Effects of Adjustable Sit-stand VDT Workstations on Workers' Musculoskeletal Discomfort, Alertness and Performance^a

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Abstract: Adjustable sit-stand workstations, which are designed to allow workers to sit and stand autonomously while working, were examined to identify the effects on workers' musculoskeletal discomfort, alertness and performance. Twenty-four healthy subjects participated in the study. The subjects were required to do an English transcription task for 150 min under the following conditions: 1) sitting at standard workstations (Standard), 2) sitting on a chair with the work surface elevated to standing position (High-chair) and 3) a combination of 10-min sitting and 5-min standing with the same setting as that in the high-chair condition (Sit-stand). The subjective musculoskeletal discomfort scores indicated that High-chair and Sit-stand resulted in relatively higher discomfort levels than the Standard condition. Although the ratio between low-frequency (0.04–0.15 Hz) and high-frequency (0.15–0.4 Hz) components of heart rate variability (LF/HF ratio) in Sit-stand was higher than that in other conditions, there were no significant differences in subjective sleepiness among the three conditions. As for work performance, there was a tendency to be steadily high under the Sit-stand condition compared with other conditions, but not a significant difference. This study revealed that although the use of sit-stand workstations can contribute to keeping workers' arousal level steady, it has an adverse effect in light of musculoskeletal discomfort.

Key words: Sit-stand worktable, Ergonomics, VDT, Local muscular workloads, Work-related musculoskeletal disorders, Musculoskeletal discomfort, Work performance, Arousal level, LF/HF

Introduction

Prevention of work-related musculoskeletal disorders (WMSDs) such as low back pain and upper limb disorders

is one of the most important issues in various kinds of work with visual display terminals (VDTs). In VDT work, it is well known that the incidence of musculoskeletal disorders (MSDs) of the neck, shoulders and lower back is associated with prolonged sedentary work with constrained posture^{1–3)}. Since prolonged sitting work limits the variety of workers' postures, for addressing the issue, progress in ergonomic fields such as the

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development of ergonomic office furniture has been considered to be important. Height adjustable chairs and worktables are the examples of such furniture.

In recent years, adjustable sit-stand workstations, which are designed to allow workers to sit and stand autonomously while working, have been highlighted and spreading in various sedentary office work places in Northern Europe and North America. Adjustable sit-stand workstations consist of height adjustable worktables and chairs, the work surface and sitting position of which can be elevated to the standing position. With these sit-stand workstations workers can select sitting or standing position depending on their needs, which consequently increases opportunities for body movements.

The use of adjustable workstations has the advantage of enhancing workers' productivity⁵⁾, as well as reducing foot swelling⁴⁾ and local muscular workloads (LMWLs)⁵⁻⁷⁾. There are, however, several researchers who are skeptical about the effect of sit-stand worktables. Hasegawa *et al.*⁸⁾ reported that the effect of the sit-stand posture was limited in a short-term task (within 90 min). Chester *et al.*⁹⁾ stated that sit/standing significantly causes more leg swelling than sitting. Wilks *et al.*¹⁰⁾ showed evidence on the low level of usage of the sit-stand function in real workplaces where sit-stand worktables are introduced. Similarly, inadequate installation of adjustable workstations without educating workers on their proper use leads to increases in WMSD risks¹¹⁾.

Thus, we have not yet come to a consensus on the effectiveness of sit-stand workstations in real work settings. In addition, the evidence discussed at the present stage is inconclusive, because most of the previous studies were descriptive ones or field studies with quasi-experimental designs without a control group or random assignment. Confounding factors such as age, sex and work environment were not adjusted in many of the previous studies either, though some studies discussed the relation between workers' musculoskeletal discomfort and productivity. Multifaceted and conclusive evidence for the impact of sit-stand workstations is much needed.

In the present study, experimental research with a factorial design was undertaken to identify the effects of sit-stand workstations on workers' musculoskeletal discomfort, alertness and performance.

Material and Methods

Subjects

We put an announcement calling for participation in this experiment at five universities. A temporary employment agency was also used for recruiting aged workers. The inclusion criteria were: age 20–29 or 60–69, normal vision either with or without glasses, experience

using a word processor and spreadsheet application, ability to type on a keyboard with both-hands, and right-handed. The exclusion criteria were: body height less than 150 cm or higher than 180 cm, previous history of musculoskeletal disorders within the last year, and the use of medications affecting sleepiness.

A total of 24 subjects, 12 undergraduates (6 male and 6 female subjects, Mean $\pm$ SD; 21.2 ± 1.1 yr old) and 12 aged subjects (6 male and 6 female subjects, Mean $\pm$ SD; 62.7 ± 1.6 yr old), participated in the study.

As for the sample size in the study, statistical power analysis was conducted prior to the experiment to estimate the appropriate sample size. We applied the standard levels of probabilities ($\alpha=0.05$, $\beta=0.20$) and estimated the sample size based on the statistical power for the two-tailed *t* test, referring to previous studies. As a result, focusing on the result of the LF/HF ratio as a primary endpoint, we obtained $n=15.68$ for the minimum required sample size. Within-subject designs take fewer subjects and typically have more statistical power, hence the sample size in this experiment is sufficient in light of the statistical reliability of these measures.

Experimental Design

As shown in Fig. 1, the experiment had three different conditions: 1) sitting at standard workstations as a control group (Standard), 2) sitting on a chair with the work surface elevated to standing position (High-chair), and 3) a combination of 10-min sitting and 5-min standing with the same chair and work surface setting as that in the high-chair condition (Sit-stand). The subjects performed a task with a counterbalanced order under these conditions. The workstations used in each condition were worktables with an electronic height adjustment mechanism (NeX desk, Uchida Yoko Co., Ltd, Japan). The table height is continually adjustable from 68.5 cm to 105.5 cm.

The schedule of the experiment is shown in Fig. 2. The subjects were required to do an English transcription task for 150 min (40 min $\times$ 3 sessions, including 5 min for measurement before and after each session) under one condition from 13:30 to 16:00 each day so as to eliminate temporal effects on the results of the experiment. To minimize carry-over effects, an interval of at least 3 days was placed between each experimental condition.

Procedure

Before the beginning of the first series of experiments the subjects visited the laboratory and were given a detailed description of the study by oral explanation along with a document. Consent for the experiment was obtained in written form. Then, they were instructed how to use the software for taking measurements and practiced

Fig. 1. Three conditions tested in the experiment.

Fig. 2. Experimental protocol.

the English transcription task to minimize the learning effect (mentioned below). The study was approved by the Human Research Ethics Committee at Nagoya City University (No.250).

Prior to getting started on the task in each condition, the subjects were requested to adjust the workstation according to the ergonomic guidelines for VDT work with sitting and standing postures, which were determined according to OSHA¹²⁾ and ANSI/HFS¹³⁾ guidelines.

The subjects were required to do an English transcription task in each condition. Each word, which was automatically selected from a medical dictionary database, was randomly shown on the left side of the display, and they inputted the each word on the right side. The subjects were instructed to pay attention to both speed and accuracy in typing the words.

In the experiments, the subjects were also required to report the subjective musculoskeletal discomfort level and subjective sleepiness before and after each session (see Fig. 2).

Measurements

The study included two independent variables, 'condition' and 'time'. The condition had three levels mentioned above: 'Standard', 'High-chair' and 'Sit-stand'. Within-subject design was administered and each subject was randomly assigned to three different days. The time factor consisted of four levels: 'before work (0 min)', 'after 40 min (40 min)', 'after 80 min (80 min)' and 'after 120 min (120 min)'.

The dependent measures collected in this experiment were as follows:

- 1) Subjective musculoskeletal discomfort: Subjective fatigue symptoms were collected through a visual analogue musculoskeletal scale (VAMS), which consists of a 100-mm horizontal line and human body diagrams shown on the display. The diagrams of the human body, which were drawn based on the questionnaire provided in the ISO/TS 20646-1¹⁴⁾, were divided into 14 regions (both sides of neck, shoulders, forearms, wrists/hands, hips/thighs and

lower legs, and upper back and lower back). The subjects rated the tiredness level of each body part at the time by marking the 100-mm line with the mouse cursor. The value ranged from 0 mm (not at all) to 100 mm (excessive).

- 2) Subjective sleepiness: A 100-mm visual analogue scale (VAS) as well as the VAMS was used to evaluate subjective sleepiness. The data of subjective sleepiness and musculoskeletal discomfort were automatically collected using self-developed software.
- 3) Sympathetic nerve activity: The ratio between low-frequency (LF; 0.04–0.15 Hz) and high-frequency (HF; 0.15–0.4 Hz) components of heart rate variability (LF/HF ratio) was assessed in the study. Since LF/HF ratio reflects sympathetic nerve activity^{15, 16)}, it has been used as an index of the arousal level. R-R intervals were measured with a Holter electrocardiogram (ECG) recorder (Active Tracer AC301, GMS Inc., Tokyo, Japan) during all the experiments. The data were downloaded to a computer after measurement, and the power spectrum of R-R intervals was calculated sequentially every 10 min. Of the obtained R-R intervals, those which fell into the ranges of 0.04–0.15 Hz and 0.15–0.4 Hz were separated to form the two frequency components (LF and HF, respectively). LF/HF ratio was then calculated. The steps from the download of the data to the calculation of LF and HF were followed using the Memcalc system (Suwa Trust Co., Ltd., Japan).
- 4) Work performance: The mean number of letters correctly transcribed every 10 min (letters/min) was collected. The work performance rate was calculated using the number of letters inputted in the first 10 min as the baseline in each condition. Self-developed software that integrates English transcription tasks was used to collect the log data.

Statistical analysis

All data were shown as mean $\pm$ SEM and were analyzed using a two-way analysis of variance (ANOVA) with repeated measures. If a significant effect was observed for any of the simple main effects, the Bonferroni test was subsequently applied for post-hoc comparisons. A p value of <0.05 was considered to indicate statistical significance. The Greenhouse-Geisser correction was used to adjust degrees of freedom whenever an inequality of sphericity was rejected by Mauchly's test. All statistical analyses were performed on a personal computer with a statistical package SPSS for Windows (Version 14.0.1.J, Japan).

Results

Subjective musculoskeletal discomfort examined with VAMS

Table 1 shows the mean scores indicating the musculoskeletal discomfort level for each body part under three conditions. All of the mean scores have a tendency to increase with time. Table 2 summarizes the main effects and the interaction of two dependent measures obtained with ANOVA. The main effect of the condition was significant in the right forearm ($p=.03$), right wrist/hand ($p=.02$), right and left hips/thighs ($p=.01$, respectively) and right and left lower legs ($p=.03$, $p=.02$, respectively). The condition $\times$ time interaction was significant in the right thigh ($p=.03$) and right and left lower legs ($p=.02$, respectively). Multiple comparisons indicated significant differences ($p<.05$) between High-chair and Standard conditions in both thighs, and Sit-stand and Standard conditions in the right forearm and right wrist/hand. The comparisons found that High-chair and Sit-stand conditions resulted in relatively higher discomfort levels than the Standard condition. Similar trends, but not significant, were observed in the right forearm, right wrist/hand and lower legs ($p<.10$).

Subjective sleepiness examined with VAS

The level of subjective sleepiness increased with time during the experiments under all three conditions as shown in Table 1. The result of ANOVA shows that time had a significant effect on the rise of the mean scores to indicate subjective sleepiness ($p<.01$). Although the mean scores in the Standard condition seem to be higher than those in High-chair and Sit-stand conditions, the main effect of the condition was not significant ($p=.19$).

LF/HF ratio of the heart rate variability

The LF/HF ratio indicated that there was a tendency for the arousal level to be steadily high under the Sit-stand condition, while under the other two conditions it declined rapidly 20 min after the start of the work and stayed at the same level thereafter (Fig. 3). The main effects of both condition ($p=.01$) and time ($p<.001$) were significant on the LF/HF ratio. The post-hoc tests indicated a significant difference between Sit-stand and Standard conditions ($p<.05$).

Work performance

As for work performance, the similar tendency to that seen in the LF/HF ratio was found (Fig. 4). Work performance tended to be steady being around the baseline under the Sit-stand condition, while the other conditions brought a decline in work performance over time. The main effect of the condition, however, was not significant regarding work performance ($p=.19$).

Table 1. Mean scores to indicate subjective musculoskeletal discomfort on body parts and subjective sleepiness in each condition

	Standard condition				High-chair condition				Sit-stand condition			
	0 min	40 min	80 min	120 min	0 min	40 min	80 min	120 min	0 min	40 min	80 min	120 min
VAMS												
neck (R)	1.3 ± 0.6	10.9 ± 3.3	23.3 ± 4.7	30.5 ± 5.9	1.9 ± 0.8	14.5 ± 4.9	28.3 ± 5.3	38.3 ± 5.9	1.6 ± 0.6	14.0 ± 3.8	22.5 ± 4.6	31.0 ± 5.1
neck (L)	1.3 ± 0.6	8.8 ± 3.1	21.5 ± 4.6	31.5 ± 4.9	1.3 ± 0.5	9.5 ± 2.9	18.3 ± 4.5	29.5 ± 4.8	2.9 ± 1.3	8.3 ± 2.4	18.9 ± 3.7	32.4 ± 4.7
shoulder (R)	0.9 ± 0.4	6.9 ± 2.1	18.7 ± 4.4	28.9 ± 5.8	0.8 ± 0.4	10.6 ± 2.9	20.8 ± 4.8	35.1 ± 6.3	2.7 ± 1.1	12.8 ± 3.7	23.1 ± 4.4	32.0 ± 5.2
shoulder (L)	1.2 ± 0.6	7.3 ± 3.3	19.1 ± 4.7	26.6 ± 5.0	0.7 ± 0.3	5.2 ± 1.9	13.0 ± 3.6	22.9 ± 5.0	1.7 ± 0.8	6.8 ± 2.2	17.8 ± 3.7	29.3 ± 5.4
forearm (R)	0.8 ± 0.4	7.9 ± 2.6	19.2 ± 5.0	26.5 ± 6.1	0.8 ± 0.4	10.4 ± 2.4	25.0 ± 4.6	36.2 ± 5.8	3.2 ± 1.7	17.0 ± 4.7	24.6 ± 5.3	34.9 ± 6.2
forearm (L)	0.9 ± 0.3	7.1 ± 2.9	16.4 ± 5.1	24.4 ± 4.9	0.7 ± 0.3	7.3 ± 2.1	23.0 ± 4.1	29.3 ± 5.2	3.2 ± 1.6	13.3 ± 4.0	21.1 ± 4.9	29.7 ± 5.2
wrist/hand (R)	0.7 ± 0.5	6.8 ± 2.3	16.9 ± 5.1	26.1 ± 6.9	1.1 ± 0.7	11.6 ± 3.8	23.0 ± 5.2	34.0 ± 6.8	1.5 ± 0.7	10.7 ± 3.9	23.1 ± 4.9	33.3 ± 6.3
wrist/hand (L)	1.5 ± 0.7	6.0 ± 3.0	18.2 ± 5.2	21.7 ± 5.3	2.0 ± 1.2	7.7 ± 3.5	18.6 ± 4.5	29.7 ± 6.0	2.6 ± 1.3	8.0 ± 3.7	18.2 ± 4.2	30.5 ± 5.1
upper back	1.8 ± 1.4	9.4 ± 2.4	22.4 ± 4.4	34.7 ± 6.5	0.6 ± 0.4	12.6 ± 3.6	28.3 ± 5.2	39.8 ± 5.4	1.8 ± 0.7	10.4 ± 2.6	24.9 ± 5.0	31.8 ± 5.2
lower back	1.0 ± 0.4	11.3 ± 2.8	22.5 ± 5.3	31.8 ± 6.0	2.0 ± 1.1	13.2 ± 2.8	26.5 ± 5.4	36.5 ± 6.2	1.3 ± 0.6	12.0 ± 3.3	21.8 ± 4.6	31.4 ± 5.1
hip/thigh (R)	1.5 ± 1.0	5.8 ± 2.3	14.5 ± 4.2	20.0 ± 4.9	1.0 ± 0.4	12.0 ± 3.5	23.9 ± 4.6	36.3 ± 6.5	2.1 ± 0.8	9.9 ± 3.1	17.5 ± 3.9	25.0 ± 5.1
hip/thigh (L)	1.5 ± 1.0	4.2 ± 1.8	12.9 ± 3.5	16.4 ± 4.1	0.9 ± 0.3	11.3 ± 3.2	23.6 ± 4.7	32.2 ± 6.3	4.3 ± 2.2	9.5 ± 3.5	18.1 ± 3.6	26.8 ± 5.1
lower leg (R)	3.1 ± 1.8	9.3 ± 2.7	17.2 ± 4.4	24.1 ± 5.9	2.0 ± 0.9	10.9 ± 3.1	25.5 ± 5.2	36.3 ± 6.6	3.8 ± 2.1	16.5 ± 3.9	21.0 ± 4.2	31.5 ± 5.7
lower leg (L)	2.8 ± 1.7	8.7 ± 2.6	16.5 ± 4.2	21.5 ± 5.2	2.0 ± 0.9	9.6 ± 2.8	24.6 ± 4.9	35.0 ± 6.6	5.4 ± 2.3	12.0 ± 3.7	22.1 ± 3.9	32.5 ± 5.4
Subjective sleepiness	9.1 ± 3.4	21.3 ± 4.4	25.9 ± 6.9	22.1 ± 6.3	6.7 ± 2.6	19.3 ± 4.9	19.4 ± 5.2	24.0 ± 6.6	6.5 ± 3.0	14.0 ± 3.6	19.9 ± 4.1	20.0 ± 4.9

VAMS: Visual analogue musculoskeletal scale, (R): Right side of body, (L): Left side of body.
 All data are indicated as Mean ± SEM (mm), ranging from 0 to 100 mm.

Table 2. Summary of the main effects and interaction of dependent measures with two-way repeated ANOVA

	Main effect		Time		Interaction		Multiple comparison (Bonferroni test)
	Condition				Condition × Time		
	<i>F</i> (df)	<i>p</i>	<i>F</i> (df)	<i>p</i>	<i>F</i> (df)	<i>p</i>	
VAMS							
neck (R)	<i>F</i> (2, 46)=1.56	0.219	<i>F</i> (3, 69)=33.34	<0.001**	<i>F</i> (6, 138)=0.78	0.585	—
neck (L)	<i>F</i> (2, 46)=0.17	0.842	<i>F</i> (1.72, 39.76)=36.28	<0.001**	<i>F</i> (6, 138)=0.48	0.821	—
shoulder (R)	<i>F</i> (2, 46)=2.01	0.146	<i>F</i> (3, 69)=33.02	<0.001**	<i>F</i> (6, 138)=0.62	0.716	—
shoulder (L)	<i>F</i> (2, 46)=2.37	0.105	<i>F</i> (1.47, 33.77)=28.07	<0.001**	<i>F</i> (3.54, 81.38)=0.724	0.562	—
forearm (R)	<i>F</i> (2, 46)=3.72	0.030*	<i>F</i> (1.41, 32.42)=30.16	<0.001**	<i>F</i> (3.15, 72.35)=1.61	0.193	Sit-stand > Standard*, High chair > Standard [†]
forearm (L)	<i>F</i> (2, 46)=1.78	0.179	<i>F</i> (1.60, 36.83)=28.25	<0.001**	<i>F</i> (4.00, 92.03)=1.24	0.300	—
wrist/hand (R)	<i>F</i> (2, 46)=4.13	0.022*	<i>F</i> (1.32, 30.34)=22.08	<0.001**	<i>F</i> (3.12, 71.82)=0.96	0.420	Sit-stand > Standard**, High chair > Standard [†]
wrist/hand (L)	<i>F</i> (2, 46)=1.45	0.245	<i>F</i> (1.77, 40.61)=18.98	<0.001**	<i>F</i> (3.01, 70.22)=1.64	0.187	—
upper back	<i>F</i> (2, 46)=1.18	0.317	<i>F</i> (1.48, 34.04)=39.73	<0.001**	<i>F</i> (3.67, 84.48)=1.14	0.343	—
lower back	<i>F</i> (2, 46)=0.89	0.419	<i>F</i> (1.36, 31.35)=33.22	<0.001**	<i>F</i> (3.79, 87.24)=0.33	0.847	—
hip/thigh (R)	<i>F</i> (2, 46)=5.028	0.011*	<i>F</i> (1.50, 34.47)=27.43	<0.001**	<i>F</i> (2.99, 68.79)=3.10	0.032*	High chair > Standard*
hip/thigh (L)	<i>F</i> (2, 46)=4.52	0.016*	<i>F</i> (1.65, 37.94)=28.54	<0.001**	<i>F</i> (3.12, 71.66)=2.60	0.056 [†]	High chair > Standard**
lower leg (R)	<i>F</i> (2, 46)=3.95	0.026*	<i>F</i> (1.43, 32.99)=23.19	<0.001**	<i>F</i> (4.01, 92.10)=3.14	0.018*	Sit-stand > Standard [†] , High chair > Standard [†]
lower leg (L)	<i>F</i> (2, 46)=4.11	0.023*	<i>F</i> (1.58, 36.27)=26.89	<0.001**	<i>F</i> (3.78, 86.88)=3.08	0.022*	Sit-stand > Standard [†] , High chair > Standard [†]
Subjective sleepiness	<i>F</i> (2, 46)=1.74	0.188	<i>F</i> (1.97, 45.21)=6.77	0.003**	<i>F</i> (4.26, 98.07)=0.54	0.717	—

***p*<0.01, **p*<0.05, †*p*<0.10 (trend).

VAMS: Visual analogue musculoskeletal scale, (R): Right side of body, (L): Left side of body.

Data are means $\pm$ SEM. Measurements: measurements of subjective musculoskeletal discomfort and subjective sleepiness using VAS.

Condition: $F(2, 46) = 5.34, p = 0.011$.

Time: $F(5.01, 115.19) = 7.549, p < 0.001$.

Condition $\times$ Time: $F(5.15, 118.42) = 1.563, p = 0.174$.

Multiple comparison (Bonferroni test): Sit-stand $>$ Standard ($p = 0.027$).

Fig. 3. Change in LF/HF ratio under each condition.

Data are means $\pm$ SEM. The rate was calculated using the number of letters inputted in the first 10 min as baseline in each condition. Measurements: measurements of subjective musculoskeletal discomfort and subjective sleepiness using VAS.

Condition: $F(2, 46) = 1.71, p = 0.19$.

Time: $F(3.27, 71.94) = 2.84, p = 0.039^*$.

Condition $\times$ Time: $F(6.24, 137.23) = 0.93, p = 0.478$.

Multiple comparison (Bonferroni test): n.s.

Fig. 4. Change in work performance under each condition.

Discussions

One of the main findings was that the use of sit-stand workstations did not demonstrate beneficial effects in light of their subjective musculoskeletal discomfort in comparison with standard workstations. This basically supports the result of Hasegawa *et al.*⁸⁾ who reported that there was no clear effect from a combination of sitting and standing postures over 90 min working time. In contrast, this finding is not consistent with some previous studies⁵⁻⁷⁾, which have reported that adjustable sit-stand workstations can reduce musculoskeletal discomfort across all body parts. There may be some explanations for this conflict.

One reason might be the difficulty in finding appropriate working height for the standing position. Prior to the experiment, we instructed the subjects to adjust the height of the table and the chair according to the ergonomic guidelines for sit-stand workstations. However, VDT work with standing position is unfamiliar to the subjects, especially in Japan. It is possible that they didn't adjust the height appropriately.

Secondly, the higher discomfort felt only in the right upper limbs may be representative of the subjects' dominant hand. The frequency of right hand use, when they input words, seemed to be relatively high compared with that of left hand use, though they could type with both hands.

Thirdly, we have to focus on the different settings between field surveys and laboratory studies. The data taken in the previous studies were collected using questionnaires in field surveys or field intervention studies. In real work settings, there are many physical and psychosocial factors affecting the subjective responses¹⁷⁾. Thus, many confounding factors affecting musculoskeletal discomfort should be adjusted. However, it is generally considered to be difficult to conduct a well-controlled intervention study during field surveys due to limited sample sizes, research time and costs. On the other hand, in laboratory studies, controls must be strictly maintained to eliminate other factors affecting the results of experiment even if they are unnatural or unusual. In the present study, a combination of 10-min sitting and subsequent 5-min standing was introduced in the Sit-stand condition. It is, however, not so common to use the sit-stand function in real work settings¹⁰⁾. In this study subjects were made to take the standing position 6 times during a 120 min task, though the standing position was used an average of 3.6 times in a working day⁵⁾. Thus, it might not be appropriate to compare our findings directly with those from the previous studies.

It should be noted that negative effects were also seen on lower limbs (thighs and lower legs) under the High-

chair condition where subjects were continuously sat on a highchair. This finding should be interpreted with caution, since the High-chair condition, with the feet far from the floor, increases the pressure on the thighs and the compression of the blood vessels in the lower limbs. Another explanation can be found in the constrained postures. The use of highchairs might limit posture variations compared with that of standard chairs. It is well known that prolonged and limited sitting posture results in an increase of subjective musculoskeletal discomfort. Consequently, further analysis of each condition is needed in light of the posture variability or subsidiary behavior^{18, 19)} that is related to the low level of workers' consciousness during monotonous work.

The LF/HF ratio in the Sit-stand condition was higher than that of other conditions. There were, however, no significant differences in subjective sleepiness among the three conditions in this study. This apparently conflicts with the result of the LF/HF ratio. One possible explanation can be found in the time points of measurements. The subjects answered the questions to examine their subjective sleepiness after the measurements were taken on musculoskeletal discomfort. These different stimuli might have relieved the subjects from their monotonous task and led to the recovery of their arousal level. Subjects' sleepiness level at the beginning of each session, for example, tended to recover from the level at the end of the previous session. This trend might be evidence for the above hypothesis.

As for work performance, there was a tendency for it to be steadily high under the Sit-stand condition compared with other conditions. The micro break effect²⁰⁾ may be reflected in this trend, since the use of sit-stand workstations plays a role in providing workers with opportunities for body movements when workers change their sitting/standing postures. Sit-stand workstations therefore seem to have the possibility to keep up workers' performance. Further testing is needed with respect to the effect of micro breaks while using sit-stand workstations.

Strengths and limitations

This study conducted to identify the effects of sit-stand workstations has several important advantages for the development of studies on VDT work. The information was obtained from an experiment analyzed using two-way ANOVA with a within-subject design. It was based on a large sample size considering it was a laboratory study, and the confounding effects such as demographic characteristics (age, sex, dominant hand), subjects' education level, computer skill and literacy, experimental environment and a period of experiment time were generally well controlled. The quantitative work performance obtained from actual transcription tasks is a strength of this study.

In previous studies on the effects of sit-stand workstations productivity was measured using subjective scores rated by questionnaires.

There are a few limitations in the present work. The 120-min tasks might have been insufficient to evaluate the subjective musculoskeletal discomfort level under each condition. We should have analyzed the differences in work performance between conditions in respect to the error rates, as well as the correct input of letters. If we had done so, we could have gained clear evidence on work performance. Another potential problem the study had was related to the English transcription tasks. Using this quite monotonous task as stimuli for the experiment bears little resemblance to work done in actual working conditions. Further research is needed to identify the effects brought about by doing different kinds of tasks.

Conclusions

The present study revealed that sit-stand workstations can contribute to keeping workers' arousal level steady during the English transcription task with VDTs. However, regarding musculoskeletal discomfort, adjustable sit-stand workstations had an adverse effect on the right forearm, right wrist/hand, thighs/hips and lower legs. Work performance tended to be steady being around the baseline under the 'sit-stand' condition, while the other conditions brought a decline in work performance with time. Although further analyses are needed, for the meantime, attention must be paid when sit-stand workstations are introduced to real work places where workers also have a chance to use high chairs for prolonged sedentary work.

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