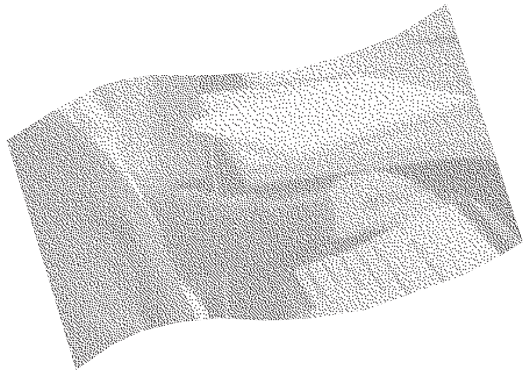
Musculoskeletal disorders and computer work

The impact of workstation layout on posture and muscle load of the upper limbs

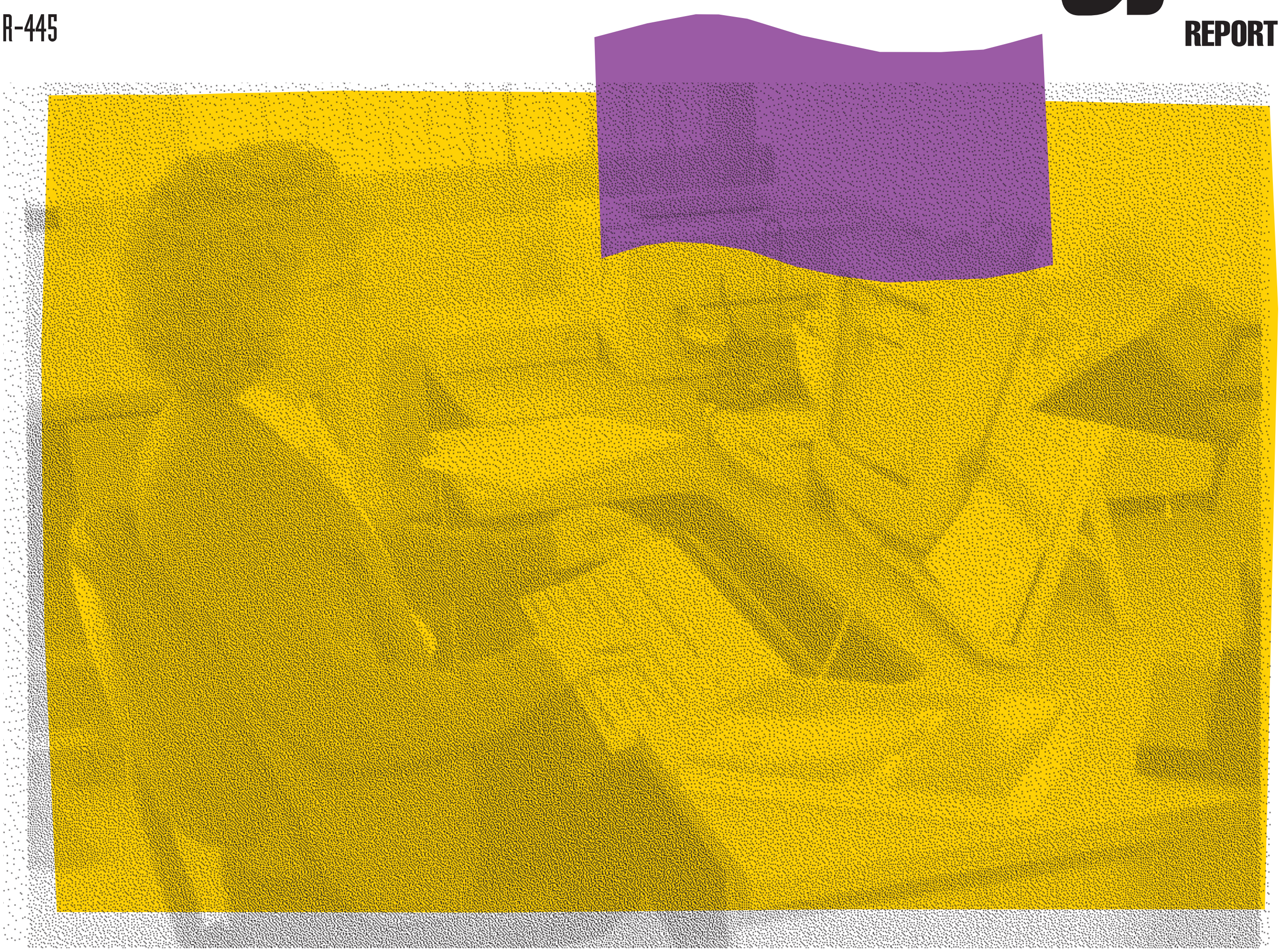


STUDIES AND RESEARCH PROJECTS

Alain Delisle
Christian Larivière
André Plamondon
Daniel Imbeau

R-445

REPORT



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IRSST – Communications Division
505, De Maisonneuve Blvb West
Montréal (Québec)
H3A 3C2
Telephone: 514 288-1551
Fax: 514 288-7636
www.irsst.qc.ca
Institut de recherche Robert Sauvé en santé et en sécurité du travail,
January 2006

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The impact of workstation layout on posture and muscle load of the upper limbs

Alain Delisle, Christian Larivière et André Plamondon, Safety Ergonomics, IRSST

Daniel Imbeau, École Polytechnique de Montréal

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This study was financed by the IRSST. The conclusions and recommendations are those of the author.

ABSTRACT

The objective of this study is to determine if the use of height-adjustable office furniture offering forearm support on the work surface results in a reduction in muscle load while minimizing the impact on the posture of the upper limbs. Eighteen subjects performed computer work for 20 minutes, alternating between keyboard work and mouse work, with three different office workstations: a single-surface workstation with independent monitor support, completely adjustable in height, providing support for the forearms (Workstation A); a workstation with an independent keyboard tray, with independent monitor support, completely adjustable in height (Workstation B); and a workstation with keyboard tray, not height-adjustable (Workstation C). Surface electromyography of four muscles (non-dominant and dominant trapezius, anterior deltoid, extensor digitorum communis) and three-dimensional kinematics of the dominant upper limb and head were used to compare the workstations.

The workstation with a single adjustable surface and offering forearm support (Workstation A) resulted in (1) a reduction in muscle load on the non-dominant trapezius, (2) less muscle load on the anterior deltoid during mouse work compared to the standard workstation (Workstation C), and (3) an increase in muscle load on the extensor digitorum communis. With respect to upper limb posture, Workstation A showed (1) smaller wrist extension compared to Workstation C during mouse work, and (2) greater flexion and abduction of the shoulder during keyboard work. No effect from the different workstations on head posture was observed.

The absence of any effect from office furniture on the activity of the dominant trapezius with the workstation permitting forearm support is rather surprising since, according to several studies, a reduction in muscle load on the dominant trapezius is reported with the use of an armrest. However, our study is distinguished by an important difference: the work task studied involved work alternating between the mouse and the keyboard, while in most previous studies, the task involved only one type of input interface at a time (keyboard or mouse).

The increase in muscle load on the extensor digitorum with Workstation A combined with a decrease in the muscle load on the anterior deltoid during use of the mouse corresponds in a way to a transfer from a proximal strategy to a distal strategy for the performance of mouse work. It therefore seems that the use of forearm support can be beneficial at the level of the neck/shoulder region to the detriment of the wrist/forearm region. A workstation permitting alternation between mouse work with the forearm supported and not supported would therefore likely be a promising alternative. This would permit alternating the greatest muscle loads between the muscles of the forearm and the muscles of the neck/shoulder region in order to provide intermittent rest periods.

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1. INTRODUCTION

Since the early nineties, a growing number of people have been using personal computers, both for their work and for their personal use. The introduction of computers has had major consequences on office work. For example, twenty years ago, typical office work involved a range of activities, including reading, writing, typing, etc. Because of the constant change in activities, there were natural short breaks, and the activities themselves were sufficiently varied to produce changes in posture and provide a form of variation in the nature of the mental, visual, and muscle activity. Today, it is possible to carry out many of these activities using a computer without ever having to move from the workstation. In addition to this change in the nature of the work, there are more and more significant time constraints, and complaints about various health problems have begun to appear. Disorders involving the shoulders and neck, and the upper limbs in particular are associated with computer work (Carter and Banister 1994; Grieco et al. 1998).

Workstation layout and work organization can be sources of musculoskeletal disorders. Workstation layout can, for example, force people to adopt poor posture, and/or not provide support, and work organization can, for example, limit the variations in work and lead to the adoption of prolonged static positions. Although this type of work entails a low level of muscle activation, it has been recognized that this type of muscle contraction can lead to chronic pain when maintained over long periods of work [see the literature review in Sjogaard and Sogaard 1998 on this subject]. In fact, it appears that partial obstruction of the blood vessels can result in fatigue and degeneration of the muscle fibres that are recruited at low intensity and over long periods of time ("Cinderella fibres" hypothesis, Sjogaard and Sogaard 1998). These observations seem to be particularly well documented for the trapezius, which could explain the pain often reported in the neck/shoulder region in association with computer work.

It therefore seems important to develop ways of permitting complete relaxation of the muscles involved in work as often as possible. Furthermore, the adoption of pauses during work have often been recommended in order to avoid discomfort (Fisher et al. 1993; Mclean et al. 2001; Sundelin and Hagberg 1989). However, the introduction of pauses during work is difficult to implement, and the frequency and optimal length of these pauses have not been established. Another proposed means is to favour support for the upper limbs during work in order to increase opportunities to relax the muscles involved. Support can be provided in various ways, either at the level of the wrist or at the level of the forearm (on an adjustable or fixed armrest, or on the work surface) and at the elbow (on the armrest of the chair). The literature contains data showing the effectiveness of the use of armrests in reducing the electromyographic activity (EMG) of the trapezius muscle, and other upper limb muscles (Aaras et al. 1997; Schuldt et al. 1987; Feng et al. 1997; Fernstrom and Ericson 1997; Hasegawa and Kumashiro 1998; Lintula et al. 2001; Visser et al. 2000;Wells et al. 1997). However, although this beneficial effect has been demonstrated, the consequences of the use of armrests on the wrist and shoulder postures as well as on the load on different muscle areas have not, to our knowledge, been documented simultaneously. According to Wells et al. (1997), support of the forearm or elbow is preferable for mouse work. In the study by Aaras et al., (1997) support of the forearms was provided on the work surface in front of the keyboard by moving it away from the front edge of the work surface. These authors reported a beneficial effect for the right and left trapezius for keyboard work, but did not document the impact on the other muscle regions, nor for mouse work. This configuration also offered the possibility of working with support for all the different activities performed, i.e., for keyboard work, mouse work, and for writing tasks. The use of the armrest of a chair, and even an adjustable armrest, did not provide support for all these activities, which are often performed alternately. Moreover, this type of configuration resulted in more distance from the keyboard, which could also have positive consequences on head posture. For example, for a person who is not a touch typist, greater distance from the keyboard could limit neck flexions associated with looking at the keyboard. The choice of office furniture and the layout of workstations can therefore have considerable repercussions on muscle load for individuals.

The purpose of the study is therefore to compare three types of workstation (one providing support for the forearms on the work surface) with respect to their impact on the posture kinematics of the entire upper limb and on the muscle load for four muscles.

2. OBJECTIVES

The main objective of this activity is to document the impact of three types of office furniture on the three-dimensional kinematics of the dominant upper limb and the EMG activity of four muscles.

The following question is asked: Does the use of height-adjustable office furniture offering forearm support on the work surface result in a reduction in muscle load while minimizing impact on the posture of the upper limbs?

3. METHODOLOGY

The procedure we followed consisted of an experimental assessment in the laboratory with office employees whose jobs include a large component of computer work.

3.1 Subjects

Twenty subjects volunteered to take part in the study. Two subjects had to be excluded because of technical problems. Of the 18 remaining subjects, 15 were women and 3 men, with a mean age of 37 (23 to 53), a mean height of 1.66 m (1.49 to 1.85 m), and a mean weight of 67.5 kg (54.1 to 98.0 kg). The anthropometric data and individual characteristics for the subjects are provided in appendix 1. Only one of the subjects was left-handed and he used the mouse with his left hand. Nine of the subjects stated they were touch typists, and the other nine were not. All subjects used a computer for most of their work duties.

3.2 Procedures

Three office workstations were compared (Figure 1):

1. a single-surface workstation with independent monitor support, completely adjustable in height, providing support for the forearms (Workstation A, Figure 1A)
2. a workstation with an independent keyboard tray, with independent monitor support, completely adjustable in height (Workstation B, Figure 1B)
3. a workstation with a keyboard tray that was not height-adjustable (Workstation C, Figure 1C)

The position of the monitor was kept constant for the three workstations in order to isolate the effects of the workstations. Unlike what is shown in Figure 1, the chair was always the same for the three layouts. The armrest component of the chair was adjusted according to the type of workstation. The monitor was positioned at eye level, approximately one arm's length from the subject so that the eyes were even with the top third of the screen, with the monitor slightly tilted to the rear. The backrest of the chair was adjusted in height to provide lumbar support, with an inclination between 100^{o} and 110^{o}. No wrist supports were used.

With Workstation A, the keyboard and the mouse had to be moved away from the edge of the desk in order to permit forearm support on the desk surface. The rear legs of the keyboard had to be left down, and the mouse was kept as close as possible to the keyboard on the dominant hand side. The entire work surface was the same height. The chair armrest was lowered so that the chair could be moved forward as close as possible to the desk, in order to permit forearm support on the desk surface. The height of the seat was adjusted so that the feet were flat on the floor, with knees at a 90^{o} angle. The chair was adjusted in the same way for workstations A and B, except for the armrests.

Figure 1. Comparison of the three workstations¶: (A) a single-surface workstation with independent monitor support, completely adjustable in height, providing support for the forearms (B) a workstation with an independent keyboard tray, with independent monitor support, completely adjustable in height; (C) a workstation

with an independent keyboard tray, with independent monitor support, non-adjustable.

¶ These photos do not show the actual context of the study.

With Workstation B, the keyboard was aligned with the edge of the keyboard tray, with the rear legs down and adjusted to elbow height (elbows flexed 90^{o}). The chair armrests were adjusted in height and width to provide elbow support. The mouse was kept as close as possible to the keyboard, on the keyboard tray, on the dominant hand side.

The keyboard tray for Workstation C was not height-adjustable, but the heights of the seat and the chair armrests were adjusted so that the elbow was at keyboard height (elbow bent 90^{o}). The chair armrests were adjusted in height and width to provide elbow support. The mouse was kept as close as possible to the keyboard, on the keyboard tray, on the dominant hand side.

For each workstation, the subjects performed a series of tasks involving moving and pointing at objects, entering data in forms and standard word processing, tasks that required alternating keyboard work and mouse work. Some of the tasks required the inputting of text read from paper, and others involved writing on paper a text read on the monitor. The order of presentation of the different parts was random. The time allowed for the performance of the tasks was 20 minutes, and if a subject completed all the tasks in less than 20 minutes, additional tasks already performed were presented to the subject randomly. Therefore all the subjects did not perform exactly the same work on the computer, but they all worked 20 minutes. This situation is very similar to a real work situation. Thanks to the optoelectronic system used, it was possible to distinguish the phases when the mouse was used and those when the keyboard was used (see section 3.3.1 below). A period of familiarization (15 minutes) with the different tasks was allowed before the acquisition period. A pause of 10 minutes was provided between each workstation and the order of presentation of the workstations was random. The total time for data acquisition was approximately 2 h 30 (preparation of the subject: 45 minutes, familiarization with the task: 15 minutes, acquisition: 60 minutes, pauses: 20 minutes.).

3.3 Measurement Techniques

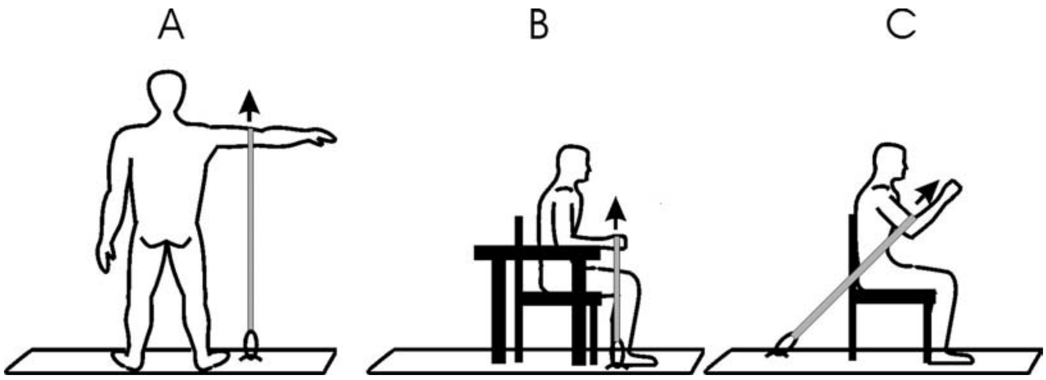
3.3.1 Electromyography

Four pairs of differential pre-amplified electrodes (gain: 1000) with a band-pass filter of 20 to 500 Hz (Delsys, Boston, MA) were used to measure EMG activity. The signal was recorded at a sampling frequency of 1024 Hz and digitized using an analogue-to-digital 12-bit acquisition card (National Instrument, DAQ-E). A high-pass digital filter with a cut-off frequency of 30 Hz was used to eliminate the electrocardiac signal, also reducing the potential influence of movement on the signal (Hansson et al., 2000). The RMS (root mean square) amplitude of the signal was calculated on successive 100 ms windows.

The EMG activity of the right and left trapezius muscles, of the dominant anterior deltoid and of the extensor digitorum communis/wrist extensor of the dominant arm were recorded according to procedures described in the literature. The choice of these muscles was based on the fact that many studies on computer work have examined these muscles (Bystrom et al., 2002; Jensen et al., 1998; Keller and Strasser, 1998; Laursen and Jensen 2000; Visser et al., 2002). For example, for the trapezius, the position of the electrodes followed the recommendations of Jensen et al. (1993). Briefly, the midpoint between the bony landmarks at C7 and the acromion was measured, and the pair of electrodes was placed two centimetres on either side of this midpoint. For the deltoid and the extensor digitorum communis, the electrodes were positioned according to the recommendations of Basmajian and Blusmenstein (1983). Three maximal reference contractions (duration: 5 s) for each muscle (trapezius, anterior deltoid, extensor digitorum communis) were performed to calibrate the EMG signal. For the second and third maximal contractions, a feedback of the maximum strength attained in the first contraction, increased by 10%, was provided to the subjects to encourage them to apply maximum effort (Baratta et al. 1998).

For the trapezius muscles, the subjects stood with one arm abducted at 90° with a strap attached to the floor at one end and to the elbow at the other end in order to perform an abduction of the shoulder against static resistance (strap), according to a procedure described by Mathiassen et al. (1995). Only one trapezius was tested at a time (Figure 2A). For the extensor digitorum communis/wrist extensor, a procedure similar to that described by Akesson et al. (1997) was used. The subject was sitting, with the arm flexed and the forearm pronated, resting on a table, with the hand unsupported, the wrist in a neutral position and the fingers extended. A strap, placed over the dorsal side of the hand and attached to a dynamometer providing static resistance to the subject, who applied maximum effort by attempting to extend the wrist (Figure 2B). For the dominant anterior deltoid, the subject was sitting with the elbow flexed 90°, the arm flexed 45°. A strap over the arm just above the elbow placed perpendicular to the arm and attached to a dynamometer provided static resistance against which the subject tried to flex the shoulder (Figure 2C).

Figure 2. Procedures to produce the reference muscle contractions to calibrate the EMG signal.



3.3.2 Kinematics

An optoelectronic system (Optotrak 3020, Northern Digital inc., Waterloo, Ontario) was used to determine the position and orientation of the hand, the forearm and the arm on the subject's dominant side. A rigid body with three light emitting diodes (LEDs) was attached to each segment, thus making it possible to determine their position and orientation in space at any time (Figure 3). In addition, two LEDs separated by approximately 0.14 m were placed at the seventh cervical vertebra (Figure 3).

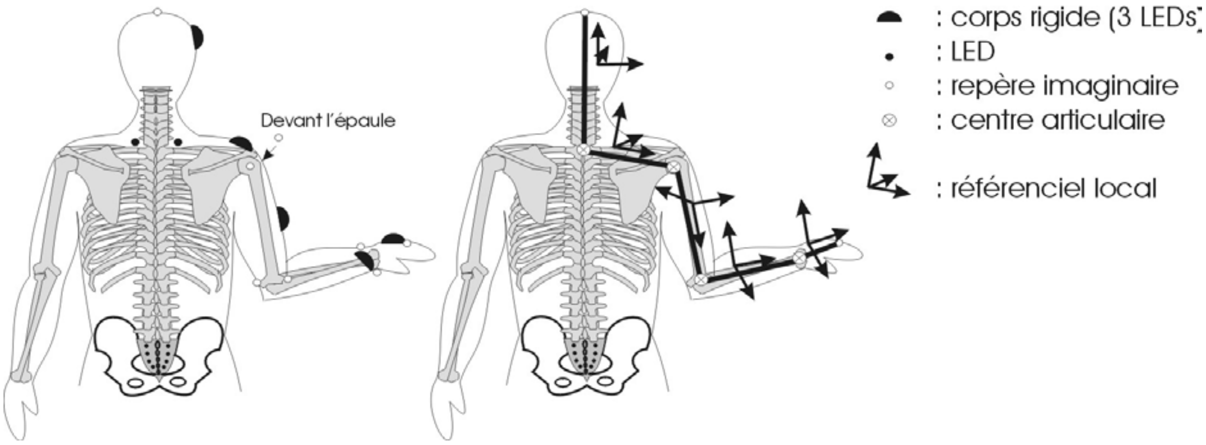
Bony landmarks (virtual landmarks) were digitized using a pen-probe to construct a local referential coordinate system for each segment. These virtual landmarks were associated with the most appropriate rigid body (on the same segment) so they could be reconstructed throughout the entire movement. Table 1 lists the digitized virtual landmarks and Figure 3 illustrates these landmarks.

Figure 3 also illustrates the local referential coordinate system for each segment. More specifically, the longitudinal axis of the hand was determined by a vector joining the mid-point between the two styloid processes and the third metacarpus. The transverse axis of the hand was the same as that of the forearm, and was determined by the vector joining the styloid process of the radius with that of the ulna. The sagittal axis of the hand was determined by the vector product of the transverse and longitudinal axes. The longitudinal axis of the forearm was determined by a vector joining the midpoint between the lateral and medial epicondyles and the midpoint between the styloid processes. The sagittal axis of the forearm was perpendicular to the longitudinal and transverse axis. The transverse axis of the arm was constructed using the inside and outside epicondyles of the elbow. The longitudinal axis of the arm ran through the midpoint between the epicondyles and the midpoint between two points in front of and behind the shoulder 0.03 m under the acromion. The sagittal axis of the arm was perpendicular to the transverse and longitudinal vectors. The transverse axis of the segment called the shoulder girdle ran through the cervicothoracic junction (C7/T1, determined according to the method described in Chaffin and Andersson (1991)), and through the midpoint between two points in front of and behind the shoulder 0.03 m below the acromion. The sagittal axis of the shoulder girdle was defined by the two points in front of and behind the shoulder. The longitudinal axis of the shoulder girdle was perpendicular to the sagittal and transverse axes. The longitudinal axis of the head extended from the cervicothoracic junction (C7/T1) to the top of the head. The tip of the nose provided a first estimation of the sagittal axis of the head, and its vector product with the longitudinal axis gave the transverse axis of the head. A system of axes was also constructed on the trunk; the transverse axis was parallel to the LEDs placed on either side of C7 and ran through the C7/T1 junction, and its corresponding longitudinal axis vertically, and its sagittal axis was the vector product of the previous axes.

Table 1 – The virtual anatomical landmarks digitized for every segment

Segment	Digitized landmarks
Hand	Distal tip of the 3rd metacarpus
Forearm	Styloid process of the radius
	Styloid process of the ulna
Arm	Inside epicondyle
	Outside epicondyle
Shoulder girdle (name given to a segment between C7 and the shoulder joint)	A point anterior to and 0.03 m below the acromion
	A point posterior to and 0.03 m below the acromion
Head (segment between C7 and the top of the head)	The top of the head
	The tip of the nose

Figure 3. Layout of the external landmarks (on the left) and definition of the junctions and the local referential coordinate system used to define the three-dimensional joint angles (on the right). [picture labels: Front of the shoulder / rigid body (3 LEDs) / LED / virtual landmark / junction / local referential system]



The joint angles were calculated from the local referential coordinate system described above, according to the approach described by Grood and Suntay (1983). Thus, the flexion/extension of the wrist was defined by the angle between the longitudinal axes of the hand and the forearm around the transverse axis of the forearm, with extension positive. The radial/ulnar deviation was defined by the angle between the longitudinal axis of the hand and the transverse axis of the forearm around an axis perpendicular to the longitudinal axis of the hand and transverse axis of the forearm, with ulnar deviation positive. The flexion/extension of the shoulder was defined by the angle between the longitudinal axes of the shoulder girdle and the arm around the transverse axis of the shoulder girdle, with flexion positive. Internal/external rotation of the arm was defined by the angle between the transverse vectors of the shoulder girdle and the arm around the longitudinal axis of the arm (an angle of 0^{o} corresponding to the neutral position, with external rotation positive). Abduction/adduction of the shoulder corresponded to the angle between the longitudinal axis of the arm and the transverse axis of the shoulder girdle around an axis perpendicular to the longitudinal axis of the arm and the transverse axis of the shoulder girdle. The flexion/extension angle of the head was defined by the angle between the longitudinal axis of the head and a longitudinal axis of the trunk (vertically), around the transverse axis of the trunk. The rotation of the head corresponded to the angle between the transverse axis of the head and the transverse axis of the trunk around the longitudinal axis of the head, and the lateral inclination of the head was the angle between the longitudinal axis of the head and the transverse axis of the trunk around an axis perpendicular to the longitudinal axis of the head and transverse axis of the trunk.

Finally, in order to be able to determine when the hand was on the mouse or on the keyboard, rigid bodies with LEDs had also been placed on the keyboard and the mouse. The four corners of the keyboard, as well as the three extremities of the mouse, were digitized using a pen-probe. It was therefore possible to compare the position of the hand (right or left) in relation to the keyboard or the mouse.

3.3.3 Perception

In order to evaluate the perceived effect of the workstations, three questions were asked of each subject after they used each workstation, with an evaluation on a scale of 1 to 10. Two questions dealt with perceived tension (1= no tension, 10 = extreme tension), one for the neck/shoulder region, the other for the hands/wrist/forearm region. The third question was on an estimation of the level of comfort with each workstation (1= very comfortable, 10 = extremely uncomfortable).

3.4 Data Analysis

In order to analyze and process the data so that the effect of each experimental condition (three workstations) on the different muscles could be appreciated, we used three types of analysis. The same analyses were carried out on the EMG signal normalized according to a maximal reference contraction (MVE), independently for mouse work and keyboard work. It was only possible to analyze the portions of the task performed with the mouse and the keyboard, because the portions of the task involving writing could not be dissociated from movements from one interface to another.

First of all, the Amplitude Probability Distribution Function (APDF) (Jonsson 1978) was used to calculate the EMG activity levels corresponding to the 10th (static level), 50th (median level) and 90th (maximum level) percentile (%ile). In other words, the amplitude values corresponding to these percentiles represent activity levels that are exceeded 90%, 50% and 10% of the time, respectively.

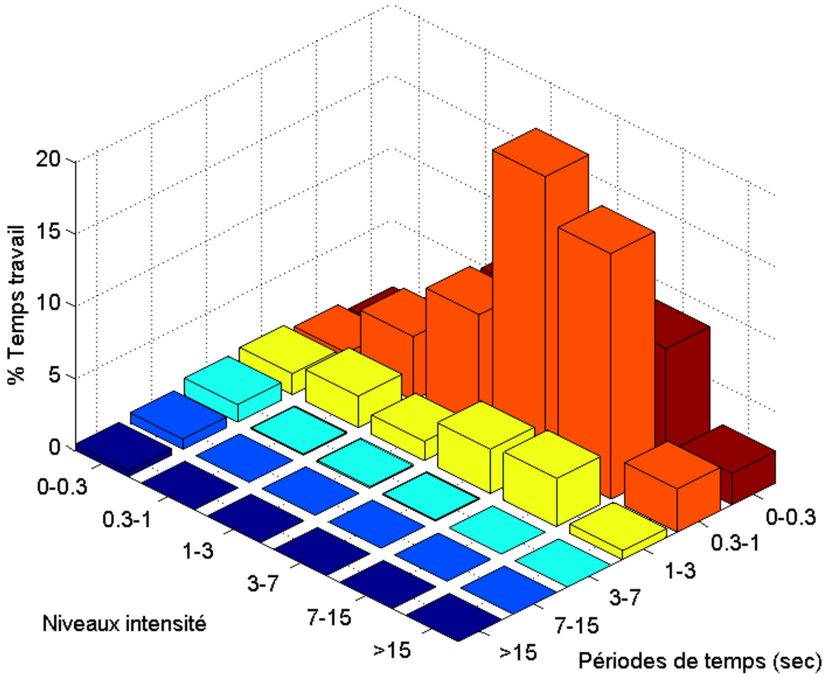
Second, an Exposure Variation Analysis (EVA) (Mathiassen and Winkel, 1991) was also performed (Figure 4). This analysis made it possible to describe the EMG signal as a distribution of predetermined intensity classes (EMG amplitude, X-axis) according to a distribution of predetermined duration classes (temporal properties of the signal, Y-axis). The Z-axis corresponds to the time cumulated in each combination of intensity and duration classes expressed as a percentage of the total measurement time. The classes on the X- and Y-axes used were the same as those described by Mathiassen and Winkel (1991). Although the EVA method seems to contain sufficiently complete information on exposure, the data are not reduced to a single index (n = 36 for the EMG analyses), which makes it difficult to use them to compare processes or to do an assessment of a change using measurements repeated over time. To this end, we used an approach found in the literature (Jensen et al., 1999) which consists of doing a summary of the intensity classes for each duration class and the summary of the duration classes for each intensity class, which reduces the number of comparisons to 12 in the case of the EMG.

Thirdly, analyses of the number of gaps (muscle rest) in the activity pattern (EMG "gap analysis": Veiersted et al., 1990, Hansson et al., 2000), and of the portion of time at rest (Hansson et al., 2000) were performed for the right and left trapezius only. A gap in the EMG activity pattern is defined as being a period equal or greater in duration to 0.2 s with an activation level less than 0.3% of the MVE. The total number of these gaps is the first index, and the summary of the duration of the gaps constitutes the second index.

For posture analysis, EVA similar to that described above, in addition to values for the 10th, 50th and 90th %iles for the angles (APDF), were used to determine the impact of the three conditions on the six joint angles calculated. This type of analysis has not yet been used to describe kinematic data, and the intensity and duration classes for maintaining postures had to be defined. The intensity classes chosen vary from joint to joint since the amplitudes measured are clearly different, but the duration classes for the maintenance of postures are the same. As for the EMG, each of these analyses was performed independently for keyboard work and mouse work.

Analyses of variances for repeated measures were performed to determine the effect of the workstation (Workstation effect), and the effect of the input interface (Interface effect) as well as their interaction (Workstation × Interface). For the kinematic data, analyses were performed on the APDF values for angle only. Multiple post-hoc comparisons using the Bonferroni correction were performed to identify significant differences between the different workstations and double interactions. A level of significance $p \leq 0.05$ was used. Finally, for the three perception questions, the Friedman analysis of variance by ranks was used to determine if perceptions differed from workstation to workstation (Workstation effect).

Figure 4. Exposure Variation Analysis (EVA). Typical example of the results of this type of analysis. It should be noted that the more the distribution was in the low intensity and short duration classes, the lower the physical exposure. [picture labels: % Work time / Intensity levels / Time periods (sec)]



4. RESULTS

On average, the task performed required the use of the keyboard 68% of the time, the mouse 18% of the time, and 14% of the time was used for writing and moving from one interface to the other (Table 2). The average time spent for each interface was similar for all the workstations, except for Workstation C, which involved a little more time for keyboard work (6% more), and a little less for writing and other movements (6% less). Although the averages and standard deviations were calculated for each input interface, only the overall averages (combining keyboard and mouse) for each type of workstation will be presented in the result tables. However, the most revealing Workstations × Interface interactions will be presented graphically.

Table 2. Average percentage of time (standard deviation) spent with each interface to perform the task according to the workstation and the average for all three workstations.

	Keyboard	Mouse	Other
Workstation A	65.4 (10.1)	19.4 (7.2)	15.1 (10.8)
Workstation B	66.9 (15.2)	17.8 (8.5)	15.3 (10.4)
Workstation C	72.8 (12.2)	17.2 (9.1)	9.9 (9.0)
Average	68.4 (12.9)	18.2 (8.2)	13.5 (10.3)

4.1 Effect on muscle load

4.1.1 *Amplitude Probability Distribution Function (APDF)*

The extensor digitorum communis turned out to be the only muscle for which the amplitude of the EMG signal was affected by the type of workstation (Workstation effect, Table 3). Workstation A resulted in greater "static" (10th %ile) and "median" (50th %ile) EMG amplitudes for the extensor in the order of 1%, while the "maximum" amplitude (90th %ile) was weaker for Workstation B, in the order of 2%. Moreover, the anterior deltoid was affected differently according to the workstation-interface combination used (significant interaction, Table 3). In fact, as shown in Figure 5, Workstation C resulted in lower "median" (50th %ile) and "maximum" (90th %ile) activation amplitudes for the deltoid during keyboard work, the most remarkable difference being the "maximum" activation amplitude, which was 4% lower than that for Workstation A. However, during mouse work, Workstation A resulted in "median" and "maximum" amplitudes for the deltoid lower than those for Workstation C (Figure 5), by approximately 2%. Finally, relative activation amplitude (MVE) for the extensor digitorum communis were clearly the greatest (Table 3, 10th %ile: ~ 8% MVE; 90th %ile: ~ 24% MVE), followed by those for the anterior deltoid (10^e %ile: ~ 2% MVE; 90th %ile: ~ 9% MVE), and those for the dominant trapezius and the non-dominant trapezius, which had similar levels (10th %ile: ~ 1.5% MVE; 90th%ile: ~ 7% MVE).

Table 3. Average values (standard deviation) for the APDF for the different muscles (expressed in percentage of the MVE).

		Bureau A	Bureau B	Bureau C	Effet Bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Trapèze non-dominant	10e	1 (1)	2 (1)	2 (1)	0.290				0.001	0.787
	50e	3 (3)	4 (2)	4 (2)	0.700				0.001	0.854
	90e	7 (4)	7 (3)	7 (3)	0.596				0.002	0.757
Trapèze dominant	10e	2 (2)	2 (2)	2 (1)	0.842				0.011	0.228
	50e	4 (3)	4 (3)	3 (2)	0.508				0.005	0.834
	90e	8 (4)	7 (4)	6 (3)	0.123				0.110	0.942
Deltoïde antérieur	10e	2 (3)	2 (3)	2 (3)	0.156				0.048	0.005
	50e	4 (5)	5 (5)	4 (4)	0.208				0.000	0.000
	90e	10 (8)	10 (7)	9 (7)	0.333				0.006	0.000
Extenseur des doigts	10e	9 (3)	8 (2)	8 (2)	0.001	*	*		0.157	0.436
	50e	15 (5)	14 (4)	14 (4)	0.000	*	*		0.969	0.292
	90e	24 (8)	22 (6)	24 (9)	0.009	*		*	0.113	0.277

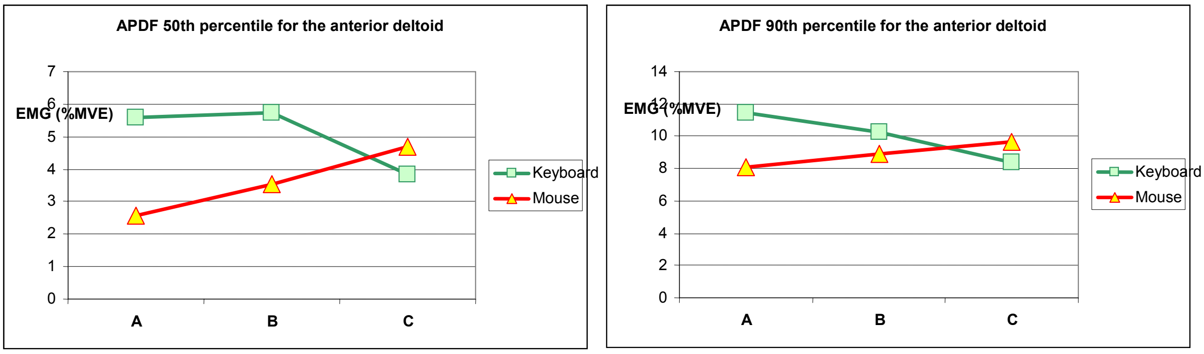
[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Non-dominant trapezius / 10th / 50th / 90th
Dominant trapezius / 10th / 50th / 90th
Anterior deltoid / 10th / 50th / 90th
Extensor digitorum / 10th / 50th / 90th]

¶ So the information could be summarized in a single table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

4.1.2 Exposure Variation Analysis (EVA)

Given the nature of EVA, it is understood that a decrease in time in a given class of intensity or duration necessarily implies an increase in time in another class of intensity or duration in order that the total is always 100% of the work time (sum of the percentage of work for all the classes). In the presentation of the results and in the discussion, we will use the term "transfer" to describe this phenomenon. It sometimes happens that the time transfer occurs from one specific class to several other classes. It is therefore obvious that significant differences will be obtained only for classes in which the largest changes occur.

Figure 5. APDF of the anterior deltoid for the 50th and 90th percentile during keyboard and mouse use according to each workstation.



Non-dominant trapezius. The EVA reveals that the use of Workstation A was beneficial for the non-dominant trapezius. Thus, with Workstation A, significantly less time was spent in the 3-7% MVE intensity class (Table 4), and slightly more time (transfer) in the minimal and maximum intensity classes (insignificant difference). The percentage of time spent with a very short contraction time (0.0-0.3 s) was also longer with Workstation A compared to Workstation C (Table 4), while less time was spent with contraction durations of 1 to 3 s.

Dominant trapezius. The type of workstation had almost no effect on the EVA variables for the dominant trapezius, with only slightly (1%) more time spent in the maximum intensity class (> 15% MVE) with Workstation A compared to Workstation C (Table 5).

Anterior deltoid. Workstation A contributed to reducing muscle load on the deltoid by reducing the percentage of time spent in the 3-7% MVE intensity class (significant difference with Workstation B) and by increasing the percentage of time spent in the 0.3-1% MVE intensity class (significant difference with Workstation C) (Table 6). However, the contraction duration seemed longest for Workstation A, since less time was spent in the 0.0-0.3 s. duration class (differences with workstations B and C) and since more time was spent in the 3-7 s. duration class (difference with Workstation C). Figure 6A shows that the increase in time spent in the 0.3-1% MVE intensity class with Workstation A occurred mostly during mouse work. In the same way, the decrease in the time spent in the 0.0-0.3 s duration class and the increase in time in the 3-7 s. duration class with Workstation A occurred mostly during mouse work (Figure 6C and D respectively).

Extensor digitorum. For the extensor digitorum, Workstation A had the effect of increasing muscle load compared to Workstation B since less time was spent in the 7-15% intensity class, and since more time was spent in the maximum intensity class (>15% MVE, Table 7).

Workstation A also resulted in the longest contractions, since less time was spent in the 0.3-1 s. duration class and more time was spent in the 3-7 s. duration class (Table 7).

Table 4. Average values (standard deviations) for the different EVA intensity and duration classes for the non-dominant trapezius (expressed in percentage of total exposure time).

	Bureau A	Bureau B	Bureau C	Effet Bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Classes d'intensité (sommation des classes de durée)									
0-0.3 %	6.0 (15.0)	1.5 (5.0)	0.8 (2.5)	0.079				0.047	0.043
0.3-1%	16.0 (20.6)	13.7 (21.2)	12.4 (15.7)	0.465				0.004	0.223
1-3 %	30.7 (19.4)	27.4 (20.9)	30.7 (24.0)	0.765				0.162	0.314
3-7 %	31.2 (18.4)	42.0 (23.4)	42.8 (23.7)	0.017	*	*		0.013	0.094
7-15 %	13.5 (16.6)	14.3 (20.5)	12.5 (14.8)	0.876				0.016	0.951
> 15 %	2.6 (5.0)	1.1 (2.0)	0.8 (1.7)	0.075				0.080	0.092
Classes de durée (sommation des classes d'intensité)									
0-0.3 s	16.8 (7.4)	14.5 (6.6)	13.7 (4.9)	0.006		*		0.002	0.518
0.3-1 s	43.1 (12.3)	37.0 (12.8)	36.6 (11.9)	0.031				0.000	0.730
1-3 s	22.3 (7.3)	26.5 (8.6)	27.0 (7.5)	0.007	*	*		0.223	0.400
3-7 s	9.1 (6.6)	10.6 (7.4)	10.7 (7.8)	0.471				0.107	0.160
7-15 s	4.2 (6.2)	5.2 (8.6)	5.5 (6.4)	0.576				0.004	0.635
> 15 s	4.4 (11.2)	6.1 (12.9)	6.4 (10.0)	0.577				0.003	0.834

[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Intensity classes (summary of duration classes)
Duration classes (summary of intensity classes)]

¶ So the information could be summarized in a single Table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

Table 5. Average values (standard deviations) for the different EVA intensity and duration classes for the dominant trapezius (expressed in percentage of total exposure time).

	Bureau A	Bureau B	Bureau C	Effet Bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Classes d'intensité (sommation des classes de durée)									
0-0.3 %	1.0 (3.3)	1.3 (4.2)	1.2 (5.3)	0.937				0.116	0.775
0.3-1%	16.1 (24.3)	16.7 (24.8)	13.7 (19.6)	0.710				0.003	0.366
1-3 %	27.5 (18.2)	26.9 (22.0)	34.3 (22.5)	0.214				0.630	0.945
3-7 %	36.1 (18.3)	35.8 (21.7)	37.5 (21.2)	0.882				0.104	0.538
7-15 %	17.4 (19.9)	18.4 (22.9)	12.7 (19.6)	0.351				0.039	0.783
> 15 %	2.0 (3.4)	0.9 (1.9)	0.6 (1.2)	0.033		*		0.122	0.723
Classes de durée (sommation des classes d'intensité)									
0-0.3 s	16.5 (6.7)	16.6 (6.2)	16.0 (5.9)	0.817				0.000	0.277
0.3-1 s	42.6 (13.9)	42.4 (13.0)	41.3 (12.9)	0.892				0.000	0.187
1-3 s	23.1 (8.0)	25.4 (9.6)	25.2 (6.8)	0.407				0.271	0.130
3-7 s	8.7 (7.3)	7.3 (5.7)	9.6 (8.0)	0.370				0.054	0.132
7-15 s	4.3 (7.6)	5.1 (8.5)	4.7 (7.2)	0.877				0.000	0.212
> 15 s	4.7 (8.7)	3.2 (7.5)	3.2 (7.4)	0.605				0.012	0.272

[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Intensity classes (summary of duration classes)
Duration classes (summary of intensity classes)]

¶ So the information could be summarized in a single Table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

Table 6. Average values (standard deviations) for the different EVA intensity and duration classes for the anterior deltoid (expressed in percentage of total exposure time).

	Bureau A	Bureau B	Bureau C	Effet Bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Classes d'intensité (sommation des classes de durée)									
0-0.3 %	0.0 (0.00)	0.0 (0.00)	0.0 (0.00)	/				/	/
0.3-1%	23.4 (31.09)	18.4 (24.53)	16.4 (21.97)	0.006		*		0.002	0.004
1-3 %	30.2 (24.08)	28.6 (24.09)	35.6 (24.93)	0.018			*	0.257	0.002
3-7 %	22.3 (16.70)	28.4 (19.58)	25.0 (15.78)	0.033	*			0.031	0.113
7-15 %	17.2 (16.72)	17.1 (17.34)	16.1 (15.65)	0.863				0.031	0.001
> 15 %	6.9 (17.60)	7.5 (20.13)	6.9 (16.72)	0.822				0.281	0.011
Classes de durée (sommation des classes d'intensité)									
0-0.3 s	16.1 (8.46)	18.9 (8.44)	19.8 (9.16)	0.000	*	*		0.074	0.050
0.3-1 s	40.1 (18.00)	43.6 (16.81)	44.5 (15.37)	0.157				0.009	0.047
1-3 s	20.3 (7.87)	20.7 (7.94)	22.0 (10.04)	0.442				0.440	0.190
3-7 s	11.5 (10.24)	8.9 (10.39)	8.1 (9.31)	0.037		*		0.003	0.041
7-15 s	6.2 (9.03)	5.2 (8.50)	3.2 (6.27)	0.124				0.511	0.390
> 15 s	5.8 (12.58)	2.8 (6.58)	2.4 (9.87)	0.162				0.583	0.178

[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Intensity classes (summary of duration classes)
Duration classes (summary of intensity classes)]

¶ So the information could be summarized in a single Table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

Figure 6. Percentage of time spent in the (A) 0.3 - 1.0% MVE and (B) 1.0 - 3.0% MVE intensity classes and in the (C) 0.0-0.3 s. and (D) 3-7 s duration classes for the anterior deltoid for each interface and according to each workstation.

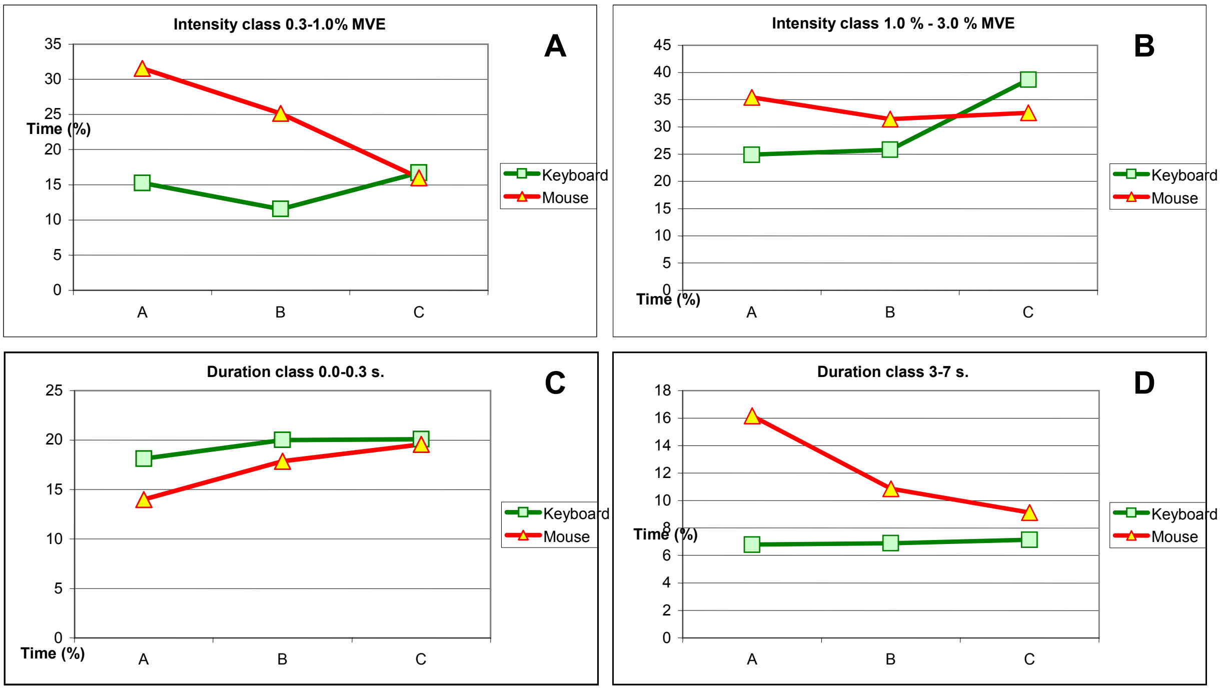


Table 7. Average values (standard deviations) for the different EVA intensity and duration classes for the extensor digitorum communis (expressed in percentage of total exposure time).

	Bureau A	Bureau B	Bureau C	Effet Bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Classes d'intensité (sommation des classes de durée)									
0-0.3 %	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	/				/	/
0.3-1%	0.0 (0.2)	0.0 (0.0)	0.0 (0.0)	0.424				0.279	0.424
1-3 %	0.8 (3.3)	0.9 (4.1)	1.4 (4.7)	0.119				0.199	0.811
3-7 %	7.0 (10.7)	9.1 (11.7)	10.2 (14.0)	0.016		*		0.776	0.576
7-15 %	45.0 (21.1)	50.3 (19.2)	45.7 (20.2)	0.008	*		*	0.155	0.586
> 15 %	47.1 (26.8)	39.7 (24.4)	42.8 (25.6)	0.001	*	*		0.341	0.458
Classes de durée (sommation des classes d'intensité)									
0-0.3 s	12.7 (4.4)	13.7 (4.0)	13.3 (3.7)	0.077				0.081	0.606
0.3-1 s	40.1 (14.4)	45.5 (13.1)	42.6 (11.7)	0.008	*			0.002	0.785
1-3 s	30.2 (7.7)	30.6 (7.5)	30.0 (6.4)	0.917				0.289	0.092
3-7 s	12.1 (10.4)	7.2 (7.5)	9.3 (9.2)	0.002	*			0.010	0.324
7-15 s	3.2 (6.3)	2.4 (5.8)	3.1 (4.3)	0.480				0.071	0.488
> 15 s	1.6 (6.5)	0.7 (3.2)	1.7 (6.1)	0.538				0.109	0.521

[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Intensity classes (summary of duration classes)
Duration classes (summary of intensity classes)]

¶ So the information could be summarized in a single Table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

4.1.3 Analysis of muscle rest

The type of workstation had no significant effect on the number of gaps or the time at rest for the trapezius muscles (Table 8), with the exception that the time at rest was greater for Workstation A during mouse work for the non-dominant trapezius only (Figure 7). It is important to note that no muscle rest was detected for the anterior deltoid and for the extensor digitorum communis.

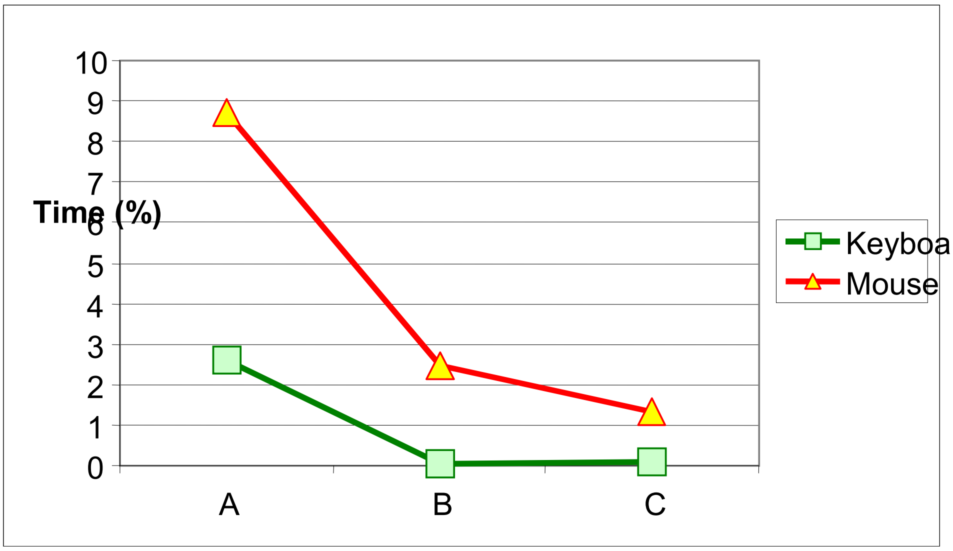
Table 8. Average values (standard deviations) for the number of gaps and the time at rest for the EMG activity of the dominant and non-dominant trapezius normalized for the maximal reference contraction.

	Bureau A	Bureau B	Bureau C	Effet Bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Nombre de repos/min.									
Trapèze non-dominant	2,88 (7,00)	0,94 (3,50)	0,51 (1,82)	0,097				0,065	0,277
Trapèze dominant	0,90 (2,80)	1,03 (3,50)	0,84 (3,50)	0,930				0,099	0,772
Temps au repos (%)									
Trapèze non-dominant	5,65 (14,60)	1,26 (4,49)	0,71 (2,34)	0,076				0,050	0,039
Trapèze dominant	0,77 (2,59)	0,98 (3,53)	1,03 (4,94)	0,907				0,125	0,865

[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Number gaps/min.
Non-dominant trapezius
Dominant trapezius
Time at rest (%)
Non-dominant trapezius
Dominant trapezius]

¶ So the information could be summarized in a single Table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

Figure 7. The cumulated time at rest in the EMG activity of the non-dominant trapezius for each interface according to each workstation.



4.2 Effect on posture

Both the type of workstation (workstation effect) and the input interface used (interface effect) affected the posture of the upper limb, differing according to the combination of workstation and interface (Workstation x Interface interaction, Table 9).

Wrist. The wrist extension was affected by the workstation used, with Workstation C resulting in the adoption of a greater wrist extension (4^{o}) compared to Workstation A (Table 9, 50th and 90th %ile). The significant interaction between the workstation and the interface used reveals that it was mouse work with Workstation C that showed greater wrist extension than the other two workstations (Figure 8A). EVA showed that the percentage of time spent with an extension between 10^{o} and 20^{o} is 46% for Workstation A, compared to 29% with Workstation C. In addition, the percentage of time spent with an extension between 30^{o} and 40^{o} was 6% for Workstation A, compared to 18% for Workstation C (data not shown). The wrist deviation was not affected by the workstation used, but a Workstation × Interface interaction was observed (Figure 8B).

Shoulder. Overall, shoulder flexion was greater (by 5 to 10 ^{o}) when using Workstation A (Table 9, 10th and 50th %iles), even though the maximum flexion with Workstation C was similar (Table 3, 90th %ile). The significant interaction between the workstation and the interface shows that the shoulder flexion with Workstation A was greater (by approximately 9^{o}) than with the other workstations solely for keyboard work (Figure 8C). The EVA shows that, for keyboard work, the percentage of time spent with a shoulder flexion greater than 20^{o} was 83% with Workstation A, compared to 52% for Workstations B and C, i.e., 30% more time with angle greater than 20^{o} using Workstation A (data not shown). Overall, shoulder abduction was slightly (3-4^{o}) but significantly less for Workstation B, compared to Workstations A and C (Table 9, 10th %ile). The significant interaction shows, however, that during keyboard work, shoulder abduction was larger for Workstation A, compared to the other two workstations (Figure 8D). EVA reveals that the percentage of time spent with arm abduction greater than 40^{o} with Workstation A was 59%, compared to 37% with Workstation B. Finally, slightly larger internal rotation angles for the arm (negative value less than $2\text{-}3^{o}$) were observed with the use of Workstation A (Table 9, 90th %ile).

Neck. Finally, neck flexion was not affected by the workstation used, except for the fact that Workstation C resulted a few times in a slightly smaller flexion ($2\,^{o}$) (Table 9, 90th %ile).

4.3 Effect on perception

There was no difference in the perception of tension in the neck/shoulders (Workstation A: rating 2.6; Workstation B: 2.9; Workstation C: 3.0) and hands/wrist/forearm regions (Workstation A: rating 2.4; B: 2.5; C: 2.7) among the workstations. However, Workstations A (rating: 2.4) and B (rating: 2.9) were perceived as significantly more comfortable than Workstation C (rating: 4.3).

Table 9. Average values (standard deviation) for the angles (°) in the 10th, 50th and 90th %ile (APDF) corresponding to the different joints and types of workstation.

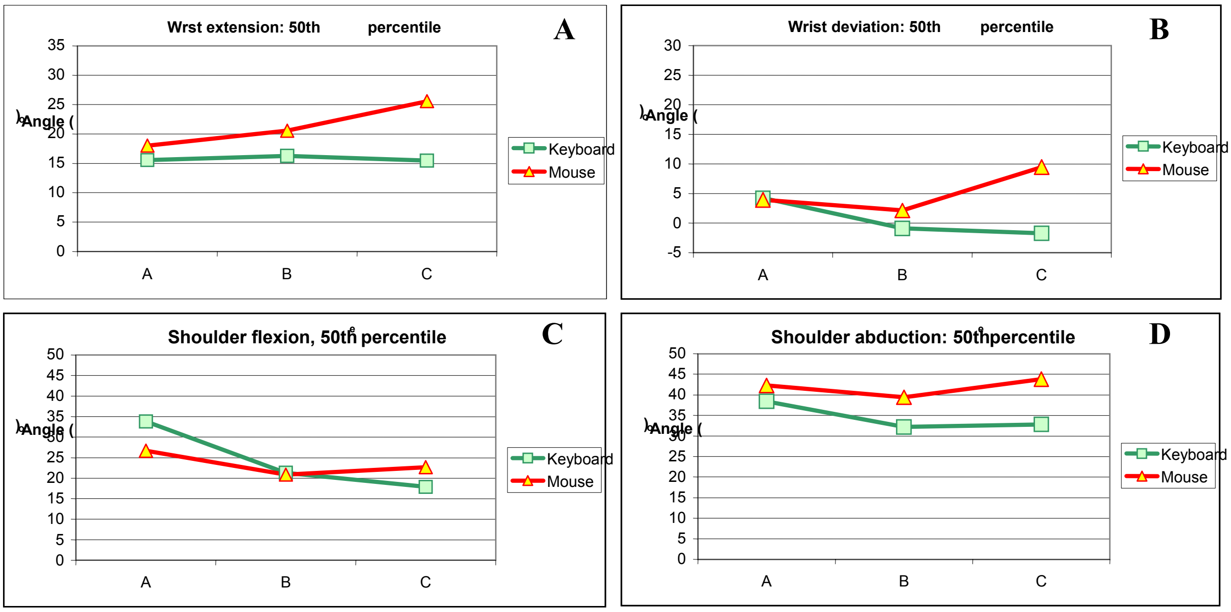
		Bureau A	Bureau B	Bureau C	Effet bureau	A vs B	A vs C	B vs C	Effet Interface	Effet B x I
Extension du poignet	10e	12 (9)	11 (11)	14 (11)	0.113				0.002	0.018
	50e	17 (9)	18 (10)	21 (11)	0.007		*		0.003	0.000
	90e	22 (8)	24 (10)	26 (10)	0.002		*		0.014	0.000
Déviation du poignet	10e	-3 (19)	-4 (9)	-4 (10)	0.894				0.718	0.026
	50e	4 (23)	1 (8)	4 (18)	0.732				0.024	0.053
	90e	11 (26)	10 (22)	9 (17)	0.941				0.004	0.068
Flexion de l'épaule	10e	25 (14)	17 (12)	16 (14)	0.000	*	*		0.339	0.002
	50e	30 (13)	21 (12)	20 (14)	0.000	*	*		0.661	0.001
	90e	35 (13)	25 (12)	34 (19)	0.001	*		*	0.009	0.013
Abduction de l'épaule	10e	37 (12)	33 (10)	36 (11)	0.002	*		*	0.000	0.002
	50e	40 (11)	36 (11)	38 (11)	0.001	*			0.000	0.008
	90e	44 (11)	40 (11)	47 (13)	0.016			*	0.003	0.017
Rotation de l'épaule	10e	-30 (18)	-27 (17)	-28 (20)	0.195				0.000	0.001
	50e	-25 (17)	-23 (17)	-20 (18)	0.000		*	*	0.000	0.107
	90e	-20 (18)	-18 (18)	-16 (18)	0.001	*	*		0.000	0.269
Extension/flexion du cou	10e	-14 (10)	-16 (12)	-15 (11)	0.194				0.000	0.024
	50e	-9 (11)	-10 (12)	-9 (11)	0.258				0.000	0.132
	90e	-4 (10)	-4 (11)	-2 (9)	0.016			*	0.000	0.239

[picture labels:
Workstation A / Workstation B / Workstation C / Workstation Effect / A vs B / A vs C / B vs C / Interface Effect / W x I Effect
Wrist extension / 10th / 50th / 90th
Wrist deviation / 10th / 50th / 90th
Shoulder flexion / 10th / 50th / 90th

Should abduction / 10th / 50th / 90th
Should rotation / 10th / 50th / 90th
Neck extension/flexion / 10th / 50th / 90th]

¶ So the information could be summarized in a single table, only the overall averages (combining keyboard and mouse) for every type of workstation are presented here. However, these statistical results reflect the overall results.

Figure 8. The values for extension angles (A) and wrist deviation (B), and the values for flexion (C) and abduction (D) angles for the shoulder for the 50th percentile during use of each input interface according to workstation.



5. DISCUSSION

5.1 Methodology

It is difficult to make comparisons with the literature for EMG because of the different tasks studied (data input, word processing, computer-aided drawing, pointing and clicking), the different experimental conditions (mouse only, keyboard only, alternating mouse and keyboard), as well as the methodological differences in normalizing the EMG signal. Large differences in the reported values are observed for computer work. For example, for the dominant trapezius, (Keller and Strasser 1998) report values of 25% MVE compared to values of 7% MVE in this study and those of Bystrom et al. (2002) and Jensen et al. (1998). For the anterior deltoid, the activation levels in this study are roughly similar to those reported by Keller and Strasser (1998), i.e. 5 to 10% MVE. Finally, the activation level for the extensor digitorum communis evaluated in this study is higher than what is reported in certain studies (Bystrom et al., 2002; Jensen et al., 1998; Keller and Strasser, 1998; Laursen and Jensen 2000), but similar to that reported in a recent study on mouse work (Visser et al., 2002)

Comparison of the results from this study with those in the literature with regard to posture is also difficult, since very few studies have reported angles computed in three dimensions. However, it is interesting to note very great similarities for the angles of neck flexion, and wrist extension and deviation between this study and those in Bystrom et al. (2002), even though the task in the latter study was computer-aided drawing. In addition, in the latter study, an elevation angle for the shoulder was reported. This angle obtained with an inclinometer represented an elevation angle with respect to gravity, and it was not possible to dissociate it from the flexion and abduction angles of the arm. If one considers the results for flexion and abduction angles in this study, they are quite similar to the elevation angle reported by Bystrom et al. (2002). In both studies, the fact that the forearms were supported probably explains in part the larger values reported in comparison with other studies (Jensen et al. 1998; Karlqvist et al. 1994; Karlqvist et al. 1998). However, the significant differences in the methods used to determine the shoulder angles could also help explain part of the difference in results. The studies of Jensen et al. (1998) and Karlqvist et al. (1994) were based on observation using planar video views, and that of Bystrom et al. (2002) on direct measurement (inclinometer). Like this study, the study by Karlqvist et al. (1998) was based on three-dimensional kinematic data, but with different angle definitions.

It is obvious that the EVA, which are more refined than APDF analyses, are also more sensitive for the detection of changes in level of physical exposure. It was not possible with APDF to detect that the largest differences were observed with respect to the extensor digitorum, while the EVA make it possible to detect distinctly more subtle changes for other muscles. For example, on the basis of the APDF analysis of the anterior deltoid, a greater (in amplitude) load was observed for Workstation A during mouse work (Figure 5). The EVA, however, revealed that this decrease in activation amplitude for the deltoid was accompanied by an increase in the contraction durations, resulting in a variation in exposure that was more complex than anticipated. Moreover, analysis of the number of gaps and time at rest revealed that no muscle rest was observed for the anterior deltoid and extensor digitorum communis. This confirms the EVA, since nothing was found in the intensity classes from 0.0 to 0.3% MVE (Tables 6 and 7).

The EVA therefore seem very appropriate especially for this type of comparison (between workstations) where the changes in physical exposure are relatively small (2 to 5%). In accordance with the hypothesis of Cinderella muscle fibres (Sjogaard and Sogaard 1998) these changes, which appear insignificant, are physiologically important. In fact, a decrease in muscle activation as small as 2% MVE can be beneficial in the long term (Finsen et al. 2001).

5.2 Effect of the workstation

The workstation used had effects both on posture and on muscle load on the upper limb with laboratory-simulated computer work. The workstation with a single adjustable surface and offering forearm support (Workstation A) resulted in (1) a reduction in muscle load on the non-dominant trapezius, (2) less muscle load on the anterior deltoid during mouse work compared to the standard workstation (Workstation C), and (3) an increase in muscle load on the extensor digitorum communis. With respect to upper limb posture, Workstation A showed (1) smaller wrist extension compared to Workstation C during mouse work, and (2) greater flexion and abduction of the shoulder during keyboard work. No effect from the type of workstation on head posture was observed.

The absence of any effect from the choice of office furniture on the activity of the dominant trapezius with the workstation permitting forearm support is rather surprising since according to several studies, a reduction in muscle load on the dominant trapezius is reported with the use of an armrest (Aaras et al. 1997; Feng et al. 1997; Wahlstrom et al. 2000; Wells et al. 1997). However, our study is distinguished by an important difference: the work task studied involved work alternating between the mouse and the keyboard, while in all the studies mentioned above, the task studied involved only one type of input interface at a time (keyboard or mouse). Furthermore, another study examined a task involving keyboard work and mouse work (word processing) without performing an analysis for each type of work, and the use of an armrest had no effect on the dominant trapezius (Fernstrom and Ericson 1997). There are various possible explanations: first of all, in all three setups the subjects could support their arms, which could reduce load on the trapezius; second, the need to go frequently from mouse to keyboard (and vice versa) could also explain the absence of any effect on muscle load on the dominant trapezius, since the subject always needs to be ready to move his or her arm. The task performed could consequently have a substantial effect on the results. The proportion of time spent using the mouse to perform the simulated task in this study was 18%. This proportion of time is slightly lower to that reported in a study in which the use of the mouse was documented specifically in a real work situation, in which the proportion of time spent using the mouse was 24% (Johnson et al. 2000), and therefore corresponds quite well to that observed for real computer work. The results therefore seem to apply to work that requires using the mouse and keyboard alternately. Finally, it is also possible that the height at which Workstation A was adjusted was not optimal to favour decreasing muscle load on the dominant trapezius. Rather than adjusting it to the same height as Workstation B, it probably would have been preferable to raise it appreciably. In fact, since the input interfaces were farther away, shoulder flexion was necessary to reach them, which had the effect of raising the forearm.

The reduction in wrist extension during mouse work with the workstation offering the possibility of forearm support (Workstation A) could be considered advantageous. However, the increase in muscle load on the extensor digitorum with this workstation instead shows the opposite, and corroborates the results in Fernstrom and Ericson (1997). The increase in the muscle load on the extensor digitorum with Workstation A combined with a decrease in the muscle load on the anterior deltoid for the use of the mouse corresponds in a way to a transfer from a proximal strategy to a distal strategy for the performance of mouse work, which some authors refer to. In fact, mouse work without forearm support can be initiated from the shoulder, while mouse work with forearm support is performed more using the wrist. In one study that compared these two work methods, mouse work with the forearm supported showed the least load on the trapezius muscles, while mouse work without forearm support showed the greatest load on the trapezius muscles (Wahlstrom et al. 2000). However, no difference was observed between these two work methods on the load on the extensor digitorum in this study, even though more force was applied to the sides of the mouse with the method offering forearm support. It is important to note that the level of muscle activation of the extensor digitorum was high compared to other studies, and it was continuous, i.e. with no muscle rest, as defined here. A load with little muscle rest for this muscle was also reported by Bystrom et al. (2002) and Laursen et al. (2001). Moreover, a recent follow-up study over 6 years of an intervention proposing the use of forearm support on the work surface reported a decrease in pain in the neck/shoulder region, but an increase in pain at the forearm level (Aaras et al. 2001). It therefore seems that the use of a support at the forearm level can be beneficial at the level of the neck/shoulder region to the detriment of the wrist/forearm region. A workstation permitting alternation between mouse work with the forearm supported and not supported would therefore likely be a promising alternative. This would permit alternating the greatest muscle loads between the muscles of the forearm and the muscles of the neck/shoulder region in order to provide intermittent rest periods. This observation confirms the fact that a simple technical modification in office furniture is not sufficient to completely eliminate risks associated with computer work. A similar observation has already been made for other types of work (e.g.: Attebrant et al. 1997) On the one hand, for a computer user who is experiencing discomfort in the neck/shoulder region, Workstation A could contribute to reducing this discomfort. On the other hand, this workstation is not recommended for someone who experiences discomfort in the wrist/forearm region. It also appears that a joystick-type mouse contributes to reducing muscle load on the forearm (Aaras and Ro, 1997), and reducing musculoskeletal symptoms (Aaras et al., 2002).

The increase in shoulder flexion and abduction for keyboard work with Workstation A could be considered an important risk factor for the shoulder (Hagberg et al. 1995). However, the fact that the levels of muscle activation for the dominant trapezius and the anterior deltoid were no greater with this workstation confirms that support was partly used at the forearm level, since these activation levels were not reduced either.

Finally, it is not surprising that the perceived tension was not affected by the type of workstation, given the low level of muscle load usually required for computer work. As for the perception of comfort with each workstation, Workstation C was clearly the most uncomfortable of the three, while there was no difference in the perception for Workstations A and B.

5.3 Limitations of the study

The subjects did not have much time to familiarize themselves with each type of workstation, which may have reduced the effects associated with the different workstations. A longer period of adaptation, especially with Workstation A, might favour the use of forearm support on the work surface and thus reduce muscle load in the long term. In addition, it is possible that different adjustments to the workstations could produce different results. For example, appreciably increasing the height of the work surface for Workstation A, compared to Workstation B, could favour a decrease in muscle load on the right trapezius. Moreover, the simulated task involved a variety of actions using the keyboard and the mouse alternately. It is therefore difficult to generalize the results to work contexts in which alternation between keyboard and mouse is infrequent. This was, of course, a laboratory simulation, and other organizational or social factors that could also affect muscle load could affect the results.

6. CONCLUSION

In comparison with layouts offering the possibility of support on the chair armrests, the use of the workstation offering the possibility of forearm support on the work surface (Workstation A) produced different effects according to the muscles involved. Workstation A resulted in a reduction in muscle load at the level of the non-dominant trapezius while the results for the dominant trapezius were not significant. However, there is reason to believe that becoming accustomed to this type of layout could help users benefit from the advantages offered by forearm support on the work surface. Another study would be required on this subject to elucidate this aspect. With respect to the wrist/hand region, an increase in the muscle load was observed for the extensor digitorum. Alternating between work with the forearm supported and not supported could be a useful way to introduce variation in muscle load between the neck/shoulder and wrist/hand regions.

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