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Biomechanical Stresses in Computer-Aided Design and in Data Entry

François Cail[a] & Michel Aptel[a]
[a] Biomechanics and Ergonomics Laboratory, Institut National de Recherche et de Sécurité, Vandoeuvre, France
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François Cail
Michel Aptel

Biomechanics and Ergonomics Laboratory,
Institut National de Recherche et de Sécurité,
Vandoeuvre, France

A study of the risk factors of musculoskeletal disorders (MSDs) of the upper limbs was carried out on 2 populations, 1 performing a computer-aided design (CAD) task and the other performing a data entry task. A questionnaire on MSD complaints and working life was completed by a sample of each population. Biomechanical measurements of the forces, the angles, and the repetitiveness of movements of the upper limbs were carried out on some operators in each sample. It emerged that complaints of the upper limbs seem to be linked to the use of input devices. The grip forces exerted when using the keyboard and mouse were higher in CAD than in data entry.

VDU work MSD biomechanical stresses

1. INTRODUCTION

Postural problems caused by working with computer display screens have been highlighted in numerous epidemiological surveys (Punnett & Bergqvist, 1997). The parts of the body concerned are primarily the neck, the shoulders, the lower back, and increasingly the upper limbs. Among these operators, the occurrence of upper-limb musculoskeletal disorders (MSDs) has been increasing rapidly since the end of the 1980s, particularly in the USA. It more than doubled each year in this country from 1988 to 1992 and continued

Correspondence and requests for offprints should be sent to François Cail, Institut National de Recherche et de Sécurité, Avenue de Bourgogne, B.P. 27, F-54501 Vandoeuvre Cedex, France. E-mail: <cail@inrs.fr>.

to rise less rapidly in 1993 and 1994 (Martin, 1994). In 1996, 15% of lost working time due to repetitive movements was attributed to typing with a keyboard (Amell & Kumar, 1999). Upper-limb MSDs now affect a large proportion of American office workers (Carayon & Smith, 1994), particularly data entry operators (Punnett, 1994) as well as those working on telecommunications screens (Hales et al., 1994) and in newspaper offices (Polanyi et al., 1997). A recent bibliographic review (Punnett & Bergqvist, 1997) noted that the greatest risks concern problems with the hands and wrists. The incidence of carpal tunnel syndrome is therefore sometimes high among display screen equipment operators (Hales et al., 1994; Sauter et al., 1993). In this respect, of a population of 164 workers working with display screens, Franzblau et al. (1996) observed that 13% had carpal tunnel syndrome. This pathology is also predominant during mouse use (Fogleman & Brogmus, 1995). Other MSDs associated with the use of this input device are cubital neuropathy, tenosynovitis of the wrist and fingers, and epicondylitis (Punnett & Bergqvist, 1997).

The factors at the origin of MSDs are multiple. They include individual factors (previous medical history, state of health, age, gender, etc.), work organisation, psychosocial factors, and stress, but also biomechanical stresses, which encompass the forces, the angles of the joints, and the repetitiveness of movements (Malchaire, Vergracht, & Cock, 2000; Punnett & Bergqvist, 1997). These biomechanical stresses are however often studied in the laboratory (Serina, Tal, & Rempel, 1999; Simoneau, Marklin, & Monroe, 1999) and rarely in the field. In addition, these studies often examine only one joint and do not always include the collection of subjective data.

To better understand the biomechanical stresses of all the upper limbs in in-situ information technology tasks, Institut National de Recherche et de Sécurité (France) undertook a field study in the service sector. The hypothesis formulated in this study was that there is a typology of biomechanical constraints linked to the task. To determine this, two populations, each numbering some 40 operators carrying out computer-aided design (CAD) tasks or data entry tasks, were chosen, as information technology is widely employed in both these tasks. These two populations worked in public organisations.

2. METHODOLOGY

The methodology used included the application of a questionnaire, an ergonomic study encompassing workstation dimension measurements, and biomechanical measurements carried out on the right upper limb.

Out of the aforementioned population of 40 operators, the questionnaire was put to 30 men working in CAD and 26 women working in data entry, who worked at least 4 hrs per day on display screens. These samples were composed on the basis of operator availability. The disparity in terms of gender between the two samples did not result from a deliberate choice on the part of the authors but reflected reality in the field. Workstation dimension measurements were conducted on all the CAD stations and on most of the data entry stations of the operators who completed the questionnaire. Finally, the biomechanical recordings concerned 11 CAD operators and 11 female data entry operators who had all filled in the questionnaire.

2.1. Questionnaire

The interviews were individual and they were carried out in isolated rooms. The questionnaire used comprised two parts: one concerning MSD complaints and the other personal experience of working life.

The part on MSDs came from a Norwegian questionnaire (Kuorinka et al., 1987). This allowed a list to be drawn up of the complaints of MSDs of the neck and upper limbs of the two populations. These covered the pain experienced in these parts of the body during the preceding 12 months. For each upper limb, the questions concerned the shoulder, the elbow, and the wrist-hand.

The part on working life included questions relative to the temporal organisation of the work, the workstation, and the use of input devices (Cail, Morel, & Aptel, 2000).

2.2. Ergonomic Study

An analysis of employee activity was carried out by observing them at work and by interviewing them and their managers. The dimensional measurements of the workstations concerned the height, length and width of worktops, the position of the display screen in relation to eye level, the distance between the edge of the table and the edge of the keyboard, the distance between the part of the keyboard located in the median plane of the operator and the mouse, the dimensions of these input devices, and the supports of the worktop. Finally, the length of time the input devices were used was evaluated from video recordings made during the biomechanical measurements.

2.3. Physiological Study

A physiological study was conducted aimed at determining the biomechanical constraints of the force, angle, and repetitiveness of movements of the right upper limb at joint level, with the exception of the elbow. The muscles chosen were the flexor muscles of the hand and fingers, the extensor muscles of the wrist, and the trapeze muscle. Only right-handed operators with no recognised pathology of the right upper limb having completed the questionnaire were retained. During these biomechanical measurements, the operators were filmed with a video camera.

2.3.1. Forces

The forces were evaluated by means of the electromyogram (EMG) of the flexor muscles of the hand and fingers, the extensor muscles of the wrist, and the trapeze muscle. The EMGs were recorded during a calibration trial and during work, and then they were integrated (EMGi). The EMG integration step was 100 ms. For the calibration concerning the flexor and extensor muscles the participant was seated with the arm vertical in slight abduction. The angle between the arm and the forearm was 90°. The forearm was horizontal and resting on an armrest. With the middle finger, the ring finger, and the little finger folded, the thumb and the index finger formed the two branches of a dynamometer that allowed maximum grip force to be exerted. For the calibration of the trapeze, the participant remained in a standing position for 20 s with the upper limbs in abduction at 90° and the hands dangling (Mathiassen, Bao, Attebrant, & Winkel, 1994).

The integrated EMG recorded during the calibration corresponded to the maximum isometric force for the flexors and extensors and to the submaximal contraction for the trapeze. Every value of EMGi recorded when working was then related to the corresponding calibration value. The force was therefore expressed as a percentage of this reference value.

2.3.2. Articular positions

The flexor-extensor and the cubital-radial deviation movements of the wrist when working were continuously measured by means of PENNY-GILES® (Biometrics, UK) goniometers. The accuracy of the measurement system was about 5°. The sampling frequency was 10 Hz. In keeping with convention, the flexion and cubital deviation angles measured were positive and those of extension and radial deviation negative. The operators were filmed from behind with a video camera to determine the angle of abduction of the right arm with the mouse and keyboard (average of typing on the alphabet section and typing on the number section). This abduction was measured by means of a goniometer on the fixed image of a television screen.

2.3.3. Repetitiveness

The flexion-extension and cubital-radial deviation angular signals of the wrist were derived in relation to time. Each change of sign of the derivative was defined as a movement and was counted in terms of the number of movements per minute. This variable represents the repetitiveness of the movements of the operators, that is, two values for the wrist. For practical reasons, only the repetitiveness of mouse use in CAD and of keyboard use in data entry were calculated.

2.3.4. Data interpretation criteria

The average EMG corresponded to the average of the electromyographic data expressed as a percentage of the reference value (see section 2.3.1.). This should not exceed 20% of the maximum force. With respect to the articular positions, the hand-forearm angle must lie between 10° in flexion and 30° in extension; arm elevation, either in a forward or lateral direction, must not exceed 20° compared to the trunk (Aptel, Lahaye, & Gerling, 2000).

2.3.5. Procedure

The biomechanical and video recordings were performed at a rate of one person per half-day, either in the morning or afternoon. For each participant, these data were recorded over two or three sequences 15 min apart. Each sequence lasted about 10 min. On account of signal quality problems, the average EMG of the flexors of one participant could not be processed.

2.3.6. Data processing

The keyboard utilisation times (calculated from the video recordings and expressed as a percentage of the total recording time) were separated from the mouse utilisation times in each sequence for both tasks.

For the articular positions and the electromyographic data, the counting was done according to the task and the tool. Thus, four classes were created: mouse in CAD, mouse in data entry, keyboard in CAD, and keyboard in data entry.

Chi^2 tests were carried out from the complaints of MSDs of the upper limbs to compare the two samples as well as the two sides. An ANOVA and a multiple range test were performed on the four classes for each EMG and each articular position. Student's *t* test was used to judge the differences between the averages of the biomechanical data. For the tests, the probability had to be less than 5% for the difference to be considered as significant.

3. DESCRIPTION OF THE SAMPLES AND THE WORK SITUATIONS

3.1. Samples of Employees Questioned

The CAD sample was exclusively male (N = 30) and the data entry sample exclusively female (N = 26). The level of qualification required for the CAD task was a Technical University Diploma in Civil Engineering; for the data entry task no qualification specific to the activity was required.

According to the results of the questionnaire, the average age of the sample was 42.5 ± 11.3 in CAD and 44.0 ± 7.8 in data entry; the difference in age of the two samples was not significant. The average height was 175.9 cm ± 6.1 in CAD and 162.7 cm ± 4.7 in data entry. Only 1 operator in each sample was left-handed. In addition, 1 CAD operator had a MSD of the wrist recognised as an occupational disease.

3.2. Input Device Utilisation Times

According to the results of the questionnaire, the average daily period of display screen work was 6.7 hrs ± 1.3 in CAD and 6.3 hrs ± 1.4 in data entry. This difference was not significant. The mouse was mostly used in CAD and the keyboard mostly used in data entry. According to the video data, on average, the mouse was used 81% of the time and the keyboard 10% of the time in CAD; in data entry the mouse was used 12% of the time and the keyboard 12% of the time (Figure 1). In addition, the time during which the input devices were not used was 9% in CAD and 26% in data entry.

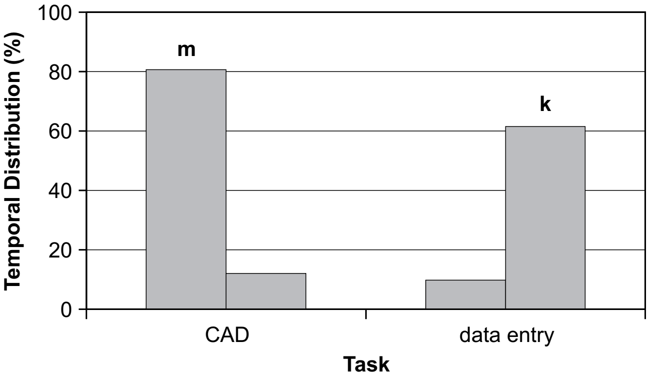

Figure 1. Temporal distribution of the use of the input devices according to task.
Notes. CAD—computer-aided design, m—mouse, k—keyboard.

3.3. Tasks

In CAD, the operators used a desktop computer with a keyboard and mouse. The task consisted in drawing up plans for the creation or renewal of road networks. In the first case, the operators worked from a specification including field data such as the location of the houses of local residents, cadastral plans, plans of the town, and existing structures. In the second, they worked with field observation files that are transformed into computer data. The plans were produced in a multilayer format with CAD software and were more or less unique in two dimensions. All the functions were grouped in the perimeter of the display screen. Moreover, the operators were required to consult various documents, particularly plans. According to the observations, the mouse was used with the right hand by all the operators, with the exception of one person, and generally with the forearm resting on the table. This type of support was noted in 80% of the operators. The other hand was mostly laid at the side of the keyboard. When the latter was used, 20% of the operators mentioned a wrist support.

In data entry, the female operators also used a desktop computer with a keyboard and mouse. The task consisted in entering the alphanumerical data appearing on the forms sent in by policyholders on a data-entry form. Once the identification of the policyholder had been entered, his or her details appeared on the screen. The operators were also able to search for the details of a person with the computer. The mouse was employed for this search and to process certain forms. Fifteen headings were available in the menu of the software. There was also a simplified data entry process that allowed all the information concerning the policyholder to be entered blindly (without using the screen). According to the observations, typing was mainly carried out with the right hand and generally with the wrist on the table when typing on the number keypad and the wrist floating when using the alphabet section of the keyboard. This wrist support was indicated by 42% of the female operators. With the mouse, 93% of the operators mentioned supporting the forearm.

3.4. Workstations

In CAD, the average height of the desks was 74.3 cm ± 1.5. The edge of the tables had a trapezoidal or rounded form. The back of the seat could be height adjusted. Twenty-one-inch screens were used. The height of the monitor was located above the level of the eyes of 54% of the operators. The keyboards used were standard types; Their average thickness was 2.5 or 3 cm. The mouse in most widespread use had a central wheel and two buttons.

In data entry, all the desks had a height of 72 cm. Their length was 140 cm in one building and 160 cm in the other. Their depth was 80 cm. The back of the seat could be height adjusted. Seventeen-inch screens were used. All of the monitors were on a jointed stand that was more than 15 cm above the table. Sixty-two percent of the operators answering the questionnaire pointed this out. Standard keyboards were used: Their average thickness was 3 cm. The mouse used had a width of about 6 cm and a maximum thickness of about 3 cm. They had two front buttons. The documents were placed between the keyboard and the operator or they were held in the left hand.

The average distances between operator and mouse as well as between the edge of the table and the edge of the keyboard in both tasks are given in Table 1.

TABLE 1. Average Distances and Standard Deviations (in cm) Between Operator and Input Device

Input Device	CAD	Data Entry
Mouse	39.8 ± 11.3	35.3 ± 7.0
Keyboard	17.7 ± 10.3	27.3 ± 3.7

Notes. CAD—a computer-aided design.

With the mouse, the difference between CAD and data entry was not significant. According to the results of the questionnaire, 40% of the CAD operators and 54% of the data entry operators considered that their mouse was far away. In CAD, the mouse was outside the proximal reach zone (35–45 cm) for 38% of the operators (Figure 2).

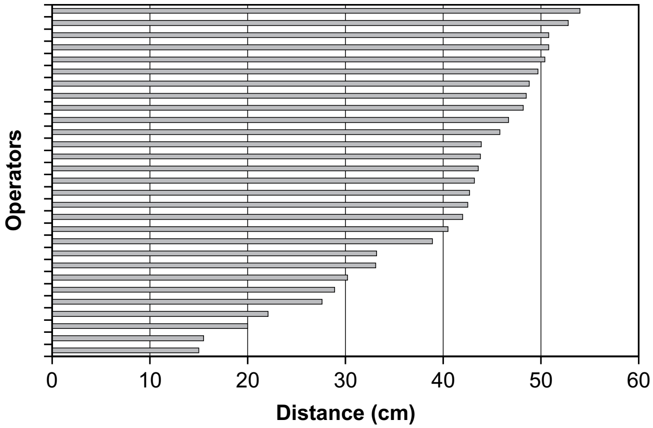

Figure 2. Distance between the edge of the table (median plane of the operator) and the mouse in CAD (individual results). *Notes.* CAD—computer-aided design.

With the keyboard, the difference between CAD and data entry was significant ($t = 3.92$, $p < .001$). The keyboard was further away in data entry than in CAD, as the operators placed or held their documents between themselves and the keyboard; this situation did not exist in CAD. Part 5 of the ISO 9241 standard (International Organization for Standardization [ISO], 1998) recommends that the distance between the edge of the keyboard and the edge of the table should be at least 10 cm, but it does not give an upper limit. However, one of the texts drafted prior to the final text recommends that the edge of the keyboard should be located between 10 and 15 cm from the edge of the table. The distance of the keyboard in data entry also explains the low interindividual variability concerning the positioning of this input device (Figure 3).

3.5. Conclusion

The CAD workstations were characterised by a variability of the mouse and keyboard arrangement, the mouse being the predominant tool. The data entry workstations were characterised by the keyboard, the predominant tool used, being further away. The position of the mouse was independent of the task whereas that of the keyboard depended on it. In both tasks, the use of the mouse generally led to supporting the forearm. Wrist support was indicated by the operators in both tasks for keyboard use.

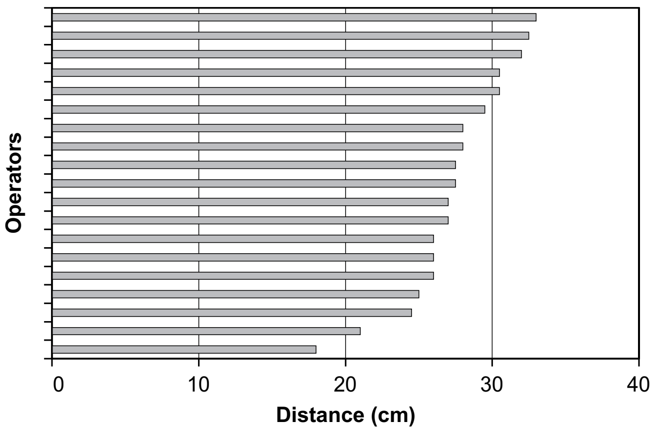

Figure 3. Distance between the edge of the keyboard and the edge of the table in data entry (individual results).

4. RESULTS

4.1. MSD Complaints

The percentage of operators complaining of cervical pain was 50 in data entry and 33 in CAD; the difference was not significant ($\chi^2 = 1.60$, $p = .21$).

The percentage of operators complaining of MSDs of the right upper limb was 62 in data entry and 43 in CAD; again the difference was not significant ($\chi^2 = 1.85$, $p = .17$). The percentage of operators complaining of MSDs of the left upper limb was 35 in data entry and 10 in CAD; the difference was close to the threshold of significance ($\chi^2 = 3.66$, $p = .06$; Figure 4).

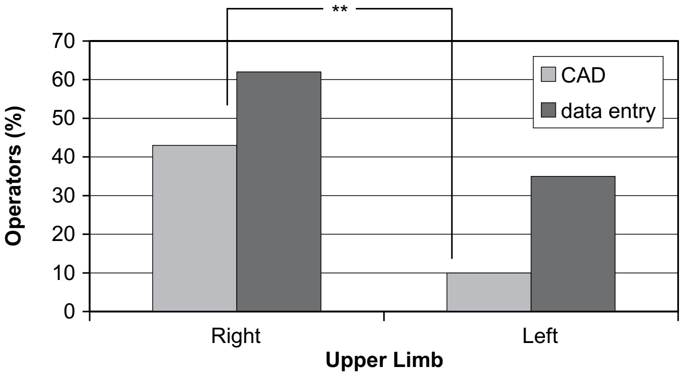

Figure 4. Percentage of operators complaining of musculoskeletal disorders (MSDs) of the upper limbs according to task. *Notes.* **$p < .01$, CAD—computer-aided design.

In addition, the percentage of operators complaining of MSDs of the upper limbs was significantly higher ($\chi^2 = 6.90$, $p < .01$) for the right side than for the left side in CAD. Moreover, the number of operators complaining of MSDs of the upper limbs was higher for the right side than the left side in data entry; the difference was at the threshold of significance ($\chi^2 = 3.77$, $p = .05$).

4.2. Articular Positions

The average articular positions of the upper limb extremity and the shoulder are presented in Figure 5. Only significant differences between tasks, for the same device, are shown in this figure.

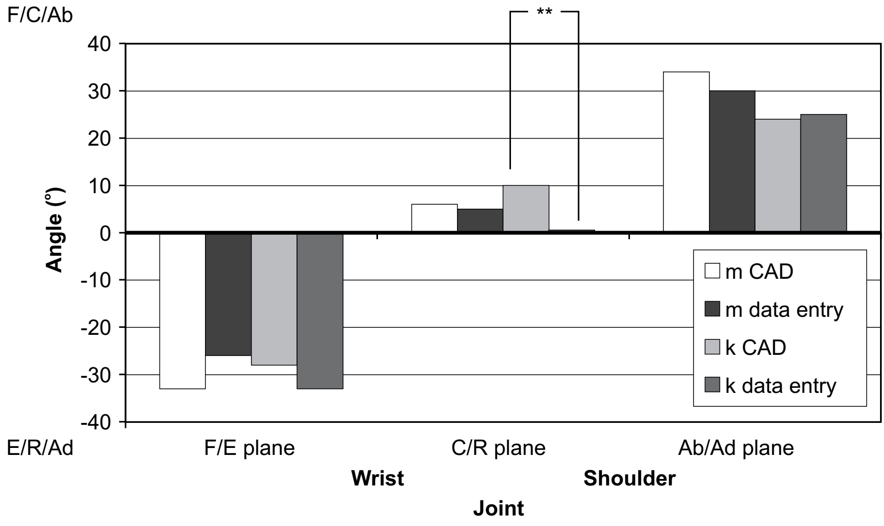

Figure 5. Average articular positions of the right upper limb according to task and tool. *Notes.* ***p* < .01; CAD—computer-aided design, m—mouse, k—keyboard; Ab—abduction, Ad—adduction, C—cubital, E—extension, F—flexion, R—radial.

For the wrist angle in the flexion-extension plane ($F = 1.88$, $p = .15$), the ANOVA showed no significant difference between the averages of the four classes. These averages were the following: mouse in CAD –33° ± 8, mouse in data entry –26° ± 10, keyboard in CAD –28° ± 6, keyboard in data entry –33° ± 8.

For the wrist angle in the cubital-radial plane, the ANOVA showed no significant difference between the averages of the four classes ($F = 2.10$, $p = .11$), but the multiple range test revealed a significant difference ($t = 2.99$, $p < .01$) between keyboard in CAD (10° ± 9) and keyboard in data entry (0° ± 5).

For the other two classes, the averages were –6° ± 11 for mouse in CAD and –5° ± 6 for mouse in data entry.

For the abduction-adduction angle of the shoulder, the ANOVA showed a significant difference between the averages of the four classes ($F = 6.93$, $p < .01$). The multiple range test revealed a significant difference between mouse in CAD (34° ± 4) and keyboard in CAD (24° ± 5; $t = 4.85$, $p < .001$) as well as between mouse in CAD (34° ± 4) and keyboard in data entry (25° ± 8; $t = 3.30$, $p < .01$). The average was 30° ± 1 for mouse in data entry.

To sum up, with the keyboard, the average cubital deviation angle of the wrist was higher in CAD than in data entry. The average abduction angle of the shoulder was higher with the mouse than with the keyboard, especially in CAD.

4.3. Electromyographic Data

The average EMGs of the flexor, extensor, and trapeze muscles are presented in Figure 6. Only significant differences between tasks, for the same device, are reported in this figure.

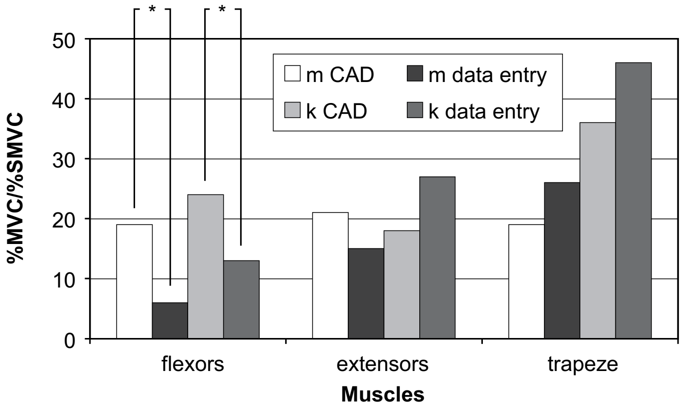

Figure 6. Average electromyograms (EMGs) of the right upper limb according to task and tool. *Notes.* $**p < .01$; CAD—computer-aided design, m—mouse, k—keyboard; MVC—maximal voluntary contraction (for flexors and extensors), SMVC—submaximal voluntary contraction (for the trapeze).

For the EMG of the flexor muscles, the ANOVA showed a significant difference between the averages of the four classes ($F = 3.85$, $p < .05$). The difference was significant ($t = 2.46$, $p < .05$) between mouse in CAD (19% ± 11) and mouse in data entry (6% ± 4). The difference was also significant ($t = 2.24$, *p* < .05) between keyboard in CAD (24% ± 13) and keyboard in data entry (13% ± 8). There was also a significant difference (*t* = 2.90, *p* < .01) between keyboard in CAD and mouse in data entry.

For the EMG of the extensor muscles, the ANOVA showed no significant difference between the averages of the four classes (*F* = 1.34, *p* = .27). These averages were the following: mouse in CAD 21% ± 17, mouse in data entry 15% ± 7, keyboard in CAD 18% ± 13, keyboard in data entry 27% ± 13.

For the EMG of the trapeze muscle, the ANOVA showed a significant difference between the averages of the four classes (*F* = 4.10, *p* < .05). The difference was significant (*t* = 3.37, *p* < .01) between mouse in CAD (19% ± 14) and keyboard in data entry (46% ± 23). The difference was significant (*t* = 1.98, *p* < .05) between mouse in data entry (26% ± 18) and keyboard in data entry (46% ± 23). The average was 36% ± 21 for keyboard in CAD.

To sum up, the average EMG of the flexor muscles was higher in CAD than in data entry, both with the mouse and keyboard. The average EMG of the trapeze muscle was higher with the keyboard than with the mouse, particularly in data entry.

4.4. Repetitiveness

The average repetitiveness of wrist movements in the flexion-extension plane and in the cubital-radial plane is presented in Figure 7.

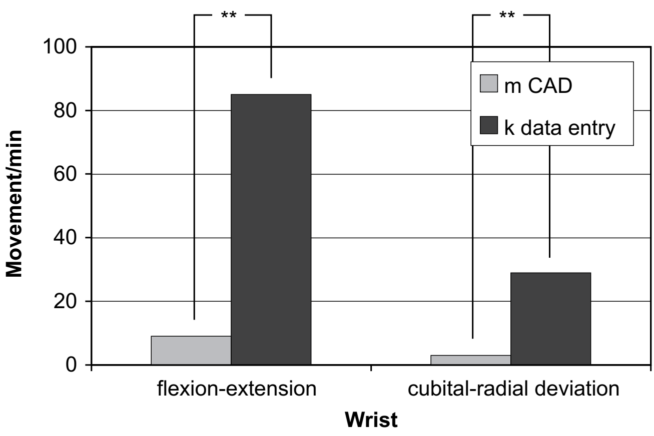

Figure 7. Average repetitiveness of wrist movements according to tool. *Notes.* ***p* < .01; CAD—computer-aided design, m—mouse, k—keyboard.

For the repetitiveness of flexion-extension wrist movements, the difference between mouse in CAD and keyboard in data entry was significant

($t = 9.60$, $p < .001$). The average repetitiveness was 9 movements/min ± 6 in CAD and 85 movements/min ± 25 in data entry.

In terms of cubital-radial repetitiveness, the difference between mouse in CAD and keyboard in data entry was significant ($t = 6.13$, $p < .001$). The average repetitiveness was 3 movements/min ± 3 in CAD and 29 movements/min ± 14 in data entry.

4.5. Interindividual Differences

Interindividual variability was high, both for the forces and for the angles of the joints. For example, the standard deviation, which expresses this variability, was 8 with keyboard in data entry for the average EMG of the flexor muscles (Figure 8).

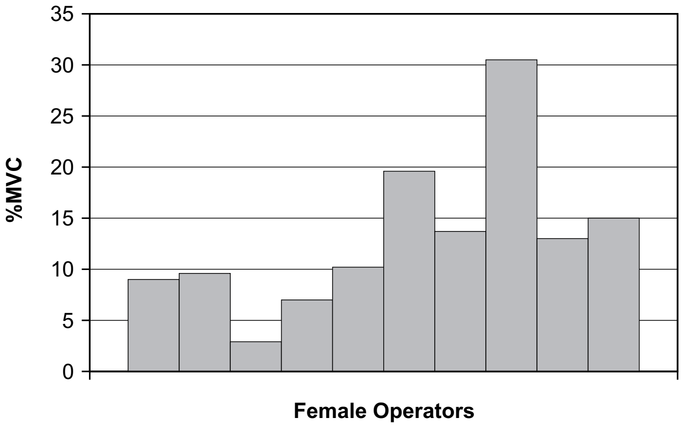

Figure 8. Inter-individual variations of the electromyogram (EMG) of the flexor muscles for keyboard use in data entry. *Notes.* MVC—maximal voluntary contraction.

4.6. Relationship Between MSDs and Biomechanical Data

In data entry, the female operators who complained of pain in the right wrist-hand had an average angle for this joint of 37° ± 7 in the flexion-extension plane when using the keyboard, whereas for those who did not complain about this wrist, this angle was 26° ± 4; the difference was significant ($t = 2.55$, $p < .02$). The differences were not significant between complaints of MSDs and other biomechanical factors, either in data entry or in CAD.

5. DISCUSSION

The study carried out showed no great difference between the levels of MSD complaints in CAD and in data entry, particularly for the right upper limb. In contrast, left upper limb complaints tended to be more numerous in data entry than in CAD. This difference might be explained by the fact that the left hand is used more in data entry than in CAD. Indeed, the left hand holds documents and types on the keyboard in data entry whereas it is often at rest in CAD. Complaints concerning the right upper limb were more numerous than for the left upper limb, particularly in CAD, which was also observed by Jensen et al. (1998) for this task. In both tasks, these complaints are probably linked to the high level of right-hand mouse use in CAD and keyboard use in data entry. Among the data entry operators who complained about the right hand-wrist, the average angle of this wrist was further in extension than for those who did not complain. A relationship between wrist complaints and wrist articular angle was therefore found in this study. In addition, wrist extension is a major determinant of carpal tunnel syndrome as it increases intracanal pressure (Rempel & Horie, 1994). This generally results from resting the wrist on the table when typing. Lack of typing training may partly explain this behaviour as the female operators who receive such training type without leaning.

With the use of a keyboard, the average flexion-extension angle of the wrist did not differ significantly between CAD and data entry but it exceeded 30° in data entry (see Figure 5). This angle is higher than that obtained in the laboratory by Serina et al. (1999), which was –20°, and by Simoneau et al. (1999), which was –17°, but in both these experiments the operators had furniture that could be adapted to their morphology, which was not the case in the present study. The average angle of the wrist in the cubital-radial plane was higher in CAD than in data entry with keyboard use. This difference might be explained by the greater distance between the edge of the table and the edge of the keyboard in data entry than in CAD. In terms of the wrists, the distance of the keyboard, even if excessive in data entry, undoubtedly allows better hand-forearm alignment. It should also be pointed out that the average angle obtained in CAD was identical to that measured by Simoneau et al. (1999), which was 10° in an alphabetic typing tasks. The average abduction-adduction angle of the shoulder when using the keyboard did not differ between CAD and data entry, but this angle was higher than 20° in both tasks. The average EMG of the flexor muscles was higher in CAD (where it exceeded 20%) than in data entry with keyboard use. This result cannot be explained by the difference in grip force that generally exists between men and women because force is expressed as a percentage of maximum voluntary contraction (MVC). Perhaps this difference is due to the way of working. In contrast, the EMGs of the extensor and trapeze muscles did not significantly differ between the two tasks with keyboard use. Moreover, the average EMG of the trapeze was higher with keyboard use in data entry than with mouse use in CAD or in data entry. This difference is explained by the fact that typing on the alphabet section of the keyboard during data entry was generally performed without leaning whereas 80% of the CAD operators and 93% of the data entry operators stated that the mouse was held with the forearm leaning. However, resting the forearm on the table reduces the electrical activity of the muscles of the shoulder (Aarås & Ro, 1998). Worthy of note is that in the case of keyboard use in data entry, the average EMG of the flexors is comparable to the EMGs obtained in the laboratory by Martin (1994), who noted that in four out of the five operators examined, this average EMG represented 8–20% of their maximum force. Finally, the repetitiveness of flexion-extension and cubital-radial deviation movements of the wrist was much higher with the keyboard than with the mouse. The repetitiveness of flexion-extension can be qualified as somewhat high compared to those observed in the secondary sector. Moreover, in a laboratory study, Serina et al. (1999) noted that wrist movements when typing are rapid and similar in amplitude to those of the wrists of workers performing high MSD risk tasks.

With the use of the mouse, the average flexion-extension angle of the wrist did not differ significantly between CAD and data entry but it exceeded 30° in CAD (see Figure 5). Average wrist flexion-extension angles of between –25 and –29° depending on the type of mouse were measured in the laboratory by Keir, Bach, and Rempel (1999). In the study conducted by Wahlström (2001) an average value of –26° ± 6 was obtained among operators using this type of input device. In both these studies, the operators also had adjustable furniture available. Nevertheless, the values obtained in the present study were coherent with those of these two studies. In addition, the average angle of the wrist in the cubital-radial plane did not differ significantly between CAD and data entry as far as mouse use was concerned. These average angles were close to those recorded (0.5 to 5.2°) by Keir et al. (1999) with different types of mice in laboratory-based movement and pointing tasks. Karlqvist, Hagberg, and Selin (1994) also noted that the wrist was often in cubital deviation when a mouse was used. Finally, the average abduction-adduction angle of the shoulder did not differ between CAD and data entry with mouse use but exceeded 20° (see Figure 5). In contrast, this angle was higher with mouse use in CAD and in data entry than with keyboard use in CAD. The mouse was too far away from the keyboard in the case of several operators assigned to the CAD or data entry task. This result is identical to that obtained by Karlqvist et al. (1994), who noted that, compared to keyboard users, the abduction angle of the shoulder of operators manipulating a mouse was often higher than 30°. However, manipulating a mouse far from the keyboard promotes the onset of pain not only of the wrist but also of the shoulder (Karlqvist, Hagberg, Wenemark, Anell, & Koster, 1996). The average EMG of the flexor muscles was higher in CAD than in data entry with mouse use. This result is incompatible with that obtained by Wahlström, Svensson, Hagberg, and Johnson (2000), who noted that women applied higher forces to the mouse than men. The same can be said for keyboard use but another remark is worthy of mention. Grip force indeed increases with cognitive load level (Van de Ven, & De Haan, 2000). Besides, a CAD task requires a great deal of attention, accuracy, and data processing, which could constitute risk factors that add to the continuous use of the mouse in this task (Jensen et al., 1998). In contrast, the EMGs of the extensor and trapeze muscles did not differ significantly between the two tasks with mouse use. Finally, the repetitiveness of flexion-extension and cubital-radial deviation wrist movements was very low when handling the mouse, which highlights the level of static work performed by the wrist when using this input device.

The study therefore showed no difference in the biomechanical constraints between CAD and data entry for the same tool, except for the EMG of the flexor muscles and the average angle of the wrist in the cubital-radial plane with the keyboard. The average flexion-extension angle of the wrist, the abduction-adduction angle of the shoulder and the average forces exerted by the extensor and trapeze muscles were not influenced by the task, whether for mouse or keyboard use. In contrast, the forces exerted and the wrist angles differed greatly between operators in both tasks, as the standard deviations of the averages of these biomechanical factors highlight. As a result, the biomechanical risk is not the same for everyone, as can be seen in Figure 8, which shows that the average force of one of the female operators when typing on the keyboard greatly exceeds 20%. This interindividual variability was also observed by Burgess-Limerick and Green (2000) in standardised tasks with a mouse and by Byström et al. (2002) in CAD.

The study has also shown that the biomechanical stresses of the upper limbs caused by input devices concern the wrist and the shoulder. However, these stresses can be exerted differently on a joint depending on the tool used. With the mouse, the stresses occur primarily in the form of postural constraint of the shoulder; this constraint results from the distance of the mouse. With the keyboard, the stresses are mainly in the form of repetitiveness of wrist movements but also in the muscular load of the shoulder as the upper limb is less often used as a support than when manipulating the mouse. A postural constraint of the wrist is present with the predominant tool in each task.

In addition, this study brings into question the mathematical model of the incidence of MSDs established by our laboratory (Aptel & Cail, 1996). In this model, repetitiveness then the forces exerted are the predominant biomechanical factors whereas articular amplitudes have a negligible impact. However, in the present study, MSD complaints of the right side did not differ significantly between the two tasks although the repetitiveness was much higher in data entry than in CAD. Furthermore, the pain of the right wrist was related to the extension of the wrist in data entry. Our model was defined on the basis of the results of studies carried out in the industrial sector for tasks where the muscular work is mainly dynamic. It probably cannot be transposed to computer tasks where the degree of static work and postural constraint is considerable.

Finally, as far as the link between MSD complaints and biomechanical data is concerned, this still remains difficult to establish as the number of operators undergoing biomechanical constraint recordings was much lower than that retained for the questionnaire. Indeed, the procedure to collect biomechanical data is long and constraining for the operators; it is therefore very difficult to extend the questioning to all the operators of an enterprise. In addition, the relationships between MSD complaints and EMG are still poorly understood. In this respect, among the CAD and data entry operators who took part in the metrology, the two (one in CAD and one in data entry) who complained frequently about the shoulder had the lowest electrical activation of the trapeze (3.8% instead of 20.3% on average in CAD and 5.9% instead of 50.3% on average in data entry) when using their main input device. Given that this observation concerned only two people, it is obviously impossible to come to the conclusion that they economise the shoulder. An in-depth study of the relationships between complaints and biomechanical data could therefore constitute the next challenge for field research in the area of MSD.

6. CONCLUSION

In both tasks, MSD complaints appear to be linked to the use of input devices. In terms of the upper limb extremities, they are related to wrist extension during keyboard typing. The grip forces exerted when using input devices are higher in CAD than in data entry and may be caused by the different cognitive load of the two populations. The biomechanical stresses of the upper limbs concern the wrist and the shoulder but they are generally different according to the input device used. With the mouse, the stresses primarily manifest in the form of postural constraint of the shoulder. With the keyboard, the stresses mainly manifest in the form of repetitiveness of wrist movements and muscular load of the shoulder. A postural constraint is present with the predominant tool in each task. It is therefore necessary to study the upper limb in its entirety and not merely one of its joints. In addition, this field study has confirmed certain results obtained in the laboratory studies quoted concerning the biomechanical constraints linked to input devices. It would therefore appear that display screen workstations can be modelled better in the laboratory than can workstations of the industrial sector.

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