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The effect of using a laptopstation compared to using a standard laptop PC on the cervical spine torque, perceived strain and productivity

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Abstract

The objective of this study was to assess the effect of using a laptopstation and a laptop PC and how this difference in work set-up affected the mechanical load on the neck (C7-Th1 segment), the subjective evaluation of strain on the neck and productivity. Ten healthy male students at Umeå University, Sweden with an average of 10 years of PC work experience and an average of 18 months of laptop PC work experience participated in the study. For each research subject measurements were divided into two parts; sitting working at the ErgoQ laptopstation in test situation *A*, and sitting working at a conventional laptop PC, test situation *B*. Each part took 4 h and was scheduled on two consecutive days. Photography and biomechanical analysis was used to calculate the torque at the neck. To examine perceived strain the Borg Scale was used and to assess performance a productivity score was calculated. *The results* in the study demonstrated a significant ($p < 0.05$) difference with the use of the laptopstation resulting in decreased torque at the C7-Th1 segment, less perceived strain at the neck and a higher productivity score. *In conclusion,* the results of the study confirm the importance of adjustable work tools that recognize anthropometric differences and biomechanics to meet the needs of individual customers during continuous visual display terminal work.

Keywords: Ergonomics; Visual display terminals; Musculoskeletal disorders; Laptop PC

1. Introduction

Laptop computers have become widely used in many workplaces and schools and are currently the largest growth area within the personal computer (PC) market (Harris and Straker, 2000). The need to access information technology on a daily basis continues to grow and the laptop PCs advantages of being portable, lightweight and space saving, enabling the users to work anywhere and anytime, have increased its popularity among PC users.

There has been substantial research carried out to evaluate the effects of working on a visual display terminal (VDT), keyboard and input device using desktop PCs. These studies have resulted in recommendations and guidelines to address ergonomics, adjustability, comfort and associated health risks for visual discomfort and musculoskeletal disorders in using desktop PCs.

Also, in the laptop PC the issues of comfort, adjustability and ergonomics are important to avert foreseeable ergonomic and occupational health problems. Most laptop PCs are designed with the screen hinged to the keyboard and are non-detachable, resulting in awkward or constrained body postures and movements.

Given this ergonomic disadvantage of the conventional laptop PC several studies have shown an increase in neck flexion, torque and physical discomfort/strain (Harris and Straker, 2000; Straker et al., 1997; Harbison and Forrester, 1995). In a study by Saito et al. (1997), the neck muscle load (EMG value) was significantly greater using the laptop PC than with the desktop PC. Furthermore, there was greater forward

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head inclination, less head movement and shorter viewing distance increasing the visual and musculoskeletal workload at the laptop PC as compared to the desktop PC.

In response to this problem of user discomfort, poor posture and restricted movement due to the inability to separate the keyboard and VDT in laptop PCs, "laptopstations" have been introduced to the market. Many previous studies on desktop VDT support the recommendation that a VDT workstation should allow keyboard height and screen height and distance to be adjustable to be suitable for continuous work (Chung and Choi, 1997; Saito et al., 1997; Kroemer and Grandjean, 1997; Psihogios et al., 2001).

However, no specific study has been done to assess if the use of the "laptopstation" is effective in reducing discomfort, the mechanical load on the cervical joints and improving productivity. The goal of this study is to assess the physical effects of a "laptopstation" product using both objective and subjective measures.

1.1. Objectives

Specific aims of the study were to examine the effects of the ErgoQ laptopstation that allows for adjustability of a separate keyboard and screen height and distance and how the difference in workstation to the standard laptop affects:

- *the torque* (*flexion moment*) on the cervical spine (C7-Th1 segment);
- *the perceived strain on the neck*;
- *the productivity*.

1.2. Relevance to industry

Healthy and high work performance in regard to quality and productivity are essential to sustain growth and competitiveness of any business. In the Netherlands the total cost of neck pain was estimated to be nearly $690 million in 1996 (Borghouts et al., 1999). In France, a large study of 4.4 million employees reported a period prevalence for neck pain of 21% among males and 37% for female employees (Nachemson and Jonsson, 2000). Based on a study done in Sweden by Nachemson and Jonsson (2000) the relative percentage of days absent due to neck pain increased from 24% in 1987 to 56% in 1997. In Europe and internationally the financial burden of work-related musculoskeletal disorders (WMSDs) are very high, alarming both companies and governments. In this respect it is essential to users and employers to have access to products that are safe and comfortable with high performance. This study is unique as for the first time the addition of a mechanism for adjusting the laptop VDT height and distance will be investigated.

2. Materials and methods

2.1. Subjects

Ten healthy male students at Umeå University, Sweden with the mean age of 24 years (range 21–28 years), whose work/studies involve regular PC use in their work practices, participated in the study. The subjects had 10 years of mean PC work experience (range 5–15 years) and 18 months of mean laptop PC work experience (range 0.5–48 months). The subjects mean height was 179 cm, with a range of 174–192 cm. The mean weight was 76 kg, with a range of 65–94 kg. All subjects participating in the study were free from any current musculoskeletal injuries in the neck or shoulders.

Participation was voluntary and subjects gave their written informed consent prior to their inclusion in the study. The facility for the office setting during experiments and approval for the study was provided by Umeå University.

2.2. Instruments and procedure of measurements

A camera (Minolta Riva Zoom 115EX, 38–115 mm f/3,5–9,9 power zoom lens) was mounted on a tripod and used to obtain photos from a direct right and lateral view of each subject when the subject was seated at the computer workstation. The height of the camera was adjusted to the level of cervical vertebra C7 of each subject. Floor markers were used to mark the distance from the subject's right shoulder to the camera and ensure a lateral view. A vertical reference line (1 m ruler marked every 10 cm) hung from the ceiling directly behind the subjects' chair. A laptop PC with a 14.1-inch TFT screen and the ErgoQ laptopstation with an IBM regular size keyboard and mouse were used in the study.

For each research subject measurements were divided into two parts; sitting working at the ErgoQ laptopstation in test situation *A* (Figs. 1 and 2), and sitting working at a conventional laptop PC, test situation *B* (Fig. 3). Each part took 4 h and was scheduled on two consecutive days. The computer test situation was

Fig. 1. ErgoQ Laptopstation.

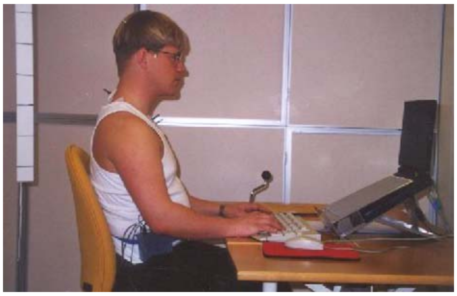

Fig. 2. ErgoQ Laptopstation, test situation A = The subjects adjust the keyboard, VDT screen height, tilt and distance to their preference and comfort, following instructions on the adjustability of the ErgoQ laptopstation.

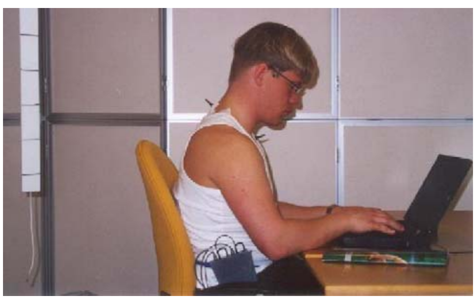

Fig. 3. Conventional laptop, test situation B = The subjects place the laptop computer on the tabletop surface and adjust the VDT screen tilt to their preference.

changed from test day one to test day two but the chair height and desk height remained unchanged. The two test situations were studied in random order for each research subject.

The subject was instructed to perform a computer text-entry task that required keyboard, mouse and screen observation while working in Microsoft Word. The subject was instructed to choose typing work that was comparable when working in test situation A and B and to work at his typical work tempo. The subjects were dressed appropriately for the head, neck and upper thoracic to be clearly visible. Small adhesive markers were applied to the subjects to identify anatomical landmarks; 2 cm ventral of the external auditory meatus on the zygomatic arch (center of mass of the head), spinous process of C7 and at the jugular notch of manubrium.

The height of the desk surface was adjusted manually by the subjects and the desk surface mean height was recorded to be 73 cm (range 69–76 cm). The table had sufficient depth for the laptop PC and laptopstation to be placed to allow for space in front of the keyboard for the operator to rest the forearms while typing. Each of the subjects placed the VDT, keyboard and mouse at a distance to their preference. The subject was seated in an adjustable chair, with the subject adjusting the height of the office chair, seat depth and back support to their preference. The mean chair height was measured to be 49 cm with a range of 44–51.5 cm. A goniometer was used to measure the screen tilt of the VDT with reference to the vertical, after the subject adjusted the tilt to their preference. The mean laptop screen tilt was 27° with a range of 16–32° of upward tilt. The mean laptop screen tilt when using the laptopstation was 11°, with a range of 5–18° of upward tilt.

Thirty minutes into the work the subject was to be photographed directly from the side exactly every 2 min for a total of 5 photos. The total 10 photos of each person were used to complete a biomechanical analysis. The C7-Th1 joint axis of movement was defined as the middle point between spinous process of C7 and incisura jugularis. The distance from the vertical line through C7-Th1 joint axis of movement to the center of mass of the head and to the atlanto-occipital joint axis of movement was measured on the enlarged photo images. The torque at C7-Th1 was calculated using a computer according to the following mathematical formulas:

(1) Torque at atlanto-occipital joint ($T\,\mathrm{ao}$) $= (0.055 \times \mathrm{BW} \times 9.81)\,(\mathrm{A}-\mathrm{B})$.
(2) Torque at C7-Th1 joint ($T\,\mathrm{C7\text{-}Th1}$) $= (0.021 \times \mathrm{B}/2 + 0.055 \times \mathrm{A})\,(\mathrm{BW} \times 9.81)$.

0.055 = Weight of the head in relationship to the body weight.
0.021 = Weight of the neck in relationship to the body weight.
BW = Body-weight in kg.
A = Distance in meters from the vertical line to the center of mass of the head.
B = Distance in meters from the vertical line to the atlanto-occipital joint axis of movement. The transverse joint axis of the atlanto-occipital joint was assumed to coincide with a transverse axis throught the ear lobes.
B/2 = Distance in meters from the vertical line to center of mass of the neck.

For the subjects rating of the perceived neck strain the Borg's CR-10 scale was used and placed in the visual field of the subject so that he could quickly rate the perceived strain. One minute before working, at 40, 50, 60, 125 and 220 min the subject was asked, "How do you perceive the strain to be at your neck right now? Give a number." and the subject's response was recorded.

Borg's CR-10 scale

0	Nothing at all
0.5	Very, very weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very strong Maximal

Table 1
C7-Th1 Torque (Flexion moment), Subjective evaluation of strain, productivity score and screen tilt recorded when using a laptopstation and a laptop computer ($n = 10$)

Variable	Mean		Standard deviation		Median		Range	
	LPstation	Laptop	LPstation	Laptop	LPstation	Laptop	LPstation	Laptop
Torque (Nm)	3.90	5.13	1.25	1.52	3.97	4.98	2.03–6.60	2.03–8.26
Subjective eval. of strain	1.75	2.12	1.13	1.21	1.60	2.50	0–4	0–5
Productivity score	23.9	21.10	9.32	9.49	21.3	16.25	12.5–40.8	12.2–39.7
Screen tilt angle (°)	11	27	4.99	5.15			5–18	16–32
Screen height (cm)	107	88	3.13	1.61			104–112	84–90

Note: Desk surface mean height, 73 cm and chair mean height, 49 cm.

To assess the difference in productivity in test situation A and B the subject was instructed to type a standardized task (including entering text and numbers from a paper copy) in Microsoft Word. The subject was asked to complete the task "as much and as correct as possible in 10 min". A productivity score was calculated according to the following formula:

(# of typed entries - # of incorrect entries)/ 10 min = # correct entries/minute.

2.3. Statistical analysis

Data are presented as mean, standard deviations, median and range. Paired t-tests were used to evaluate the difference of the C7-Th1 torque (flexion moment), subjective evaluation of strain and the productivity score.

3. Results

The mean, median values, standard deviations and ranges for each dependent variable can be seen in Table 1 when using a laptopstation and a laptop PC. The C7-Th1 mean torque in Nm was less using the laptopstation. The mean subjective evaluation of strain was also recorded to be less with use of the laptopstation. Furthermore, the results showed that compared with the laptop PC, using the laptopstation gave a higher mean productivity score.

The results of the paired t-tests are shown in Table 2. Included in the table are the mean differences for the C7-Th1 torque, subjective evaluation of strain and the productivity score. Statistical analysis showed significant differences ($p<0.05$) between laptopstation and laptop PC use in the torque at C7-Th1, the perceived strain on the neck, and in the productivity score.

Fig. 4 illustrates that the mean C7-Th1 torque was significantly less in using the laptopstation. In fact data analysis revealed that the mean torque at C7-Th1 was 24% less with using the laptopstation as compared to the laptop PC. The mean subjective evaluation of strain (during a 3 h and 40 min time span) using the laptopstation and laptop PC are compared in Fig. 5. Fig. 5 also demonstrates the linear trend of an increase in discomfort with the duration of time in both test situations. Overall the subjects assessment of the strain on the neck was 17% less when working on the laptopstation as compared to the laptop PC.

The laptopstation showed a higher mean productivity score compared to the laptop PC as seen in Fig. 6. Fig. 7 shows the individual productivity improvements when

Table 2
Results of paired t-tests to compare the effect of change when working with a laptopstation and a laptop PC ($n = 10$)

Variable	Mean difference	t
Torque (Nm)	1.23	-4.92^{***}
Subjective evaluation of strain	0.37	-2.40^{*}
Productivity score	2.81	2.9^{*}

$^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.
Note: For comparison non-parametric Wilcoxon test were conducted which showed similar results as paired t-tests.

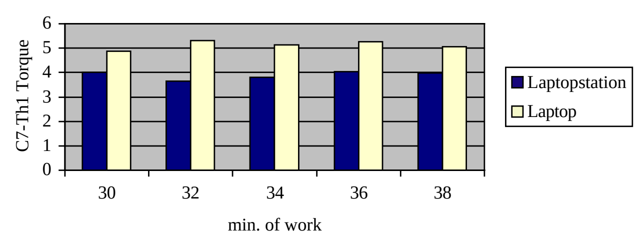

Fig. 4. Mean torque (Nm) on cervical segment C7-Th1 using a laptop station and a laptop PC ($n = 10$).

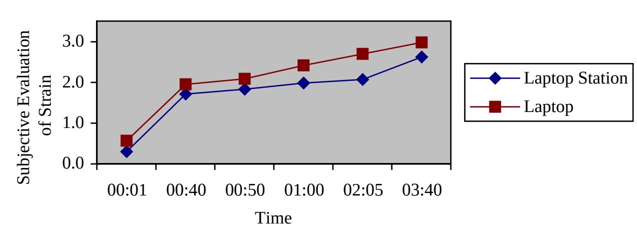

Fig. 5. Subject's evaluation of strain (Borg CR-10 Scale) when working on the laptopstation and the laptop PC ($n = 10$).

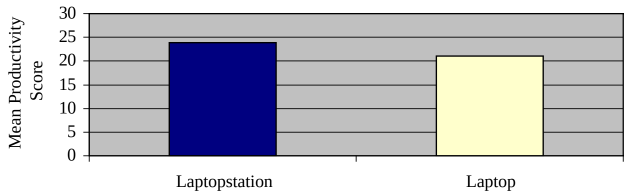

Fig. 6. Mean productivity score when using a laptopstation and a laptop PC ($n = 10$).

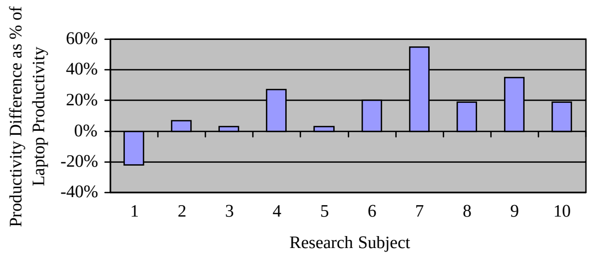

Fig. 7. Productivity improvement (%) using a laptopstation vs. laptop PC.

subjects were using the laptopstations as compared to the laptop PC as a percentage. Nine out of 10 subjects had a higher productivity score using the laptopstation. Overall the subjects were 17% more productive working on the laptopstation.

4. Discussion

The results of the present study showed a significant difference between working at a laptop PC and the laptopstation when calculating the moment of force on the neck, the subjective complaints of strain at the neck and in regard to productivity. The use of the laptopstation produced an average 24% decrease in the mechanical load (torque) on the C7-Th1 cervical segment, an average 17% smaller discomfort score and an average 17% higher productivity score when compared to the results from the laptop PC.

The results of the study confirm the importance of adjustable work tools that recognize anthropometric differences and biomechanics to meet the needs of individual customers during continuous VDT work. Recently several published studies that address physical implications and ergonomic issues in regard to laptop PC use have emerged (Straker et al., 1997; Saito et al., 1997; Harris and Straker, 2000; Horikawa, 2001; Szeto and Lee, 2002, Jonai et al., 2002). As discussed by Villanueva et al. (1997) biomechanical concepts confirm that an upright neck position will produce less mechanical load on the neck. The study also lends support to the finding that a more flexed neck produced higher neck extensor muscle activity. Another study by Kilbom and Persson (1987) found that those who worked at a VDT with increased forward flexion of the neck ran a higher risk for musculoskeletal disorders. The results of a study by Bauer and Wittig (1998) showed "that preference is to be given to a screen position in which the vision axis is horizontal or inclined slightly downward" when using a desktop PC. The present study found that during continuous laptop PC work the access to adjusting screen height, distance and the use of a separate keyboard and mouse will improve user comfort, productivity and reduce the mechanical load on the neck.

The use and sales of laptop PCs have increased steadily over the past 5 years. For example, Dell sales of laptop computers grew almost 60%, showing a growth rate twice as fast as that for their desktop PCs in the second quarter of 2001 (Source; University of Virginia, McIntire School of Commerce). The increase of laptop computers among mobile workers such as sales professionals is not surprising but the laptop PC is also an attractive solution to many other professional groups in response to lack of space, high worker density and enthusiasm for flexible working practices. With the growing use of laptop PCs it is more important than ever for users and organizations to consider advantages and disadvantages of the technology available to them and how to best apply it in their context. Because of the ergonomic disadvantages and awkward postures associated with laptop PC use the results of the present study confirm that the user would benefit from using a laptopstation during continuous work. The laptopstation used in this study was designed to be portable and lightweight with the mobile worker and the human-system interface in mind.

However, in situations where an external monitor can be used this is likely to be preferred over the use of the laptop screen with the laptopstation. Further research is needed to investigate the difference in using a laptopstation and a "docking station" using a desktop flat screen monitor. In using a desktop screen, ergonomic disadvantages of the laptop display such as narrow ranges of brightness and contrast, decreased linearity of displays gray scale, poor range of viewing angles, small size screens and occasional darkening of the screen during battery use can be avoided (Saito et al., 2000). This is significant when one considers the finding that when there is a conflict between vision and posture comfort the user normally privilege the first (Jonai et al., 2002, Saito et al., 2000).

5. Conclusion

In conclusion, the results of the present study found a reduction in mechanical load on the neck (C7-Th1 cervical segment) and an improvement in productivity and reported comfort with the use of the laptopstation as compared to the laptop. These results highlight the importance of design to allow for adjustability to meet anthropometric differences. They also highlight the need for laptop computer manufacturers and industrial designers to concentrate on the human-system interface technology in their next generation laptop PCs to address ergonomic disadvantages and produce a portable PC solution that allows for continuous work, low risk of Work-Related Musculoskeletal Disorders, high user productivity and comfort.

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