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BIOMEDICAL ENGINEERING | REVIEW ARTICLE

Benefits of alternative computer mouse designs: A systematic review of controlled trials

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Abstract: Prolonged use of a standard mouse is associated with musculoskeletal symptoms. This review provides professionals with in-depth analysis of the literature regarding the evidence behind the use of alternative computer mouse designs and their ability to reduce discomfort in mouse users, in addition to the potential effect of ergonomics training and forearm supports. Multiple data bases were searched by independent researchers to identify 17 high-quality controlled trials including varieties of acceptable mouse designs (vertical, slanted, upright, roller bar, biofeedback and others). Methodological quality of these studies were assessed by independent raters utilizing the PEDro quality assessment scale and the Cochrane Risk of Bias (ROB) scale, and the results revealed that included studies were of moderate quality (5–6/10) and had some intrinsic ROB. It is concluded that there is moderate quality of evidence to support the use of alternative mouse designs to reduce discomfort, promote posture and decrease unnecessary muscle activation, especially if accompanied by appropriate ergonomic training. However, standard mouse still offers appropriate users preference levels. Hence, the consensus is that, mouse selection and purchase should be an individualized process based on individual needs and work demands and that there is no universal model that works well with everyone.

Subjects: Ergonomics; Assistive Technology; Rehabilitation Medicine; Physiotherapy and Sports Medicine

Keywords: computer mouse; pain; fatigue; discomfort; and repetitive stress injuries

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Dr. Ahmed Radwan, Associate Professor of Physical Therapy, Utica College, New York, is a certified professional ergonomist and a Director of the center for ergonomic analysis and research (CEAR) at Utica College. He holds a Doctor of Philosophy (PhD) degree in Biomechanics and a Doctor of Physical Therapy (DPT) degree. Dr. Radwan's current research interests include Ergonomics and Biomechanical analysis of different clinical problems. This Ergonomics initiative aims to search the evidence behind certain office ergonomics tools as alternative mouse designs, seat designs, sit-to-stand work stations and others.

PUBLIC INTEREST STATEMENT

Some current evidence supports the use of alternative mouse designs to reduce discomfort, promote posture amongst computer users, especially if accompanied by appropriate ergonomic training. However, standard mouse still offers better users preference. That is why the authors of this study recommend that mouse selection should still be an individualized process that is preceded by careful analysis of each individual's needs and occupational demands. Currently, there is no particular mouse design that fits all.

1. Introduction

The adoption of the graphical user interface, at the turn of the century, brought pointing devices (i.e. computer mouse, trackballs, etc.) into every office environment (Fagarasanu & Kumar, 2003). Originally, the computer workstation design only took the keyboard into consideration, but current computer usage requires manual control of the mouse, typically exceeding as much as three times as long as keyboard usage. (Feathers, Rollings, & Hedge, 2013; Odell & Johnson, 2015). The usage of a regular computer mouse forces most users to adopt abnormal or "less ideal" postures for an elongated period of time. Statistics show that 16–33% of computer workers experience symptoms in the arm, wrist and hand (Garza & Young, 2015).

The lateral position of the mouse typically puts the user's shoulder in an abducted and externally rotated position, with the arm in forward flexion and the wrist in extension, ulnar deviation and pronation (Cook, Burgess-Limerick, & Papalia, 2004). This is thought to increase pressure within the carpal tunnel, impair nerve function, increase muscular stress, such as static loading in the antigravity muscles, and predispose to subsequent myotendinous inflammation. (Fagarasanu & Kumar, 2003)

By using a computer mouse that is ergonomically designed and matches the anthropometry of the user, it may be possible to reduce the biomechanical loads placed on the joints of the upper extremity, thereby reducing the instance of musculoskeletal injury.

A broad spectrum of alternative mouse designs have been developed, such as the pen-shaped mouse, vertical mouse, vertical optical mouse, trackball and touchpad, among others, based on the anthropometrics of the human hand. Some designs allow a more central location of the mouse, which was shown to decrease shoulder elevation, neck and shoulder muscle activity and perceived shoulder exertion. (Garza & Young, 2015). However, such effect of alternative mouse designs has not yet been supported by high-quality clinical trials and systematic reviews yet. Additionally, the impact of ergonomic training protocols to enhance their use has not yet been appropriately evaluated.

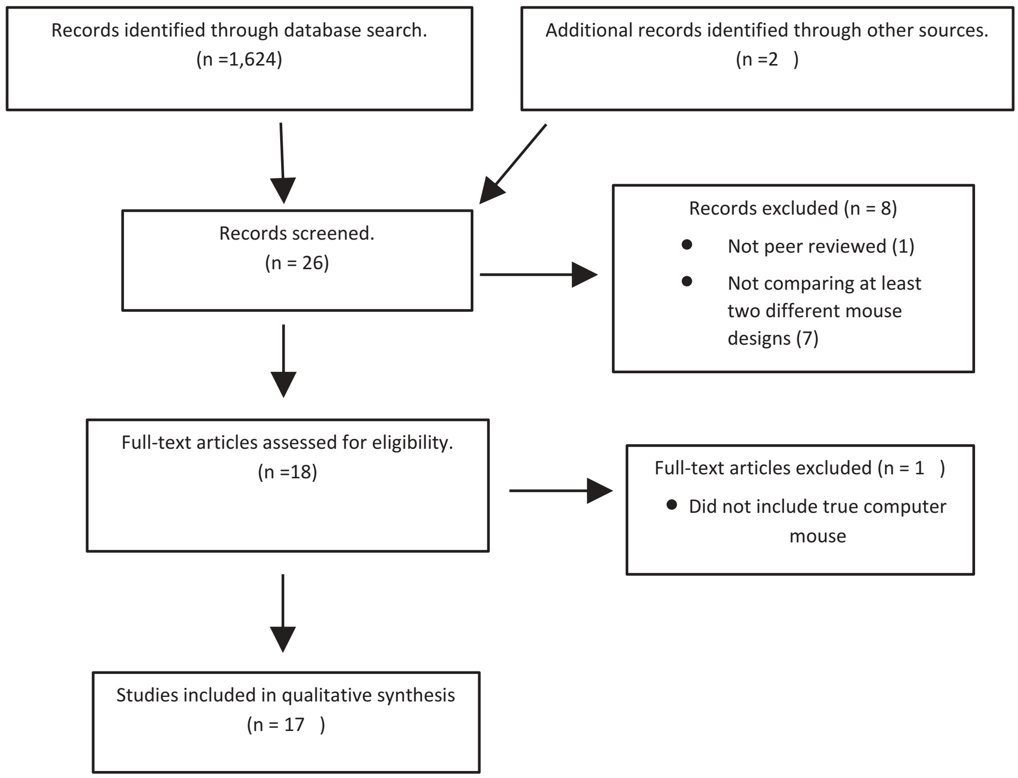
The purpose of this systematic review is to provide professionals with a more in-depth analysis of the literature regarding the efficacy of alternative computer mouse designs and their ability to reduce physical and mental stress of computer users in addition to the potential effect of incorporating ergonomics training and forearm supports to those alternative designs. This can ultimately reduce the occurrence of repetitive or overuse injuries in the workplace.

2. Methods

This systematic review included peer reviewed controlled trials comparing alternative and standard computer mouse designs in controlled fashion with predominantly a cross over design. For articles to be included in this review, they had to be controlled studies, published in English language (or translation was available), and published within the period of January 2007 till January of 2017. Articles were identified through electronic searches of four blinded researchers in the following data bases, PubMed, Sciencedirect, CINAHL, Google scholar, in addition to specific journal archives (Journal of Industrial Ergonomics, Journal of Occupational Ergonomics and Journal of Applied Ergonomics and several websites of computer mouse manufacturers). Key words utilized in the search process included a combination of the following terms; computer mouse, pain, fatigue, discomfort and repetitive stress injuries (RSI). Titles and abstracts of articles in the above-mentioned resources were first screened by two raters. Disagreements between raters about inclusion of an article were rectified either by an unbiased third rater. Please refer to Figure 1 for graphic representation of article search and selection process.

Seventeen articles that met the inclusion criteria were evaluated for methodological quality using both the Cochrane Risk of Bias tool (ROB) and PEDro scale. Two reviewers independently

Figure 1. Graphic representation of article search and selection process using PRISMA chart adapted from (Moher, Liberati, Tetzlaff, & Altman, 2009).



assessed the quality of each study. Disagreements regarding inclusion were rectified by an unbiased third senior rater.

The ROB tool assesses six domains of bias including: selection, performance, detection, attrition, reporting and other with an assignment of high, low or unclear risk. All items of the ROB tool were scored with “yes”, “no” or “unclear” (i.e. insufficient information was available) and each item’s scoring was compared between the two reviewers. ROB has been widely accepted and recommended for use in systematic reviews due to its appropriate inter-rater agreement (Savović et al., 2014).

The PEDro scale uses 11 items to assess the external validity, internal validity and interpretability of studies in terms of allocation, randomization, key outcomes, blinding, intention to treat and statistical comparisons. Using items 2–11, the sum of “yes” responses creates a score out of 10, with “0” representing the least amount of quality and “10” representing the most. This scale has been widely used among systematic reviews. Studies have shown that the PEDro has the ability to discriminate between higher and lower quality physical therapy research due to its appropriate reliability and construct validity (Macedo et al., 2010).

3. Results

After the articles had been selected and assessed for methodological quality, the data were then extracted for analysis. Researchers began by categorizing the various types of alternative mouse designs. While each respective study may have used slightly different names, descriptions and pictures, for the sake of this systematic review, the following alternative mouse design categories were used: vertical, pen vertical, hover stop, roller bar, rollerball, slanted and other.

Each with varying results, indicating either negative or positive effects, the 17 studies in this review analyzed and discussed both biomechanical and psychological outcomes. The biomechanical outcomes included pain, posture, joint angles and muscle activity, while the psychological outcomes included subjective ratings regarding pain, comfort, ease of use, attractiveness and overall preference and productivity. The results and methodological quality of the included studies are summarized in Tables 1and 2. Most articles ended up having moderate evidence to support alternative mouse use and some intrinsic ROB as follows:

3.1. Participants' demographics and occupation/setting

All 17 of the studies included in the review recruited participants with varying amounts and types of computer use experience, including volunteers, university employees, employed engineers, engineering support staff, occupational office workers and students. Some studies required minimum computer usage frequency/experience, which ranged from simply "familiar with computer mouse usage" to 20–40 h of computer use per week. The variance among types of computer users and usage frequency/experience reported in this systematic review increases its generalizability, as alternative mouse designs would be expected to have variable effects on the many different mouse use patterns, daily schedules and occupational responsibilities (Conlon et al., 2008).

Age inclusion was very similar between studies, with ages ranging from 18 to 52-years old. Eleven out of the 17 articles had an average age of participants less than 35 years(Chen & Leung, 2007; Dehghan et al., 2015; de Korte et al., 2008; Feathers et al., 2013; Jung, 2014; Kumar & Kumar, 2008; Lee et al., 2007; Lin et al., 2015; Odell & Johnson, 2015; Oude Hengel et al., 2008; Quemelo & Vieira, 2013). In addition, 4 of the 17 articles included large age ranges (Houwink et al., 2009; Karsten & Erwin, 2015; Odell & Johnson, 2015; Oude Hengel et al., 2008). Research has shown that age can play a role with different computer input devices; middle-aged users tend to be significantly slower than younger users when performing different computer tasks (Armbrüster, Sutter, & Ziefle, 2007). On the other hand, middle-to-older aged adults tend to place these stressors on their upper extremities for longer time due to specific work requirements.

In total, this review used data from 861 participants with 15 of the studies averaging roughly 20 participants (only 2 studies included in this review used sample sizes above 40 individuals; one study using 206 (Conlon et al., 2008) and the other using 354 individuals (Meijer et al., 2009)). The small sample size (20 participant average) in most of the included studies allows for quicker data collection and analysis, but serves as a limitation to the external validity of each independent study.

3.2. Methodological quality

In the present review, the majority of studies had crossover design, with mild-to-moderate quality of evidence, scoring no more than 6 out of 10 on the PEDro scale (Chen & Leung, 2007; Dehghan et al., 2015; de Korte et al., 2008; Feathers et al., 2013; Jung, 2014; Karsten & Erwin, 2015; Kumar & Kumar, 2008; Lee et al., 2007; Lin et al., 2015; Odell & Johnson, 2015; Oude Hengel et al., 2008; Quemelo & Vieira, 2013; Schmid et al., 2015).

The main disadvantage of the crossover designs is the inability of the researchers to blind study participants. Similarly, concealed allocation was not addressed by the authors of multiple studies, which put a majority of these articles at an unclear to a high ROB according the Cochrane Risk of Bias tool (Concato, Shah, & Horwitz, 2000).

In current research, randomized control trials are established as the standard for determining whether or not interventions or treatments are effective. However, only three randomized control trials were found in this topic of research and included in this review(Conlon et al., 2008; King et al., 2013; Meijer et al., 2009), and only two out of the three included studies received a PEDro score higher than 6 (Conlon et al., 2008; King et al., 2013).

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Table 1. Summary of individual articles included in the systematic review

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Chen and Leung (2007)	5	Unclear	Crossover design	12 participants 9 males and 3 females Age—23 ± 2	Familiar with using a computer mouse	Myoelectric activity of the forearm muscles of participants was assessed while using five different hand-fabricated computer mice with slanted angles of 0°,10°,20°,25°, and 30°, respectively	-Muscle activity was measured using electromyography (EMG)	−25° or 30° slanted mice caused lower muscle activity and more neutral postures
Conlon, Krause and Rempel (2008)	7	High	RCT	−206 participants -Age for conventional mouse group: 41.2 ± 8.43; for alternative mouse group: 43.3 ± 10.8; for support board plus conventional mouse group: 42.6 ± 10.3; for support board plus alternative mouse group: 44 ± 9.66	-Employed engineers or professional support for engineers with computer usage for at least 20 hrs./week. -Participants had some baseline discomfort and musculoskeletal disorder score	12 months experiment performed to compare the performance of 4 different groups where participants randomly assigned to a particular group that uses only 1 of the following mouse options throughout the study: a conventional mouse, a vertical mouse, a conventional mouse plus a forearm support board and a vertical mouse plus the forearm support board.	-Upon entry, each subject filled out a baseline health questionnaire -4 weeks after intervention began, participants underwent weekly assessments for potential presence of musculoskeletal disorders related to computer use. -Each week, participants filled out an online discomfort questionnaire that used 0–10 point scale.	-On average, the forearm support board significantly reduced right upper extremity discomfort -The vertical mouse significantly reduced neck/shoulder discomfort in comparison to the control group

(*Continued*)

Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Dehghan et al. (2015)	6	High	Crossover design	10 participants 6 males,4 Females Age: 25.8 ± 2.04	-Experienced visual display terminal operators	Following a brief familiarization period, each participant performed series of clicking, pointing and dragging tasks to compare the use of each a conventional mouse and 3 different alternative designs (vertical mouse, pen mouse and trackpad) Each mouse was used for 10 min.	-Functional parameters (task completion time and number of errors in clicking) were measured through use of appropriate software -Participants used 10-point visual analogue scales to rate clicking comfort, hand/wrist comfort and overall comfort	-Participants had the fastest task completion and lower percentage of error rate with the conventional mouse and vertical mouse more than the trackpad and pen mouse -The conventional rated significantly higher than the pen mouse and trackpad mouse in clicking comfort and overall comfort.
de Korte, de Kraker, Bongers, and van Lingen (2008)	3	High	Crossover design	15 participants 3 males, 12 females Age: 24 ± 2 years	-Experienced computer users	Each participant performed a series of mouse tasks lasting for few minutes to compare the use of a conventional and a biofeedback mouse	-Muscle activity was measured using EMG -Productivity was assessed objectively by the number of questions answered and the amount of correct answers within the time allowed and subjectively by rating four items on a 7-point scale, self-reported, questionnaire -Hovering behavior was determined using computer registration software (RSI-Master) -Discomfort was assessed by The Dutch validated method -Comfort and user friendliness were assessed with a 7-point scale, self-reported, questionnaire	-Productivity and discomfort measures showed no significant differences -The biofeedback mouse significantly decreased the amount of muscle activation and hovering behavior. This may reduce the risk for developing future musculoskeletal disorders.

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Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Feathers et al. (2013)	6	High	Crossover design	21 participants 10 males, 11 females Age: 18–25 years	Students who reported to be familiar with computer and computer mouse usage.	Following a brief familiarization period, each participant performed series of clicking, pointing and dragging tasks to compare the use of a conventional mouse and four alternative desings (Isometrically scaled, Allometrically adjusted, Vertical mouse, Pronated-reducing mouse) -Random order was used with 1 min. Rest in between	−3D structural hand and mouse measurements were taken using a coordinate measurement machine. -Wrist posture was recorded using a twin-axis electrogoniometer -Participants completed a mousing experience survey after each use and a final survey at the end regarding ease of use, perceived mouse control, perceived comfort, attractiveness and overall preference	- Conventional mouse promoted the smallest median MCP angle and ulnar-deviation -Vertical Mouse rating was significantly higher for perceived control, perceived comfort and attractiveness. -Researchers concluded that a smaller metacarpophalangeal angle may contribute to increased performance and ease of use
Houwink, Oude Hengel, Odell, and Dennerlein (2009)	4	High	Controlled Trial	30 participants 15 males, 15 females Age for the untrained group: 23–43; for the trained group: 19–58	-Experienced computer workers with an average computer usage of 38 hrs./week	Following a brief familiarization period, both groups performed standard pointing tasks with a standard mouse and an alternative (slanted) mouse. 15 participants received no training on how to hold the alternative mouse, whereas the remaining 15 participants received verbal instructions before and during use of the alternative mouse. -Randomization of mice was not performed.	-Surface EMG was used to test muscle activity for three wrist extensor muscles of the right arm. Amount of muscle activity was recorded as a percentage of maximal voluntary contraction -Position and orientation of the right forearm and hand were measured with electromagnetic motion analysis system -Time of task completion was recorded during all tasks	-Participants showed significantly less pronation, wrist deviation and muscle activity when using the alternative mouse - All positives results were further enhanced when training was provided.

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Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Jung (2014)	5	Unclear	Crossover design	40 participants 20 males, 20 females Average age for males 23.2 ± 2.6 Average age for females: 21.7 ± 1.8	-Right-handed dominant -No experience utilizing a slanted mouse prior to experiment	Following a brief familiarization period, each participant performed a 15 series of clicking, pointing and dragging tasks to compare the use of a conventional mouse (slant angle 0°) to two alternative designs with slant angles of 30° and 50°, respectively.	-Completion time and error rate were measured through computer software -Discomfort was measured with Borg's CR-10 scale -Satisfaction was measured through 7-point bipolar scale	-As the slant of the mouse increased, satisfaction decreased. -Discomfort of the upper extremity increased as the slant increased. -Due to the weight and unfamiliar posture, the standard mouse was preferred over the slanted mice for both performance and comfort.
King et al. (2013).	8	Low	RCT	-23 participants	Office workers with more than 4 hr/day of computer use	-Experimental group used the biofeedback mouse for 25 weeks -Control group used a standard mouse for 25 weeks Data was measured at weeks 0, 5 and 25	-Pain and discomfort levels of shoulder, UE and total body were assessed using the Daily Symptom Survey - Mouse and Keyboard use patterns were measured through the Hoverstop software via an electric-potential transducer in the mouse	-By the end of the study, the biofeedback mouse users had a significant reduction (37%) in the UE symptoms -A biofeedback mechanism may reduce the incidence of musculoskeletal disorders in office workers
Kluth and Keller (2015)	5	Unclear	Crossover design	-24 participants -Age range: 22–58	-Lab setting	Each participant performed a series of clicking, pointing and dragging tasks lasting for 4 h with appropriate breaks to compare the use of a conventional and roller bar mouse in a repeated measures crossover design	-Muscle activity was measured using EMG. -Comfort during task performance was measured using a bipolar 4-step scale questionnaire	-Muscle activity during the use of the rollerball mouse is substantially lower for males than for females - A significant reduction in complaints for the fingers was achieved by the rollerball mouse relative to the standard mouse

(*Continued*)

Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Kumar and Kumar (2008)	6	High	Crossover design	15 participants 7 males, 8 females Age: 30.67 (22–26)	Students and employees from a university with 6 months of working experience with computers	Following a brief familiarization period with the new mouse, each participant performed a series of clicking, pointing and dragging tasks lasting for few minutes to compare the use of a conventional and roller bar mouse in a repeated measures crossover design	-Digital telemetric EMG analysis system equipment was used to measure muscle activity for each test -After the tasks, subjects rated comfort for both input devices on a 1–5 scale for using the cursor, strain in the arm/hand and strain in the shoulder	-The roller bar mouse significantly lowered muscle activity in comparison with the conventional mouse -The conventional mouse was rated more comfortable in moving the cursor than the roller bar mouse (subject's experience with the conventional mouse could have contributed to the preference over the roller bar mouse) -The roller bar mouse was found significantly better for strain in the hand and arm
Lee, Fleisher, McLoone, Kotani, and Dennerlein (2007)	6	High	Crossover design	20 participants 10 females, 10 males. Age: 28.6 ± 5.3 years	-Experienced computer. users with a mean self-estimated usage of 4.3 ± 2.6 h per week day	Without prior familiarization, participants completed steering, point clicking and dragging tasks to compare the standard mouse to four alternative mouse designs (No-right button, High force, push-forward and slide-forward buttons) Task completion time for each mouse was monitored using appropriate software	-Surface EMG signals were measured in four hand and forearm muscles using a custom-designed computer data acquisition software program -The number of errors during the steering tasks was recorded by the task software -Subjective usability ratings were measured on pre- and post-usability, approachability, comfort and task difficulty scores on continuous scales from 0 to 10	-Muscle activity of finger extensors decreased with alternative designs that incorporated a change in the button switch direction; however, there was higher flexor muscle loading and lower performance and usability associated with these devices -Participants ranked the reference mouse as most favorable followed by the no-right-button mouse, push-forward mouse and slide-forward mouse

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Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Lin, Young, and Dennerlein (2015)	5	High	Crossover design	12 participants 6 males, 6 females Age: 27.6 ± 6.6	Volunteers	-Each participant completed a series of standardized mouse pointing and browsing tasks of 8 min duration to compare four different pointing device (Standard mouse, Trackball, Standalone touch pad, and Roller-style mouse)	-Muscle activity was measured using EMG -Posture was recorded by Optical 3D motion analysis system -All participants responded to two survey questions about overall upper extremity discomfort and task difficulty	-The roller-style mouse elicited significantly less extensor carpi radialis muscle activity. -The standard mouse was easier to use. -Shoulder abduction and flexion were greater for the laterally located mouse, whereas internal rotation and pronation were greater for the centrally located mice -Ulnar deviation was greatest for the trackball and least for the touchpad. -Small differences in posture may indicate elevated or reduced risk of developing musculoskeletal injury, depending on the design.
Meijer, Sluiter, and Frings-Dresen (2009)	4	High	RCT	354 participants 176 in control group (94 males and 82 females) and 178 in intervention group (94 males and 84 females) Average age: 44	-Office workers with working tasks consisting mainly of computer use (over 4 h a day) for at least 2 days a week	-The intervention consisted of a feedback mouse with a sensor that detected the presence of a hand on or just above the mouse without active use for more than 12 s -The control group utilized a standard computer mouse -A randomized controlled trial was performed with one baseline measurement and two post-measure-ments at 4 and 8 months after the start of the intervention.	-Physical disability was assessed using the Dutch version of the "Quick Disability Arm Shoulder Hand" questionnaire -Registration software was used to measure mouse usage duration and frequency of rest breaks	- Prevalence and incidence of musculoskeletal symptoms did not differ between the intervention group and control group at 4 and 8 months after baseline -Mouse usage duration significantly decreased in the intervention group compared to the control group - The feedback signal mouse significantly reduced disability scores compared to the control group

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Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Odell and Johnson (2015)	6	High	Crossover design	12 participants 6 males, 6 females Age: 32.7 (20–52)	Experienced computer mouse users with at least 10 h per week computer use	-Following a familiarization period of 2–4 min of mouse use, participants completed some pointing and clicking tasks to compare the efficacy of five different mouse designes (Vertical mouse, Standard mouse and three different concept mice)	-Right-hand wrist angles were measured with an electrogoniometer and forearm pronation/ supination was measured with an inclinometer mounted to the distal end-block of the electrogoniometer -Fatigue of the hand, wrist, forearm and shoulder were measured using a BORG rating scale -Mouse model preference was measured using a 7-point Likert scale	-The concept mice offered less pronated and deviated wrist postures in comparison with the standard mouse -The concept mice resulted in similar performance, in regard to pointing times, to the standard mouse -Subjective measures indicated a preference for the standard mouse
Oude Hengel, Houwink, Odell, van Dieen, and Dennerlein (2008)	5	Unclear	Crossover design	-30 participant -15 males, 15 females -Age: 29.8 (19–58)	-Healthy adult -Right-handed individuals Workstation consisted of a chair without armrest	Subjects completed a repeated measures design comparison of six different commercially available computer mice. For each mouse, participants performed standard pointing tasks, a dragging task and a steering task. Each task lasted for approximately 1 min.	-Muscle activity was measured using EMG -Comfort and preference were measured by a subjective questionnaire	-Smaller computer mice increase the biomechanical load and risk for developing musculoskeletal injury. -Acute use of these computer mice may not pose high risk, but prolonged and chronic use of these smaller mice may cause injury to the user.

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Table 1. (*Continued*)

Author (Year)	PEDro	ROB	Design	Participants	Environment	Intervention	Outcome measures	Conclusion
Quemelo and Vieira (2013)	5	Unclear	Crossover design	-16 participants -6 male 10 female -Age: 26 ± 3	-Right-handed volunteers -Physical therapy students with similar schedules and computer use requirements	-Following a familiarization period of at least 16 h of use over two weeks, participants completed some steering and pointing tasks to compare the time needed to finish the tasks with both the pen-style vertical mouse and standard computer mouse. With the Fitt's Law test.	-Muscle activity was measured using EMG -Wrist postures measured by electrogoniometry -Computer work evaluation was measured by subjective adapted questionnaire	-With the exception of wrist extension, the vertical mouse produced more favorable postures - The upper trapezius tended to be more active when using the vertical mouse - Questionnaires indicated good user satisfaction with the vertical mouse in relation to setting it up, using it, productivity while using it and comfort. -Performance was better when using the standard computer mouse
Schmid, Kubler, Johnston, and Coppieters (2015)	5	Unclear	Crossover design	-21 participants -13 Female, 8 male -Age: 50 ± 8.8	-Volunteers	Subjects completed a repeated measures design comparing four different mouse designs (Standard, Standard with mouse gel pad, Standard with a gliding palm support and a Vertical mouse) while performing a series of 5 min point and click tasks	-Carpal tunnel pressure was measured using an epidural catheter -Wrist flexion-extension, wrist ulnar-radial deviation were measured using an electrogoniometer	-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.

Table 2. Quality assessment of articles included in the systematic review using the PEDro scale

Study (authors/year)	Rating (0–10)	Itemized responses
Chen and Leung (2007)	5	Eligibility criteria*: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Conlon, Krause, and Rempel (2008)	7	Eligibility criteria: yes; random allocation: yes; concealed allocation: yes; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: yes; adequate follow-up: no; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Dehghan et al. (2015)	6	Eligibility criteria: yes; random allocation: yes; concealed allocation: yes; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: no; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
de Korte et al. (2008)	3	Eligibility criteria: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: no; intention-to-treat analysis: no; between-group comparisons: yes; point estimates and variability: yes.
Feathers et al. (2013)	6	Eligibility criteria: no; random allocation: yes; concealed allocation: yes; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: no; between-group comparisons: yes; point estimates and variability: yes.
Houwink et al. (2009)	5	Eligibility criteria: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: no; between-group comparisons: yes; point estimates and variability: yes.
Jung (2014)	5	Eligibility criteria: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
King et al. (2013)	8	Eligibility criteria: yes; random allocation: yes; concealed allocation: yes; baseline comparability: no; blind subjects: no; blind therapists: yes; blind assessors: yes; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Kluth,Keller (2015)	5	Eligibility criteria: no; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Kumar and Kumar (2008)	6	Eligibility criteria: yes; random allocation: yes; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.

(*Continued*)

Table 2. (*Continued*)

Study (authors/year)	Rating (0–10)	Itemized responses
Lee et al. (2007)	6	Eligibility criteria: no; random allocation: yes; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Lin et al. (2015)	5	Eligibility criteria: yes; Random allocation: No; Concealed allocation: no; Baseline comparability: yes; Blind subjects: No; Blind therapists: no; Blind assessors: no; Adequate follow-up: yes; Intention-to-treat analysis: yes; Between-group comparisons: Yes; Point estimates and variability: Yes.
Meijer et al. (2009)	4	Eligibility criteria: yes; random allocation: yes; concealed allocation: yes; baseline comparability: no; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: no; intention-to-treat analysis: no; between-group comparisons: yes; point estimates and variability: yes.
Odell and Johnson (2015)	6	Eligibility criteria: yes; random allocation: yes; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Oude Hengel et al. (2008)	5	Eligibility criteria: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Quemelo and Vieira (2013)	5	Eligibility criteria: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.
Schmid et al. (2015)	5	Eligibility criteria: yes; random allocation: no; concealed allocation: no; baseline comparability: yes; blind subjects: no; blind therapists: no; blind assessors: no; adequate follow-up: yes; intention-to-treat analysis: yes; between-group comparisons: yes; point estimates and variability: yes.

4. Discussion

During evaluation of each individual study, pros and cons of alternative mouse designs were discovered. Some alternative designs were successful in reducing muscle activity, musculoskeletal symptoms and disability scores in comparison with the standard mouse. However, it was not uncommon for these same devices to have negative effects on performance and/or user preference as follows.

4.1. Biofeedback mouse

Previous researchers described a negative habit of computer mouse use known as "hovering behavior". This behavior will result in an extended wrist posture, which has known to be a risk factor for RSI. Biofeedback mice were created with the intension of signaling the user to relax his/her hand by providing a tactile, vibrating feedback signal when the hand/wrist is hovering and/or idle for an undesirable amount of time (de Korte et al., 2008). Three of the reviewed studies were able to show the biofeedback mouse could be used to significantly decrease the amount of muscle activation and hovering behavior as compared to use of a standard mouse. This reduction in computer mouse due to the feedback mouse use was shown to decrease musculoskeletal symptoms by 37% in an RCT that lasted 25 weeks, while there was no significant effect on symptoms observed in a RCT with 16- and 32-week follow-ups (King et al., 2013; Meijer et al., 2009). It is important to note that regardless of the change in musculoskeletal symptoms, de Korte et al. (2008) found no significant change in workers “productivity”.

4.2. Rollerbar mouse

Research has also shown that the abduction of the arm seen with the lateral placement of the mouse may be related to musculoskeletal symptoms (Cook et al., 2004). The increased activity of sub-occipital muscles and a requirement for a significant amount of hand–eye coordination and strenuous wrist and shoulder postures associated with conventional computer mice may be avoidable with the placement of a roller-style mouse just below the keyboard. Multiple studies have shown that the roller bar can significantly reduce the muscle activity in comparison to a conventional mouse, with a reduction in complaints for the fingers (Karsten & Erwin, 2015; Kumar & Kumar, 2008). On the other hand, Lin et al. (2015) conducted a repeated measures design using 12 participants (6 male, 6 female) and observed the effectiveness a similar roller-style mouse. Researchers determined that individuals experienced increased difficulty, when using this design compared to a conventional mouse, stand-alone touchpad. This can be related to increased shoulder activity and the need for users to lift certain fingers to click and scroll, while holding the device with the rest (Lin et al., 2015).

4.3. Slanted mouse

Some researchers believe that upper extremity discomfort and pain associated with computer mouse use can be attributed to the forearm pronation, ulnar deviation and wrist extension observed with use of a standard (non-slanted) conventional-style mouse (Chen & Leung, 2007; Feathers et al., 2013; Houwink et al., 2009). The participants in a control trial carried out by Houwink et al. (2009) showed significantly less pronation, wrist deviation and muscle activity when using the slanted mouse. Specifically, a slant of 25–30° from full pronation has been shown to cause a decrease in forearm pronation as well as a decrease in surface electromyography (EMG) values of the extensor carpi ulnaris, trapezius and pronator teres muscles (Chen & Leung, 2007). In contrast, in a repeated measures control trial using 40 participants, between the ages of 20–30-years old, Jung (2014) found that the angle of the pronation-reducing slant of alternative mouse designs might be inversely related to user satisfaction as well as comfort, specially, if ergonomic training on the new mouse use was inadequate. (Jung, 2014)

4.4. Vertical mouse

The vertical mouse, which offers arguably the largest deviation from full forearm pronation, was also created in an attempt to reduce pressure over the palmer aspect of the wrist. Instead of maintaining a pronated forearm and forward flexed shoulder, a vertical mouse user remains neutral in the forearm and experiences less neck and shoulder discomfort (Dehghan et al., 2015). Using an epidural catheter to observe carpal tunnel pressure and an electrogoniometer to monitor wrist angles during movement, Schmid et al. (2015) observed a significant reduction in ulnar deviation without a significant decrease in carpal tunnel pressure (Schmid et al., 2015). While the vertical mouse may have variable effects on posture, Feathers et al. (2013) compared the use of 5 alternative mouse designs, to show higher subjective ratings (from their 21 right-handed student participants) in regard to perceived control, perceived comfort and attractiveness of the vertical mouse (Feathers et al., 2013).

4.5. Addition of hand/arm support device

Great amount of effort has been given in studies to create and assess alternative mouse designs in terms of shapes, sizes and overall concepts of these devices, but two studies included in this review paid more attention to hand and arm support devices during mouse use. A randomized control trial that included 206 participants found that forearm support boards can significantly reduce discomfort of the upper extremity (Conlon et al., 2008). On the contrary, a crossover design with 21 participants found that the gliding palm support used in conjunction with the standard mouse did not have an effect on carpal tunnel pressure. Wrist pads and palm supports require significantly more ulnar deviation, which may offset the benefits of decreased wrist extension (Schmid et al., 2015). Such support devices for the forearm, wrist and hand should be studied further and in depth to be able to establish better evidence behind their use.

4.6. Standard mouse

The most common subjective outcome used to analyze the effectiveness of alternative mouse designs was comfort (and/or discomfort) followed by pain perception, ease of use, approachability, appearance, satisfaction, performance, productivity and overall preference (Conlon et al., 2008; Dehghan et al., 2015; de Korte et al., 2008; Feathers et al., 2013; Jung, 2014; Karsten & Erwin, 2015; King et al., 2013; Kumar & Kumar, 2008; Lee et al., 2007; Lin et al., 2015; Oude Hengel et al., 2008; Quemelo & Vieira, 2013).

Despite the benefits of alternative mouse designs, many computer users report a preference for the standard computer mouse (Jung, 2014; Kumar & Kumar, 2008; Lee et al., 2007; Odell & Johnson, 2015). Lee et al. (2007) believe that lower usability ratings of alternative designs suggests that subjects do not prefer increased effort needed to use them or to learn a new way of doing things. Oude Hengel et al. (2007) found a direct relationship between the decrease in mouse size (when compared to the standard computer mouse) and a decrease in participant comfort.

The standard computer mouse also allows for better performance, measured by faster completion times and lower error rates, than alternative designs (Dehghan et al., 2015; Lee et al., 2007; Odell & Johnson, 2015; Quemelo & Vieira, 2013). Jung (2014) found that individuals who utilized a computer mouse with no slant angle (standard computer mouse) presented with decreased time and error, with various pointing and clicking tasks, than when using a mouse with a 30°and a 50°-slanted angle. Participants found the standard design to be more light weight than either of the alternative designs they were given (Jung, 2014).

4.7. Mouse use and ergonomic training

One unique control trial included in this systematic review also analyzed the effects of mouse use training. The researchers found that all positive results from using the alternative mouse were further enhanced when participants were provided with instructions on how to hold the alternative mouse (Houwink et al., 2009). It is an inherent property of the alternative mouse to have a different shape or additional feature that makes it uniquely different from the standard mouse. These features introduce a significant level of unfamiliarity and the need to new motor learning for efficient use. It seems that without effective mouse use training for the alternative design, participants may simply choose to continue using the standard mouse, to avoid the unfamiliar and uncomfortable.

4.8. Discussion end result

Mild-to-moderate quality of evidence supported the use of alternative mouse designs to reduce neck/shoulder discomfort, promote posture and decrease the amount of muscle activation within the neck and upper extremity. If one's occupation requires prolonged computer mouse usage, a biofeedback mouse design will help create rest periods throughout the day (de Korte et al., 2008; Meijer et al., 2009). Likewise, if the user is experiencing shoulder impingement syndrome and/or has a rotator-cuff pathology and suffers from pain every time, the shoulder is moved to the side, the roller-bar mouse may be a good choice to achieve a more neutral shoulder position (Karsten & Erwin, 2015; Kumar & Kumar, 2008). Similarly, if the computer user has pain due to repetitive wrist extension, the vertical mouse may be the best available option (Dehghan et al., 2015; Schmid et al., 2015). On the contrary, if the user is not experiencing any current symptoms, as a result of standard computer mouse use, it may be unnecessary to seek alternative designs, especially that standard mouse has been related to increased productivity and performance among users. Moreover, the concept of ergonomic training appears to be of equal importance to fitting someone with the appropriate mouse design due to the proven effects of such training on enhancing the effectiveness of alternative designs and workers perceived acceptance of their use.

5. Conclusion

The findings of this systematic review suggest moderate evidence to the benefits of using alternative computer mouse designs especially if enhanced by appropriate ergonomics training. There is no specific computer mouse design that is appropriate for everyone. Computer mouse selection should be an individualized process that is preceded by careful analysis of each individual's needs and occupational demands.

6. Limitations

This review was only able to find and discuss the effects of both alternative and standard mouse designs in studies that included limited follow-up period of participants for less than 12 months. Assessment of the long-term effects of both mouse designs is needed and is currently lacking in the literature.

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