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The effect of upper extremity support on upper extremity posture and muscle activity during keyboard use

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Abstract

Forearm support during keyboard use has been reported to reduce neck and shoulder muscle activity and discomfort. However, the effect of forearm support on wrist posture has not been examined. The aim of this study was to examine the effect of 3 different postures during keyboard use: forearm support, wrist support and "floating". The floating posture (no support) was used as the reference condition. A wrist rest was present in all test conditions. Thirteen participants completed 20 min wordprocessing tasks in each of the test conditions. Electromyography was used to monitor neck, shoulder and forearm muscle activity. Bilateral and overhead video cameras recorded left and right wrist extension, shoulder and elbow flexion and radial and ulnar deviation. The forearm support condition resulted in significantly less ulnar deviation ($<p = 0.007$), less time spent in extreme ulnar deviation ($p = 0.002$) and less reports of discomfort than the "floating" condition ($p = 0.002$). The wrist support but not the forearm support condition resulted in less trapezius and anterior deltoid muscular activity ($p < 0.007$). These findings indicate that typing with upper extremity support in conjunction with a wrist rest may be preferable to the "floating" posture implicit in current guidelines.

Keywords: Computer keyboard; Musculoskeletal symptoms; Forearm support; Wrist rest

1. Introduction

Recent studies have demonstrated that computers are used by more than 25% of the workforce, for more than half of their working day (Hjelm et al., 2000). The relationship between computer use and musculoskeletal disorders of the neck and upper extremity has been well documented.

The prevalence of musculoskeletal symptoms among keyboard users has been reported to be as high as 76% (Aaras et al., 1997). Risk factors associated with computer use include physical ergonomic factors such as desk, chair and screen heights and working postures, (Grandjean et al., 1984; Aaras et al., 1997) and the use of input devices such as the computer mouse (Cook et al., 2000; Burgess-Limerick et al., 1999). Organisational factors such as long working hours, the duration of computer use per day, psychosocial factors such as stress (Smith and Carayon, 1996) and visual factors (Aaras et al., 1998; Aaras et al., 2001) have also been associated with musculoskeletal disorders amongst computer users. Symptoms of the neck, proximal and distal upper extremities have been associated with the keyboard, which continues to be the most widely used data entry device. Physical risk factors associated with keyboard use include awkward working postures, the design of the keyboard, the repetitiveness of the keyboarding task and the force with which the keys are depressed (Amell and Kumar, 2000).

Extreme ranges of wrist extension, pronation and ulnar deviation are common in keyboard users and have been reported to contribute to the development of occupational overuse syndromes. Extreme wrist postures and contact stress have been reported to increase carpal tunnel pressures (Rempel et al., 1998).

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The continuous activation of muscles of the arms, shoulder girdle, neck and trunk to maintain a quasi-static position to allow the hands and arms to operate the keyboard has been proposed as one of the causal factors of neck/shoulder and arm/hand diagnoses (Bergqvist et al., 1995). Despite this, the traditional recommendation for typists to 'hover or float' over the keyboard whilst keying, maintaining a neutral wrist posture without supporting the arms is still advocated (WorkSafe Victoria, 2001).

Upper extremity support has been reported to reduce muscular load in work tasks and has been proposed as a way of reducing static shoulder and neck muscle load during keyboard use (Aaras et al., 1998, 2001). In a recent prospective epidemiological study of computer users, Marcus et al. (2002) reported that use of the keyboard placed more than 12 cm from the edge of the desk was associated with a lower risk of hand arm symptoms. Upper extremity support can be provided by either supporting the forearms or the wrists.

1.1. Forearm support

Forearm support can be provided by arm supports attached to either the work surface, chair or suspended overhead (Feng et al., 1997), by resting on the arms of the chair, or by resting the forearms on the work surface (Aaras et al., 1998, 2001). Attached arm supports provide a rest on which to support either the elbow or forearm. The arm's weight is suspended by means of cables or other mechanisms. Findings regarding the benefits of these supports have been conflicting, with some authors reporting them to be effective in reducing trapezius load, resulting in increased comfort and reduced effort (Westgaard and Aaras, 1985). Others have reported that these supports did not significantly change working posture or reduce neck/shoulder muscle activity (Hedge and Powers, 1995). A disadvantage of such supports is that their usefulness is limited if the arm needs to cover a large work area, or where mobility at the elbow is required.

Supporting the forearms on the chair armrests had been reported to reduce muscular load on the shoulders and arms but to constrain working posture (Westgaard and Aaras, 1985). Support of the forearms on the worksurface has been reported to be effective in reducing muscular load and discomfort in the neck/shoulder. Following a 6 year intervention study, Aaras et al. (2001) reported a significant decrease in static trapezius load, neck and shoulder pain in a group of participants who were able to support their whole forearm and hand on the table top. No change was found for forearm or hand pain. While these results suggest that forearm support may be beneficial for the proximal upper extremity and neck, the effect of forearm support on wrist posture during keyboard use was not reported.

1.2. Wrist support

An alternate means of supporting the arm is to support the wrists. The wrists can be supported by the work surface, or by wrist or palm rests. In a field study of wrist rests, none of the 40 data entry operators who participated reported that wrist rests were useful (Parsons, 1991). However, the sample consisted of data entry operators who used a numeric keypad only, using one hand. Albin (1997) reported that the use of wrist rests reduced wrist flexion/extension resulting in more neutral wrist postures. Studies of wrist support with older style keyboards have reported that wrist support may increase neck and shoulder muscle load (Bendix and Jessen, 1986). The use of wrist support (desktop or when a wrist rest is used) has been reported to increase intracarpal tunnel pressure (Horie et al., 1993), which is considered a risk factor for wrist disorders.

2. Methods

2.1. Participants

Thirteen healthy volunteer computer users (10 F, 3 M; median age 24 years; range 17–51 years) participated in the study. Eight participants were right handed. Four wore glasses for computer use. The median hours of computer use per day was 4, interquartile range (IQR) 4. The median typing speed was 31 words per minute (IQR:18.5).

2.2. Design and measures

The study was a laboratory based, experimental design. Participants completed a 20 min copy typing task in each of 3 conditions: (a) forearms fully supported; (b) wrists supported; (c) no arm support ('floating' posture). Testing order was randomised, subjects were given a 10 min break between each test condition. An adjustable chair, adjustable height computer table and standard keyboard were used. A wrist rest (Rubbermaid Adjustable Wrist Rest No.6800) of the same height as the keyboard (height 17 mm, width 65 mm, length 67 mm) was positioned in front of the keyboard for each test condition. The keyboard (IBM Model 8923) was placed 100 mm from the worksurface edge for the wrist support and floating conditions. In the supported conditions, the worksurface height was adjusted so that when either the forearms or wrists were supported, the elbow was at 90° and there was no shoulder elevation (Standards Australia, 1990) (Figs. 1a–c).

The following data were collected:

(i) *Posture analysis*: Peak motion analysis system was used to record bilateral wrist, shoulder and elbow extension/flexion and wrist ulnar/radial deviation (Hedge and Powers, 1995).

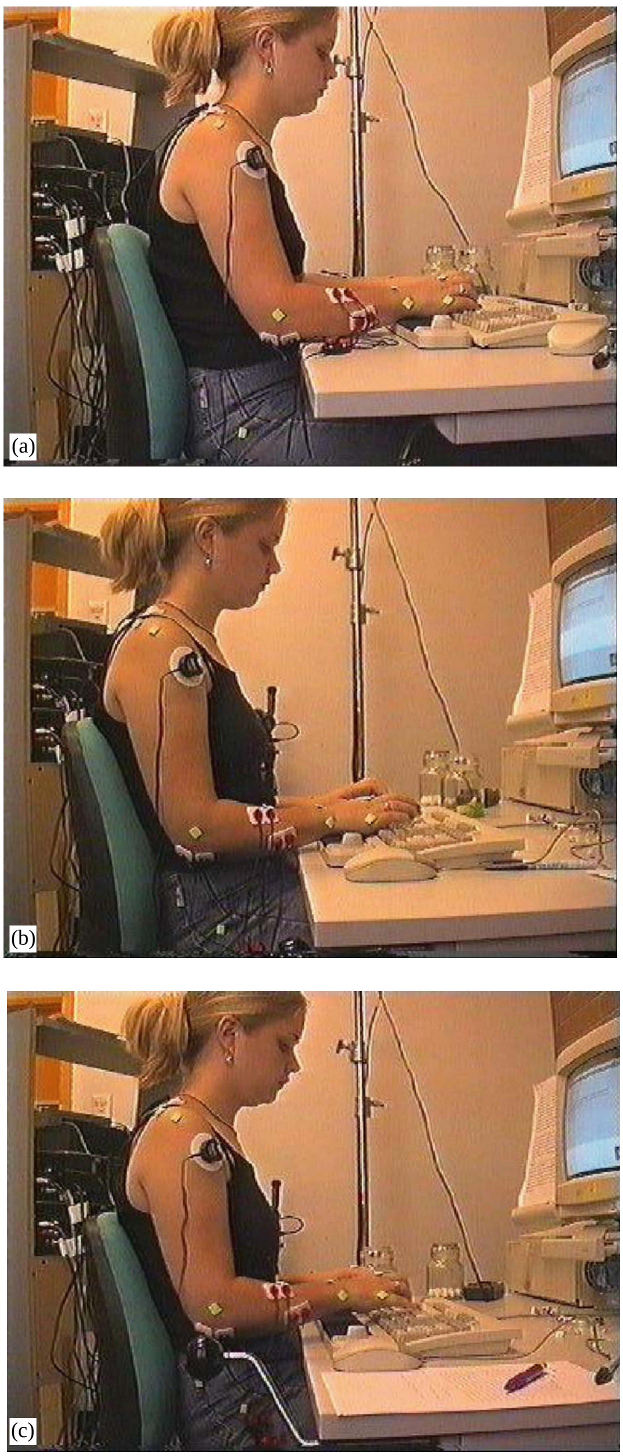

Fig. 1. Photographs of experimental conditions: (a) forearm support; (b) wrist support; (c) no support (floating). Note lower worksurface for floating condition.

(ii) *Muscle activity*: Electromyographic (EMG) activity of the extensor digitorum communis, extensor carpi ulnaris, upper trapezius and anterior deltoid was recorded bilaterally via a FlexComp/DSP system (Thought Technology Ltd., Montreal).

(iii) *Discomfort*: Participants were asked to report the location and severity of musculoskeletal discomfort at 5 min intervals during the work tasks (Corlett and Bishop, 1976).

2.3. Posture analysis

Three 50 Hz video cameras (overhead, left and right lateral) were positioned perpendicular to the plane of movement to be studied. Adhesive reflective markers were placed on the following bony landmarks bilaterally:

- Ulnar/radial deviation—head of 3rd metacarpal, midpoint of a line joining the radial and ulna heads and 90 mm from the wrist marker in the middle of the dorsal surface of the forearm.
- Wrist flexion/extension—head 5th metacarpal, styloid process of ulna, lateral epicondyle.
- Shoulder flexion—lateral epicondyle, greater tubercle of humerus, femoral head.

Cameras continuously recorded movements of left and right shoulder, elbow and wrist flexion/extension, and wrist ulnar/radial deviation throughout each of the 20 min work tasks. The reference position was 0°, or the anatomical position. Each of the above landmarks were manually digitized at 10 Hz for 10 s segments of video footage taken at 0, 5, 10, 15 and 20 min into the task. Maximum and mean angles and standard deviations were calculated for each participant for each trial for each angle. The traditional floating posture was used as a reference. Comparisons were made between the floating posture and the forearm support condition and the wrist support condition. Paired *t*-tests were applied to determine the differences between the conditions. 95% confidence intervals of the effect size statistic (d) were calculated.

Frequency distributions were constructed for radial/ulnar deviation using 5° bins. The number of video frames that the wrist remained in each range was expressed as a percentage of trial duration. The percentage of time spent in extreme angles, i.e. more than 15° ulnar deviation was determined for each test position (Weiss et al., 1995; Werner, 1997). Comparisons between time spent in extreme angles were made between the three test conditions. One way analysis of variance was used to assess the probability of obtaining effects of the observed magnitude, given a null hypothesis of zero effect.

2.4. Electromyography

Silver–silver chloride 12 mm surface electrodes (Thought Technology Ltd., Montreal) were positioned 6 mm apart over the belly of anterior deltoid, extensor digitorum and flexor carpi ulnaris. Electrodes were positioned over the horizontal fibres of middle trapezius, a quarter of the distance from the acromion to the seventh cervical vertebra (Basmajian and De Luca, 1985). All electrodes remained in situ throughout and between test periods. Reference contractions were recorded (15 s) while the participant was seated, using the following positions while holding a 1 kg weight: trapezius–arms held at 90° abduction in the coronal plane, elbows straight, forearm pronated; anterior deltoid–arms held at 90° flexion, elbows straight; wrist extensors: wrists held in full extension.

2.5. Data collection

Thirty second samples were taken at 0, 5, 10, 15 and 20 min. Root-mean-square (RMS) values of raw EMG signals were calculated for each of the 30 s epochs. A 20 Hz highpass filter eliminated low-frequency artifact, such as movement and a 50 Hz notch filter eliminated mains noise. Electromyographic signals were sampled at a rate of 992 samples/s. RMS values of raw EMG signals were calculated with an averaging constant of 65 ms, for each of the 30 s samples. Mean RMS values were calculated for each posture for each participant. These mean values were represented as a proportion of the reference voluntary electrical activity (%RVE) (Hansson et al., 2000). Paired *t*-tests were applied to determine the differences between mean EMG values (%RVE) between the reference and each test condition. 95% confidence intervals of the effect size statistic (d) were calculated.

2.6. Discomfort

Participants were asked to report the location of discomfort using a Body Map and severity using a 7 point scale (0) = no discomfort to (7) = extreme discomfort prior to task commencement and at 5 min intervals during each condition (Corlett and Bishop, 1976). Body part discomfort frequency (the number of times discomfort was rated as greater than zero for any body region) and body part discomfort severity (average of all non zero ratings) was calculated for each of the work conditions (Liao and Drury, 2000). Participants were also asked to report their perceptions of the comfort or discomfort of each of the different work conditions. McNemar Chi square was used to determine differences in proportions of reported discomfort for each work condition.

3. Results

3.1. Posture analysis

Proximal and distal upper extremity posture was assessed during the three different work conditions. The right lateral view was not available for one participant.

3.1.1. Shoulder and elbow

Forearm support resulted in significantly greater shoulder flexion and elbow extension bilaterally due to the placement of the keyboard at a greater distance from the edge of the worksurface. For example, mean right shoulder flexion increased from 5° (SD9.6) in the floating condition to 18° (SD5.9) in the forearm support condition (Tables 1 and 2).

3.1.2. Wrist

Use of the wrist rest was associated with a typical increase in wrist extension of between 6° and 8° over the forearm support and floating conditions. Left wrist extension was significantly less in the forearm support than the floating posture (Table 2). All postures were close to neutral, the average maximum extension being only 16° (SD 4.1) for the right wrist and 29° (SD 4.2) for the left wrist.

Forearm support resulted in a decreased mean ulnar deviation over the floating condition for both the left and right hands (Table 2). The average reduction in

Table 1
Descriptive statistics for angles from lateral and overhead cameras indicating mean and standard deviations

Posture	Forearm support mean (SD)	Wrist support mean (SD)	Floating mean (SD)
Right wrist extension	−1.4(5.8)	4.1(5.7)	−2.5(5.4)
Left wrist extension	−0.7(9)	4.2(10.6)	−5.3(10.6)
Right ulnar deviation	14.8(5.6)	17.6(6.7)	18.1(5.3)
Left ulnar deviation	13.6(5.3)	17.6(4.7)	16.3(5.9)
Right shoulder flexion	17.9(5.9)	5.8(8.6)	4.8(9.6)
Left shoulder flexion	17.2(7.8)	3.5(9.4)	4.6(9.4)
Right elbow extension	77.8(7.6)	84.6(12.7)	87.7(14.9)
Left elbow extension	79.9(7.9)	85.8(13.8)	92.9(12.1)

Negative values indicate degrees of wrist flexion, positive values indicate extension.

Table 2
Results of posture analysis and electromyography when floating position is used as reference. Paired t tests (t), level of significance (p) and 95% confidence intervals of the effect size (d) statistics are detailed

Condition	p	t	d	CI	
				Lower	Upper
Right wrist extension					
Floating and forearm support	0.51	0.69	0.045	−2.4	4.5
Floating and wrist support	0.006	3.48	0.56	2.4	10.8
Left wrist extension					
Floating and forearm support	0.001	4.43	0.62	2.3	6.8
Floating and wrist support	<0.001	9.8	0.89	7.4	11.6
Right ulnar deviation					
Floating and forearm support	0.007	3.26	0.47	−5.5	−1.1
Floating and wrist support	0.705	0.39	0.012	−3.2	2.2
Left ulnar deviation					
Floating and forearm support	0.004	3.51	0.508	−4.3	−1.0
Floating and wrist support	0.204	1.34	0.13	−0.8	3.5
Right shoulder flexion					
Floating and forearm support	<0.001	7.38	0.85	9.2	17.1
Floating and wrist support	0.316	1.05	0.1	−1.7	3.3
Left shoulder flexion					
Floating and forearm support	<0.001	6.98	0.80	8.6	16.5
Floating and wrist support	0.454	0.78	0.05	−4.3	−0.8
Right elbow flexion					
Floating and forearm support	0.007	3.33	0.50	−16.4	−3.4
Floating and wrist support	0.29	1.10	0.09	−9.4	3.1
Left elbow flexion					
Floating and forearm support	<0.001	6.04	0.75	−17.4	−8.2
Floating and wrist support	0.001	4.67	0.65	−10.3	−3.8
R Trapezius					
Floating and forearm support	0.39	−2.4	0.36	−21.6	−0.67
Floating and wrist support	0.007	−3.37	0.53	−22.7	−4.6
L Trapezius					
Floating and forearm support	0.19	−1.39	0.16	−7.9	1.8
Floating and wrist support	0.002	−4.0	0.62	−10.5	−3.0
R Ant Deltoid					
Floating and forearm support	0.14	−1.62	0.21	−4.0	0.63
Floating and wrist support	0.002	−4.13	0.63	−5.2	−1.6
L Ant Deltoid					
Floating and forearm support	0.33	−1.02	0.09	−4.1	1.5
Floating and wrist support	0.006	−3.4	0.54	−7.1	−1.5
R Ext Dig					
Floating and forearm support	0.45	−0.79	0.06	−5.6	2.8
Floating and wrist support	0.25	2.65	0.41	0.4	4.7
L Ext Dig					
Floating and forearm support	0.42	−0.83	0.07	−9.4	4.3
Floating and wrist support	0.11	−1.76	0.23	−11.8	1.4
R ECU					
Floating and forearm support	0.10	1.8	0.25	−1.1	10.5
Floating and wrist support	0.35	0.99	0.09	−2.4	6.3
L ECU					
Floating and forearm support	0.12	1.69	0.22	−1.5	10.8
Floating and wrist support	0.17	1.48	0.18	−6.4	31.9

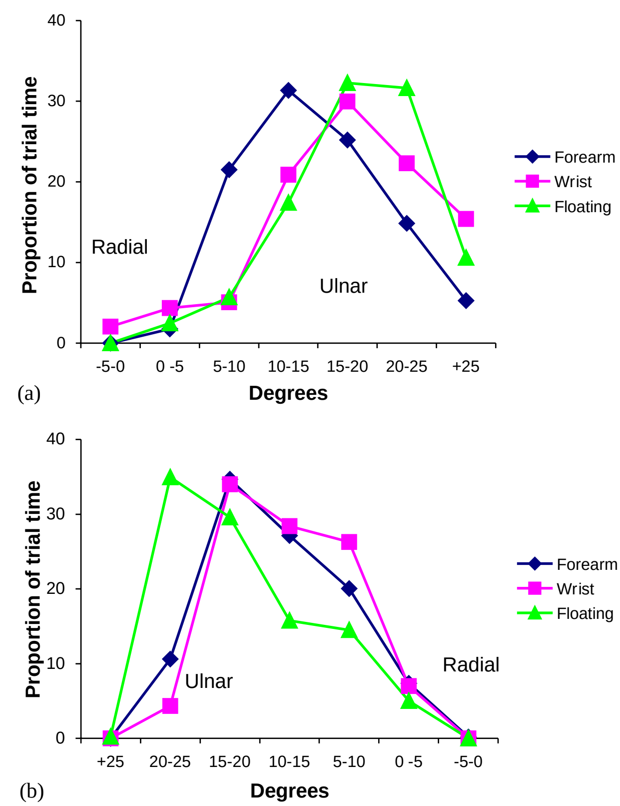

Fig. 2. (a) Right hand: The percentage of trial duration time spent in different ulnar deviation (5° bins), for each test position ($n = 13$). (b) Left hand: The percentage of trial duration spent in different ulnar deviation (5° bins), for each test position ($n = 13$).

angle was 3° for both the right and left hands. The differences in mean ulnar deviation between the wrist support and floating positions were not significant. More importantly, the use of forearm support resulted in significantly less time in an extreme ulnar posture of >15° for the right hand (mean 45%) than either the wrist support (mean 68%) or the floating positions (mean 71%) ($F = 7.98$; $p = 0.002$) (Fig. 2a).

Similar results were found for the left hand, with forearm support resulting in less mean ulnar deviation than the floating condition (Table 2). The proportion of time spent in extreme ulnar deviation of the left hand was also significantly less for the forearm support condition (mean 45%) than either the wrist support (mean 67%) or the floating conditions (mean 65%) (Fig. 2b).

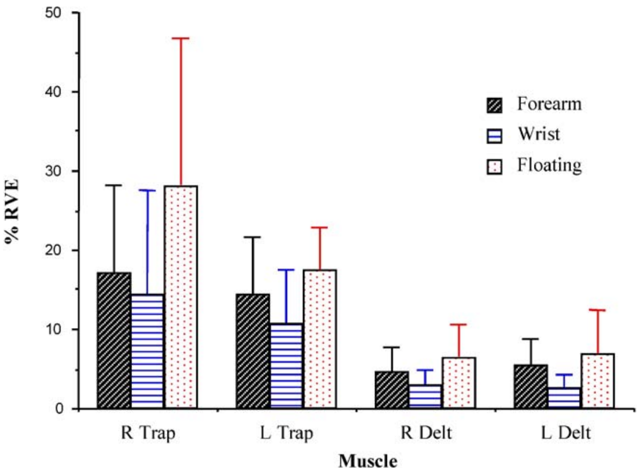

Fig. 3. EMG: Group mean RMS values and standard deviations for the trapezius and anterior deltoid for each test condition. Values expressed as a percent of the RVE (reference voluntary electrical activity).

3.1.3. EMG

Two participants were omitted from the EMG analysis due to equipment problems.

Proximal muscle activity: The wrist support condition resulted in significantly lower muscular activity in the trapezius and the anterior deltoid bilaterally (Table 2). There were no differences in muscle activity between the forearm support and floating conditions (Fig. 3).

Distal muscle activity: There were no significant differences or consistent patterns for extensor digitorum or extensor carpi ulnaris between the test conditions.

3.2. Discomfort

All participants reported discomfort in one or more body parts during the experiment. Significantly more participants (12) reported discomfort in the floating condition (Chi = 9.308, $p = 0.002$) than the wrist support condition (10) or the forearm support condition (9). The frequency (total number of reports of body discomfort) was higher in the floating condition (79) than the forearm support (53) or wrist support (57) condition. Reports of severity were lower for the forearm condition (73) than the floating condition (90) or wrist condition (83).

4. Discussion

The impact of forearm and wrist support on upper limb and wrist postures and muscle activity during keyboard use was compared with a "floating" posture. Forearm support was found to lead to a reduction in extreme ulnar deviation with a corresponding decrease in the amount of time spent in extreme ulnar deviation. However, only wrist support, not forearm support was found to lead to a reduction in proximal muscle activity. Reports of discomfort were highest for the floating condition.

Forearm support resulted in significantly less ulnar deviation bilaterally and significantly less time spent in extreme ulnar deviation during keyboard use. This decrease in ulnar deviation appears be a consequence of a combination of factors. Shoulder flexion increases when the forearms are supported and the hands are further away from the body. In the wrist support or floating positions, the arms appeared to be more constrained by the proximity of the arms to the body, resulting in more ulnar deviation. When the forearms were supported, the forearms were observed to pivot on the worksurface, rather than deviating the hand to reach the keys. This influence of forearm support on ulnar deviation has not previously been reported.

Wrist support, but not forearm support resulted in a decrease in trapezius and anterior deltoid muscle activity when compared with the floating posture. Placement of the keyboard away from the body results in an increase in shoulder flexion and elbow extension when the forearms are supported. The differences in muscle activity between the forearm support and wrist support conditions can probably be explained by the differences in shoulder flexion between these two conditions. The more neutral shoulder flexion posture during wrist support, combined with a decrease in muscle activity in the trapezius and anterior deltoid when compared with the floating condition, indicate an unloading effect due to support. In this study, forearm support when using a conventional desk did not have the same effect on muscle activity as found by Aaras et al. (1998) who reported reduced trapezius muscle activity during arm support when using a concave desk.

Reports of discomfort were highest for the floating position. The reports of discomfort in the neck and back are consistent with previous literature that reports an association between lack of forearm support and shoulder and arm hand diagnoses (Bergqvist et al., 1995). This is also consistent with the findings of Marcus et al. (2002) who reported a lower risk of hand arm symptoms in association with keyboard placement of more than 12 cm from the edge of the desk, indicating the arms were able to be supported. A decrease in discomfort with arm support has also been reported (Aaras et al., 1998, 2001). Although a number of participants reported that the forearm support position felt 'different' on commencement of the task, the overall frequency of discomfort reports for this posture was lowest.

Comparison between this and other studies is problematic due to differences in study design and measurement techniques. A range of methods has been applied to the analysis of wrist flexion/extension and deviation during keyboard use. The two main methodologies utilised are electrogoniometers and video markers viewed by lateral cameras. Electrogoniometers are mounted on the dorsum of the hand/forearm over the 3rd metacarpals and midline of the wrist, resulting in extension angles taken from the middle of the hand (Serina et al., 1999). In 2-D video analysis, markers such as used in the current study are placed over the head of the 5th metacarpal, the styloid process and the lateral epicondyle, resulting in angles taken from the medial border of the hand.

Wrist extension angles in this study were close to neutral for all test conditions. Studies in which data has been collected using markers on the medial edge of the hand generally report lower ranges of extension (11–13°) than those using electrogoniometers (range 17–25°). The wrist angles in the current study are lower than other comparable video analysis studies (Hedge and Powers, 1995). The use of a wrist rest for all test positions in the current study may have contributed to lower angles of wrist extension. The height of the wrist rest was level with the edge of the keyboard. It was used for both the forearm and wrist positions and was left in place for the floating position. Although the rest was not used while working in the floating position, the presence of the rest may have had an effect on wrist posture.

The ulnar deviation found in this study was within the ranges of 9–18° previously reported for standard keyboard use (Serina et al., 1999). The current study used overhead cameras. The dorsal markers were positioned over the 3rd metacarpal, as per placement of electrogoniometers resulting in similar deviation angles to those previously reported (Serina et al., 1999; Hedge and Powers, 1995). Deviated wrist postures have been demonstrated to increase carpal tunnel pressure (Weiss et al., 1995) with the lowest pressures recorded when the wrist is ulnarly deviated in the range of 10–15°. In the current study, forearm support resulted in mean deviation within the extreme range for a little less than half the total duration for the right hand, whereas the other positions resulted in two thirds to three quarters to of the time spent in the extreme range. This suggests that the reduction of ulnar deviation during forearm support is clinically significant.

There are a number of limitations to this study. The sample size was relatively small, the duration of exposure to each test condition was brief and conducted within a laboratory setting. The short exposure time and the imposition of the workstation set up by the researcher may have had an effect on the working posture of the participants.

5. Conclusions

The results of this study indicate that confirm that typing with upper extremity support may be preferable to the traditional floating posture due to a reduction in extreme wrist postures, a reduction in upper extremity load during wrist support and a decrease in discomfort. However, results indicate that use of a concave desk or workstation that enables a more neutral shoulder flexion posture may be preferable to a straight edged conventional desk.

6. Summary

Supporting the forearm on the work surface may increase comfort and decrease muscular load of the neck and shoulders. However, the effect of forearm support on wrist postures has not been examined. Before a recommendation regarding support during keyboard use can be made, the effect of forearm and wrist support requires further examination.

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