Biomechanics and performance when using a standard and a vertical computer mouse

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Biomechanics and performance when using a standard and a vertical computer mouse

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Objective: to compare the biomechanics and performance while using a vertical computer mouse (VM) and a standard mouse (SM).

Methods: muscle activation (electromyography), forearm movements (electrogoniometers), performance (Fitts' Law test) and satisfaction (questionnaire) of 16 subjects were evaluated.

Results: there were significant differences between the VM and the SM, respectively, on motion (28° vs. 42° pronation, \( p = 0.001 \); 5° ulnar vs. 7° radial deviation, \( p = 0.016 \)) and muscle activity (13% vs. 16% of extensor carpi activity, \( p = 0.006 \); 10% vs. 13% extensor digitorum activity, \( p = 0.001 \)). VM user satisfaction was good (68); however, time to target was longer (4.2 vs. 3.4 s, \( p < 0.001 \)).

Conclusions: using the VM decreased wrist pronation and lowered wrist extensor muscle activity, but additional training and familiarisation time may be required to improve user performance.

Practitioner Summary: Using a vertical mouse can decrease the exposure to biomechanical risk factors for computer mouse use-related musculoskeletal disorders. Using a vertical computer mouse resulted in less wrist pronation and lower wrist extensor muscle activity. But, training and familiarisation are required.

Keywords: office ergonomics; biomechanics; controls and input devices; upper limb disorders

1. Introduction

The use of computers is increasingly common in the workplace and at home. A recent study showed that computer users may develop musculoskeletal disorders (MSD) due to the forces used, the sustained isometric muscle contractions, the awkward postures, and the high wrist velocities and accelerations during computer tasks (Bruno Garza et al. 2012). Prolonged computer use can lead to decreased blood circulation and increased static loading of musculoskeletal tissues resulting in MSD (Sjogaard et al. 2004; Visser and van Dieen 2006). There is a direct relationship between increased computer use and MSD (Ijmker et al. 2007; Village, Rempel, and Teschke 2006). Using a computer for more than 3 h per day is associated with reporting MSD symptoms (Chang et al. 2007).

The use of computer mouse devices started in the 1980s because of graphic design media needs. Since then, it became a standard tool for user–computer interface and interaction. However, the standard computer mouse design requires upper extremity postures that may increase carpal tunnel pressure and median nerve strain, decrease blood flow and result in muscle fatigue, all of which are associated with carpal tunnel syndrome (CTS) and other upper extremity MSD (Keir, Bach, and Rempel 1999). Recent systematic reviews of literature have identified methodological limitations among previously conducted studies on the association between computer work and MSD, and recommended additional quantitative studies (da Costa and Vieira, 2010; Waersted, Hanvold, and Veiersted 2010). Further studies on the risks associated with the use of standard computer mouse devices are required, and improved designs may have significant public health benefits and therefore need to be evaluated (Gerr, Marcus, and Monteilh 2004).

The forces involved in using computer mice are small, but need to be sustained for prolonged periods of time; in addition, the postures adopted when using standard computer mouse devices increase the risk of MSD affecting the upper body, neck, shoulders and arms (Aaras et al. 1998; Fernstrom and Ericson, 1997; Jensen et al. 1998, 2002). The design of standard computer mouse devices affects the postures of the wrist, hand and fingers, resulting in increased flexion, abduction and external rotation of the shoulder and increased muscular load (Cook and Kothiyal, 1998; Karlqvist, Hagberg, and Selin 1994; Karlqvist et al. 1998). The use of standard computer mouse devices is associated with maintaining less than optimum static postures and sustained muscle contraction for long periods of time; these factors increase the risk of MSD (Westgaard et al. 1986).

Computer mouse designs that optimise postures and minimise muscle activation during use may improve comfort and reduce the risk of MSD. For this reason, different types of devices, ergonomics interventions and alternative data entry
methods have been proposed (de Korte et al. 2008; Feathers, Rollings, and Hedge 2013; Juul-Kristensen et al. 2004; King et al. 2013; Levanon et al. 2012). However, the benefits to users need to be further evaluated (Hoe et al. 2012). The vertical mouse (VM) is an alternative to the standard mouse (SM) because it has a different design that intends to minimise some of the problems previously identified with the standard computer mouse. Therefore, the objective of this study was to compare the upper limb biomechanics and task performance when using a standard and a vertical computer mouse (VM).

2. Methods

2.1. VM description

The VM tested is registered in the Brazilian Patent Office (File#PI0401982-2). The VM was constructed based on the ergonomics and biomechanics of handwriting. The VM design aimed to position the hand and the forearm in a more neutral position (Peres, Quemelo, and Graeff 2006). Neutral positions optimise function and require less muscle activity, reducing strain and fatigue, and minimise compression and sprain of musculoskeletal structures (e.g. muscles, tendons, ligaments, blood vessels and nerves). Forearm muscles are least active when the wrist is in $5^{\circ} - 7^{\circ}$ of ulnar deviation and $7^{\circ} - 9^{\circ}$ of wrist extension (Fagarasanu, Kumar, and Narayan 2004). The VM has a rod that can be moved according to the user’s preference and anthropometry to help sustain wrist/hand postures closer to neutral. The rod has right and left click buttons that can be activated using the indicator or the thumb fingertips. The VM can be used by either the right hand or the left hand by rotating the rod position. The VM’s base is constructed as a V-shape for ease of use and cursor control on the computer screen (Figure 1).

2.2. Subjects

Sixteen right-handed volunteers (6 males and 10 females), 26 ± 3 years old, 1.71 ± 0.12 m tall, with a body mass of 71 ± 18 kg and body mass index of 24 ± 3 kg/m² participated in the study. All participants were physical therapy students with similar schedules and computer use requirements. The sample size was calculated using the DIMAM 1.0 software (Guaranabara Koogan, Rio de Janeiro, Brazil) based on the effect sizes reported in previous studies and with a significance level of 0.05 (Arango, 2005). At least 15 subjects were needed to have a power of 0.95 to identify differences between the two mouse devices.

Institutional Review Board approval was obtained before the initiation of the project (Approval No. 112911-00). The subjects were recruited from a university setting. Interested subjects received an information letter explaining the study’s objectives and procedures and were given the opportunity to ask questions. Those willing to participate signed an informed consent form. The inclusion criterion was to have used a computer mouse every week during the previous year. The exclusion criteria were to be experiencing musculoskeletal injuries or pain, recent muscle strain/sprain, fractures or upper limb surgery.

2.3. Setting

The study was conducted in a university office. The workstation included a computer desk and adjustable chair with backrest and arm support. The height of the seat, position of the computer monitor (19-inch, 1280 × 1024 pixels of resolution), keyboard and mouse were adjusted according to each participant anthropometry (Figure 2).

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Figure 1. (a) Vertical computer mouse, (b) vertical computer mouse handling posture and (c) standard computer mouse handling posture.
2.4. Task description

The evaluation of biomechanics and performance while using a standard and a VM was done during tests to measure steering and pointing skills, known as the Fitts’ Law test (Accot and Zhai, 1999; MacKenzie, 1995). This test is used in human–computer interface evaluation based on the concept that the time required to reach a target is a function of the distance and size of the target (Fitts, 1954). The steering tests required moving the cursor from the centre of the screen to a circular target that appears at random coordinates on the screen. The tests were used to compare the time to reach the target when using the two types of computer mouse. Figure 3 presents a screenshot of the computer during the pointing task with some of the measures undertaken. The target size and amplitude varied systematically (fixed random distribution) during the task.
the subsequent pointing tasks. The size of the target varied between 9 and 50 pixels, and the distance to target varied from 63 to 645 pixels to each of the subjects over the 20 trials.

2.5. **Equipment**

Surface electromyography (sEMG) signals were recorded at 1000 Hz using differential bipolar Biometrics Ltd electrodes (SX230) with a preamplifier (1 kHz, 20 × Gain), fixed inter-electrode distance of 20 mm, and input impedance > 10⁹ kΩ. The signals were filtered with a bandpass frequency of 20–450 Hz. Wrist and forearm movements were recorded at 200 Hz using Biometrics Ltd electrogoniometers (SG65) and torsiometers (Q110). All signals were synchronised and digitised using an AD-conversion of 12-bits resolution, and stored using the DataLINK system (Biometrics Ltd, Gwent, UK).

2.6. **Procedures**

The subjects provided information on the following demographic parameters: age, gender, height, weight, handedness and occupation. In addition, they responded to an adapted questionnaire for computer work evaluation (Slotd et al. 2009). It included five-point scales (1 = lowest, 5 = highest ranking) on the ease of integration of the mouse into the work system (integration with desk, computer equipment and self), ease of use (convenience, functionality, stability, safety and cushioning), effect on productivity (general tasks, general computer tasks, mouse tasks and graphics), comfort (overall comfort, stress, fatigue, tension/pain in the hands, wrists, arms, shoulders, back and neck) and an open question on potential improvements to the VM.

First, the VM device was given to the subjects for them to use it at their own time for at least 8 h per week for two weeks before coming for testing (Slotd et al. 2009). After the adaptation period, the subjects completed a series of computer mouse tasks using both devices and then answered a questionnaire. Therefore, the intervention consisted providing users with the VM and with an adaptation/familiarisation time before testing. Consistency of treatment was controlled for by providing the same design VM and the same adaptation/familiarisation time (minimum of 16 h over two weeks) to all the subjects, and testing them with the same devices.

Before each test was initiated, the sensors were placed (Figure 2(a),(b)). The sEMG electrodes were placed on the skin over the muscle bellies of the extensor carpi ulnaris (ECU), extensor digitorum communis (EDC), pronator teres (PT), flexor digitorium superficialis (FDS) and upper trapezius (UT) muscles to measure the timing and amplitude of muscle activation. The common ground electrode was placed on the lateral malleolus, and the average root mean square values of the sEMG signals were assessed for the muscles recorded and normalised by the values obtained during baseline maximum voluntary isometric contractions (Agarabi, Bonato, and De Luca 2004; Byström et al. 2002; Dennerlein and Johnson, 2006).

The wrist electrogoniometer was placed on the posterior aspect of the joint with the proximal end block placed at the distal forearm and with the distal end block placed between the second and third metacarpals to measure wrist flexion/extension and radial/ulnar deviation (Figure 2(a)). The torsiometer (electrogoniometer to measure pronation/supination) was placed on the forearm with the proximal end block on the proximal and lateral aspect of the forearm and the distal end block placed on the distal and anterior aspect of the forearm with the slider mechanism midway between the two extremes (Figure 2(b)). Skin movements, inter-subject variability and crosstalk can affect electrogoniometric measurements. Crosstalk and the other sources of variance can be an issue in tasks that require large prono-supinations, but the tasks evaluated in this study did not require large motions (Hansson et al. 2004). To compensate for inter-subjects variability, the goniometer and torsiometer were zeroed in each subject’s neutral position before the test initiation. To minimise the effects of skin and cable movements, the forearm with the sensors attached were covered with pre-wrap (Figure 2(c),(d)). After all the tasks were completed with each type of mouse, the volunteers answered the questionnaire.

2.7. **Data collection**

Before initiating data collection, the subjects completed familiarisation tests using both mice. After that, the data were collected during 20 subsequent trials of cursor pointing tasks. An auditory clue was given to the subjects to begin the testing during which they had to move the cursor towards 20 consecutive targets in a straight line, as quickly and accurately as possible. The cursor was always in the centre of screen at the starting time. The test was repeated with each computer mouse in a random order using the index finger to activate both devices. The data were collected during the entire test, which lasted between 30 s and 1 min depending on how quick each subject completed the 20 pointing tasks.
2.8. Data analysis
The subjects acted as their own control. The movement time evaluator (MTE) interactive software was used for designing, executing and analysing the Fitts’ Law tests (Fitts, 1954). The MTE platform is available under the GNU Public License as open source software (http://www.cs.uml.edu/~mschedlb/mte). The software calculates the movement time (MT) in seconds. The performance was compared based on the MT in seconds obtained when using the standard and the VM. The biomechanics were compared based on the normalised sEMG signals and mean joint angles measured when using each of the two computer mouse designs, and the questionnaire scores were presented descriptively.

2.9. Statistical analysis
A multivariate Hotelling $t^2$-test was used to compare the means while using the standard and the VM devices (Manly, 1997). When there were significant differences, paired $t$-tests (for normally distributed data) and Wilcoxon–Mann–Whitney tests (for the data that were not normally distributed) were used post hoc to investigate where the differences occurred (Arango, 2005). All analyses were conducted using the GraphPad Prism 4.0 software (Prism, Chicago, IL, USA) with the level of significance set at 0.05.

3. Results
Overall, there were statistically significant differences between the standard and the VM (Hotelling’s $t^2$ statistic = 98.96; $F_{obs} = 8.06 (p = 1.110223 \times 10^{-15}$); $F_{tab} (p = 0.01) = 3.35$). The post hoc comparisons showed significant differences between the standard and the VM on the three planes of motion ($p < 0.02$, Figure 4), extensor carpi and digitorum muscle activity ($p < 0.007$, Figure 5). With the exception of extension, the values were lower with the VM. Similar, but not statistically significant, trends were found for the PT and FDS muscles. On the other hand, the UT muscle tended to be more active when using the VM. The MT was higher when using the VM (total of $1345 \pm 280$ vs. $1077 \pm 191$ s; average of $4.2$ vs. $3.4$ s per trial for each subject, $p < 0.001$). The questionnaires indicated good user satisfaction with the VM in relation to setting it up, using it, productivity while using it and comfort (Figure 6). Suggestions included reducing the forces required to press the VM buttons ($n = 5$) and adding a scroll wheel to the VM ($n = 6$).

4. Discussion
Similar to our findings, more wrist extension was found in a previous study using a trackball mouse compared to an SM (Burgess-Limerick et al. 1999), but another study found less extension when using a VM (Gustafsson and Hagberg, 2003). The differences may be related with the design of the devices and amount of training and familiarisation provided. It is necessary to consider some factors that can result in error and variation in the results, for example movements of the skin, inter-individual variation and crosstalk error. The first two were minimised by applying overwrap on top of the electrogoniometer end blocks in addition to the double-sided tape used to attach the sensors to the skin. Sample variability was reduced by including participants with reasonably similar anthropometrics. In relation to crosstalk, when combined movements are assessed (e.g. pronation with flexion or supination with extension) there is a crosstalk that may result in

Figure 4. Mean and standard deviation of the motions when using a standard and a vertical computer mouse. Flex = flexion (+), Ext = extension (−), Uln = Ulnar deviation (+), Rad = Radial deviation (−), Sup = supination (+), Pron = pronation (−). *$p < 0.05$. 

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measurement errors, especially when the ranges are high. The tasks performed in the present study did not require end-range motions. Therefore, even though we did not take any measures to correct for crosstalk, the magnitude of the differences encountered ($10^8$) is higher than the potential measurement errors.

Despite the increased wrist extension, there was less wrist extensor muscle activity when using the VM. This can be explained by the fact that when the forearm is in a more neutral pronation–supination position, gravity effects are minimised to accomplish extension. When using a standard computer mouse, the participants had to sustain wrist extension against gravity (Figure 2). This effect was removed when using the VM by repositioning the forearm in a more neutral posture. Other computer mouse designs also reduced forearm muscle activity, but to a lower extent (Agarabi, Bonato, and De Luca 2004; Gustafsson and Hagberg, 2003; Harvey and Peper, 1997). Decreased forearm muscle activity is an important positive outcome of using the tested computer mouse design because myofascial pain syndrome of forearm extensors is one of the most common upper extremity disorders associated with occupational keyboard/mouse use (Bleecker, Celio, and Barnes 2011).

A previous study of the effects of using slanted computer mouse designs found that as the slanted angles increased, ulnar/radial deviation decreased, wrist flexion/extension increased and sEMG levels of the ECU, PT and UT muscles decreased (Chen and Leung, 2007). We had similar findings, but the UT muscle tended to be more active when using the vertical rather than the standard computer mouse. This might have happened because the subjects did not rest their forearms on the table when using the new mouse. Thus, further training is required because when the forearm is supported, there is
only modest activation of shoulder muscles during computer mouse use (Laursen and Jensen, 2000). Also, the decreased performance possibly occurred due to insufficient adaptation time, and may have contributed to increased UT muscle activity as a compensation strategy to increase precision (Spiegel et al. 1996). Studies comparing performance when using a standard and other kind of mice also found better performance with the SM (Brown, Albert, and Croll 2007; Card, English, and Burr 1978; Feathers, Rollings, and Hedge 2013). The SM also showed better performance than touch screens and trackballs in vibration environments (Lin et al. 2010). Similar to our study, Gustafsson and Hagberg (2003) found that using a VM decreased not only wrist extensors’ muscle activity, but also productivity. They observed that all subjects preferred to work with the SM and half of the subjects considered the VM to have less precision and to be more difficult to move than the SM. Different from our results, these authors found lower levels of comfort when using the VM they tested. People are used to standard computer mouse devices. It is difficult to change to another kind of computer mouse. It is possible that the subjects were not sufficiently accustomed to the new mouse.

We instructed the subjects to use the VM for a minimal of 8 h per week for two weeks. But one of the limitations of the study is that we did not ask the subjects to keep a log of their use time. So, we do not know for sure how long the subjects actually used the device for before coming for testing. Even if the subjects used the device for the recommended time, the minimum 16-hour period of accommodation might not have been sufficient. We noticed that some subjects did not handle the VM properly. Further instructions and an instruction guide on how to use the VM are necessary. Training, clear instructions, workstation adjustments and better chairs, computer mouse, riser and monitor can help reduce computer use-related MSD (Houwink et al. 2009; Jacobs et al. 2009, 2011).

There is evidence supporting a causal relationship between high repetition levels, static contractions, awkward postures, high levels of force and MSD (da Costa and Vieira, 2010; Hupert et al. 2004; Ijmker et al. 2007; Jenkins et al. 2007; Village, Rempel, and Teschke 2006). CTS in computer users is related with increased carpal tunnel pressure due to prolonged awkward postures and sustained wrist motions (Fagarasanu and Kumar, 2003). Jensen et al. (1998) found an association between computer mouse use and MSD; participants who always used the same hand to operate the mouse, presented higher muscle activity, angular motion and prevalence of MSD symptoms in that side than in the other upper limb and shoulder. The authors suggested introducing more variation in computer mouse use. The VM we tested can be used by either the right hand or the left hand by rotating the rod position, and it allows activating the buttons using the indicator finger or the thumb, which might reduce static contraction, increase postural variability and decrease repetition. In addition, the more neutral postures and decreased sEMG activity of the wrist extensor muscles when using a VM may reduce the risk of upper extremity MSD. Potential improvements to the VM include reducing the forces required to press the buttons, including a scroll wheel, decreasing the size of the base and adjusting the handle position to allow resting the arm on the table during use. Prospective/longitudinal studies are necessary to evaluate if VM users have a lower rate of discomfort and upper extremity MSD than SM users.

5. Conclusion
Using a VM decreased the exposure to biomechanical risk factors for computer mouse use-related MSD. Pronation, ulnar deviation and wrist extensor muscle were lower when using a VM. However, performance was better with a standard computer mouse; additional training and familiarisation is required when using a VM to optimise performance. The questionnaires indicated good user satisfaction with a VM.

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