0.100	3.700	−4.39 (0.002*)	1.500	3.500	−2.93 (0.017*)
Right shoulder	0.700	3.600	−4.66 (0.001*)	0.300	2.300	−2.79 (0.021*)	1.600	3.600	−5.07 (0.001*)
Left shoulder	0.700	2.900	−3.24 (0.010*)	0.300	2.500	−3.09 (0.013*)	1.300	3.400	−3.71 (0.005*)
Upper back	0.500	4.100	−3.86 (0.004*)	0.700	3.500	−3.18 (0.011*)	1.400	3.400	−3.59 (0.006*)
Low back	1.400	5.100	−5.84 (0.000*)	0.100	2.400	−4.44 (0.002*)	0.700	7.200	−11.98 (0.000*)
Buttock	0.400	3.500	−4.04 (0.003*)	0.200	3.500	−3.74 (0.005*)	0.700	4.600	−6.66 (0.000*)

*$p < 0.05$.
BPD, Body Perceived Discomfort scale.

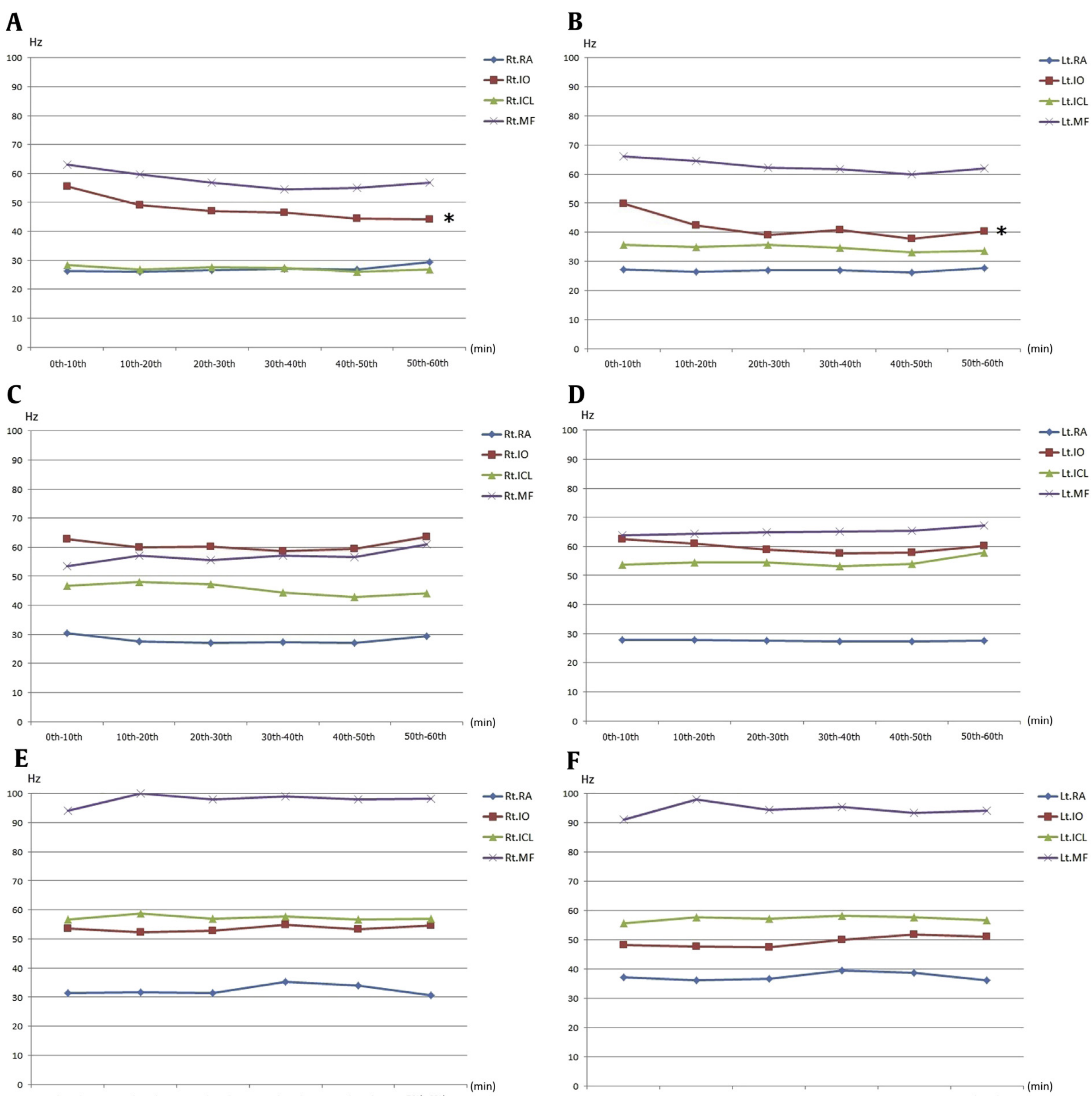

Fig. 3. Median frequency values of the electromyographic signal of rectus abdominis (RA), internal oblique (IO), iliocostalis lumborum pars thoracis (ICL), and superficial lumbar multifidus (MF) during 1 hour of sitting in various sitting postures. (A and B) Slumped sitting. (C and D) Upright sitting. (E and F) Forward leaning sitting. *$p < 0.05$.

fatigue occurred earlier during sitting (approximately 20 minutes after sitting) in the slumped posture compared to the other sitting postures.

The results of the present study are in line with the findings of previous studies showing that body perceived discomfort increased significantly during prolonged sitting [9]. Vergara and Page [28] reported that discomfort occurred mainly in the neck and low back during sustained sitting. Gregory et al [29] found that overall body discomfort was significantly higher after a 1-hour period of sitting. Perceived musculoskeletal discomfort is a predictor of LBP among healthy participants [10]. Our findings lend further support to the notion that prolonged sitting may lead to the development of LBP.

A previous study showed that crossed-leg sitting posture led to greater trunk muscle fatigue and discomfort than heel sitting posture during 30 minutes of sitting, and the findings were linked to the mechanical effects of the trunk leaning forward during the crossed-leg sitting posture and the trunk being upright in the heel sitting posture [30]. During slumped sitting, the MF is passively stretched resulting in the IO/TrA muscle increasing its cocontraction activity to balance back muscle forces. Consequently, IO/TrA muscle will fatigue over time. When the postural muscles become fatigued, the lumbopelvic region becomes dependent on its passive structures to maintain the position against gravity at the end range of spinal flexion [17]. The adverse effect of prolonged sitting in the slumped posture on the IO/TrA muscle may predispose the lumbar spine to injury, leading to the development of LBP.

Office workers are usually required to sit for long hours to perform their duty, and prolonged sitting seems to have an adverse effect on office workers' health, particularly at the low back. To date, there is still a lack of international consensus over the ideal sitting posture. The current study suggests that office workers should avoid sitting in the slumped posture for a prolonged time because it induces IO/TrA muscle fatigue. The TrA muscle is a local system for counterbalancing compressive forces on the upper lumbar segment of the spine and to increase lumbar stability [16]. Fatigue of the TrA muscle may predispose the lumbar spine to injury, leading to the development of LBP. Thus, prevention of LBP among office workers should at least include developing strategies or intervention to reduce time spent in the slumped sitting posture and to increase TrA muscle endurance.

This study has several methodological limitations that are noteworthy. First, the sitting postures tested in this study were controlled. Variations in how a person sits may exist and affect body perceived discomfort and trunk muscle activity. For example, in this study, participants were asked to cross their arms to prevent them from using their arms to support their body weight while sitting in the forward leaning sitting posture. Further research on the effect of arm support on body perceived discomfort and trunk muscle activity is recommended. Second, the present study only investigated body perceived discomfort and trunk muscle fatigue in young healthy participants. Change in body perceived discomfort and trunk muscle fatigue during various sitting postures for a prolonged time in those with LBP may not correspond to that of an asymptomatic population. Thus, extrapolation of these results to people with LBP should be made with caution. Further research is required to examine the effect of prolonged sitting posture on body perceived discomfort and trunk muscle fatigue in patients with LBP. Third, the effect of 1 hour of sitting in three different postures on body perceived discomfort and trunk muscle fatigue was investigated. The majority of muscle fiber types in trunk muscles are mainly type I fibers (slow oxidative), which are fatigue-resistant. Thus, an hour of sitting may not be sufficient time to induce muscle fatigue. Further research is required to examine the effect of prolonged sitting posture, greater than an hour, on body perceived discomfort and trunk muscle fatigue. Fourth, participants' body weight was quite different among groups, despite the fact that the sitting posture for each participant was randomly selected using a random number table. The degree to which body weight influences the outcomes of the present study (i.e., body perceived discomfort and trunk muscle fatigue) is unknown and is beyond the scope of this study. A future study should attempt to investigate the effect of body weight on body perceived discomfort and trunk muscle fatigue during 1 hour of sitting as well as the effect of body weight on sitting posture in office workers.

In summary, the current study examined the characteristics of body perceived discomfort and trunk muscle fatigue during 1 hour of sitting in three common postures in office workers (i.e., upright, slumped, and forward leaning). The results showed that sitting for 1 hour in all three sitting postures led to increased discomfort at all body parts. Although there were increased BPD scores in all body regions, there was no sign of muscle fatigue in MF, ICL, IO/TrA, and RA muscles over 1 hour of sitting in the upright or forward leaning postures. However, the slumped sitting posture was associated with the right and left IO/TrA muscle fatigue after 1 hour of sitting, and it occurred very early (i.e., approximately 20 minutes after sitting). Fatigue of the IO/TrA muscle may compromise the stability of the spine, leading to the occurrence of LBP in office workers.

Conflicts of interests

The authors declare that there are no conflicts of interest.

Authors' Contributions

The authors have contributed in the following ways: PW provided concept/research design, data collection, data analysis, and manuscript writing. BS and PJ provided concept/research design and manuscript writing. All authors read and approved the final version of the manuscript.

Acknowledgments

The author thanks Ms Wan Fang Yuan and Mr Watchara Sroykham for technical support during data collection. This study was funded by grants from the Institute of Asian Studies, Chulalongkorn University, the 90th Anniversary of Chulalongkorn University Fund (Ratchadaphiseksomphot Endowment Fund), and the School of Health Sciences (Allied Health), Nanyang Polytechnic.

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