Applied Ergonomics 47 (2015) 151–156

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

A vertical mouse and ergonomic mouse pads alter wrist position but do not reduce carpal tunnel pressure in patients with carpal tunnel syndrome

Annina B. Schmid [a, b], Paul A. Kubler [c, d], Venerina Johnston [e], Michel W. Coppieters [a, f, *]

[a] Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia, QLD 4072, Australia
[b] Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford OX3 9DU, United Kingdom
[c] Department of Clinical Pharmacology, Royal Brisbane and Women's Hospital, Herston, QLD 4029, Australia
[d] School of Medicine, The University of Queensland, Herston, QLD 4029, Australia
[e] Division of Physiotherapy, School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia, QLD 4072, Australia
[f] Faculty of Human Movement Sciences, MOVE Research Institute Amsterdam, VU University Amsterdam, Amsterdam, The Netherlands

A R T I C L E I N F O

Article history:
Received 19 May 2014
Accepted 27 August 2014
Available online

Keywords:
Carpal tunnel syndrome
Computer use
Ergonomic workplace

A B S T R A C T

Non-neutral wrist positions and external pressure leading to increased carpal tunnel pressure during computer use have been associated with a heightened risk of carpal tunnel syndrome (CTS). This study investigated whether commonly used ergonomic devices reduce carpal tunnel pressure in patients with CTS. Carpal tunnel pressure was measured in twenty-one patients with CTS before, during and after a computer mouse task using a standard mouse, a vertical mouse, a gel mouse pad and a gliding palm support. Carpal tunnel pressure increased while operating a computer mouse. Although the vertical mouse significantly reduced ulnar deviation and the gel mouse pad and gliding palm support decreased wrist extension, none of the ergonomic devices reduced carpal tunnel pressure. The findings of this study do therefore not endorse a strong recommendation for or against any of the ergonomic devices commonly recommended for patients with CTS. Selection of ergonomic devices remains dependent on personal preference.

1. Introduction

Carpal tunnel syndrome (CTS) is one of the most common musculoskeletal occupational injuries (Schneider and Irastorza, 2010). The prevalence of CTS in industries in which workers perform repetitive, high force manual tasks, such as meat and fish processing (Kim et al., 2004) or grinding (Hagberg et al., 1992), is substantially higher than in the general population. Some studies suggest that exposure to low load repetitive tasks, such as computer usage in office workers is also a risk factor for the development of CTS especially with prolonged use (Andersen et al., 2003; Ali and Sathiyasekaran, 2006; Eleftheriou et al., 2012; Lam and Thurston, 1998). However, as a recent systematic review pointed out, other authors did not identify an association between CTS and the duration of computer use (van Rijn et al., 2009). Features of computer use thought to be associated with an increased risk of CTS are non-neutral wrist and forearm postures, and repetitive and sustained loading of the small muscles of the hand while using the keyboard and mouse (Rempel et al., 1997, 1998; Fung et al., 2007; Keir et al., 2007). The common mechanism underlying these features is an intrinsic elevation of carpal tunnel pressure (Rempel et al., 1997, 1998; Keir et al., 1999; Rempel et al., 2008; Keir et al., 1998). Carpal tunnel pressure may also be increased by external pressure over the palmar wrist region (Lundborg et al., 1982), as may be present when the wrist is positioned on the table or a wrist support during computer use (Wigley, 2004).

In healthy people, the association between both keyboard (Rempel et al., 2008) and computer mouse use (Keir et al., 1999) and elevated carpal tunnel pressure has been confirmed. Such sustained pressure is believed to have a detrimental effect on neural blood circulation and neural integrity (Sunderland, 1976; Mackinnon, 2002; Powell and Myers, 1986).

Patients with CTS already have elevated carpal tunnel pressure during rest (Gelberman et al., 1981; Luchetti et al., 1998) which may be further increased during computer tasks. Various ergonomic

* Corresponding author. MOVE Research Institute Amsterdam, VU University Amsterdam, Van der Boechorststraat 7, 1081 BT Amsterdam, The Netherlands. Tel.: +31 (0)20 5988601; fax: +31 (0)20 5988529.
E-mail address: m.coppieters@vu.nl (M.W. Coppieters).

http://dx.doi.org/10.1016/j.apergo.2014.08.020

devices that promote a more neutral wrist and forearm position or prevent external pressure over the palmar wrist region have therefore been created. The expectation is that these devices prevent excessive carpal tunnel pressure during computer work with a subsequent reduction of symptoms. For example, the vertical mouse was developed to maintain the forearm in a more neutral pronation-supination position whereas different mouse pads were developed to maintain the wrist in a more neutral flexion-extension position, or reduce external pressure over the palmar wrist region.

A recent Cochrane review reported that there is insufficient evidence for the benefit or harm of ergonomic equipment or positioning regimes during computer use for people with CTS (O'Connor et al., 2012). Only two studies met the inclusion criteria of the review and these two studies investigated the effect of ergonomic keyboards. The effectiveness of ergonomically designed mice and mouse pads has not yet been evaluated in patients with CTS. The effects of forearm boards and an alternative mouse which placed the forearm in a more neutral position have been investigated in engineers who used a computer for more than 20 h per week (Conlon et al., 2009, 2008). Whereas the forearm support board induced a reduction in upper extremity discomfort, the alternative mouse did not result in a significant reduction in the incidence of musculoskeletal disorders, or discomfort in the upper quadrant (Conlon et al., 2009, 2008), and had no effect on median nerve function (Conlon et al., 2009, 2008). Also in healthy people, three computer mice from different manufacturers were compared. The devices induced comparable increases in carpal tunnel pressure (Keir et al., 1999). The tested mice differed however only marginally in terms of size and shape (standard mice of different manufacturers), and were not specifically designed to address wrist/forearm position or external pressure over the carpal ligament. To date, there are no data available for a potential effect of ergonomically designed mice and mouse pads on carpal tunnel pressure. Furthermore, all pressure recordings during mouse operation have so far been conducted in healthy participants. This study therefore investigated whether patients with CTS have a smaller increase in carpal tunnel pressure when using either an ergonomically designed vertical mouse (to promote a more neutral forearm position), a gel mouse pad (to promote a more neutral wrist position) or a gliding palm support (to promote a more neutral wrist position while decreasing external pressure over the carpal tunnel) compared to using a standard mouse.

2. Study population and methods

2.1. Participants

Twenty-one patients who met the clinical and electrodiagnostic criteria for mild ($N = 6$) or moderate CTS ($N = 15$) were recruited through the local print media and volunteered to participate in this study (female: 13, male: 8; mean (SD) age: 50.0 (8.8) years; duration of symptoms: 5.6 (8.9) years). Potential participants were first screened for symptoms and a history indicative of CTS according to the clinical criteria outlined by the American Academy of Neurology (AAEM, 1993), which suggest that the likelihood of CTS increases with an increasing number of standard symptoms, and provocative and mitigating factors (Symptoms: (1): dull, aching discomfort in the hand, forearm or upper arm; (2): paraesthesia in the hand; (3): weakness or clumsiness of the hand; (4): dry skin, swelling or colour changes in the hand. Provocative factors: (1): sleep; (2): sustained hand or arm positions; (3): repetitive actions of the hand or wrist. Mitigating factors: (1): changes in hand posture; (2): shaking the hand). We refrained from performing physical tests (e.g., Phalen's, Tinel's signs) since the diagnostic accuracy of most tests is suboptimal (Mondelli et al., 2001) and the presence of a normal physical examination does not exclude the presence of CTS (AAEM, 1993). Following the clinical screening, patients who were likely to have CTS were sent for electrodiagnostic testing. We used the scale by Bland (2000) to grade electrodiagnostic test severity. To be classified as mild or moderate CTS, sensory nerve conduction velocities of the median nerve (recorded over the first or second digit) needed to be recordable but slowed (<40 m/s) and median compound motor action potential latencies (recorded over the abductor pollicis brevis) had to be below 6.5 ms. Patients either had to have unilateral CTS on the right side or bilateral CTS, had to be right hand dominant and had to have normal or corrected-to-normal vision. Patients were excluded if electrodiagnostic findings were indicative of peripheral neuropathies other than CTS, if another medical condition which affected the upper extremity or neck was present, if a history of previous surgery or significant trauma to the upper limb or neck existed, or if CTS was related to pregnancy or diabetes.

Baseline symptoms and function were evaluated with the Boston CTS questionnaire (Levine et al., 1993), the s-LANSS (Bennett et al., 2005), as well as visual analogue scales (VAS) for the level of pain, paraesthesia, and numbness over the last 24 h (Table 1).

The study was approved by the institutional ethics committee and all participants gave informed written consent prior to participating.

2.2. Mouse tasks

The effect of an ergonomically designed mouse and mouse pads on carpal tunnel pressure was evaluated during a series of 5-min point-and-click tasks. The relatively short task duration was chosen because of the invasive nature of the experiment and the number of test conditions. Furthermore, the initial increase in pressure with keyboard use changes little over a 4 h period (Rempel et al., 2008) and it was therefore assumed that the plateau which was achieved during the 5-min task would be representative for the increased carpal tunnel pressure during prolonged mouse tasks. During each task, patients were instructed to use the highlighter in Microsoft Word to highlight words that contain one letter 'e' at a comfortable pace. The following four conditions were evaluated in random order (Fig. 1): (1) a standard computer mouse (Dell, Round Rock, Texas, USA), (2) a standard computer mouse in conjunction with a gel mouse pad to promote a neutral wrist position (InSystem ergonomic mouse pad, Officeworks, Australia), (3) a standard computer mouse in conjunction with a gliding palm support designed to maintain a neutral wrist position and limit contact pressure over the carpal tunnel by supporting only the thenar and hypothenar area of the hand (Fellowes, Itasca, IL, USA) and (4) a vertical mouse designed to promote a neutral forearm posture (Evoluent vertical mouse 3-Rev2, CA, USA).

As patients were unfamiliar with the vertical mouse, a short instruction according to the user manual (Evoluent) followed by a 5-min familiarisation period and a short rest preceded the actual

Table 1
Baseline characteristics of the participants.

Item	Mean (SD)
Boston CTS questionnaire (Symptom scale)	2.5 (0.5)
Boston CTS questionnaire (Function scale)	1.6 (0.4)
s-LANSS	10.0 (4.5)
VAS pain (0–10 cm)	3.2 (2.7)
VAS paraesthesia (0–10 cm)	4.7 (2.7)
VAS numbness (0–10 cm)	4.1 (3.0)

s-LANSS: self-report version of the Leeds Assessment of Neuropathic Symptoms and Signs questionnaire. $N = 21$.

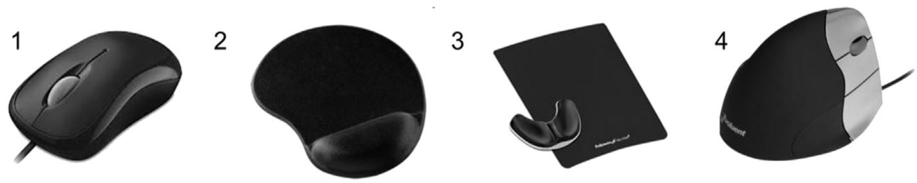

Fig. 1. Different mice and ergonomic devices used: (1) standard mouse, (2) gel mouse pad, (3) gliding palm support with a Health-V channel to reduce contact pressure over the wrist, (4) vertical mouse.

vertical mouse task. During the 2 min change-over time of the ergonomic devices, the patients were asked to relax their hand on the table. During the tasks, patients were seated in a comfortable position in front of a computer screen. The height of the chair was adjusted so that their feet were positioned flat on the floor with their knees at ~90° and their elbows resting on the table in ~90° flexion (Conlon et al., 2008). Their back was supported by a backrest. We did not provide further directions or corrections regarding their sitting posture, as it might have been difficult to maintain non-habitual sitting postures for the duration of the experiment. The top of the computer screen was set at eye level. The mouse was located directly in front of the right shoulder close to the body and at the same level as the keyboard. This set-up is consistent with recommended guidelines for computer use (Government, 2008).

Immediately after each mouse task, patients rated the level of perceived comfort for each condition on a 10 cm VAS, ranging from 'not at all comfortable' to 'extremely comfortable'. Participants were allowed to adjust their ratings at the completion of the experiment to correctly reflect the relative comfort levels of the different conditions. The number of words with one 'e' that were highlighted at the completion of each task was counted as a measure of performance.

2.3. Carpal tunnel pressure and wrist goniometry

Carpal tunnel pressure recordings were made continuously for 5 min during the mouse tasks, as well as 1 min before and after each task, while the hand was resting on the mouse. To measure carpal tunnel pressure, an epidural catheter (Portex Epidural Minipack (18 gauge), Smith Medical, Australia) was inserted into the carpal tunnel via an epidural needle under local anaesthesia. The tip of the needle was positioned at the level between the hook of hamate and the pisiform bone in the centre of the carpal tunnel. Once the epidural catheter was in situ, the needle was retracted. Real time diagnostic ultrasound imaging was used for visual feedback during the procedure. The catheter was connected to a single-use, sterile pressure transducer (TranStar Patient Mount Monitoring Kit, Smith Medical, Australia). The reliability of this method to measure carpal tunnel pressure is high and a detailed description of the method can be found elsewhere (Coppieters et al., 2012).

Recordings were amplified (Strain Gauge Transmitter WT127, Analogue Process Control Services, Seven Hills, Australia) and sampled at 100 Hz with a Micro 1401 data acquisition system using Spike2 software (Cambridge Electronic Design, Cambridge, UK). After completion of the recordings, the pressure transducer was calibrated using an MLA 1052 pressure gauge (AD Instruments, Bella Vista, Australia).

Wrist flexion-extension and radio-ulnar deviation angles were monitored during all tasks with an electrogoniometer (Model SG65; Biometrics Ltd, Gwent, UK). The electrogoniometer was calibrated with a standard goniometer. Signals were sampled with the same data acquisition system as described above.

2.4. Sample size calculation and statistical analysis

A-priori sample size calculation was performed using GPower software (Version 3.1.9. Kiel, Germany). Considering that carpal tunnel pressure is ~30 mm Hg during computer mouse use in healthy participants (Keir et al., 1999) and pressures being approximately twice as high in patients with CTS (Coppieters et al., 2012), we anticipated the mean pressure using a standard mouse to be ~60 mm Hg. We considered it a meaningful effect if an ergonomically designed device could limit the increase in pressure to 45 mm Hg. A reduction by 15 mm Hg is half the difference between healthy people and patients with CTS. Allowing for a large standard deviation of 20 mm Hg, the effect size is 0.32. Calculation revealed that 20 participants were needed to detect significant differences with a power of 80% and significance set at $p = 0.05$.

Pressure recordings were analysed using a two-way repeated-measures analysis of variance (ANOVA), with CONDITION (four levels) and TIME (three levels: pressure before, during and after the task) as repeated factors. For a small number of recordings, the pressure measurement either before ($N \le 3$) or after ($N \le 1$) the task was unstable and therefore replaced by the more stable recording after or before the task, respectively. Comparison of the stable recordings before and after the task revealed no difference in pressure (paired *t*-test, $p = 0.88$), indicating that this method of replacing missing data to prevent loss of data was unlikely to have affected the results.

To investigate whether patients with an overall low baseline pressure would perhaps conceal a potential pressure reduction with ergonomically designed mouse and mouse pads, we performed an additional two-way repeated-measures ANOVA on half of the patients (11/21 participants) who had the highest carpal tunnel pressures at rest (before the task).

The number of highlighted words as a measure of task performance and the perceived comfort scores for each mouse task were compared with one-way repeated-measures ANOVAs. Pearson correlation coefficients were calculated to determine potential associations between comfort and carpal tunnel pressure, and between comfort and performance.

Wrist angles for flexion-extension and radio-ulnar deviation during the different mouse conditions were analysed using separate two-way repeated-measures ANOVA, with CONDITION and TIME as repeated factors. LSD tests were used for post-hoc analysis. For all analyses, the level of significance was set at $p < 0.05$ and the statistical software PASW (SPSS Inc Chicago, USA) was used.

3. Results

Analysis of the pressure data revealed that there was no significant interaction effect for CONDITION × TIME ($p = 0.34$) (Fig. 2), i.e., the pattern of pressure changes over time was similar for the different conditions. There was a significant main effect for TIME ($p < 0.0001$), with higher pressure recordings during the mouse task, compared to the resting periods before and after the mouse task (both $p < 0.0001$). As previously indicated, there was no

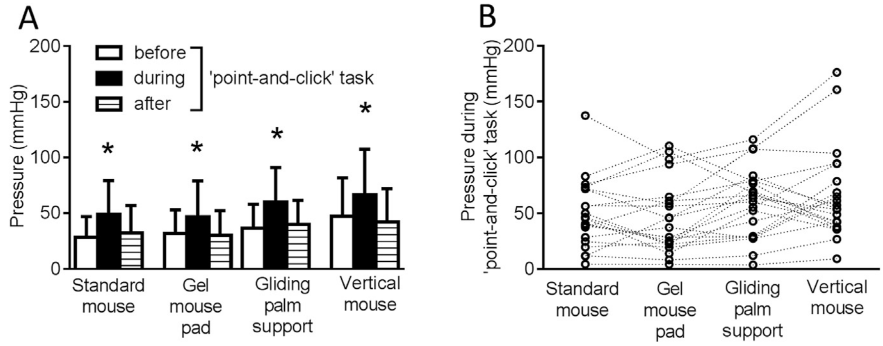

Fig. 2. (A) Mean carpal tunnel pressures during the four different conditions (in mm Hg) before (white column), during (black column) and after (horizontal hatching) the point-and-click task. *: Significantly elevated pressure during the clicking task compared to the resting period before and after the task. The error bars represent 1 SD, $N = 21$. (B) Carpal tunnel pressure (in mm Hg) of individual patients during the 'point-and-click' tasks. The pressure levels during the different conditions are connected with dotted lines for each participant.

Table 2
Mean (SD) pressure and wrist angles during the 'point-and-click' task.

	Pressure (mm Hg)	Wrist flexion-extension position (degrees)*	Wrist radio-ulnar deviation position (degrees)#
Standard mouse	48.9 (30.4)	14.9 (10.9)	16.9 (12.2)
Gel mouse pad	46.5 (32.5)	5.3 (10.4)	17.0 (12.6)
Gliding palm support	60.0 (31.0)	6.1 (12.1)	24.5 (10.2)
Vertical mouse	66.2 (41.3)	29.3 (10.7)	5.8 (9.4)

Positive values indicate wrist extension (*) or ulnar deviation (#). $N = 21$.

difference in pressure recordings between the two rest recordings (before and after each condition) ($p = 0.88$), suggesting that a 5-mins period of mouse operation did not carry over to a sustained pressure increase after cessation of the task. There was no main effect for CONDITION ($p = 0.17$), indicating that the pressure levels were comparable for the different mice and mouse pads (Table 2). The analysis of the 11 patients with the highest baseline pressure levels revealed a comparable result with no significant interaction effect of CONDITION × TIME ($p = 0.88$) and no significant main effect for CONDITION ($p = 0.37$). The previously identified main effect for TIME remained ($p < 0.0001$). This suggests that a floor-effect did not occur and that patients with low baseline pressures did not conceal a potential decrease in pressure.

Evaluation of the wrist angles revealed no significant interaction effect for CONDITION × TIME for both flexion-extension ($p = 0.55$) and radio-ulnar deviation ($p = 0.31$). This indicated that the pattern of angle changes over time was similar for the different conditions. There was a significant main effect for TIME for all wrist angles ($p < 0.0001$). Post-hoc analysis revealed that wrist extension and ulnar deviation increased during all four mouse task compared to the rest period prior to the task ($p < 0.0001$). Wrist extension and ulnar deviation remained increased after completion of the mouse tasks compared to the baseline position ($p < 0.01$). There was a main effect for CONDITION for all wrist angles ($p < 0.0001$). Compared to the standard mouse condition, the addition of the gel mouse pad and the gliding palm support decreased wrist extension ($p < 0.003$), but not ulnar deviation ($p > 0.07$) (Fig. 3, Table 2). The vertical mouse condition was associated with the largest wrist extension ($p < 0.0001$), but smallest ulnar deviation compared to all other devices ($p < 0.006$).

The level of comfort was comparable across the four conditions ($p = 0.71$), but there was a relatively large variability within each condition (standard mouse (mean (SD)): 5.7 (1.9); vertical mouse: 6.0 (3.2); gliding palm support: 6.1 (2.7); gel mouse pad: 5.2 (3.2)) (Fig. 4). Fig. 4 also illustrates the largely different patterns between participants with respect to comfort ratings for the different conditions. There was also a marked division in perceived comfort for the vertical mouse.

The number of highlighted words was also comparable across the four conditions (standard mouse (mean (SD)): 59.1 (15.4) words; vertical mouse: 57.0 (14.5) words; gliding pad: 54.9 (14.1) words; gel pad: 56.0 (17.3) words; $p = 0.83$). This suggests that the different mice and wrist pads, and level of familiarity with the devices, did not impact on performance.

There were no significant correlations between perceived comfort and pressure ($p > 0.087$) or wrist angles ($p > 0.23$) for any condition (Table 3).

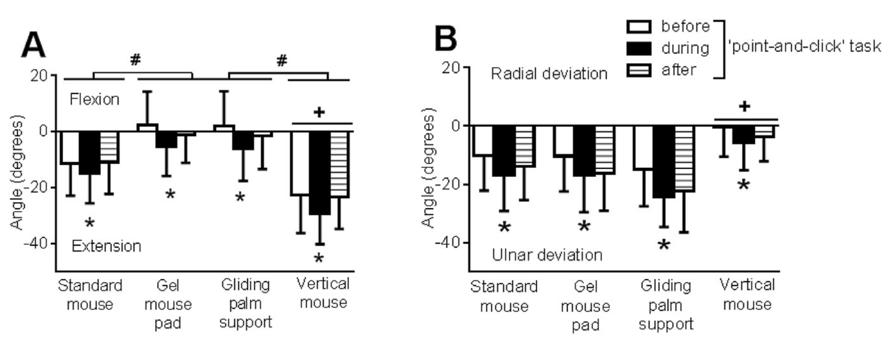

Fig. 3. Mean flexion-extension (A) and radio-ulnar deviation (B) angles at the wrist before (white column), during (black column) and after (horizontal hatching) the point-and-click task. *: Significantly increased wrist extension and ulnar deviation compared to the resting period before and after the tasks. #: Significantly more wrist extension during the standard and vertical mouse condition compared to the gel mouse pad and gliding palm support. The error bars represent 1 SD; $N = 21$.

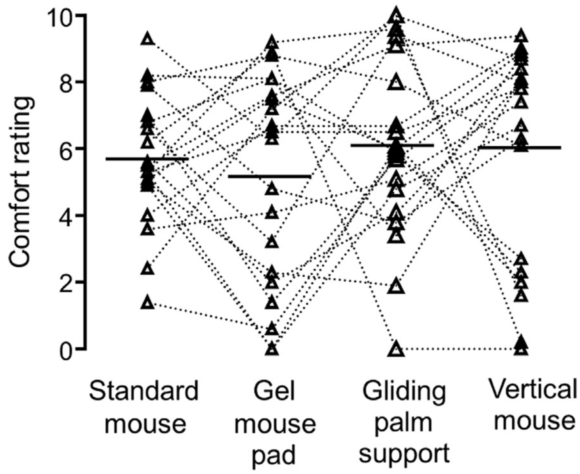

Fig. 4. Comfort ratings for the different mice and ergonomic devices. The symbols represent the comfort ratings for each condition. The ratings of individual participants are connected with dotted lines. No significant differences were identified between conditions. The multiple crossings of the dotted lines show that different participants rated the comfort of the four conditions very differently. Note that data are presented for 20 participants as the comfort ratings were not obtained from the first participant.

4. Discussion

The results of this study demonstrated that the already elevated carpal tunnel pressure in patients with CTS is further increased while operating a computer mouse. The observed mean increase in pressure (~20 mm Hg) was similar to the increase previously reported for asymptomatic participants (Keir et al., 1999). The pressure levels while performing a mouse task with the different devices ranged from 46.5 to 66.2 mm Hg, which is well above the level reported to interfere with normal nerve function (30 mm Hg) (Lundborg et al., 1982). Importantly, none of the evaluated ergonomic devices that are commonly recommended for CTS resulted in a reduction in pressure. Thus, based on the findings of this study, wrist pads and the vertical mouse cannot be recommended for patients with CTS over a standard mouse if reduction of carpal tunnel pressure is the main criterion.

Although the tested devices are designed to promote a more neutral wrist and forearm position, they could not entirely prevent an increase in wrist extension and ulnar deviation during computer mouse use compared to the resting position. It is well established that progressive wrist extension and ulnar deviation increase carpal tunnel pressure in healthy participants (e.g., (Coppieters et al., 2012; Weiss et al., 1995)) and patients with CTS (e.g., (Gelberman et al., 1981; Luchetti et al., 1998; Coppieters et al., 2012)). The observed increase in wrist angles during computer mouse use may thus explain the concurrent elevation in carpal tunnel pressure. Although the vertical mouse limited the amount of ulnar deviation and the addition of ergonomic wrist pads reduced wrist extension compared to using a standard mouse, this was not associated with lower pressure levels in the carpal tunnel. Possibly, the benefit of using wrist pads (i.e., less wrist extension) might have been offset by the larger amount of ulnar deviation. Similarly, the potential benefit of a neutral forearm position and less ulnar deviation while using the vertical mouse may have been neutralised by a more extended wrist position, which was prominent in this condition. Other authors have also reported a reduced ulnar deviation but increased wrist extension with the vertical mouse compared to a standard mouse (Feathers et al., 2013).

Table 3
Correlation between comfort, pressure and wrist angle.

	Correlation coefficient	*p*-value
Comfort versus radio-ulnar deviation[a]	−0.072	0.550
Comfort versus flexion-extension[a]	−0.138	0.225
Comfort versus pressure	0.194	0.087

[a] Negative correlation coefficients indicate lower comfort with increased ulnar deviation or wrist extension. $N = 20$.

To date, differences in finger position when using different mice and ergonomic devices have not yet been investigated. Finger position can influence carpal tunnel pressure but to a much lesser extent than forearm or wrist position (Werner et al., 1997). Because the design of where the fingers rest on the different mice is similar and the ergonomic devices do not aim to influence finger position, we assume that differences in finger position for the devices under investigation in this study were small and did not influence the pressure recordings substantially.

Besides non-neutral wrist positions, the internal forces created by gripping the mouse and fingertip loading with repetitive clicking may also have contributed to the observed increase in carpal tunnel pressure. Although the effect of repetitive low intensity fingertip loading on carpal tunnel pressure while standardising wrist and forearm positions has never been investigated, static fingertip loading with 6 N resulted in an increase of carpal tunnel pressure in asymptomatic participants (Rempel et al., 1997). This effect of fingertip loading seems to be independent of wrist position (Rempel et al., 1997).

Given that both the gliding palm support and the vertical mouse did not reduce pressure, it seems unlikely that the identified increase in pressure can be attributed to contact pressure over the tunnel.

A possible limitation of the study was that we did not specifically target office workers with CTS. Including patients with CTS with various occupations may have increased the variability in the results due to differing competency levels of using a computer and computer mouse. Although all participants were familiar with the standard mouse, most participants had no previous experience with the wrist pads and vertical mouse. Nevertheless, task performance and level of comfort did not differ across conditions. As mentioned previously, we also did not monitor finger position when using the different ergonomic devices. Although finger position may influence carpal tunnel pressure, it appears that mainly end range positions (forced passive extension and full flexion) may result in carpal tunnel pressure increases (Werner et al., 1997).

Other possible limitations were that the tasks might have been performed slightly differently or more carefully due to the presence of the catheter, electrogoniometer and various small cables. Although the set-up was planned carefully, some interference cannot be ruled out or could not have been prevented due to the invasive nature of the recordings. Even though we standardised the location of the catheter tip to the middle of the carpal tunnel where pressure has been shown to be maximal (Luchetti et al., 1998), this standardised localisation may not have revealed the highest pressures in all participants. The trend towards higher rather than lower pressure with the vertical mouse and gliding palm support together with comparable results when excluding patients with low baseline pressures suggest however that catheter placement is unlikely to have led to an oversight of reduced carpal tunnel pressure using ergonomic devices.

Because the catheter was in place during the mouse tasks and because four different conditions were evaluated, we limited the duration of each mouse task to 5 min. We have no reasons to assume that the findings would have been different when evaluation periods would have been longer, especially since it has been reported that the initial increase in pressure with prolonged keyboard use changes only little over a 4 h period (Rempel et al., 2008). Considering the distinct configuration of the vertical mouse, the relatively short familiarisation period and task duration may have contributed to the polarisation in comfort rating for this condition. It has previously been shown that instructions prior to using alternative mouse designs further enhance their biomechanical benefits (Houwink et al., 2009). It remains to be explored whether a longer familiarisation period and more detailed explanations would improve the comfort rating for the vertical mouse or whether a subset of people continue to find this configuration uncomfortable.

We also believe that a larger sample size would not have altered our findings. In the a-priori sample size calculation, we had allowed for the variability in pressure between patients with CTS (20 mm Hg) to be up to three times the variability observed in healthy participants (6.0–6.7 mm Hg (Keir et al., 1999)). Although the variability was larger than anticipated which may have reduced the power to detect differences, there was no tendency that the ergonomic devices limited the increase in pressure. In fact, the pressure with the vertical mouse and gliding palm support was marginally higher compared to a standard mouse.

Because the vertical mouse and wrist pads did not limit the increase in carpal tunnel pressure, the findings of this study do not endorse a strong recommendation for or against any of the ergonomic devices commonly recommended for patients with CTS. There may however be other mechanisms apart from changing carpal tunnel pressure by which ergonomic devices may exert potential beneficial effects. For instance, they may reduce pressure over the palmar branch of the median nerve which travels outside the carpal tunnel but can cause symptoms mimicking CTS (Wigley, 2004). Furthermore, ergonomic mice with a slanted design have been shown to modify forearm muscle activation (Chen and Leung, 2007). Similarly, forearm supports during mouse use have been shown to reduce muscle activation in the neck and shoulder region, but a similar beneficial effect for wrist pads could not be found (Onyebeke et al., 2013; Visser et al., 2000). Potentially, the identified alterations of wrist position by the vertical mouse and wrist pads may lead to changes in forearm muscle activation patterns. Furthermore, the fingers are not working with and against gravity but are working horizontally when using the vertical mouse, which may be associated with different muscle activation patterns and tendon loading. Further studies are needed to investigate whether such changes are present and may exert beneficial effects not only for CTS, but also for other hand/arm conditions such as repetitive strain injury or rheumatoid arthritis. While awaiting further studies, personal preference will be an important factor in selecting ergonomic devices for people with CTS and other conditions that are potentially aggravated by prolonged computer use.

References

AAEM, 1993. Practice parameter for carpal tunnel syndrome (summary statement). Report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology 43, 2406–2409.

Ali, K.M., Sathiyasekaran, B.W., 2006. Computer professionals and carpal tunnel syndrome (CTS). Int. J. Occup. Saf. Ergon. 12, 319–325.

Andersen, J.H., et al., 2003. Computer use and carpal tunnel syndrome: a 1-year follow-up study. JAMA 289, 2963–2969. http://dx.doi.org/10.1001/jama.289.22.2963.

Bennett, M.I., et al., 2005. The S-LANSS score for identifying pain of predominantly neuropathic origin: validation for use in clinical and postal research. J. Pain 6, 149–158. http://dx.doi.org/10.1016/j.jpain.2004.11.007. S1526590004011162 [pii].

Bland, J.D., 2000. A neurophysiological grading scale for carpal tunnel syndrome. Muscle Nerve 23, 1280–1283.

Chen, H.M., Leung, C.T., 2007. The effect on forearm and shoulder muscle activity in using different slanted computer mice. Clin. Biomech. (Bristol, Avon) 22, 518–523. http://dx.doi.org/10.1016/j.clinbiomech.2007.01.006.

Conlon, C.F., Krause, N., Rempel, D.M., 2008. A randomised controlled trial evaluating an alternative mouse and forearm support on upper body discomfort and musculoskeletal disorders among engineers. Occup. Environ. Med. 65, 311–318. http://dx.doi.org/10.1136/oem.2006.032243.

Conlon, C.F., Krause, N., Rempel, D.M., 2009. A randomized controlled trial evaluating an alternative mouse or forearm support on change in median and ulnar nerve motor latency at the wrist. Am. J. Ind. Med. 52, 304–310. http://dx.doi.org/10.1002/ajim.20674.

Coppieters, M.W., et al., 2012. Description, reliability and validity of a novel method to measure carpal tunnel pressure in patients with carpal tunnel syndrome. Man. Ther. 17, 589–592. http://dx.doi.org/10.1016/j.math.2012.03.005.

Eleftheriou, A., et al., 2012. Cumulative keyboard strokes: a possible risk factor for carpal tunnel syndrome. J. Occup. Med. Toxicol. 7, 16. http://dx.doi.org/10.1186/1745-6673-7-16.

Evoluent. User Manual for the Vertical Mouse. http://www.evoluent.com/support.htm.

Feathers, D.J., Rollings, K., Hedge, A., 2013. Alternative computer mouse designs: performance, posture, and subjective evaluations for college students aged 18–25. Work 44 (Suppl. 1), S115–S122. http://dx.doi.org/10.3233/WOR-121487.

Fung, B.K., et al., 2007. Study of wrist posture, loading and repetitive motion as risk factors for developing carpal tunnel syndrome. Hand Surg. 12, 13–18. http://dx.doi.org/10.1142/S0218810407003341.

Gelberman, R.H., et al., 1981. The carpal tunnel syndrome. A study of carpal canal pressures. J. Bone Jt. Surg. Am. 63, 380–383.

Government, C.A, 2008. Officewise– a Guide to Health and Safety in the Office. http://www.comcare.gov.au/__data/assets/pdf_file/0006/39570/Officewise_OHS1_Apr_10.pdf.

Hagberg, M., Morgenstern, H., Kelsh, M., 1992. Impact of occupations and job tasks on the prevalence of carpal tunnel syndrome. Scand. J. Work Environ. Health 18, 337–345.

Houwink, A., et al., 2009. Providing training enhances the biomechanical improvements of an alternative computer mouse design. Hum. Factors 51, 46–55.

Keir, P.J., et al., 2007. Guidelines for wrist posture based on carpal tunnel pressure thresholds. Hum. Factors 49, 88–99.

Keir, P.J., Bach, J.M., Rempel, D.M., 1998. Fingertip loading and carpal tunnel pressure: differences between a pinching and a pressing task. J. Orthop. Res. 16, 112–115. http://dx.doi.org/10.1002/jor.1100160119.

Keir, P.J., Bach, J.M., Rempel, D., 1999. Effects of computer mouse design and task on carpal tunnel pressure. Ergonomics 42, 1350–1360.

Kim, J.Y., et al., 2004. Prevalence of carpal tunnel syndrome in meat and fish processing plants. J. Occup. Health 46, 230–234.

Lam, N., Thurston, A., 1998. Association of obesity, gender, age and occupation with carpal tunnel syndrome. Aust. N. Z. J. Surg. 68, 190–193.

Levine, D.W., et al., 1993. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. J. Bone Jt. Surg. Am. 75, 1585–1592.

Luchetti, R., Schoenhuber, R., Nathan, P., 1998. Correlation of segmental carpal tunnel pressures with changes in hand and wrist positions in patients with carpal tunnel syndrome and controls. J. Hand Surg. Br. 23, 598–602.

Lundborg, G., et al., 1982. Median nerve compression in the carpal tunnel–functional response to experimentally induced controlled pressure. J. Hand Surg. Am. 7, 252–259.

Mackinnon, S.E., 2002. Pathophysiology of nerve compression. Hand Clin. 18, 231–241.

Mondelli, M., Passero, S., Giannini, F., 2001. Provocative tests in different stages of carpal tunnel syndrome. Clin. Neurol. Neurosurg. 103, 178–183.

O'Connor, D., et al., 2012. Ergonomic positioning or equipment for treating carpal tunnel syndrome. Cochrane Database Syst. Rev. 1, CD009600. http://dx.doi.org/10.1002/14651858.CD009600.

Onyebeke, L.C., et al., 2013. Effects of forearm and palm supports on the upper extremity during computer mouse use. Appl. Ergon. 45 (3), 564–570.

Powell, H.C., Myers, R.R., 1986. Pathology of experimental nerve compression. Lab. Invest. 55, 91–100.

Rempel, D., et al., 1997. Effects of static fingertip loading on carpal tunnel pressure. J. Orthop. Res. 15, 422–426. http://dx.doi.org/10.1002/jor.1100150315.

Rempel, D., et al., 1998. Effects of forearm pronation/supination on carpal tunnel pressure. J. Hand Surg. Am. 23, 38–42.

Rempel, D.M., Keir, P.J., Bach, J.M., 2008. Effect of wrist posture on carpal tunnel pressure while typing. J. Orthop. Res. 26, 1269–1273. http://dx.doi.org/10.1002/jor.20599.

Schneider, E., Irastorza, X., 2010. In: E.A.f.S.a.H.a. Work (Ed.), European Risk Observatory Report. OSH in Figures: Work-related Musculoskeletal Disorders in the EU – Facts and Figures. Publications Office of the European Union, Luxembourg. http://dx.doi.org/10.2802/10952.

Sunderland, S., 1976. The nerve lesion in the carpal tunnel syndrome. J. Neurol. Neurosurg. Psychiatry 39, 615–626.

van Rijn, R.M., et al., 2009. Associations between work-related factors and the carpal tunnel syndrome–a systematic review. Scand. J. Work Environ. Health 35, 19–36, 1306 [pii].

Visser, B., et al., 2000. The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clin. Biomech. (Bristol, Avon) 15 (Suppl. 1), S34–S38.

Weiss, N.D., et al., 1995. Position of the wrist associated with the lowest carpal-tunnel pressure: implications for splint design. J. Bone Jt. Surg. Am. 77, 1695–1699.

Werner, et al., 1997. Intracarpal canal pressures: the role of finger, hand, wrist and forearm position. Clin. Biomech. (Bristol, Avon) 12, 44–51. S0268003396000447 [pii].

Wigley, R.D., 2004. Desk-edge syndrome: median nerve injury proximal ot the carpal tunnel. APLAR J. Rheumatol. 7, 215–218.