ORIGINAL PAPER

Huining Pei[1]
Suihuai Yu[1]
Kari Babski-Reeves[2]
Jianjie Chu[1]
Min Qu[1]
Baozhen Tian[1]
Wenhua Li[1]

QUANTIFICATION OF LOWER EXTREMITY PHYSICAL EXPOSURES IN VARIOUS COMBINATIONS OF SIT/STAND TIME DURATION ASSOCIATED WITH SIT-STAND WORKSTATION

[1] Northwestern Polytechnical University, Xi'an, China
Shaanxi Engineering Laboratory for Industrial Design
[2] Mississippi State University, Mississippi, USA
Department of Industrial and Systems Engineering

Abstract

Background: Sit-stand workstations are available for office work purposes but there is a dearth of quantitative evidence to state benefits for lower limb outcomes while using them. And there are no guidelines on what constitutes appropriate sit/stand time duration. The primary aim of this study has been to compare muscle activity and perceived discomfort in the lower extremity during various combinations of sit/stand time duration associated with a sit-stand workstation separately and to evaluate the effects of the sit-stand workstation on the lower extremity during the text entry task. **Material and Methods:** During the 5 days, all participants completed a 2-h text entry task each day for various sit/stand time duration combinations as follows: 5/25 min, 10/20 min, 15/15 min, 20/10 min, 25/5 min. Lower extremity muscular exposure of 12 male and 13 female participants was collected at 8 sites by surface electromyography and body discomfort was calculated by a questionnaire under those 5 conditions. **Results:** Results have demonstrated that lower extremity muscle activity has been significantly varied among the 5 sit/stand time duration groups. Perceived level of discomfort (PLD) has not differed significantly for 9 out of 10 body parts. **Conclusions:** The muscle activity of the thigh region was influenced by sit/stand time duration significantly. Ergonomic exposures of lower extremity when using a sit-stand workstation were increased, particularly during the long time standing posture. Results indicate that body mass index (BMI) and gender were not significant factors in this study. Combination of sit/stand time duration 25/5 min appears to show positive effects on relief of muscle exposure of back of thigh in the shifts of sitting and standing work position. Med Pr 2017;68(3):315–327

Key words: electromyography, ergonomic intervention, perceived level of discomfort, root mean square, body mass index, gender differences

INTRODUCTION

It has been proven that office workers spend, on average, about 45% of the job doing computer-based tasks and work is becoming more sedentary [1]. Roughly 50% of the U.S. working population is employed in tasks requiring significant time spent sitting [2]. Prolonged sitting has been linked to a number of health issues [3]. Great deals of practices were introduced, according to this problem, to reduce unbroken sitting time to improve health not only by individuals [4] as well as several organizations [5,6]. As a result, a number of sit-stand workstations have been developed to promote changes

in working postures from seated to standing. The usage of sit-stand workstations seems to reduce the sitting time of office works at the workplace efficiently according to several studies [7,8], and may have positive effects on workers' health.

However, long-term standing posture has been shown to be associated with many health risks and occupational disease, mainly focusing on lower extremity as well, such as lower extremity discomfort, fatigue, swelling and venous blood pooling [9]. Halim et al. [10] claimed that 4 h and 45 min of standing work (with a morning break of 15 min and a lunch break of 90 min) was contributed to leg muscle fatigue among the production workers.

Subjective discomfort in the lower extremity, such as pain in the lower leg and calf muscles, was investigated during prolonged standing and sitting [11]. Moreover, the study found that prolonged standing work during 2 h caused oedema formation in the feet [12]. Comparison of the perceived discomfort of level for lower extremity in sitting, standing, and sit/standing posture was established by Chester et al. [13], but there is a lack of objective data to measure physical exposure associated with sit-stand stations (e.g., electromyography (EMG) data).

In addition, EMG is one of the reliable approaches that is used for quantifying muscle fatigue levels and physical exposure [14–16]. The musculoskeletal load was measured by several researchers associated with EMG for analyzing muscular response of upper limb [15–17], and for studying the muscle activities of lower limb [18,19].

Some studies were associated with sit/stand posture in an ergonomic perspective mainly focused on the physical load of low back, shoulder and upper extremity [8,20,21]. Few, if any, studies proved data or evidence of quantification of lower extremity exposures. Moreover, previous studies lacked precision in the estimated ratio of sit and stand time period to reduce fatigue and exposure of lower extremity. To fill these gaps, this research quantitatively evaluated the influences of sit/stand time duration on muscular activation and perceived level of discomfort with the focus on lower extremity. Another objective of the study has been to examine various combinations of sit/stand time durations and related impact on musculoskeletal responses and user perceptions to help guide recommendations for sit-stand workstation usage.

MATERIAL AND METHODS

Participants
Twenty-five participants, including 12 males and 13 females, participated in the study (Table 1). Participants were required to perform keyboard-typing and potential subjects had to have a typing speed of 50 words/min measured in a 3 min standard typing test. None of the participants had ever worked as a professional typist, but all worked with a computer regularly. Sixty percent of the participants could type blindly. All participants were free of pain, numbness or tingling in the arms, neck, back and legs.

Experimental design
A repeated-measure design was used for testing the main effects of muscle activity (i.e., EMG measures) and perceived level of discomfort (PLD) in varied time durations by using a sit-stand workstation. Participants were asked to complete a typing task for 2 h during each of 5 days, and the 5 experimental days were separated by minimum 48 h in order to diminish the influence of muscle fatigue caused by previous trials. There were five 30-min sit/stand combinations with 4 repetitive cycles: 5/25 min, 10/20 min, 15/15 min, 20/10 min, and 25/5 min. Exposure to these combinations was controlled using a balanced Latin square design [22].
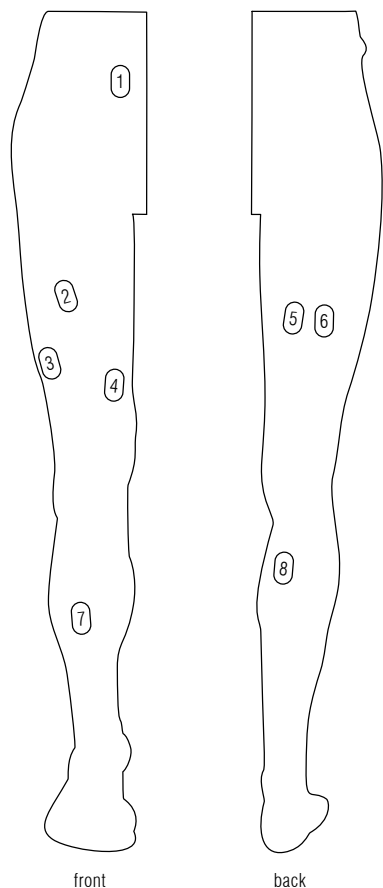
Independent variables
Independent variables for this study included sit/stand time duration combinations (5 levels), muscle (8 levels), body part (10 levels), body mass index (BMI) (2 levels) and gender (2 levels). Combinations of sit/stand time duration are described under the experimental task section and included: 5/25 min (C1), 10/20 min (C2), 15/15 min (C3), 20/10 min (C4), and 25/5 min (C5). These combinations were estimated based on discussions of the acutal sit/stand time durations during the task of text entry. The electrodes were sited on the following muscles of the dominant extremity mainly focusing on lower body (Figure 1): *rectus abdominis* (RA), *rectus femoris* (RF), *vastus lateralis* (VL), *vastus medialis* (VM), *semitendinosus* (ST), *biceps femoris* (BF),

Table 1. Morphological data of respondents in the study of muscle activity and perceived discomfort in the lower extremity during various combinations of sit/stand time duration at a workstation

Characteristics	Respondents (M±SD)	
	females (N = 13)	males (N = 12)
Age [years]	20.8±2.2	22.9±4.8
Height [cm]	164.1±7.1	175.9±5.7
Mass [kg]	69.5±12.7	68.3±11.4
Body mass index (BMI) [kg/m^2]	26.0±5.9	22.0±3.1

M – mean, SD – standard deviation.

trodes were attached using standard preparation and placement procedures [23]. Myosystem 1400A (Noraxon, USA) was used for recording the measurements and processing the EMG signals amplified, band-pass filtered (10–500 Hz), acquired at a sampling frequency of 1 kHz. Following a 15-min stabilization period, impedance was measured to ensure that it was below 10 kΩ (otherwise, the electrode site was re-prepared and electrodes reattached). Since EMG data was investigated across 5 different days, electrode locations were marked using a permanent marker pen to make sure that the electrode locations were relocated in the same area.

Resting EMG and sub-maximal voluntary contractions (SMVCs) were performed and recorded to normalize the EMG signal. Resting EMG signals were sampled at 5 Hz for 5 s and recorded with the participant standing in a relaxed posture [24]. A 5 s ramp-up and ramp-down procedure was used for collecting the SMVCs. The ramp-up and ramp-down procedure had required subjects to steadily increase the abduction force in certain reference positions over a 2 s verbal count up to their sub-maximum voluntary force, then the abduction force had been sustained at this force for about 1 s before it was gradually reduced over a 2 s count back to loosen muscle. For RA, the participant lay on the floor with arms resting at body side and legs lifted up at 30° [25]. For RF, VL, VM and TA the participant was half-squatting on the ground with arms and legs bending at 90° [26]. For ST and BF, the participant was touching a wall with hands at dominant leg flexing backwards at 10°. For GC, the participant was standing straight on the ground with toes raising at 60° [27]. A minimum of 3 SMVCs will be collected for each muscle. If the final SMVC measures result in the peak muscle activation recorded, additional SMVCs will be collected until maximum is not observed. And the peak value recorded for each muscle was used for normalization purposes.

Perceived level of discomfort

Perceived level of discomfort was assessed using a modified Borg's perceived level of exertion scale [28], the scores of which are presented in the Table 2. Participants were asked to verbally provide the score of PLD for the parts of abdomen (ABD), hips (HIP), left front of thigh (LFT), left back of thigh (LBT), right front of thigh (RFT), right back of thigh (RBT), left front of calf (LFC), left back of calf (LBC), right front of calf (RFC), right back of calf (RBC) before and after every testing.

1 – *rectus abdominus*, 2 – *rectus femoris*, 3 – *vastus lateralis*,
4 – *vastus medialis*, 5 – *semitendinosus*, 6 – *biceps femoris*,
7 – *tibialis anterior*, 8 – *gastrocnemius*.

Fig. 1. Position of the electrodes on the respondent's body

tibialis anterior (TA) and *gastrocnemius* (GC). Moreover, BMI was calculated by the formula body mass/height^2 and was taken into account to investigate the variation of EMG data and PLD values. According to the World Health Organization's (WHO) recommendations, BMI was categorized as underweight (< 18.5 kg/m^2), normal (18.5–24.99 kg/m^2), and overweight (25–29.99 kg/m^2). Given only one underweight participant, the underweight and normal categories were combined.

Dependent variables

The dependent variables were muscle activation, and perceived level of discomfort (PLD).

Electromyography measurements

Surface EMG was quantified for the lower abdomen and lower limb muscles of the dominant side. Rectangular Ag/AgCl pre-gelled bipolar disposable elec-

Table 2. Perceived level of discomfort (PLD) scale [28]

| Scale [pts]	Description
0	not noticeable discomfort
0.5	very, very light discomfort (just noticeable)
1	very light discomfort
2	light discomfort
3	moderate discomfort
4	somewhat high discomfort
5–6	high discomfort
7–9	very high discomfort
10	very, very high discomfort

Experimental task

The experimental task consisted of 5-day task simulations by using a sit-stand workstation, which is an articulated arm that attaches to the back or side of a regular desk/a stand that attaches to the front of a regular desk that raises or lowers by pulling the handle in the front (manual adjustment) and has a work surface to place a keyboard, mouse and/or docking station, typing text according a specific book in scanned version (Photo 1). The five testing sessions (for each of the sit/stand time duration combinations) lasting 2 h [29] and separated by a minimum of 48 h and five 30-min sit/stand combinations were studied. All test sessions were completed at approximately the same time of a day. Participants were equipped with data collection equipment, which allowed to practice using the sit-stand workstation, complete baseline data collection procedures.

Procedures

Participants received a written and verbal description of the study and its objectives, and completed informed consent documents approved by the Mississippi State University's Institutional Review Board (IRB) prior to data collection. Participants also completed a demographic questionnaire for determining participant eligibility. Data collection equipment was attached, participants rested for 10 min. Impedance was assessed, and SMVC trials were completed. Prior to commencement of the tasks, participants were briefed about the tasks and completed a 1-min familiarization session on the use of the sit-stand workstation. The familiarization period was followed by a 5-min rest period and the test session. All participants completed a single 2-h test session and finished with the completion
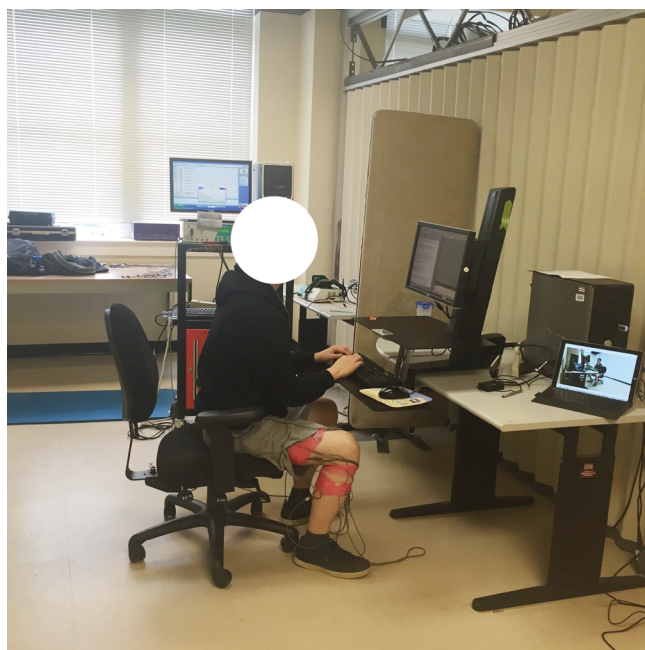
Photo 1. Text entry task at a) sit and b) stand workstation

of a questionnaire of perceived level of discomfort. At the end of the session, participants were monetarily compensated.

Data analysis

Descriptive statistics were evaluated for each dependent variable. The experimental data showed that the PLD values satisfied the homogeneity of variance

Table 3. Descriptive statistics for the dependent variables by combinations of sit/stand time duration at a workstation

Dependent variable	Sit/stand time duration				
	5/25 min (C1)	10/20 min (C2)	15/15 min (C3)	20/10 min (C4)	25/5 min (C5)
Electromyography [Hz] (M±SD)					
rectus abdominus (RA)	1.93±0.72	1.97±0.70	2.15±0.89	2.21±1.24	2.25±0.88
rectus femoris (RF)	1.66±0.42	1.68±0.58	1.81±0.64	1.53±0.46	1.46±0.22
vastus lateralis (VL)	1.66±0.55	1.53±0.50	1.99±0.12	1.49±0.36	1.42±0.30
vastus medialis (VM)	1.34±0.30	1.44±0.45	1.71±0.64	1.36±0.31	1.29±0.24
semitendinosus (ST)	1.90±0.57	1.98±0.61	2.34±1.30	1.66±0.24	1.46±0.21
biceps femoris (BF)	2.19±0.71	2.26±0.85	2.15±0.82	1.73±0.51	1.49±0.25
tibialis anterior (TA)	3.06±1.26	2.51±1.30	2.80±1.49	3.04±1.64	2.38±1.29
gastrocnemius (GC)	2.27±1.21	2.39±1.96	2.59±2.04	2.20±1.95	1.79±1.01
Perceived level of discomfort [pts] (M±SD)					
abdomen (ABD)	0.72±1.20	0.48±1.12	0.64±1.35	0.24±.59	0.48±1.29
hips (HIP)	1.36±1.89	1.00±1.60	1.04±1.92	0.76±1.53	0.64±1.72
left front of thigh (LFT)	1.76±2.06	1.04±1.54	0.92±1.63	0.60±1.22	0.56±1.38
left back of thigh (LBT)	1.44±1.89	1.44±2.10	1.48±1.80	0.88±1.71	0.76±1.36
right front of thigh (RFT)	1.92±2.13	1.40±1.73	1.36±1.91	0.80±1.19	0.80±1.63
right back of thigh (RBT)	1.52±1.96	1.56±1.98	1.64±1.72	0.84±1.70	0.80±1.32
left front of calf (LFC)	1.80±2.12	1.72±2.18	1.20±1.93	0.80±1.78	0.64±1.25
left back of calf (LBC)	2.72±2.45	2.44±2.43	2.40±2.67	1.52±2.14	0.72±1.45
right front of calf (RFC)	1.84±2.03	1.96±2.31	1.40±1.97	0.88±1.74	0.84±1.43
right back of calf (RBC)	2.40±2.44	2.64±2.46	2.56±2.58	1.84±2.11	0.88±1.64

Abbreviations as in Table 3.

assumption and the normality assumption of the one-way analyses of variance (ANOVAs), but the muscle activities values did not. Nonparametric tests were employed to analyze the mean EMG.

The 1-way analysis of variance (ANOVAs) was carried out to test for effects of sit/stand time duration combinations, BMI and gender on the PLD values for 10 body parts. Tukey tests were used in *post hoc* comparisons where appropriate.

Kruskal-Wallis 1-way analysis of variance was utilized to determine significant differences for the 8 muscles' mean EMG in the various combinations of sit/stand time duration. The differences in changes in muscle activities among 5 sit/stand time duration groups were compared with Wilcoxon's rank sum test (Mann-Whitney U test). Line plot has been calculated as well as the mean of PLD for lower extremity across different groups was tested.

Spearman's correction was used for explaining the repeatability of each dependent variable. The analysis was completed using SPSS (IBM SPSS Statistics, v. 20) and all results were considered significant at α level of 0.05.

RESULTS

Electromyography data
Descriptive statistics for the dependent variables were presented in the Table 3. Sit/stand time durations C5 required less muscle activity than any other combinations of sit/stand time durations and the mean EMG value of TA and GC was relatively higher than any other 6 muscles.

The ANOVA results showed that the mean EMG was affected by combinations of sit/stand time durations (Table 4) and ST and BF muscle activity differed significantly ($r = 17.974$, $p = 0.01$; $r = 16.368$, $p = 0.03$). The Table 5 showed that, in general, significant differences for the muscle activation of ST and BF were found across the sit/stand time durations C5, among others

Table 4. One-way ANOVA between the dependent variables across combinations of sit/stand time duration at a workstation

Variable	Nonparametric one-way ANOVA Kruskal-Wallis		Parametric one-way ANOVA	
	Chi^2	asymptotic significance	F	significance
Electromyography (M)				
rectus abdominus (RA)	1.234	0.873		
rectus femoris (RF)	3.401	0.493		
vastus lateralis (VL)	4.273	0.370		
vastus medialis (VM)	8.642	0.071		
semitendinosus (ST)	17.974	**0.001**		
biceps femoris (BF)	16.368	**0.003**		
tibialis anterior (TA)	5.895	0.207		
gastrocnemius (GC)	6.882	0.142		
Perceived level of discomfort				
abdomen (ABD)			0.645	0.632
hips (HIP)			0.638	0.637
left front of thigh (LFT)			2.299	0.063
left back of thigh (LBT)			0.952	0.437
right front of thigh (RFT)			1.812	0.131
right back of thigh (RBT)			1.399	0.238
left front of calf (LFC)			1.931	0.110
left back of calf (LBC)			3.303	**0.013**
right front of calf (RFC)			1.840	0.126
right back of calf (RBC)			2.584	**0.040**

M – mean.
Bolded values indicate significant differences ($p < 0.05$).

for ST – C1 vs. C5 ($p = 0.006$), C2 vs. C5 ($p = 0.002$), C3 vs. C5 ($p = 0.002$), C4 vs. C5 ($p = 0.003$); for BF – C1 vs. C5 ($p = 0.000$), C2 vs. C5 ($p = 0.012$), C3 vs. C5 ($p = 0.002$).

In addition, the muscle activation of VM also differed significantly for 3 group comparisons: C1 vs. C3 ($p = 0.044$), C3 vs. C4 ($p = 0.036$), C3 vs. C5 ($p = 0.036$).

Mann-Whitney U test was utilized to determine effects of BMI and gender on EMG values. No significant differences ($p > 0.05$ for all of 8 muscles) for muscle activation among BMI groups (normal vs. overweight) were identified.

Likewise, there was no significant difference for muscle activation between genders. Among them, EMG of overweight subjects ranked higher than in the case of standard subjects (mean rank, overweight vs. normal): RF (8.50 vs. 7.67), VL (8.67 vs. 7.00), VM (8.83 vs. 7.44), ST (9.17 vs. 7.22), BF (8.00 vs. 8.00), TA (8.56 vs. 7.17), and GC (9.17 vs. 7.22).

Perceived level of discomfort

The Table 4 showed that the perceived level of discomfort values of LBC and RBC different significantly ($r = 3.303$, $p = 0.13$; $r = 2.584$, $p = 0.40$). The results of Tukey in terms of HSD (honestly significant difference) presented that significant difference for the discomfort ratings of LBC was found across C1 between C5 ($p = 0.19$) and no significant difference was found among the other 6 groups (Figure 2, Table 5). Moreover, in general, the mean PLD values of C5 was significantly lower than any other combinations (Table 3, Figure 3).

No statistically significant differences for PLD values between standard subjects and overweight subjects ($p > 0.05$) and between male subjects and female subjects ($p > 0.05$) were identified. In general, female subjects had higher discomfort rating than male on the region of calf and back thigh: LBT (female: 1.50±2.00, male: 1.31±1.43), RBT (female: 1.50±2.07, male: 1.46± 1.51), LFC (female: 1.83±2.62, male: 1.46±2.025), RFC

Table 5. Group comparison between the dependent variables across combinations of sit/stand time duration at a workstation

Test and variable	Group comparison									
	C1 vs. C2	C1 vs. C3	C1 vs. C4	C1 vs. C5	C2 vs. C3	C2 vs. C4	C2 vs. C5	C3 vs. C4	C3 vs. C5	C4 vs. C5
Nonparametric *post hoc* test: Mann-Whitney U test (asymptotic significance) (M)										
rectus abdominus (RA)	0.548	0.221	0.756	0.443	0.694	0.820	0.633	0.724	0.950	0.740
rectus femoris (RF)	0.983	0.694	0.468	0.520	0.372	0.575	0.443	0.101	0.078	0.836
vastus lateralis (VL)	0.443	0.885	0.443	0.191	0.191	0.787	0.443	0.330	0.071	0.281
vastus medialis (VM)	0.520	**0.044**	0.950	0.756	0.071	0.419	0.290	**0.036**	**0.007**	0.901
semitendinosus (ST)	0.494	0.468	0.165	**0.006**	0.820	0.054	**0.002**	**0.036**	**0.002**	**0.003**
biceps femoris (BF)	0.820	0.494	**0.049**	**0.000**	0.787	0.059	**0.012**	0.141	**0.002**	0.198
tibialis anterior (TA)	0.120	0.330	0.575	0.059	0.351	0.191	0.787	0.520	0.178	0.115
gastrocnemius (GC)	0.633	0.950	0.130	0.059	0.520	0.468	0.141	0.078	**0.033**	0.740
Parametric *post hoc* test: Tukey HSD (significance)										
abdomen (ABD)	0.947	0.999	0.578	0.947	0.988	0.947	1.000	0.732	0.988	0.947
hips (HIP)	0.949	0.967	0.742	0.591	1.000	0.988	0.949	0.979	0.927	0.999
left front of thigh (LFT)	0.503	0.344	0.082	0.066	0.999	0.866	0.825	0.954	0.931	1.000
left back of thigh (LBT)	1.000	1.000	0.804	0.666	1.000	0.804	0.666	0.761	0.616	0.999
right front of thigh (RFT)	0.831	0.790	0.165	0.165	1.000	0.744	0.744	0.790	0.790	1.000
right back of thigh (RBT)	1.000	0.999	0.648	0.596	1.000	0.596	0.544	0.493	0.443	1.000
left front of calf (LFC)	1.000	0.793	0.337	0.196	0.866	0.423	0.261	0.944	0.831	0.998
left back of calf (LBC)	0.992	0.987	0.341	**0.019**	1.000	0.609	0.064	0.649	0.075	0.726
right front of calf (RFC)	0.999	0.928	0.399	0.357	0.842	0.280	0.245	0.874	0.842	1.000
right back of calf (RBC)	0.996	0.999	0.907	0.133	1.000	0.727	0.055	0.797	0.075	0.570

M – mean, HSD – honestly significant difference.
C1–C5 represent different groups of sit/stand time duration combination: C1 – 5/25 min, C2 – 10/20 min, C3 – 15/15 min, C4 – 20/10 min, C5 – 25/5 min.
Bolded values indicate significant differences (p < 0.05).
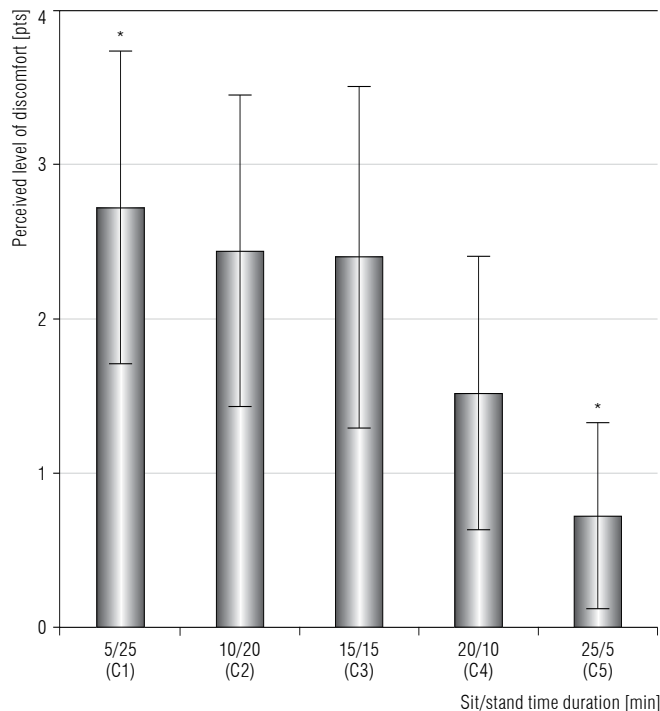
Abbreviations as in Table 3.
* Significant difference.

Fig. 2. Mean perceived level of discomfort (PLD) for left back of calf (LBC) across combinations of sit/stand time duration at a workstation
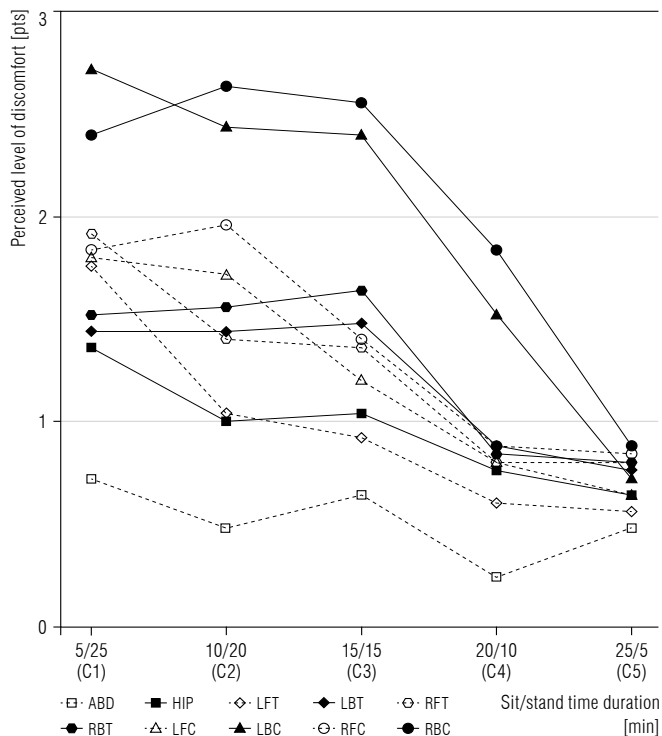

Abbreviations as in Table 3.

Fig. 3. Mean perceived level of discomfort (PLD) across combinations of sit/stand time duration at a workstation by body part

(female: 2.17±2.66, male: 1.69±1.75), RBC (female: 2.17±2.66, male: 1.69±1.75).

Repeatability

Linear correlations were computed to assess repeatability across combinations of sit/stand time duration (Table 6). All nonparametric correlations had Spearman's rho above –0.148 except for the mean EMG of ST, BF, GC (Figure 4), which had correlation coefficient of –0.389, –0.445, –0.252, respectively. Apart from the mean of RFT, RBT values, Pearson's correlations were above –0.159, indicating a weak correlation between sit/stand time durations. Out of the correlations, 78% were weak (p > 0.05), 16% were moderate (0.05 ≤ p < 0.01) and 6% were strong (p ≤ 0.01).
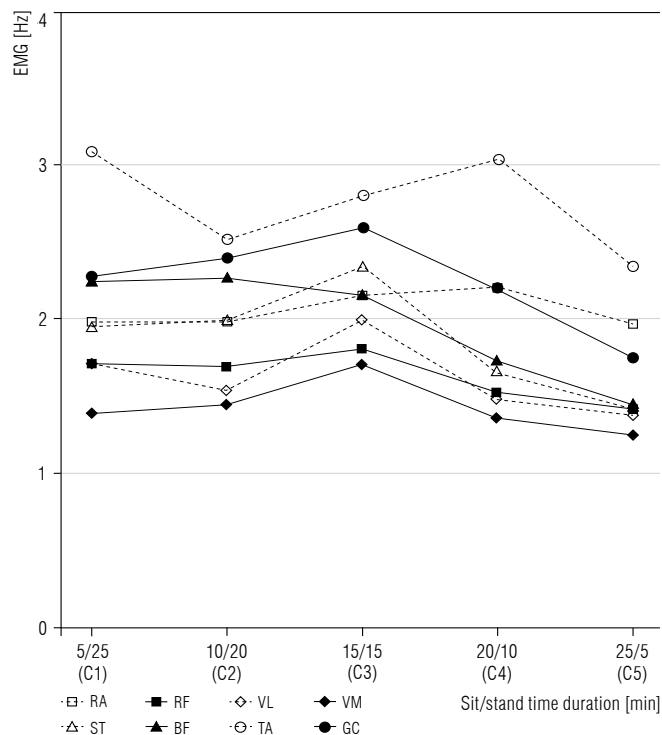
DISCUSSION

Utilizing sit-stand workstations is one of the interventions that has been proven having positive impact on the health of office workers. Most of the pervious research mainly focused on the muscle exposures of upper limb, shoulder, neck and lower back using sit-stand workstations. However, few studies examined the physi-

Abbreviations as in Table 3.

Fig. 4. Mean electromyography (EMG) across combinations of sit/stand time duration at a workstation

Table 6. Spearman's correlation coefficients for the variables across combinations of sit/stand time duration at a workstation

Variable	Nonparametric correlations: Spearman's		Parametric correlations: Pearson's	
	rho	significance	R	significance
Electromyography (M)				
rectus abdominus (RA)	0.096	0.205		
rectus femoris (RF)	−0.120	0.153		
vastus lateralis (VL)	−0.148	0.102		
vastus medialis (VM)	−0.078	0.254		
semitendinosus (ST)	−0.389**	0.000		
biceps femoris (BF)	−0.445**	0.000		
tibialis anterior (TA)	−0.143	0.110		
gastrocnemius (GC)	−0.252*	0.014		
Perceived level of discomfort				
abdomen (ABD)			0.138	0.237
hips (HIP)			−0.159	0.172
left front of thigh (LFT)			−0.108	0.357
left back of thigh (LBT)			−0.059	0.617
right front of thigh (RFT)			−0.230*	0.047
right back of thigh (RBT)			−0.385**	0.001
left front of calf (LFC)			−0.085	0.470
left back of calf (LBC)			−0.098	0.405
right front of calf (RFC)			0.138	0.237
right back of calf (RBC)			−0.159	0.172

M – mean, rho – Spearman's rank correlation coefficient.
** Significant at 0.01 level.
* Significant at 0.05 level.

cal load of lower extremity while using the sit-stand office workstation. Besides, many health problems of lower extremity for standing work posture were reported as well. Thus, this study investigated the impact of the 5 different combinations of sit/stand time durations on lower extremity muscle activity and perceived level of discomfort while using a sit-stand workstation.

This study demonstrated the lower leg muscles (TA, GC) activities at a high rate in the standing posture, which was consistent with the finding of Balasubramanian et al. [30] (Figure 4). In addition, the Figure 3 presented a low level of perceived discomfort for C5 and the mean PLD value increased with the longer standing time. Muscle fatigue was regarded as a factor in the development of body health issues, such as muscle pain, joint disorder and soft tissue injuries [31–33] and Lin et al. [34] claimed that leg movement influenced perceived discomfort of the shank significantly. Thus, this analysis agreed with the previous research that lower limb muscular discomfort existed while standing [35] and standing was less comfortable as compared with sitting [13]. Moreover, the Table 4 reported that the mean values of LBC and RBC (the segment region of calf) differed significantly across the combinations of sit/stand time duration, these results being consistent with the opinion of Chester et al. [13]. But no significant muscle exposure differences were found among these segment regions. The lack of correlation between EMG and perceived discomfort was possibly a consequence of the poor measurement repeatability [36].

According to the Table 4, this study showed that the mean EMG of *semitendinosus* (ST) and *biceps femoris* (BF) was affected by combinations of sit/stand time duration significantly. According to Gray [37], those two muscles belong to the thigh of lower extremity segment region, therefore, the muscle exposure of the back of thigh is noticeably influenced by sit/stand time duration. However, no significant perceived discomfort differences were found among these segment regions.

Further data analysis of group comparison between the combinations of sit/stand time duration illustrated that significant differences for the muscle activation of ST and BF were found among C5 and the other 4 sit/stand time duration groups (Table 5). Besides, the Table 3 and Figure 2 showed that there was lower muscular activation on all eight muscles and lower mean perceived discomfort value on all ten body parts under the condition of C5. Increasing RMS value with an advancing fatigue was reported [38]. And pervious research proved that higher muscle activity levels may have been due to localized muscle fatigue and more physical exposure [39].

Therefore, this study identifies that combinations of sit/stand time duration 25/5 min (C5) result in less lower extremity muscle exposure, especially for the thigh of lower extremity region with significant difference in ST and BF and most of group comparisons among C5 and others (Table 4, Table 5) while using sit-stand workstation to perform 2 h text entry task. The Figure 4 showed that C5 resulted in lower PLD values although no significant difference was found for most of body parts. It is worth noting that the combinations of sit/stand time duration 30/0 min and 0/30 min were not taken into account because those conditions meant prolonged sitting and prolonged standing, respectively, and could not estimate the relationship of the shifts of sit-stand position. In addition, the muscle activation of VM also differed significantly for 3 group comparisons (Table 5). This result illustrated that the muscle exposure of the front of thigh was influenced by sit/stand time duration significantly.

In this study, although mean EMG of overweight subjects was ranked higher than for standard subjects, there was no significant effect of BMI on muscle activation using sit-stand workstation over 2-h typing tasks. To the best of our knowledge, fewer studies reported the relationship between BMI and EMG signal variations. Indeed, BMI was associated with increased prevalence of work-related musculoskeletal disorders (WMSDs) and increased scores of musculoskeletal discomfort [40,41]. It may be necessary to investigate the longer term effects of BMI on muscle activation in future work since BMI influences chronic musculoskeletal pain/discomfort in a roundabout way [42].

No significant gender difference was found, and results from males and females were pooled for this study. Likewise, gender did not result in any significant discrimination in explaining discomfort responses during 2-h sitting on vehicle seats and in reporting [43]

and in reporting EMG activities of upper extremity during 1-h computer work [44]. However, it should be noted that higher discomfort rating was found among female subjects. In this sense, it seems that female computer users are more often exposed to physical risk factors as compared with males [45,46].

Woods and Babski-Reeves [47] reported that there was no prior research that had addressed repeatability of data entry regarding physical load variables because it was difficult to locate electrodes to identify the related placement across test sessions and participants. This result matches with this research with 78% weak correlation (p > 0.05) for EMG and PLD data across five combinations of sit/stand time duration (Table 6).

There are several limitations of this study that should be presented. First of all, only muscular activation of the lower extremity was examined. Additional consideration to muscular activation of hip and buttock would be taken to investigate that how sit/stand time duration affects the lower body as a whole. Furthermore, the small sample size may limit the generalization of results, and the trial needs to be repeated using a larger sample consequently. Finally, the data of posture shift or the change of joint angle were not collected. There are several studies showing that the change of posture or joint angle is effective data to analyze the physical exposure and use electrogoniometers or kinect camera to quantify the load of physical body parts [48,49].

CONCLUSIONS

This study has sought to identify the lower extremity exposures in various combinations of sit/stand time durations associated with a sit-stand workstation. Ergonomic exposures of lower extremity when using a sit-stand workstation were increased, particularly during the long time standing posture. The muscle activity of the thigh region was influenced by sit/stand time duration significantly. The objective and subjective measure showed inconsistent results. The lack of correlation between subjective and objective estimation was possibly due to the poor measurement repeatability. Significant physiological (muscle activity) differences were found among C5 and the other 4 combinations of sit/stand duration, especially for the muscle of *semitendinosus* (ST), *biceps femoris* (BF), by using a sit-stand workstation. Thereby, combination of sit/stand time duration 25/5 min appears to show positive effects on relief of muscle exposure of back of thigh in the shifts of sitting and standing work position. More-

over, BMI and gender were not significant factors in this study. Future studies should include other sit/stand time durations and longer period (such as a whole workday period) should be tested to determine the effects of sit/stand time durations on physical exposures.

ACKNOWLEDGMENTS

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