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Effects of a vertical keyboard design on typing performance, user comfort and muscle tension

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Abstract

To circumvent the awkward pronated hand position inherent to conventional horizontal keyboards, a vertical, split keyboard was designed with flexible cushions supporting the wrists, allowing relaxed hand and arm postures. During eight twice-weekly 30-min training sessions, the performance and subjective comfort of nine experienced typists were tested. Typing speed and error percentage, and surface electromyographic activity of six forearm muscles and two postural muscles were recorded in separate sessions at the end of each week. Typing speed rapidly recovered to the preset rate of 300 keystrokes/min and error percentages were similar for the two keyboards. The vertical keyboard caused lower muscular activity in especially finger extensor muscles, did not increase postural muscle activity, and self-reported comfort was higher. Thus, the vertical keyboard was easily mastered, was experienced as comfortable, and caused less stress on muscles sensitive to repetitive strain injuries.

Keywords: Keyboard design; Repetitive strain injury; Muscle tension

1. Introduction

In VDU workers the continuous operation of computer keyboards is a primary risk factor for acquiring repetitive strain injuries (RSI), also known as work-related upper extremity disorders (WRUEDs; Bernard, 1997; Blatter and Bongers, 1999; National Research Council and the Institute of Medicine, 2001; Wahlström, 2005). RSI is defined as an activity-related musculoskeletal complaints syndrome of the upper extremities, characterized by pain, fatigue, stiffness, numbness, tingling, warm or cold feelings, impairing performance of everyday tasks, and eventually leading to loss of capacity to work (National Health Council of the Netherlands, 2000). Widely accepted primary risk factors are long-lasting exposure to a repetitive task (>4 h a day) and static, non-neutral body and limb postures. Although psychosocial factors also play a role (Bongers et al., 2002, Wahlström, 2005; Wahlström et al., 2004), preventive measures still chiefly concern recommendations to improve work schedules allowing more alternation between tasks, to invest in ergonomically enhanced tools, and to train workers to adopt better body and limb postures and more relaxed movement strategies (Blatter et al., 2004; Faucett et al., 2002; Lindegard et al., 2003; Nord et al., 2001). The latter can be facilitated by applying alternative input devices such as split keyboards, joystick mice and voice-aided typing.

The layout of the traditional, horizontal keyboard requires an extreme pronation of the forearm to press the keys with the thumb and fingers, leading to an increased pressure in the carpal tunnel and tonic tension of the arm and hand musculature. This is especially true when no wrist or arm supports are used and the arms' weight needs to be stabilized against gravity by tonic cocontraction. In addition, reactive forces related to hitting the keys in a direction along the axis of gravity will involve increased tonic tension of the arm and neck musculature, in particular due to the characteristically high frequency achieved in typing (Van Dieën et al., 2003; Visser et al., 2000). The horizontal plane of the keyboard further induces ulnar deviation in the wrist. Furthermore, the often-observed upward extension of the wrist and elbow

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also leads to continued, non-neutral upper extremity postures (Han, 2003). These non-neutral wrist postures enhance the static activity of shoulder and forearm muscles and cause an increased loading on tendons in the wrist area (Armstrong et al., 1987) and an increase in pressure in the carpal tunnel (Rempel et al., 1997; Rempel et al., 1999). The relationship between non-neutral wrist postures and RSI has been confirmed in several epidemiological studies (see review by Buckle and Devereux, 1999). Moreover, psychophysiological studies have confirmed that sustained contractions are implicated in the pathogenesis of RSI (Hägg et al., 1996; Ranney et al., 1995; Sjøgaard et al., 2000; Wahlström et al., 2004).

1.1. Alternative keyboard designs

Only few studies have tested alternative keyboard designs and seldom have alternatives penetrated the market. Without discarding the familiar QWERTY letter-key assignment, two measures can help prevent the awkward postures induced by the horizontal keyboard. One is to split the keyboard tray between the 5–T–G–B and the 6–Y–H–N columns and rotate the left and right halves clockwise and counter clockwise, respectively. A second adaptation is to lift the front (or side) edges of the two keyboard halves to create a more or less descending slope such that less pronation of the hand and wrist is required. A disadvantage with a partially or completely vertical keyboard is that key identities become less visible.

Few studies have tested these adaptations as to their subjective preference and comfort in combination with performance and muscle tension measurements (Kemeling, 2002; McFarlane, 1996). Only one study applied a completely vertical variant of the QWERTY board, the so-called SafeType, for which positive experiences have been exchanged via the internet (Muss and Hedge, 1999).

Studies aimed at determining the most favoured keyboard orientation support a preference for split keyboards with a downward slope that allow a less pronated and less ulnar-deviated posture of the hands than the traditional horizontal keyboard, even if the alternative design initially decreases performance (Tittiranonda et al., 1999a). In addition, a study involving a 3-week test showed that awkward non-neutral wrist movements were prevented to a substantial degree when such a downward-tilted keyboard tray was used (Hedge et al., 1999) and a more longitudinal usability study of the Apple Adjustable keyboard revealed that pain complaints diminished (Tittiranonda et al., 1999b). Finally, several investigators who also included measurements of muscle tension in forearm and neck muscles found that less pronation resulted in slight decreases of muscle activation (Simoneau et al., 2003; Szeto and Ng, 2000).

Results on anatomically adapted keyboards in terms of performance, subjective comfort and muscle tension as tested in a real-life computer-keyboard task during an extended period are lacking. To amend this, the present study measured the muscular activity via surface electromyography (sEMG), as well as the inter-key press times and typing errors, during performance on the Yogitype, a newly designed split keyboard with a vertical orientation of the two halves (Dutch Patent Application 2001, no. 1018584). The new device is a midway split, inward curving QWERTY-based keyboard with vertically positioned keyboard halves, combined with flexible (free 3-planar movement) supports for the wrists, palms and forearms (see Fig. 1 for technical details and Fig. 2 for a close-up view). Moreover, while with this design users type in a direction towards the frontal body plane, and thus neutral in respect to the axis of gravity, it still affords the user a full frontal view of the keys.

1.2. Research questions

Our primary goal was to investigate the Yogitype concept as to the user's typing performance, comfort and health. Three distinct research questions were derived: (1) Does the new keyboard have comparable usability to the traditional keyboard in terms of typing speed and typing errors in experienced typists? (2) Are experienced typists satisfied with the keyboard's ease of operation as assessed by self-report questionnaires? (3) Does the new keyboard indeed reduce the muscle tension levels of arms and shoulders found with traditional keyboards during realistic, prolonged typing sessions?

2. Method

2.1. Participants

Nine adults (three women, six men, mean age 28 years, age range 18–48 years) participated on a voluntary basis. They were all experienced users of horizontal personal computer (PC) keyboards, had a touch-type rate of more than 300 keystrokes a minute using the 10-finger system, and, as controlled by a self-report questionnaire concerning clinical complaints, they did not suffer from RSI. All participants were right-handed and had normal or corrected-to-normal vision. They had given their written, informed consent and received payment for their participation.

2.2. Task and material

During eight 30-min training sessions evenly distributed across a 4-week period the participants practiced a transcription-typing task on a PC configuration featuring the newly designed vertical, split keyboard. After each two training sessions two measurement sessions were held to assess typing speed, typing error and muscle tension of the forearms and shoulders during task performance with the standard horizontal keyboard and when using the vertical keyboard. The days of the 2-weekly practice sessions varied, but the two measurement sessions always took

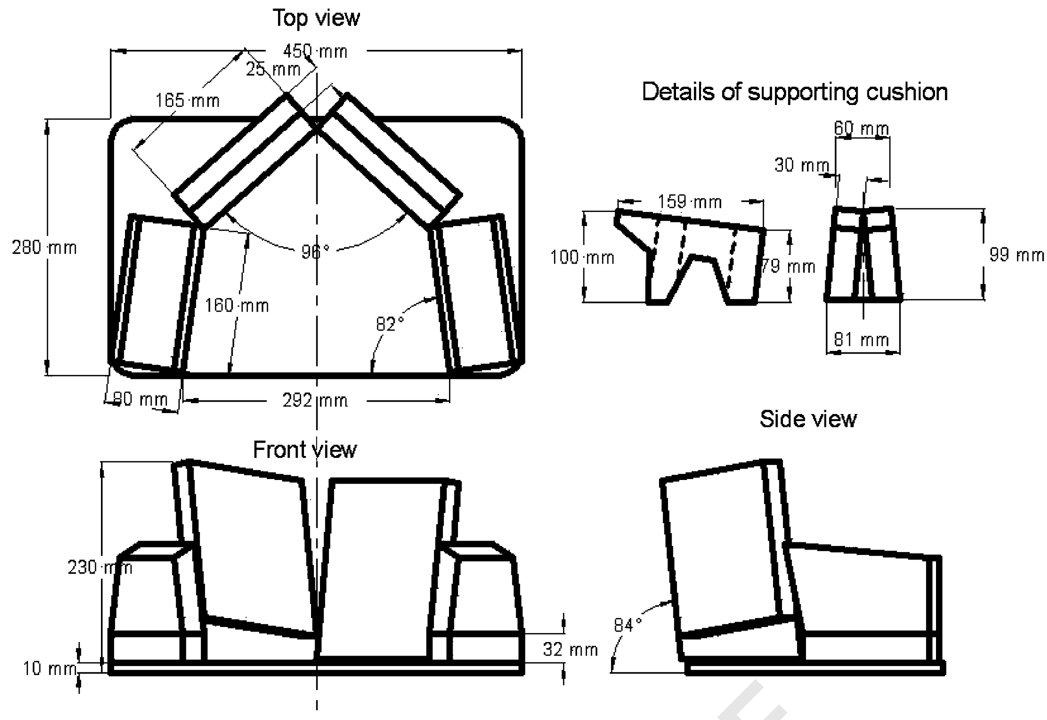

Fig. 1. Technical drawing of the Yogitype keyboard with, clockwise from upper left, top view, details of supporting cushion, side view and frontal perspective, respectively.

Fig. 2. Close-up of the experimental keyboard: On the left side, keys and finger placement of the left hand are visible. On the right side the participants' view of the keys for the right hand. The keyboard is mounted on a wooden platform that rests on the participants' upper legs. Its size allows enough freedom of leg movement. The wrists are loosely placed upon the flexible cushions.

place on the same day at the end of each week. These successive sessions were separated by a short break during which the working area and keyboard condition were changed. The participants were asked to touch-type (without visual feedback) and to use the 10-finger system with both keyboards. The prescribed texts and feedback of the transcriptions were presented via a split-screen method. Each time, a text paragraph of about 300 characters was presented in the upper half of the screen and participants were asked to copy this text in the lower half. They were instructed to type at their own optimal speed, to not pay too much attention to typing errors, and to not correct errors. After finishing a paragraph, they pressed 'enter', after which the next text fragment appeared.

The task material consisted of an informative, continuous text. In each practice session participants copied in total ten text fragments and five in the measurement sessions. Linguistic complexity of the texts was controlled by calculating the Flesch Reading Ease Score (Flesch, 1948). The text fragments had an average complexity score of 49.

2.3. Apparatus

All trials were run on the same PC with a Philips Brilliance105 screen (15 in, resolution: 800×600 refresh rate: 75 Hz). In the control condition and subsequent evaluation sessions participants used the Fujitsu Siemens K261 keyboard in a non-split configuration while resting their forearms on the table if needed.

The Yogitype keyboard used in the experimental and assessment sessions was derived from the Fujitsu Siemens K261 keyboard. The two halves of the keyboard were positioned vertically in a 96° angle from each other, with the key sides turned away from the user. In addition, both parts were tilted slightly backwards at 5° to allow for optimal reach of the keys. For user comfort two wrist supports were added, each positioned sideways of the keyboard halves. The material was sufficiently firm to give adequate support and the soft cushioning guaranteed free forward and backward movements of the supported forearms. Fig. 1 provides a detailed diagrammatic representation of the Yogitype keyboard and Fig. 2 offers a close-up view of how the keyboard was operated.

The computer screen (including the conventional keyboard in the control condition) was mounted on a 74.5-cm-tall table with the participants at 55–75 cm and a 35° eye-screen angle. Participants were seated in an adjustable office chair, allowing them to sit in a straight, comfortable posture with their feet placed either on the floor or on a footrest. When using the standard keyboard the chair was mounted with armrests positioned such that the participants could support their wrists on the table. When operating the Yogitype keyboard the armrests were removed and replaced by the wrist supports with the keyboard resting on the participants' laps.

The EMG equipment used to measure the muscle activation of eight muscles of the left arm and shoulder (see Section 2.4) consisted of an 8-channel physiological amplifier (TD 90087, custom-built), a PC featuring a WINDAQ card, and a 10-channel interface for the physiological amplifier and two binary channels for markers; all channels were sampled with a frequency of 1000 Hz, 90 dB, high-pass 20 Hz, low-pass 500 Hz. The surface EMG was measured with Kendall 10.0 mm disposable skin electrodes. The dedicated software with which the text was presented, the typing performance measured and markers placed within the EMG data stream after completion of each text fragment, was developed in the institute. In addition, the participants were filmed during their performance on all typing tasks by means of three cameras and video recorders to allow offline inspection of overall task performance and applied body postures. The photographs in Fig. 3 show the experimental arrangement and posture of a participant operating the two keyboards.

2.4. Procedure

The complete experiment consisted of 16 sessions: eight practice sessions with the Yogitype and $4 \times 2 = 8$ performance and sEMG measurement sessions with the standard and the experimental keyboards.

After the participant had read the instructions, the experimenter summarized the nature and procedure of the task, checked whether the participant was seated correctly and comfortably, and started the first practice trial. When the stimulus text appeared in the upper half of the screen the participant was instructed to start copying the fragment shown, the output text appearing in the lower half of the screen. After finishing the fragment, the participant pressed 'enter' and the next fragment would appear. This procedure was repeated until all text fragments had been completed. During each practice session, in total 10 fragments of 300 characters each were copied with a short break after the fifth fragment.

For the measurement sessions, during which the muscular activity, as well as the typing speed and typing errors were measured, the keyboard order was varied over participants to control for order effects; each condition comprised one set of five consecutive fragments. Seated in his/her customary position, the participant was connected to the EMG apparatus. The experimenter prepared the EMG electrode locations by cleaning and rubbing the skin with alcohol and gel until skin resistance was below 10 kΩ, after which he placed the electrodes on the muscles under study. Adhesive, disposable pre-gelled Ag/AgCl surface EMG disc electrodes (diameter 10 mm, inter-electrode distance 2 cm) were placed in a bi-polar derivation, parallel to the fibres at the bellies of the relevant muscles, with the reference electrode placed on the spinous process of the seventh cervical vertebra. EMG signals were tested for quality and specification, i.e. whether cross-talk stemming from adjacent muscles appeared. At the start of the first EMG measurement session, the participant typed for a

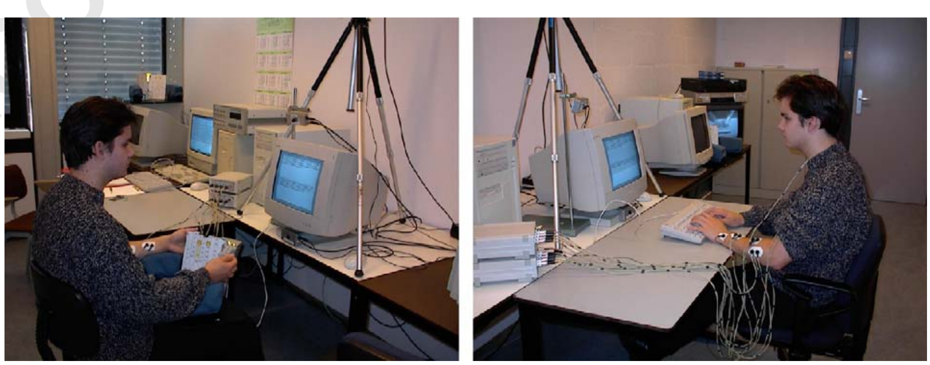

Fig. 3. View of a participant whose left arm has been wired for EMG measurements during task performance with the lap-held Yogitype keyboard (left-hand picture) and during the control condition with the standard horizontal keyboard mounted on the table (right-hand picture).

short period (about 1 min), during which the experimenter set the EMG amplifier levels for all the eight muscles so that the signals stayed between the range of the levels set. These levels were registered for each individual subject. At the beginning of each of the following measurement sessions, the EMG amplifier levels for all channels were set to the levels for all eight muscles of the individual subject, and this was tested by having the subject type for about 30 s, to ensure that all signals were registered correctly. The participant read the instructions and after the experimenter had summarized the task and answered the participant's questions, if any, the video recorder and the test program were started, which automatically activated the EMG apparatus. First a baseline level of muscular activity was measured for all muscles during the 30-s procedure where the participant was instructed to relax and to not make any movements. Next, the experimenter started the text presentation and the kinematic data measurement after which the participant copied the first set of five text fragments. Subsequently, the keyboard condition was changed and the same five text fragments were transcribed. After the final measurement session the participant completed a questionnaire about his/her experiences with the Yogitype keyboard.

2.4.1. EMG-measurements and analysis

The sEMG levels of the following eight muscles on the left side of the body were measured:

1. flexor digitorum superficialis,
2. extensor digitorum,
3. flexor carpi radialis,
4. extensor carpi radialis longus,
5. flexor carpi ulnaris,
6. extensor carpi ulnaris,
7. biceps,
8. upper trapezius.

The three extensor and flexor muscle pairs (1–6), were chosen because these pairs are highly involved in the lifting and downward pressing motions of the fingers during keying. The first pair (1–2) is mostly involved in the downward and upward movements and the forward and backward movements for the horizontal keyboard and the vertical keyboard, respectively. The second pair (3–4) has similar functions but here for movements with a medially directed vector, relative to the forearm's length axis, and the third pair (5–6) for the laterally directed movements. The laterally directed extensors are particularly at risk of RSI. It was therefore important to investigate the effects the new keyboard would have on these muscle pairs. Because the vertical keyboard allows for keying in a direction neutral to the axis of gravity muscle activation is expected to be lower for finger flexors and extensors. The m. biceps (7) and the m. trapezius (8) were monitored because these muscles are involved in upholding the postures of arms and body. The trapezius muscle has been found to be sensitive to enhanced levels of task stress. It is relevant, therefore, to test whether the new keying design would produce higher tension in this muscle.

The EMG of the aforementioned muscles was measured continuously throughout task performance. During recording all 50-Hz noise was filtered from the signal by means of a Notch filter. For the statistical analyses the raw EMG data were rectified and smoothed by means of Root Mean Square (RMS), and the EMG signal was normalized by converting rectified and smoothed raw values into percentages of Maximum Experimental Contraction. The latter measure corresponded to the average highest 5% contraction of that particular muscle in that particular experimental session.

2.4.2. Statistics

Performance and normalized EMG data were averaged per subject per session and the mean typing speed (keystrokes/min), mean typing error percentage (number of typing errors/number of keystrokes) and means of relative muscle activation of each muscle were subjected to a repeated measures ANOVA, with the within-subject factors weeks (1–4) and keyboard (Yogitype, Standard). The following within-subject contrasts were analyzed: for keyboard: none (Linear), for week: repeated (1 vs. 2, 2 vs. 3, and 3 vs. 4).

3. Results

3.1. Performance measures

Participants all proved experienced typists and reached an average typing speed of 374 keystrokes/min on the standard keyboard over the full duration of the experiment. For the vertical keyboard, initially typing speed was somewhat slower but from the second session onwards their performance rate already averaged above 300 keystrokes/min (see Fig. 4). In the multivariate test of within-subject effects, the main effect of keyboard was not significant (F (8, 1) = 4.328, n.s.), indicating that overall task performance on the Yogitype keyboard did not differ significantly from task performance on the standard keyboard. The main effect of week was significant (F (30, 44.704) = 1.991, $p<0.05$), as was the main effect of week on typing speed (F (3, 24) = 9.792, $p<0.001$). Thus, in 4 weeks with 2-weekly 30-min typing sessions, typing speed on the Yogitype keyboard approached the typing speed found for the standard keyboard. In the univariate test of within-subject effects, this interaction effect of week × keyboard on typing speed was significant, (F (3, 24) = 5.821, $p<0.005$).

The typing error percentages exhibited a similar evolution, as can be seen in Fig. 4 (right panel). In the univariate test of within-subject effects, the main effect of week on typing error percentage was significant (F (3, 24) = 5.04, $p<0.01$) indicating that the number of typing errors decreased during the 4-week period. There was no

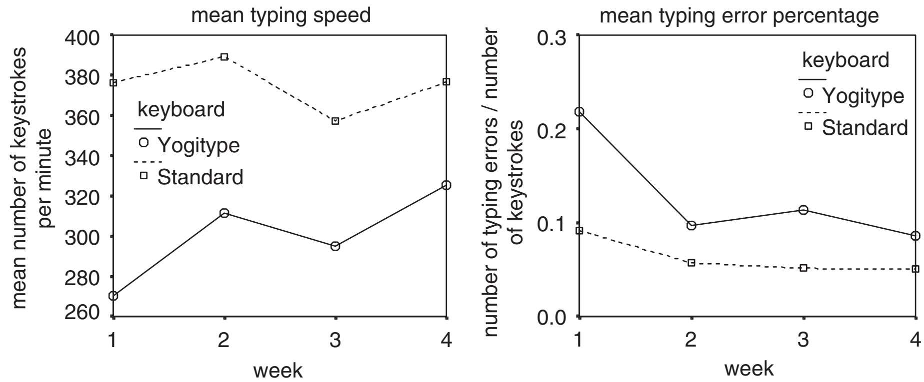

Fig. 4. Evolution of the mean typing speed in keystrokes per minute (left graph) and mean typing error percentage (right graph) over the 4-week practice period for the vertical Yogitype and the standard keyboard.

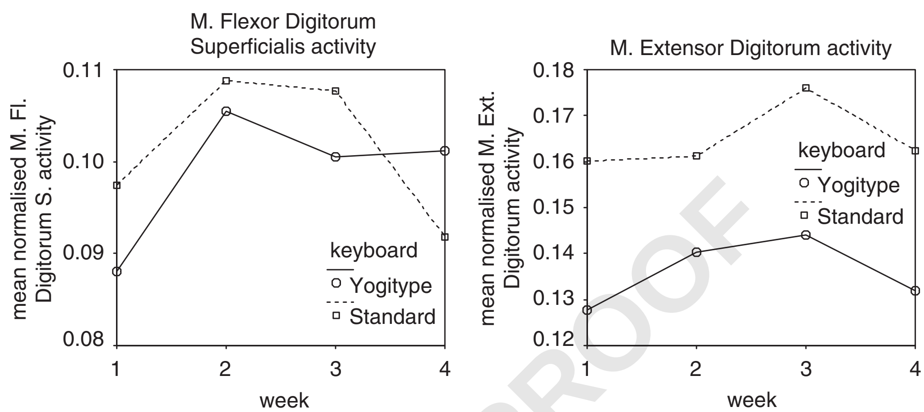

Fig. 5. Mean normalized muscle activation (in percentages of the 5% maximal activation range) of the finger flexors (left graph) and finger extensors (right graph) during the training period (weeks 1–4) for the Yogitype and the standard keyboard.

significant difference between the two keyboards with respect to typing error percentage (main effect of keyboard on typing error percentage: $F\ (1,\ 8) = 3.476$, n.s.). Furthermore, the error level for the Yogitype keyboard decreased and approached the error percentage for the standard keyboard. In the univariate test of within-subject effects, this interaction effect of week × keyboard on typing error percentage was significant ($F\ (3,\ 24) = 3.510$, $p < 0.05$).

The repeated measures ANOVAs analyzing the effects of keyboard on the performance measures Typing speed and typing error percentage separately for each week yielded the following results. The effect of keyboard on typing speed was significant for weeks 1, 2 and 3 but not for week 4. The effect of keyboard on typing error percentage was not significant throughout.

3.2. Subjective comfort measures

The majority of participants (seven out of nine) reported overall satisfaction with the posture associated with the Yogitype keyboard and rated it as more comfortable than the posture for the standard keyboard, especially with respect to position of the neck and back. Some participants reported slight problems with locating the keys on the Yogitype keyboard, and indicated that they had made more errors, although the results of our analyses showed there was no significant difference with respect to typing error percentage between the two keyboards. With respect to typing speed, the participants judged that, due to the limited practice, this was lower for the Yogitype keyboard. Initially, the results indeed also showed a speed advantage for the classical keyboard, but this difference between the two keyboards was quickly levelled out after several hours of practice.

3.3. sEMG measures

First the sEMG effects on agonist-antagonist pairs for keying movements will be discussed, followed by the effects on the more proximal upper-arm and shoulder musculature.

In Fig. 5 the evolution of muscle tension measures for the flexor superficialis and extensor digitorum muscles from weeks 1to 4 is displayed. The results confirmed that overall muscle activation was higher when working with the traditional keyboard. Although this effect was not significant for the flexor muscle, it was highly significant for the extensor muscle (m. extensor digitorum, $F\ (1,\ 8) = 14.665$, $p = 0.005$). The effect of week proved not significant for either muscle, implying that especially the effect of a lower muscle activation in the extensor muscle was already present from the outset of training, which is most likely attributable to the vertical keyboard's horizontal keying direction. Remember that the keying make forces of the two keyboard conditions did not differ because in essence the same mechanical parameters were applied.

For the keying movements with a more medially directed component, i.e. for m. flexor carpi radialis and m. extensor carpi radialis longus, an identical picture emerged (see Fig. 6). Again, from the outset the standard keyboard evoked more muscle tension in both the flexor and extensor muscles. This time both effects were highly significant (m. flexor carpi radialis: $F\ (1,\ 8) = 20.006$, $p < 0.005$; m. extensor carpi radialis longus: $F\ (1,\ 8) = 27.265$, $p = 0.001$). The effect of week was not significant, again leading to the conclusion that the effect was not subject to learning but is an inherent feature of the keyboard construction.

As can be seen in Fig. 7, the findings on the distal musculature revealed that, towards the little finger, the laterally directed m. flexor carpi ulnaris and m. extensor carpi ulnaris showed a decreasing trend for both keyboards over the training period. Again, for the extensor muscle tension proved higher for the horizontal than for the vertical Yogitype keyboard (m. extensor carpi ulnaris, $F\,(1, 8) = 30.146$, $p = 0.001$).

The findings for the two proximal muscles that are taken to be reflective of task stress did not provide evidence of any major (positive or negative) effect of the new keyboard. Although the values (depicted in Fig. 8) show that the muscular activity in m. biceps and m. trapezius was slightly elevated when typing on the Yogitype keyboard, the univariate test of within-subject effects revealed that these differences were non-significant ($F\,(1, 8) = 0.229$, n.s.; $F\,(1, 8) = 0.391$, n.s for biceps and trapezius, respectively). The slightly enhanced activity levels can be explained by the fact that both muscles are involved in regulating body posture, and as the participants kept the Yogitype keyboard on their laps during the typing task, they adopted a different posture compared to when they were using the standard keyboard. Because of the design of this keyboard, requiring hand supination, an enhanced level of activity in the biceps was to be expected. Apparently, this effect was compensated by the more proximal (lap) position.

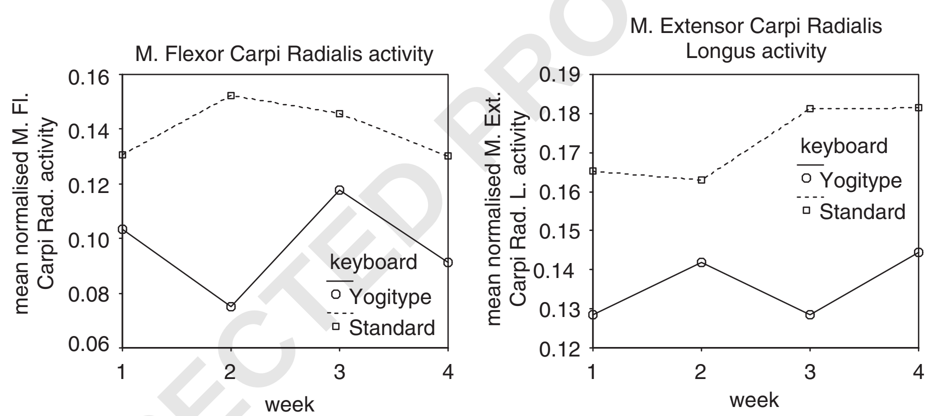

Fig. 6. Mean normalized muscle activation (in percentages of the 5% maximal activation range) of the medial finger flexors (left graph) and extensors (right graph) during the training period (weeks 1–4) for the Yogitype and the standard keyboard.

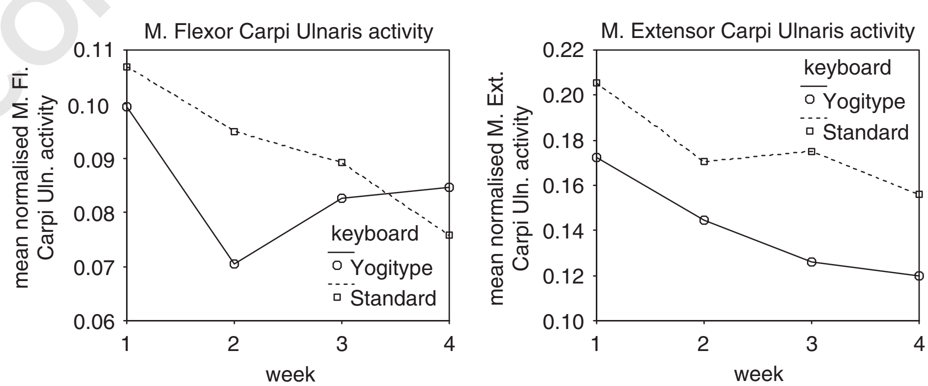

Fig. 7. Mean normalized muscle activation (in percentages of the 5% maximal activation range) of the lateral finger flexors (left panel) and extensors (right panel) during the training period (weeks 1–4) for the Yogitype and the standard keyboard.

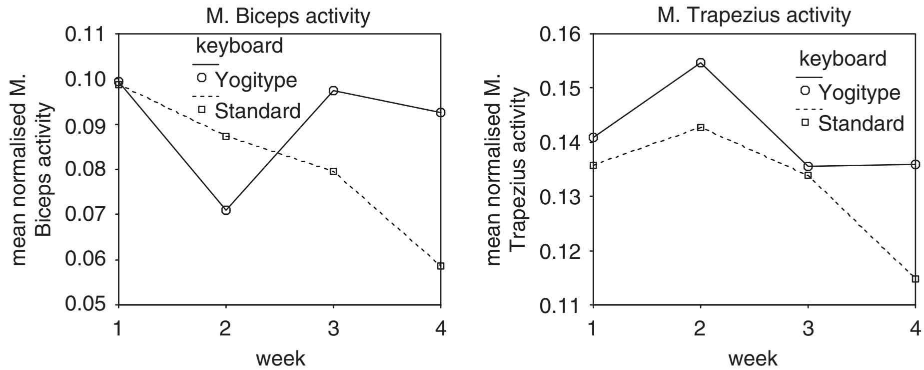

Fig. 8. Mean normalized muscle activation (in percentages of the 5% maximal activation range) of the m. biceps (left graph) and the m. trapezius descendens (right graph) during the training period (weeks 1–4) for the Yogitype and the standard keyboard.

4. Discussion

The development of typing speed and typing error rates during weeks 1–4 revealed that proficiency in operating the Yogitype keyboard was achieved within a few hours of practice. Furthermore, the self-reports showed that operating the Yogitype keyboard was rated as easy as and more comfortable than the regular keyboard. The muscular activation data confirmed that a vertical keyboard is less burdening for certain muscle groups. For all three extensors a lower mean muscle activation score was found than for the horizontal keyboard. The effect for the two neutral and more medially directed extensors was already noticeable at the start of practice and for the m. extensor ulnaris tension decreased even further during the course of the training period. The effects for the flexors were less pronounced. The reduction in the level of activation was significant for the m. flexor radialis only. It is interesting to note that in view of prevention of RSI the finding of bigger effects for the extensor muscles when operating the Yogitype keyboard is especially relevant because it is this muscle that patients predominantly report as being painful. The vertical keyboard proved to alleviate the tension in these sensitive muscles. However, even though the favourable performance levels and muscular benefits were realized within 4 weeks with a training schedule consisting of eight twice-weekly practice sessions of 30 min, this was the first study to test performance on the new Yogitype keyboard and further evidence, especially with patients groups, is required.

It needs mentioning that the observed levels of muscle activation may have been contaminated by overall typing speed. Although the differences between the two keyboards were non-significant over the entire test period, it is possible that the slightly higher typing rate reached with the standard keyboard was responsible for the higher tension levels found. However, muscle tension was expressed as a normalized, relative measure and the normalization was performed for each condition separately. The higher activation levels signify that the muscle was activated more relative to its own maximum level (5% highest activation) during that condition. This latter measure may have been higher in the standard keyboard but, since typing speed rates were quite similar after the first week, the difference in typing rates alone cannot have affected the relative scores. Secondly, even though the typing rates for the experimental keyboard increased throughout the 4-week practice period as an effect of familiarization with the key positions, the differences between the activation levels for all significant muscles were already present at the first assessment and did not change during the practice period, apart from a slight decrease for the flexor and extensor ulnaris muscles. This latter effect, however, also applied to the traditional keyboard and more importantly, it was statistically non-significant. A further critical remark could be that by normalizing observed values of EMG activation against the 5% highest activation a non-traditional method of normalization was used. Yet, for our explicit purpose, i.e. to compare measurements over different measurement sessions, the traditional method of using MVC values would also not have been ideal. We have validated the presently used method in several control studies and also compared it to traditional normalization against MVC, which yielded basically identical outcomes. Overall, the present evaluation supports equipping computer and office workers with a vertical keyboard as a preventative measure against RSI.

It is argued that, although body posture does play a role, it does so only in combination with other factors such as workload and mental pressure. From a muscular tension point of view the present data are promising. The reduction in muscle tension was between 20% and 30%, which is taken to represent a significant contribution in the avoidance of muscle overload and damage (Visser and Van Dieën, 2006).

The introduction of an ergonomic but revolutionary innovation like the vertical keyboard in the workplace is bound to meet with opposition due to its unusual layout. However, our data show that the learning process is swift and convenient, which may help to overcome any initial psychological resistance to the new keyboard. Some VDU workers might prefer to use speech-input systems to manually operated interfaces. However, speech-driven systems clearly have their limitations since they offer fewer possibilities for function keys. Moreover, work conditions are often unsuitable for speech input. It is therefore to be expected that an ergonomically enhanced keyboard may have great impact on VDU workers' proficiency and satisfaction. This might be true for normal work environments but could be even more important for stressful situations and/or for persons with a greater individual risk of developing RSI complaints. Research has shown that physical and mental stress have a cumulative effect in enhancing limb stiffness (Van Galen and Van Huygevoort, 2000; Wahlström et al., 2002) and that individual personality factors such as trait and state anxiety induce higher muscular tension in conditions of mental stress (Van Galen et al., 2002). The lower muscular tension associated with the use of a vertical keyboard can help prevent a possible transgression of critical values in VDU workers.

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