<최종 원고 템플렛>

Ergonomic Evaluation of Electrically Adjustable Table in VDU Work

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ABSTRACT

Objective: The aim of this study was to evaluate ergonomics of the electrically adjustable sit-stand workstation by comparing musculoskeletal strain, perceived features of usability, and work efficiency in work with a video display unit (VDU) at the electrically adjustable sit-stand workstation and at the traditional workstation. **Method:** The participants were 12 healthy female office workers (aged 27-53 years) from one office. This was a comparative cross-sectional study. The muscular activity, wrist angle, perceived musculoskeletal strain, perceived features of usability, and work efficiency of each worker were assessed during one day. **Results:** Muscle activity of right trapezius and left extensor digitorum communis, extension of both wrists and perceived strain of arms were lower when the subjects worked in low-sitting, high-sitting, and standing posture at the sit-stand workstation compared to the work in low-sitting posture at the traditional workstation. Work efficiency (right marks per 42 min) was 10 % better ($p=0.02$) when the subjects worked at the sit-stand workstation compared to the work at the traditional workstation. **Application:** The results of this study can be used when the new office environments are designed or old offices are redesigned.

Keywords: Ergonomics, VDU(visual display unit), Usability, Electrically Adjustable Table

1. Introduction

Ergonomic sitting and standing postures are important factors for the prevention of musculoskeletal disorders such as low back pain and upper limb disorders (Carter and Banister, 1994; Cranz, 2000, Ebara et al., 2008). Prolonged sedentary work with constrained posture is associated with the neck, shoulders and low back pain in work with visual display terminals (VDT) (Aarås, 1987; Waerstadt and Westgaard, 1997).

The adjustable sit-stand workstation consist of an electrically adjustable worktable and an adjustable chair, with which workers can select low-sitting, high-sitting and standing postures according to their needs and the tasks (Ebara et al., 2008, Wilks et al., 2006). The electrically adjustable sit-stand worktables give the possibility to change working postures and adjust the table height easily and rapidly (Wilks et al., 2006). The use of adjustable workstation can reduce physical discomfort and musculoskeletal risks (Robertsona et al., 2008) and enhance workers' productivity (Hedge and Ray, 2004, Ebara et al., 2008, Koskelo et al., 2007, Wilks et al., 2006). Hasegawa et al., (2001) reported the effects of a sit-stand schedule on a light repetitive task and concluded 'change of posture' is useful to reduce the monotonous feelings of fatigue on a short-term light repetitive task. The electrically adjustable worktables have also been used among workers with physical disabilities (Nevala et al., 2010).

Ergonomics of adjustable worktables have been reported in visual display unite (VDU) work (Hedge and Ray, 2004; Karlqvist, 1998; Wilks et al., 2006), laboratory work (Sillanpää et al., 2003), and school work (Hänninen et al., 2003; Jung, 2005) (Table 1).

Table 1. Ergonomic studies of adjustable worktables or other work levels in different occupations

Occupation	Reference	Workstation	Method	Result
Video Display Unit (VDU) Work	Hedge and Ray (2004)	Adjustable worktable on computer workers	Self report, n=33	Improved comfort at the workstation and self-rated productivity
	Karlqvist (1998)	Adjustable VDU worktable	Physical load, n=10	Support the arms vary between sitting and standing posture prevent outward rotation of the shoulder
	Stephen et al.(2006)	Sit-stand worktable for office workers	Questionnaire, n=165, 4 companies	Positive to the sit-stand worktable, poor compliance in using
Laboratory work	Sillanpää et al. (2003)	Adjustable microscope worktable	EMG, n=10	Head in an upright position the forearms supported and with less flexion of the upper arm
School work	Jung (2005)	Adjustable table for students	Record comfortable, adjustment position, n=40	Development of a prototype of an adjustable table and an adjustable chair for educational institute
	Hänninen et al. (2003)	Manual adjustable table for students	EMG, n=15	Muscle tension levels fell significantly in lumbar and trapezius muscles

However, most studies about the height adjustability concern chairs (Bobski-Reeves et al., 2005; Hochanadel, 1995; Robertsona et al., 2009). Using height adjustable furniture reduced physical discomfort and improved productivity (Vink et al., 1997). In the 'change of posture' conditions, the workload was lower and the work performance was higher than that with sitting or standing posture (Hasegawa et al., 2001).

Worktables which provide for forearm support have shown to reduce the incidence of musculoskeletal discomfort and disorders, thereby impact working posture preferences (Cook et al., 2004; Haynes 2009; Marcus et al., 2002; Rempel et al., 2006). Resting the arms on the table surface is associated with reduced risk of neck and shoulder pain (Gerr et al., 2004). Rempel et al. (2006) reported a 50% reduction in diagnosed neck/shoulder incidents among the call center workers over 12 months when using a forearm support, though no change in the risk for right upper limb disorders was found.

Utilization of the sit-stand function has reported to be low (Wilks et al., 2006). Wilks et al. (2006) found approximately 60% of men and women in the study used their table's sit–stand function once monthly or less and was less frequent among the older participants (over 51 years). Pain experienced during the past year, and education on the use of the worktable increased utilization of adjustability (Wilks et al., 2006).

The objective of ergonomics is to achieve the best possible match between the product and its users in the context of the work task to be performed (Pheasant, 1996). The aim of this study was to evaluate ergonomics of the electrically adjustable table by comparing musculoskeletal strain, perceived features of usability, and work efficiency during visual display unit (VDU) work at the electrically adjustable sit-stand workstation and at the traditional VDU workstation.

2. Method

2.1 Participants

The participants were 12 healthy female office workers (aged 27-53 years) from one office (Table 2). They all were right-handed and were accustomed to work at the electrically adjustable sit-stand workstation and the traditional workstation. During their normal work day, the subjects adjusted their electrical workstation six times per day mainly due to tiredness and strain. The volunteer participants were individually informed of the study, and they gave their written consent to participate before the study began. Before the measurements the subjects were assigned to two study groups of 6 participants and the groups had different study order of the workstation.

Table 2. Background factors of the subjects (n=12), mean, standard deviation (SD) and range

Variable	Mean	SD	Range
Age (yrs)	38	9	27-53
Height (cm)	169	6	158-180
Weight (kg)	64	8	50-76
Body mass index (kg/m2)	22	2	19-26
Experience in VDT work (yrs)	9	4	3-15
Experience in use of electric adjustable workstation (months)	14	13	2-48

2.2 Study Design

This was a comparative cross-sectional study. The measurements of each subject were done during one day in a simulated situation (Figure 1). During the study the subjects worked at both workstations (sit-stand workstation, traditional workstation) for 42 min. The subjects worked at the adjustable sit-stand workstation in a low-sitting position for 14 min, in high-sitting position for 14 min, and in standing position for 14 min. At the traditional workstation the subjects worked for 42 min in low-sitting position. The same standardized mouse and typing tasks were conducted during the measurements and the tasks were changed every 7 min. During the measurements, 6 subjects worked at first at the sit-stand workstation and 6 subjects at the traditional workstation.

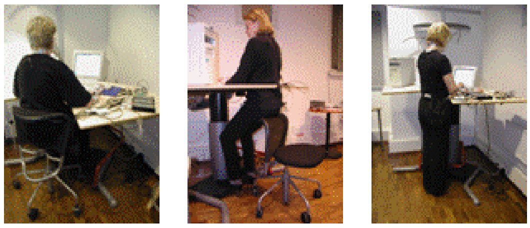
2.3Methods

Ergonomics of the electrically adjustable sit-stand workstation was evaluated with physiological measurements (muscular activity, wrist angles), questionnaire (perceived musculoskeletal strain, perceived level of activity and power of concentration, satisfaction), and measurement of work efficiency.

2.3.1 Physiological measurements

Electromyography (EMG) was recorded from four muscles bilaterally (m. erector spinae, m. trapezius pars descendes, m. extensor digitorum communis, m. erector spinae trunci) with a portable ME3000P device with a video option (Mega Electronics, Finland) (Remes et al., 1984). The EMG was recorded using the averaged mode, a sampling frequency of 1000 Hz, a time interval of 0.1 seconds, and a bipolar setting of disposable surface electrodes (M-OO-S, Medicotest, Denmark). The positions of the electrodes were defined according to the recommendations of Delagi and Perotto (1980) and Zipp (1982). The maximal muscular activity of the four muscles was registered during their maximal isometric voluntary contractions (MVC) and standardized as the percentage of the MVC (%MVC). The studied work tasks were video-recorded with a Panasonic S-VHS-C video camera. The EMG data were transferred via an optic link to a computer. The analyses and calculations were performed by attached software.

1) Traditional workstation



2) Adjustable sit-stand workstation

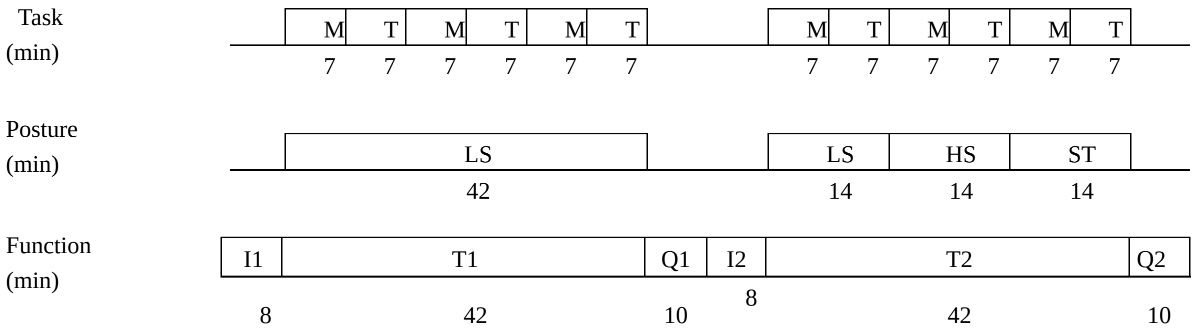


Figure 1. The test schedule of each subject (I1 = Information 1, T1 = Test 1, Q1 = Questionnaire 1, I2 = Information 2, T2 = Test 2, Q2 = Questionnaire 2, LS = low-sitting, HS = high-sitting, ST = standing, M = mouse task, T = typing)

Wrist extension/flexion and ulnar/radial deviation were measured using a two-channel electronic goniometer (Type XM110, Penny & Giles Blackwood Ltd, UK) attached to the wrists of the worker with skin adhesive tape (Buchholz and Wellman, 1997). The output from the goniometers was sampled with a portable device (ME3000P, Mega Electronics Ltd, Finland) at a frequency of 250 Hz, using the averaged mode and a time constant of 0.1 seconds and stored on a computer for analysis with ME3000P software. The validity and reproducibility of the angle measuring method has previously been determined by Buchholz and Wellman (1997).

2.3.2 Questionnair

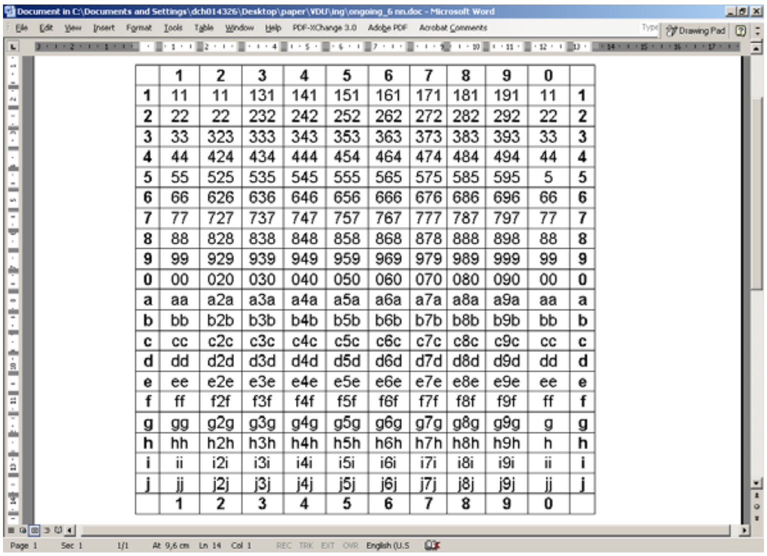
Visual analogue scales (VAS) were used to analyze musculoskeletal strain, perceived level of activity and power of concentration (Lintula and Nevala 2006; Nevala and Tamminen-Peter, 2004; Price et al., 1983). The workers rated their strain and perceived features on a modified VAS, the result of each scale being reported in millimeters (range 0-100 mm with end points of 0 not at all strainful – 100 very strainful, 0 very poor – 100 very good). The satisfaction to the workstation was asked with one open question.

2.3.3. Work Efficiency

Work efficiency was analyzed with the number of right marks per 42 min during the standardized mouse and typing tasks. In the mouse task, developed for this study, the subject deleted using the mouse the middle mark from each item in special order (111>J0J>212>I0I etc.) (Figure 2). In the typing task the same Finnish text was used to analyze the writing speed (Suomalainen et al. 2010).

2.3.4. Data Analysis

The results were analyzed using the GLM procedure



	1	2	3	4	5	6	7	8	9	0	
1	11	11	131	141	151	161	171	181	191	11	1
2	22	22	232	242	252	262	272	282	292	22	2
3	33	323	333	343	353	363	373	383	393	33	3
4	44	424	434	444	454	464	474	484	494	44	4
5	55	525	535	545	555	565	575	585	595	5	5
6	66	626	636	646	656	666	676	686	696	66	6
7	77	727	737	747	757	767	777	787	797	77	7
8	88	828	838	848	858	868	878	888	898	88	8
9	99	929	939	949	959	969	979	989	999	99	9
0	00	020	030	040	050	060	070	080	090	00	0
a	aa	a2a	a3a	a4a	a5a	a6a	a7a	a8a	a9a	aa	a
b	bb	b2b	b3b	b4b	b5b	b6b	b7b	b8b	b9b	bb	b
c	cc	c2c	c3c	c4c	c5c	c6c	c7c	c8c	c9c	cc	c
d	dd	d2d	d3d	d4d	d5d	d6d	d7d	d8d	d9d	dd	d
e	ee	e2e	e3e	e4e	e5e	e6e	e7e	e8e	e9e	ee	e
f	ff	f2f	f3f	f4f	f5f	f6f	f7f	f8f	f9f	ff	f
g	gg	g2g	g3g	g4g	g5g	g6g	g7g	g8g	g9g	g	g
h	hh	h2h	h3h	h4h	h5h	h6h	h7h	h8h	h9h	h	h
i	ii	i2i	i3i	i4i	i5i	i6i	i7i	i8i	i9i	ii	i
j	jj	j2j	j3j	j4j	j5j	j6j	j7j	j8j	j9j	jj	j
	1	2	3	4	5	6	7	8	9	0	

Figure 2. The standardized mouse task where the middle mark was deleted using the mouse from each cell in systematic order (111>J0J>212>i0i etc.)

of SAS (Statistical Analysis System v6.12). Means, standard deviations and ranges were used for the descriptive evaluation. The independent variable in all the analyses was the workstation model (sit-stand workstation, traditional workstation). The dependent variables were the muscular activity of the four muscles, the angle of the right wrist, the perceived musculoskeletal strain in different body parts, and the number of right marks. The differences between the tables were tested using a paired *t*-test. The differences were considered statistically significant if $p<0.05$.

3. Results

Muscle activity of right trapezius and left extensor digitorum communis (Table 3), extension of both wrists (Table 4) and perceived strain of arms were lower when the subjects worked in different postures (low-sitting, high-sitting, standing) at the electrically adjustable sit-stand workstation compared to the work at the traditional VDU workstation. No statistically significant differences were found in perceived level of activity and power of concentration between the studied workstations.

Table 3. Mean muscle activity (electromyography, EMG, %MVC) of the subjects (n=12) in four muscle groups bilaterally during the standardized VDU work tasks at the electrically adjustable sit-stand workstation (in low-sitting, high-sitting and standing positions) and at the traditional VDU workstation (in sitting position).

	sit-stand workstation	traditional workstation	p
Neck			
Left	5.3	4.8	ns
Right	5.5	5.2	ns
Trapezius			
Left	5.9	5.2	ns
Right	7.0	9.7	0.01
Extensor digitorum communis			
Left	9.1	9.8	0.02
Right	10.1	10.4	ns
Back extensor			
Left	2.0	1.2	ns
Right	2.1	1.2	ns

Table 4. Mean wrist extension and ulnar deviation (degree) of the subjects (n=12) during the standardized VDU work tasks at the electrically adjustable sit-stand workstation (in low-sitting, high-sitting and standing positions) and at the traditional VDU workstation (in sitting position).

	sit-stand workstation	traditional workstation	p
Wrist extension			
Left	18	21	0.002
Right	22	24	0.05
Wrist deviation			
Left	13	14	ns
Right	10	11	ns

Work efficiency (right marks per 42 min) was 10 % better (p=0.02) when the subjects worked at the adjustable sit-stand workstation compared to the work at the traditional VDU workstation.

The subjects were satisfied to the electrically adjustable sit-stand workstation, because it made possible to work in different postures and the table was easy to use. The subjects answered why the adjustable table is good:

" it is easy to come to and leave the workstation"

"it is not as tiring and simple as the traditional worktable"

"it gives more freedom and the workposture can be changed more often"

"the adjustable table gives possibilities to change the esthetics of the workstation"

"it is possible to change the workposture often and the perceived level of activity is better than in the sitting posture"

"the standing posture has decreased my neck-shoulder pain and headache"

"the adjustable table motivates to move"

"it is easier to think while standing"

"the table is easy to adjust and use"

"it gives freedom to work"

"the work tasks are changing, why not the table"

"sometimes I want to stand and think"

"when the work doesn't go on, I will stand up and the new thoughts and solutions are found".

4. Conclusion

The research was planned in cooperation with researchers, desk manufacturers, and experienced office workers. In the project both quantitative (EMG, wrist angle, productivity) and qualitative methods (VAS assessment, argumentations) were used as David and Buckle (1997) have recommended for usability assessments. The 42-minute VDU task duration was chosen because it seemed to correspond to an average continuous VDU task in an actual work situation. The number of subjects was the same as in other usability studies (Kirvesoja et al., 2001, Sillanpää et al., 2003). The range of the subjects age (27-53 years), height (158-180 cm), and weight (50-76 kg) represented the typical female workers. The subjects were accustomed to use both tested workstations.

The application of good ergonomic principles can alleviate physical stress and subsequently reduce the risk of musculoskeletal disorders. The work postures can be changed from low-sitting to high-sitting and standing postures at the sit-stand workstation. Musculoskeletal strain was lower and work efficiency was better during VDU work alternately in low-sitting, high-sitting and standing positions at electrically adjustable sit-stand workstation compared to work in sitting position at the traditional VDU workstation. Especially the muscular strain and perceived strain of upper limbs was lower at the sit-stand table. It is obvious that the easily adjustable table gives support for the arms which has been shown to be important in preventing the shoulder strain (Cook et al., 2004; Haynes 2009; Marcus et al., 2002; Rempel et al., 2006). The EMG measurements were good to show the difference between the two situations.

The electrically adjustable sit-stand workstation give the possibility to change working postures and adjust the table height easily. The workers perceived that it was easier to think when they had possibility to chance the posture. This is important in static work tasks and in open offices where the work stations are shared by several persons. The electrical workstation is easy to adjust to different users, and therefore suit modern organizational dynamics where workers form temporary and fluid project groups. The purchase of new workstation give also opportunity to reduce floor space.

The productivity was 10% better when the same tasks were done at the adjustable workstation. The result is the same as in the earlier studies (Hedge and Ray, 2004, Ebara et al., 2008, Koskelo et al., 2007, Wilks et al., 2006). The method of analyzing the productivity was developed for this study in co-operation with experts of technical ergonomics and psychology.

The results of this study can be used when the office environments are designed or redesigned. Easily adjustable workstations can be used in primary prevention when the exposure is decreased, in secondary prevention when the workability is improved of the persons with musculoskeletal disorders and in tertiary prevention when the possibilities to work is supported for persons with disabilities. However, correct use of these technical accessories, such as adjustable worktables and chairs, requires good education and systematic motivation.

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