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The effects of mouse weight and connection type on performance, muscle activity, and preferences among professional gamers

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ABSTRACT

Professional gaming requires rapid and repetitive mousing for long durations which may result in fatigue and discomfort that could increase the risk of work-related musculoskeletal disorders or impaired performance. This study aimed to determine whether mouse weight (80g versus 87g) or connection type (wireless versus wired) impacted gamers' muscle activity, performance, and device preference. Sixteen professional players were recruited to use four mice that differed in connection type and weight. The wireless mouse had a lower error rate ($p = 0.05$) and a higher overall comfort rating ($p = 0.01$). No statistically significant differences between mouse weight were found. The findings of this study indicate that professional gamers performed slightly better when using the wireless mouse and preferred the wireless mouse. These findings may provide some guidance to the design and selection of gaming mouse.

1. Introduction

Competitive video gaming, known as electronic sports (esports), is now a technological and cultural phenomenon with over 450 million viewers and 2.5 billion computer gamers worldwide (Faust et al., 2013; Lipovaya et al., 2019; Claypool et al., 2020; Migliore, 2021; Lin, 2023). The increase in popularity of esports, including console and computer gaming, has led to an increased number of professional gamers. Further, the interest in computer gaming grew more dramatically under the stay-at-home mandates and quarantines during the COVID-19 pandemic period (Kent, 2002; Emara et al., 2020; King et al., 2020). First-person shooter (FPS, e.g., Counter-Strike, Overwatch, Call of Duty) games are one of the most popular genres among gamers.

The input devices of computer games most commonly consist of a professional keyboard and a gaming mouse with additional buttons specifically developed to improve performance and reduce physical discomfort associated with prolonged competitive gaming (Li et al., 2019). Video game playtime may have a negative impact on the musculoskeletal system for game players (Tholl et al., 2022). According to DiFrancisco-Donoghue et al. (2019) and Lindberg et al. (2020), more than 40% of esport professional gamers surveyed reported musculoskeletal pain in the back, neck, wrist and shoulders. Studies have shown that the repetitive and rapid movements of the mouse may be affected by properties of both the device used (e.g., size, weight and connection type of mice) and the user (e.g., handedness and posture of users), and may be associated with an increased prevalence of musculoskeletal disorders (MSDs) of the upper limb and neck (Cook and Kothiyal, 1998; Peters and Ivanoff, 1999; Crenshaw et al., 2006; Chen et al., 2012; Emara et al., 2020; Jovanović and Šimunič, 2021; Nunes et al., 2021). Computer mousing tasks that require highly repetitive movements under time pressure and precision demands could cause a decrease in forearm muscle oxygenation without affecting wrist position sense accuracy (Heiden et al., 2005), thereby predisposing players to fatigue, pain, or MSDs. In addition to impacting precision, speed, and accuracy, mouse design characteristics could also impact muscle activity and hand/wrist posture. For example, a mouse that is too tall or too heavy may increase pressure or force at the distal transverse arch of the palm, promoting a greater degree of wrist extension while moving the mouse, thereby

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increasing pressure in the carpal tunnel (Chen et al., 2012; Harris-Adamson et al., 2015; Shiri and Falah-Hassani, 2015; McGee, 2021; Coelho and Lourenço, 2021). Although the optimal size and weight of a computer mouse may depend on the anthropometry and preference of the user, certain general principles apply (Chen and Leung, 2007; Chen et al., 2012; Chan et al., 2016; Claypool et al., 2020; McGee, 2021). According to Hedge et al. (2010), the performance and posture of users may be affected disparately by specific design features of the mouse; thus, design features that promote good performance may negatively impact the human body or vice versa. The design goal then, is to identify design features that optimize both performance and comfort.

Mouse weight is an important design characteristic that may impact a gamers performance and workload while gaming. A study by Chen et al. (2012) examined the effect of varying mouse weight on wrist motion and muscle activity. They collected data on muscle activity using surface electromyography (sEMG) on the right extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), extensor digitorum (ED) and upper trapezius (UT) muscles and found that use of the 130g mouse (compared with 70g, 100g, 160g and 190g) resulted in the lowest muscle activity and smallest overall wrist movement range. The authors suggested that the proper mouse weight could benefit users by optimizing movement efficiency while decreasing the muscular cost. However, mouse weight has not been assessed during high level gaming tasks which require higher precision and speed than typical office-based tasks. Understanding the best mouse weight for optimal gaming performance requires further study.

An additional design characteristic to consider is whether a gaming mouse is wired versus wireless (connection type). From a performance standpoint, it is possible that even milliseconds of delay (latency) could have a negative impact on performance during high level competitions. Additionally, it is possible that a wired mouse restricts or changes the movement patterns when gaming since it essentially acts as a tether. No prior studies have compared these two connection types (wired vs. wireless) to determine whether there is an impact on muscle activity, performance, and preference of users.

To understand the impact of mouse design features on the user and their performance, both subjective and objective measures should be considered by researchers and designers. Surface electromyography is adirect measurement of muscle activity that provides information on muscle recruitment and fatigue by reflecting the magnitude of muscle activity when using tools like the computer mouse (De Luca, 1997; Agarabi et al., 2004). Common muscles assessed during computer use include forearm and shoulder muscles such as the extensor carpi ulnaris (ECU), extensor digitorum (ED), pronator teres (PT) and upper trapezius (UT) muscles which have shown significant changes in activity when using different types of mice (Gustafsson and Hagberg 2003; Chen et al., 2012). Wrist extension activity is monitored through the sEMG signals of ED, ECU and extensor carpi radialis (ECR) muscles, whereas the extension of the medial fingers occurs through ED muscle activity (Perotto, 2011; Criswell, 2010). These muscles, along with the flexor digitorum superficialis (FDS), are often associated with fatigue and pain due to sustained or repetitive loading while using a computer mouse (Johnson et al., 1996; Wahlström et al., 2002; Agarabi et al., 2004; Heiden et al., 2005; Thorn et al., 2005)., Szeto and Lin's study (2011) showed that mousing tasks with greater speed demand, such as during gaming, produced significantly increased median amplitudes in the normalized activity of ECR and FCU muscles among symptomatic computer users of work-related musculoskeletal disorders (Szeto and Lin, 2011). Therefore, to adequately assess the impact of mouse design on users, evaluation of forearm and shoulder muscle activity is necessary.

The inertial measurement unit (IMU) is an electronic device that captures human motion, including the position, velocity, and acceleration of movement, and has been shown to be a reliable approach to analyzing hand motion during mousing tasks (Szeto and Lin, 2011). Researchers have used IMUs to compare wrist kinematics of office workers performing mouse-clicking tasks with varying precision and speed demands. Szeto and Lin's study focused on performance differences between symptomatic and asymptomatic computer users of work-related musculoskeletal disorders (WMSDs). Although differences were not statistically significant, they suggested that future studies use IMUs to compare the kinematics of users when performing tasks with greater speed and accuracy demands (Szeto and Lin, 2011).

Given the lack of research on connection type and mouse weight among gamers, the primary purpose of this study was to determine whether these design characteristics affected professional gamers' muscle activity, kinematics, performance, or preference while gaming. We hypothesized that both the lighter and wireless mice would reduce muscle activity, movement velocity, movement time, and be preferred by gamers. The findings of this study may help improve esports athletes' choice of a device that optimizes their performance and guide the design of computer mice used for gaming.

2. Methods

2.1. Recruitment

The inclusion criteria for participants in this study included: 1) being 18 years old or older; 2) recognized as professional gamers; 3) ranked in top 500 in Overwatch (U.S. servers); and 4) currently competing. Professional gamers were defined as those who were paid to play Overwatch as part of a professional team and competed in the largest international esports tournaments. There were no exclusion criteria. Translators were provided to gamers from non-English speaking countries. All participants belonged to teams in the 2019 worldwide Overwatch Gaming League. The study was approved by the Institutional Review Board of the University of California at Berkeley and informed consent was obtained prior to participation.

2.2. Apparatus

Surface electromyography (sEMG) data were collected (Wireless EMG Systems, Noraxon, Scottsdale, Arizona) using ten self-adhesive bipolar (2 cm inter-electrode distance) silver-chloride electrodes (CMRR >100 dB; input impedance >100 MOhm) placed on the dominant arm. Participants' skin was cleaned, shaved and cleaned again before affixing the sensors. Muscles selected followed the recommended anatomical placement (Perotto, 2011), and included the: upper trapezius (UT), middle deltoid (MD), anterior deltoid (AD), triceps, biceps, extensor digitorum (ED), flexor digitorum superficialis (FDS), flexor carpi ulnaris (FCU), extensor carpi radialis (ECR), and extensor pollicis brevis (EPB), (Fig. 1). sEMG data were sampled at 1500 Hz, and telemetrically transmitted and stored in a computer for data processing and analysis (Wireless EMG Systems, Noraxon, Scottsdale, Arizona). For each subject, maximum voluntary contractions (MVCs) were collected for each muscle according to the anatomical guide for the electromyographer: the limbs and trunk (Perotto, 2011). sEMG data were transformed into the %MVC. The variation of individual muscle activity was reflected by the amplitude probability distribution function (APDF) of the sEMG data; static (APDF 10), median (APDF 50) and peak (APDF 90) muscle activity were calculated for each muscle for each subject while performing each task with each mouse.

Hand movement and wrist joint angles were tracked real-time using the Xsens MVN Awinda system (Movella, Netherlands). It included 17 wireless inertial measurement unit (IMU) sensors which were placed on subjects' body with adjustable straps and a Lycra shirt. The joint angles, segment kinematics, and segment relative positions data collected from the IMU sensors were wirelessly transmitted to MVN Analyze PC software for real-time 3D animation, graphs, data streaming, analyzing and exporting. The IMU data were collected at a 60 Hz sample rate and were synchronized with sEMG data.

In total four views were recorded to capture the experimental process. One camera was used to record EMG collection from the side view

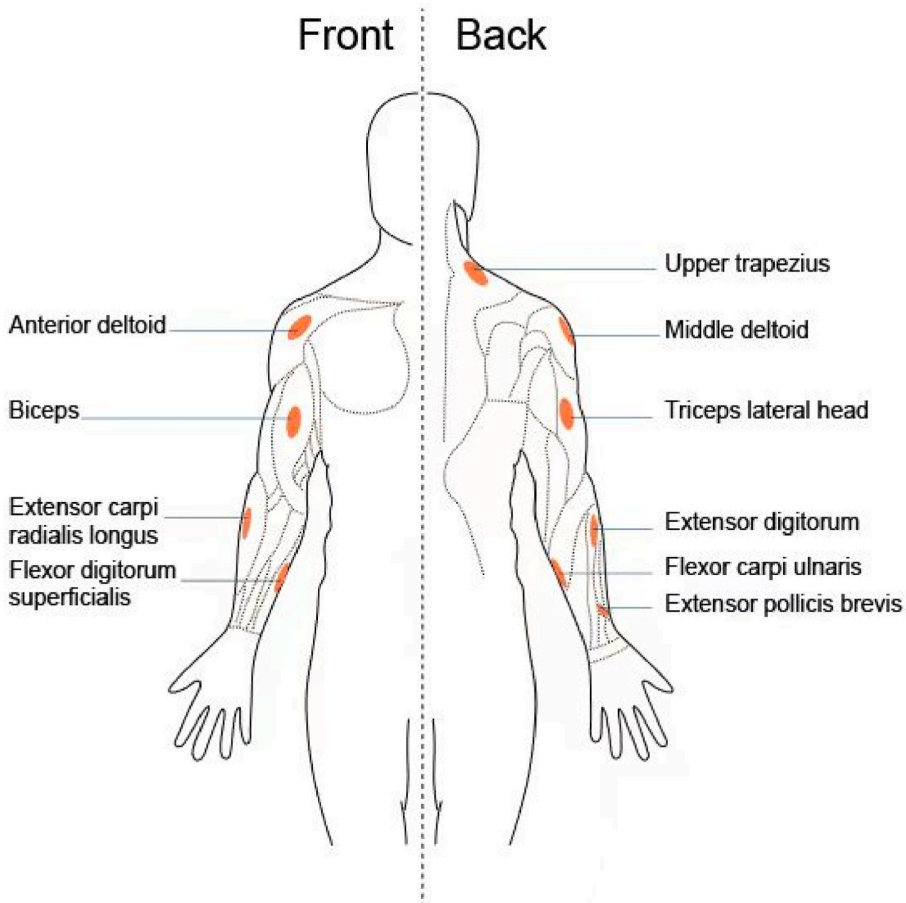

Fig. 1. Illustration of all ten muscles collected during experiment (Li et al., 2022).

(dominant side), one was used to record IMU data collection and hand activity with Xsens system (top view), and the last camera recorded a global view of the overall experimental environment (room view). The fourth view was the subjects' screen which was captured during the experiment (Screen View). All four views are shown in Fig. 2.

The current study is a part of a series of research conducted by the same group of researchers (Li et al., 2019, 2022). A high-configured gaming computer (windows 10 operating system) was used for this

Fig. 2. The top view, side view, room view and screen view of one subject performing gaming task.

experiment with the specific configuration including a GPU model of GeForce GTX 980, a CPU of Intel i7-6700K with 4 GHz, and a height adjustable LCD monitor with a 1920 × 1080 resolution, 120HZ. A Logitech - G Pro Mechanical Wired Gaming GX keyboard and a Logitech G840 XL Cloth Gaming Mouse Pad (400 mm × 900 mm) were used. The Logitech G-pro wireless mouse was used because the weight and connection type could be modified while keeping all other characteristics (shape, buttons, scroll wheel) constant (Fig. 3).

The weights were added in the small groove on the rear cover on the back of the mouse(Fig. 4). The weights were hidden in the mouse so that subjects could not be aware of the added weight from the appearance of the mouse.

Fig. 5 is the screen capture of the Noraxon system during data collection, it shows the real-time sEMG while the subject was completing the gaming task using one wired mouse.

Fig. 4. The back of experiment mice. The rear cover was shown in two conditions: with 7-g weights (87g) and without weights (80g).

2.3. Fitts' task

The performance of different mice was measured by the "GoFitts" software (MacKenzie, 1992). Subjects were instructed to complete the Fitts' task which consisted of 16 sequences with varying amplitudes (center to center distance of 100, 200, 400 and 600 pixels) and widths (target radius size of 10, 20, 40, 80 pixels), generated randomly (Fig. 6). In each sequence, subjects were instructed to click once inside the highlighted circle using the computer mouse as fast and accurately as possible. The wrong click did not repeat or stop the sequence but was classified as an error in the evaluation of performance. The timing began after first click of each sequence. The resolution of the computer mice was fixed at 800 dots per inch (DPI) through all Fitts' tasks. The performance in the Fitts' test were evaluated by movement time (MT), error rate (ER), and throughput (TP). MT refers to the duration between clicking two successive targets, the average was calculated based on all 256 clicks for each mouse. ER represented the average percentage of errors across all 16 sequences for each mouse.

The throughput measure was calculated as Equation (1) (MacKenzie, 2015a,b):

$$TP = \frac{\log_2\left(\frac{A_e}{4.133 \times SD_x} + 1\right)}{MT} \tag{1}$$

where Ae was defined as the average distance between the start position clicked by the participant, measured along the task axis that ran parallel to the line connecting the centers of the start and target circles, SDx represented the standard deviation in the selected coordinates, as projected on the task axis. The task axis referred to a straight line connecting the center of the intended starting point ("from") and the intended end point ("to"). A basic calculation utilizing the Pythagorean theorem was employed to perform the projection, and MT was the mean movement time (Soukoreff and MacKenzie, 2004).

2.4. Gaming task

Overwatch was used to evaluate performance while gaming. It's an online multi-gamer, first-person shooter (FPS) computer game developed and published by Blizzard Entertainment. Overwatch assigns 12 gamers into two opposing teams, with each gamer selecting from a roster of over 30 characters, known as "heroes", each with a unique play style. Participants could change the DPI of the mouse and choose any hero to finish the gaming task, however, only one hero could be used during the entire experiment and the selected DPI was kept consistent across all four mice. Each gaming task was defined by 10 min of active gaming time in Quickplay mode of Overwatch; waiting, death, and other animation (non-play) time were excluded. Eleven out of sixteen players kept DPI at 800, therefore, the experiment data were not adjusted according to DPI.

2.5. Experimental procedures

The experimental workstation was set up in Los Angeles, CA, USA

Fig. 3. Four experiment mice: very light wireless mouse (80g), light wireless mouse (87g), very light wired mouse (80g) and light wired mouse (80g), identical in appearance.

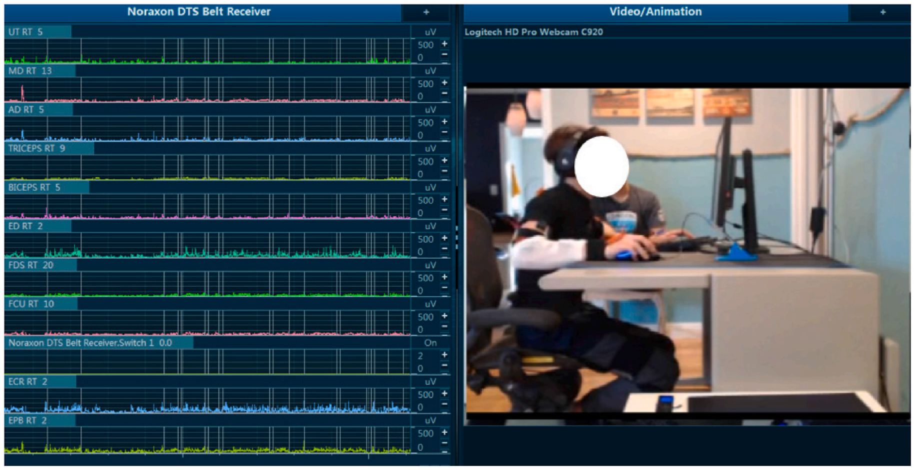

Fig. 5. Screen capture of Noraxon system during experiment showing EMG signals of ten muscles on the left and subject finishing specific task on the right.

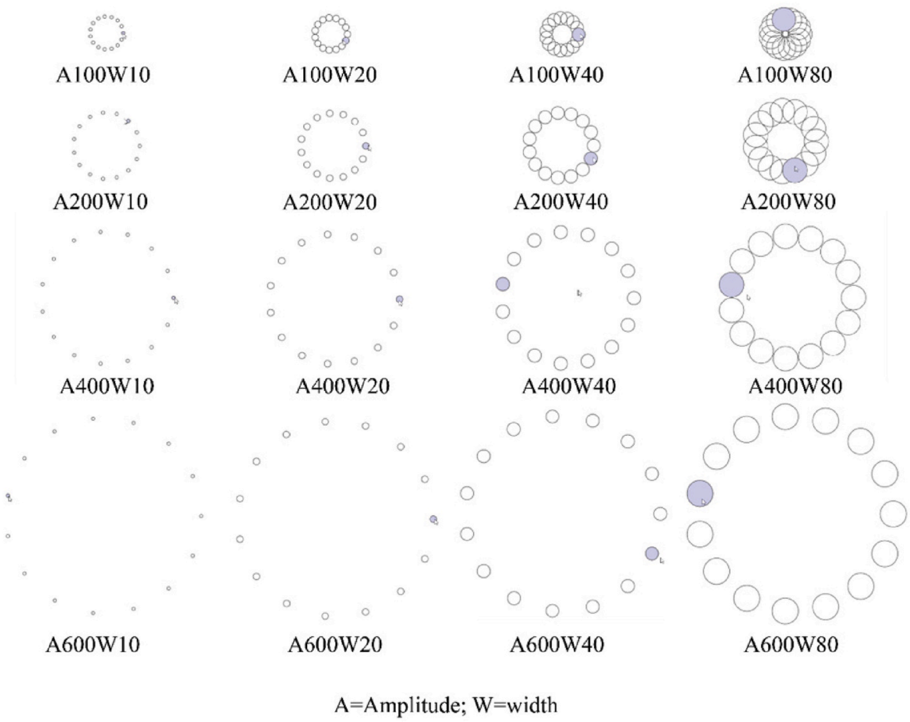

Fig. 6. Illustration of all 16 sequences of Fitts' task with varying amplitude and width.

near the Blizzard Arena where professional gamers train and compete. The room temperature was set to 25 °C throughout the whole experiment for all participants. The experiment workstation included a fully adjustable chair, a height adjustable table and the gaming computer station which participants were allowed to adjust to their preference. Once adjusted, the workstation remained consistent throughout testing. The experimental protocol took approximately 180 minutes. A baseline survey collected information on demographics and gaming history. Next, participants used four mice to complete the Fitts' task and then the gaming task (Fig. 7); the order of mice across each subject was randomized. After 10 min of active gaming, subjects rated various characteristics of the mouse and their perceived fatigue. There was a rest period of about 20 minutes between conditions. After using all four mice, subjects finish the additional comparison survey. The 10 minutes game time was derived from actual match time. We observed many professional esports competition videos of Overwatch. The duration of one game usually took between 8 and 12 minutes, so we took the average of 10 minutes as the game task time for the current study. The rest period between conditions was about 20 minutes.

2.6. Statistical analysis

Static, mean and peak muscle activity (APDF 10, 50, 90), peak kinematic values (APDF 95), and Fitts task data were averaged across all subjects for each condition. To test the differences across conditions (each mouse), results were analyzed using a repeated measures ANOVA, which included an interaction term of weight and connection type. The four mice were organized into two groups by weight (80g vs 87g) and connection type (wireless vs wired). Within subjects, the differences in performance, muscle activity, and hand kinematics in each group (weight and connection type) were compared using the Paired Sample T-Test. Differences in usability, perceived fatigue, and preference across the combined groups (weight and connection type) and all four mice conditions were estimated using the Friedman test.

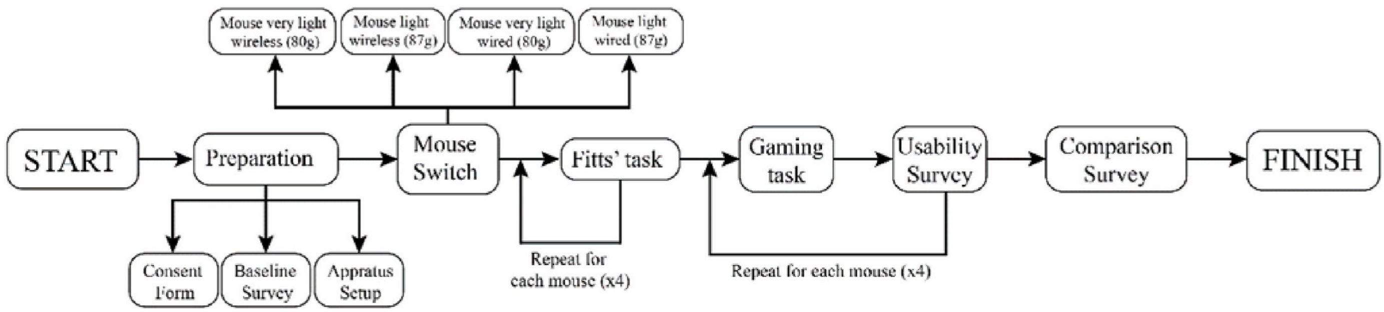

Fig. 7. Experimental procedure form start to finish.

3. Results

3.1. Participants

Sixteen professional gamers aged between 20 and 27 years old participated in this study. All participants were male and right-handed. 56.25% (N = 9) of them were Caucasian, two of whom were also Hispanic, and 43.75% (N = 7) were Asian (Table 1). The number of gaming hours per week varied dramatically between 12 and 80 hours. During gaming tasks, three subjects set DPI as 1600, one subject chose 400 DPI, one chose 1000 DPI, the remaining 11 subjects kept the DPI setting as default 800.

3.2. Fitts' test performance

Participants spent less time and made more errors when using wired mice (Table 2). Although the lighter mice achieved a lower error rate and decreased movement time, the differences were not statistically significant. Among all four mice, the very light wired mouse had the shortest movement time and the best throughput while the very light wireless mouse had the lowest error rate (Table A1).

3.3. Hand kinematics and joint angles

The wireless mice achieved slightly larger maximum (APDF95) wrist joint angles in both ulnar and radial deviation while the wired mice had larger wrist flexion and extension angles. When comparing weights, except for ulnar deviation, use of the very light mouse consistently resulted in larger joint deviations from neutral. However, none of the differences were statistically significant (Table 3).

Overall, gamers moved the mouse more when using wired devices versus wireless (Table 4). Similarly, light mice travelled slightly further than very light mice. In contrast, the movement area was slightly larger when using wireless mice compared to wired mice, and very light mice (80g) versus the light ones(87g). There were no differences in velocity across mice, but when using wireless mice, median and peak accelerations were smaller.

3.4. Muscle activity

Overall, the extensor digitorum (ED) was the most active muscle during Fitts' task (Table 5), while ECR and EPB were more active than ED in gaming task (Table 6). During the Fitts' task, there was lower muscle activity among most muscles when using the wireless mouse with the exception of the AD and Biceps. This pattern was consistent for static, median, and peak muscle activities. Participants had lower static muscle activity of the triceps, ED, and EPB when using wireless mice (Table 5). Consistently, the median and peak sEMG of the ED and UT was also significantly different between wired and wireless mice. There were no statistically significant differences in muscle activity when using the very light versus the light mice. Overall, the peak muscle activity was much higher while gaming than performing the Fitts' Task across all muscles, but the static and median results were similar to the Fitts' test. Results comparing muscle activity across all 4 mice is presented in the Appendix (Table A3, A4).

3.5. Subjective usability and overall preference

The subjective ratings of participants are shown in Table 7. The rating items were "This mouse was light and effortless to use", "I could use this mouse for an extended period of time comfortably", "This mouse allowed me to game easily", "Overall this mouse allowed me to perform well while gaming", "This mouse provided a good overall gaming experience", "I would use this mouse during competition" and "Overall Discomfort". A higher score indicated that the subject agreed with each statement. Only "overall discomfort" was rated from 0 to 10 with 0 being

Table 1
The mean (SD) value of background information among professional gamers.

	Age	Gaming years	Professional gaming years	Gaming hours/ week	DPI
Participants (N = 16)	22.13 (1.93)	4.13 (1.15)	1.93 (0.44)	49.44 (17.20)	937.50 (348.09)

Table 2
Mice performance of Fitts' test. A comparison of the Fitts' test performance when using mice of different connection types and weights.

Fitts' Test	Connection Type			Mouse Weight		
	Wireless	Wired	p-value	Very light (80g)	Light (87g)	p-value
Movement time (ms)	494.77 (61.86)	485.29 (67.64)	0.12	487.75 (58.75)	492.31 (70.61)	0.42
Error rate (%)	8.36 (5.30)	9.41 (6.22)	**0.05***	8.65 (5.21)	9.13 (6.33)	0.48
Throughput (bits/s)	6.83 (0.95)	6.95 (0.86)	0.25	6.89 (0.92)	6.9 (0.89)	0.93

"*" indicated significant difference between categories at the level of $p \leq 0.05$.

Table 3
The maximum wrist joint angles (APDF 95) during the gaming task. A comparison of the wrist angles of the right hand while performing gaming tasks when using mice of different connection types and weights.

Maximum wrist joint angles	Connection Type			Mouse Weight		
	Wireless	Wired	p-value	Very light	Light	p-value
Ulnar deviation	17.92 (11.31)	17.63 (11.23)	0.71	17.63 (11.05)	17.93 (11.49)	0.54
Radial deviation	13.43 (9.07)	12.47 (4.91)	0.58	13.68 (8.97)	12.22 (5.04)	0.40
Flexion	8.99 (3.97)	10.97 (12.21)	0.39	10.95 (11.99)	9.01 (4.59)	0.40
Extension	9.52 (5.51)	11.78 (13.51)	0.34	12.32 (13.81)	8.98 (4.38)	0.17

Table 4
The averaged right-hand kinematics during gaming task. A comparison of the kinematics of the right hand while performing gaming tasks when using mice of different connection types and weights.

Right hand movement summary	Connection Type			Mouse Weight		
	Wireless	Wired	p-value	Very light (80g)	Light (87g)	p-value
Distance Travelled (m)	26.58(10.70)	27.35(9.80)	0.35	26.89(10.80)	27.04(9.71)	0.86
Movement Area (m^2)	0.06(0.07)	0.04(0.05)	0.20	0.06(0.06)	0.04(0.06)	0.18
Median Velocity (m/s)	0.02(0.0055)	0.02(0.0047)	0.54	0.02(0.0111)	0.02(0.0094)	0.13
Peak Velocity (m/s)	0.18(0.07)	0.18(0.07)	0.78	0.18(0.08)	0.18(0.07)	0.47
Median Acceleration (m/s^2)	0.38(0.12)	0.40(0.14)	0.25	0.40(0.13)	0.39(0.13)	0.50
Peak Acceleration (m/s^2)	3.03(1.13)	3.18(1.29)	0.21	3.08(1.24)	3.13(1.19)	0.70

no pain and 10 being worst possible pain; other items were rated on a 1–5 scale with 1 being strongly disagree and 5 being strongly agree.

According to the subjective survey data, wireless mice were rated consistently higher than wired mice. The very light mice achieved a higher score from subjects in most characteristics except "overall gaming experience". Except for "I would use this mouse during competition", the difference on each item was statistically significant between the two connection types (wired vs wireless). In contrast, none of the differences between mouse weight (80g vs 87g) achieved statistical significance.

When comparing all 4 mice, the light wireless mouse got the highest rating in most items except for "light and effortless" (Fig. 8). Consistent with results presented in Table 7, the very light wireless mouse got significantly higher scores than the light wired mouse in "long time use" and "ease".

Following all conditions, 56.3% of participants chose the very light wireless mouse as their favorite and 46.7% of participants chose the light wireless mouse as their second favorite (Fig. 9). As for their third favorite, the two wired mouse had similar results.

Since the interaction effects between mouse weight and connection type were not significant (Tables A5-A8), the results of this study focused on the main effects.

4. Discussion

Overall, the differences in muscle activity, kinematics, and performance by connection type and mouse weight were small. The results of this study suggest that the muscle activities were slightly lower when professional gamers used wireless mice versus the wired ones, however, the small difference in mouse weight (7g) did not impact muscle activity significantly. For hand kinematics, compared to wireless mice, wired mice travelled slightly longer, had a smaller movement area and higher acceleration. Similar to the wired versus wireless mice comparison, the light mouse (87g) also had longer travel distance, smaller movement area and higher acceleration compared to the very light mouse (80g). The wireless and very light mice achieved lower error rates during the Fitts' test while wired mice and light mice had higher throughput. Most differences in objective measurements were not statistically significant yet wireless mice achieved significantly higher ratings in most subjective scores, possibly indicating that subjective scale preferences detected slight differences that our instrumentation was not sensitive enough to measure. For elite gamers, these small differences could be important for improving competitive performance yet may not impact fatigue, pain, or injury risk given the similar muscle activities measured across mice. Overall, this study indicates that a mouse weight difference of 7 g had negligible effect on muscle activity or hand kinematics; there were slightly better outcomes when using wireless mice.

4.1. Connection type

The performance in the Fitts' test showed that wireless mice achieved significantly better performance in error rate than wired ones ($p =$ 0.05). When using the wired mouse, the similar velocity, higher accelerations and increased distance travelled within a smaller area indicate a different movement pattern than when using the wireless mouse. This could indicate a perceived restriction from being "tethered" when using the wired mouse and may have contributed to the gamers' preference for the wireless mice. There were slightly higher levels of muscle activity in wrist/hand muscles (ECR, FCU, FDS, EPB) while using the wired mouse but the differences were small and rarely statistically significant. Interestingly, the sEMG of the UT was slightly lower for the wireless mouse than wired one during both the Fitts' test and the gaming task, a difference that was small but statistically significant. Given the average of 69 hours per week that professional gamers play, this small difference may have an impact on muscle fatigue or pain throughout a work week. Overall, muscle activity was fairly equivalent or slightly lower when using wireless mice versus wired mice indicating that there was no dramatic benefit or drawback related to muscle activity when using the wireless mouse.

Differences between wireless and wired mice were more apparent in the subjective ratings. The wireless mice were rated consistently higher than the wired ones. Interestingly, the differences in rankings were all statistically significant except for "I would use this mouse during competition", possibly indicating that there is still some doubt as to the impact of the wireless mouse on performance. The Fitts' test showed that the wireless mice had a lower error rate and increased movement time yielding a slightly smaller throughput in the Fitts' test. Despite this, gamers subjectively reported that the wireless mouse improved their gaming performance. In addition, the wireless mouse had a larger movement area with less total distance travelled. This could be due to the fact that the wired mouse was tethered, hence the movement of participants was perceived as more limited. Interestingly, the median and peak velocity of wireless and wired mouse were very similar, however, the wired mouse had higher median and peak accelerations. Therefore, the wireless mouse may be considered more effective than the wired mouse, because to finish a similar task, the wireless resulted in lower distance travelled, lower acceleration, and a larger movement area. Although the differences in kinematics were small and not statistically significant, small subtle differences may be very important to the performance and well-being of professional esport athletes who game an average of 69 hours per week and depend on milliseconds to differentiate their playing performance.

The etiology of Cumulative Trauma Disorders (CTDs) is closely linked to the dynamic aspects of wrist movement since the acceleration of the wrist can impact the force on tendons, a known risk factor for developing CTDs (Schoenmarklin and Marras, 1990; Marras and Schoenmarklin, 1993; Sommerich et al., 1996; Albers and Hudock, 2007; Schoenmarklin et al., 2007; Mazaheri and Rose, 2021). Angular acceleration is considered to be one of the expression parameters of reaction force for causing CTS (Marras and Schoenmarklin, 1993; Mazaheri and Rose, 2021). According to Marras and Schoenmarklin (1993), highly-repetitive and hand-intensive industrial jobs (e.g., high wrist and forearm motion during an 8-hour period) are significantly associated with risk of developing an upper extremity CTD, which can be attributed to the excessive wrist joint dynamics, such as the excessive flexion-extension velocity and angular acceleration. In addition,

Table 5
Averaged static, median and peak muscle activities in Fitts' task of all professional gamers across different connection types and weights. A comparison of the static, mean and peak muscle activities of the ten muscles while performing Fitts' task when using mice of different connection types and weights.

		Static						Median						Peak					
		Wireless	Wired	p-value	Very light	Light	p-value	Wireless	Wired	p-value	Very light	Light	p-value	Wireless	Wired	p-value	Very light	Light	p-value
Neck and shoulder	UT	3.50 (2.07)	3.78 (2.36)	0.44	3.67 (2.23)	3.60 (2.22)	0.83	4.58 (2.48)	5.13 (2.84)	0.07	4.70 (2.66)	5.01 (2.69)	0.14	6.06 (3.35)	6.97 (4.00)	**0.03***	6.32 (3.62)	6.71 (3.80)	0.17
	MD	2.19 (1.15)	2.19 (1.07)	0.86	2.14 (1.09)	2.23 (1.12)	0.29	2.81 (1.38)	2.82 (1.23)	0.70	2.78 (1.30)	2.85 (1.31)	0.36	3.53 (1.64)	3.56 (1.48)	0.70	3.46 (1.55)	3.64 (1.57)	0.12
	AD	1.70 (1.59)	1.46 (1.07)	0.13	1.63 (1.48)	1.54 (1.23)	0.39	2.66 (2.67)	2.36 (2.06)	0.10	2.53 (2.48)	2.49 (2.30)	0.96	3.88 (4.00)	3.67 (3.28)	0.74	3.84 (3.70)	3.71 (3.61)	0.45
	Triceps	2.54 (1.26)	2.76 (1.54)	**0.05***	2.67 (1.50)	2.63 (1.32)	0.86	3.03 (1.42)	3.35 (1.86)	0.10	3.21 (1.75)	3.16 (1.57)	0.92	3.68 (1.58)	4.23 (2.38)	0.09	4.04 (2.21)	3.87 (1.85)	0.50
	Biceps	0.81 (0.54)	0.74 (0.51)	0.08	0.80 (0.54)	0.75 (0.52)	0.10	1.10 (0.82)	1.04 (0.79)	0.37	1.09 (0.81)	1.05 (0.81)	0.40	1.53 (1.16)	1.80 (1.57)	0.25	1.77 (1.52)	1.56 (1.23)	0.19
Hand and wrist	ED	7.71 (2.95)	8.13 (3.00)	0.07	7.86 (3.05)	7.98 (2.91)	0.48	10.82 (4.12)	10.93 (4.06)	0.47	10.88 (4.09)	10.87 (4.09)	0.97	13.54 (5.25)	13.81 (4.99)	0.21	13.69 (5.11)	13.66 (5.13)	0.94
	FDS	1.77 (0.89)	1.85 (0.89)	0.31	1.78 (0.90)	1.84 (0.88)	0.45	2.69 (1.50)	2.77 (1.45)	0.12	2.71 (1.41)	2.75 (1.53)	0.77	3.79 (2.27)	4.24 (2.46)	0.06	4.05 (2.41)	3.98 (2.35)	0.70
	FCU	2.96 (2.86)	3.45 (3.19)	0.14	3.17 (3.20)	3.24 (2.87)	0.57	5.12 (4.76)	5.46 (5.18)	0.28	5.22 (4.87)	5.37 (5.07)	0.59	7.85 (6.71)	7.26 (6.22)	0.50	7.45 (6.27)	7.66 (6.68)	0.62
	ECR	7.84 (5.53)	8.12 (5.43)	0.26	7.77 (5.37)	8.19 (5.58)	0.32	10.84 (7.15)	10.78 (7.00)	0.96	10.76 (7.01)	10.86 (7.15)	0.65	13.33 (8.64)	13.35 (8.51)	0.73	13.19 (8.39)	13.49 (8.76)	0.21
	EPB	5.87 (3.20)	6.25 (2.85)	**0.03***	6.01 (3.18)	6.11 (2.88)	0.39	9.09 (4.05)	9.24 (3.98)	0.20	9.24 (4.10)	9.10 (3.92)	0.31	11.91 (4.82)	12.19 (5.04)	0.26	12.20 (5.03)	11.90 (4.82)	0.10

UT: Upper Trap; MD: Middle Deltoid; AD: Anterior Deltoid; ED: Extensor Digitorum; FDS: Flexor Digitorum Superficialis; FCU: Flexor Carpi Ulnaris; ECR: Extensor Carpi Radialis; EPB: Extensor Pollicis Brevis. "*" indicated significant difference between categories at the level of $p \leq 0.05$.

Table 6
Averaged static, median and peak muscle activities in gaming task across different connection types and weights. A comparison of the static, mean and peak muscle activities of the ten muscles while performing gaming tasks when using mice of different connection types and weights.

		Static						Median						Peak					
		Wireless	Wired	p-value	Very light	Light	p-value	Wireless	Wired	p-value	Very light	Light	p-value	Wireless	Wired	p-value	Very light	Light	p-value
Neck and shoulder	UT	3.31 (2.34)	3.68 (2.72)	0.29	3.58 (2.62)	3.41 (2.46)	0.58	5.38 (3.17)	6.01 (3.75)	**0.05***	5.76 (3.54)	5.63 (3.43)	0.59	8.98 (5.81)	9.73 (6.04)	**0.02***	9.43 (6.01)	9.28 (5.86)	0.54
	MD	2.62 (1.50)	2.53 (1.94)	0.38	2.66 (1.60)	2.49 (1.85)	0.24	4.21 (2.44)	4.24 (2.71)	0.99	4.31 (2.33)	4.14 (2.80)	0.23	7.55 (4.51)	7.61 (4.95)	0.92	7.59 (4.43)	7.57 (5.03)	0.73
	AD	1.48 (0.99)	1.45 (1.08)	0.68	1.45 (0.94)	1.48 (1.12)	0.95	3.01 (1.90)	2.94 (1.83)	0.74	2.93 (1.73)	3.01 (2.00)	0.99	5.93 (3.15)	6.04 (3.11)	0.64	5.92 (2.86)	6.05 (3.37)	0.92
	Triceps	2.46 (1.25)	2.34 (1.21)	0.40	2.49 (1.30)	2.31 (1.15)	0.31	3.32 (1.65)	3.31 (1.84)	0.78	3.37 (1.83)	3.25 (1.66)	0.56	5.93 (4.01)	6.19 (4.63)	0.41	6.16 (4.7)	5.96 (3.93)	0.78
	Biceps	1.18 (2.88)	0.69 (0.41)	0.35	1.22 (2.87)	0.65 (0.37)	0.25	1.97 (2.82)	1.60 (0.96)	0.53	2.02 (2.83)	1.56 (0.93)	0.34	3.90 (3.15)	3.79 (2.46)	0.94	4.06 (3.21)	3.64 (2.36)	0.35
Hand and wrist	ED	5.09 (2.22)	5.41 (2.90)	0.43	5.46 (2.85)	5.04 (2.28)	0.24	8.02 (2.81)	8.63 (3.76)	**0.05***	8.53 (3.62)	8.12 (3.00)	0.18	13.82 (4.86)	14.64 (5.63)	**0.00***	14.41 (5.57)	14.05 (4.97)	0.31
	FDS	1.41 (1.10)	1.22 (0.39)	0.36	1.43 (1.11)	1.20 (0.35)	0.22	2.75 (1.79)	2.58 (1.59)	0.49	2.81 (1.87)	2.52 (1.49)	0.20	6.69 (4.91)	6.61 (4.83)	0.72	6.84 (5.21)	6.46 (4.50)	0.33
	FCU	1.63 (1.25)	1.69 (1.51)	0.85	1.64 (1.30)	1.68 (1.46)	0.82	4.15 (3.48)	4.58 (4.86)	0.37	4.42 (4.37)	4.31 (4.09)	0.66	10.84 (10.06)	12.14 (12.10)	**0.04***	11.30 (11.24)	11.68 (11.06)	0.47
	ECR	5.89 (4.22)	5.44 (3.77)	0.24	5.74 (4.15)	5.58 (3.86)	0.75	9.32 (6.07)	9.18 (6.15)	0.64	9.24 (6.30)	9.26 (5.92)	0.71	16.10 (10.99)	16.02 (11.32)	0.71	16.06 (11.49)	16.06 (10.82)	0.68
	EPB	4.08 (1.97)	3.80 (2.20)	0.10	4.01 (1.86)	3.88 (2.31)	0.27	7.68 (4.15)	7.62 (4.32)	0.71	7.71 (3.95)	7.59 (4.50)	0.39	16.46 (8.34)	16.81 (8.97)	0.47	16.62 (8.35)	16.65 (8.97)	0.90

UT: Upper Trap; MD: Middle Deltoid; AD: Anterior Deltoid; ED: Extensor Digitorum; FDS: Flexor Digitorum Superficialis; FCU: Flexor Carpi Ulnaris; ECR: Extensor Carpi Radialis; EPB: Extensor Pollicis Brevis. "*" indicated significant difference between categories at the level of $p \leq 0.05$.

Table 7
Mean and SD scores of subjective mice usability between two connection types and two different weight mice, rated from 1(worst) to 5 (best).

	Connection type			Mouse weight		
	wireless	wired	p-value	Very light (80g)	Light (87g)	p-value
Light and effortless	4.16 (0.92)	3.53 (1.34)	**0.02***	3.97 (1.00)	3.72 (1.35)	0.65
Long time use	4.53 (0.67)	3.75 (1.32)	**0.00***	4.22 (0.97)	4.06 (1.24)	0.56
Ease	4.22 (0.79)	3.66 (1.04)	**0.02***	3.94 (0.98)	3.94 (0.95)	0.90
Performance	4.22 (0.97)	3.78 (1.10)	**0.04***	3.94 (1.13)	4.06 (0.98)	0.47
Experience	4.25 (0.92)	3.78 (1.10)	**0.03***	4.00 (1.11)	4.03 (0.97)	0.71
Competition	4.22 (1.01)	3.34 (1.56)	0.07	3.81 (1.31)	3.75 (1.46)	0.62
Overall Discomfort	7.89 (1.69)	5.88 (2.80)	**0.01***	7.24 (2.14)	6.53 (2.83)	0.66

"*" indicated significant difference between categories at the level of $p < 0.05$.

according to Sommerich et al. (1996) and Schoenmarklin et al. (2007), the peak flex/extension acceleration data (i.e., angular velocity and acceleration) can be considered as the indicators to establish the benchmarks of safety and injuriousness for the highly-repetitive and hand-intensive jobs. Therefore, it is recommended that angular acceleration be included to evaluate high precision equipment in future studies.

4.2. Mouse weight

The results of this study suggest that there were no clear trends in muscle activities and subjective ratings when comparing relatively light mice that differ in weight by 7g. None of the differences between the very light and light mice reached statistical significance. Although the very light mice had slightly better performance indicated by its lower movement time and error rate during the Fitts' test, the throughput was nearly identical to the light mice. Similarly, when comparing the kinematics across the two connection types, the very light mice resulted in larger movement areas with shorter distances travelled and lower peak accelerations. Research has shown that higher precision demands lead to higher accelerations in the first part of the movement and higher decelerations near the target (Visser et al., 2004). Relatively higher

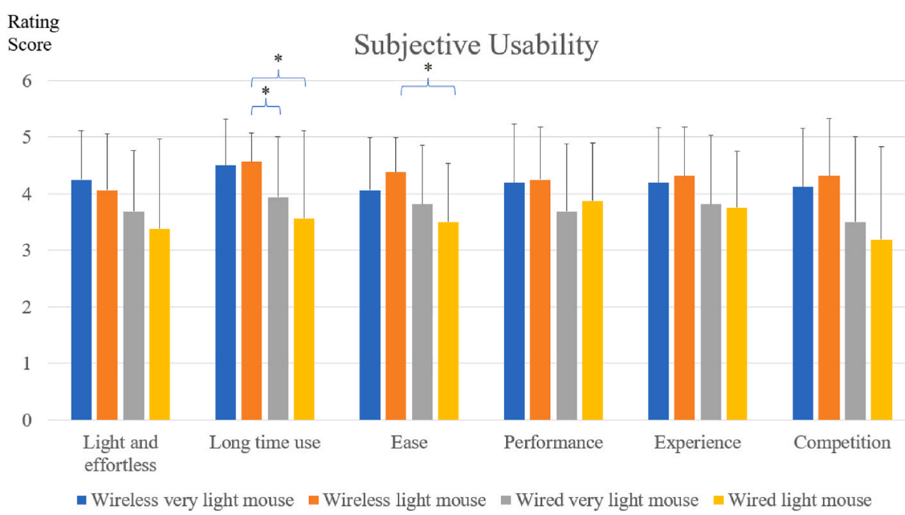

Fig. 8. The subjective rating of four specific mice among all participants with 1 being worst, 5 being best, and elements sharing '*' denotes there was a statistical significance in subjective usability between two mice at the level of $p < 0.05$.

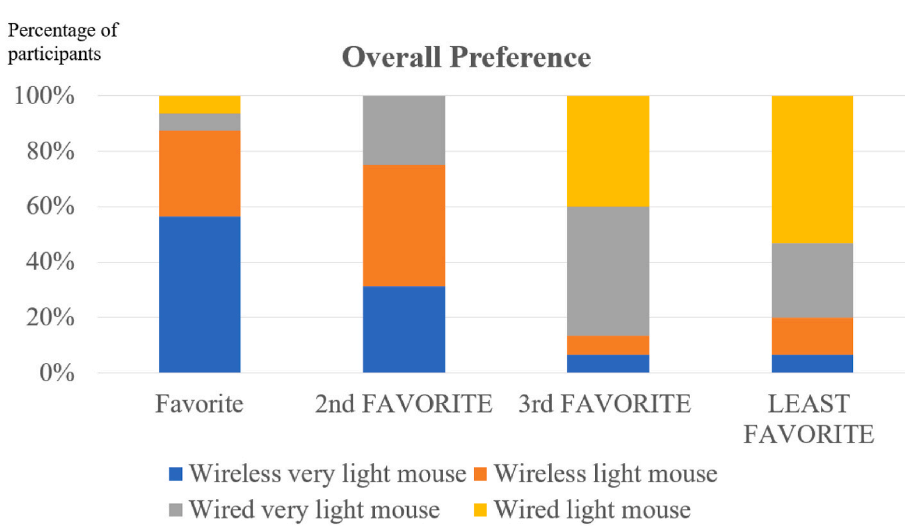

Fig. 9. Overall preference of four mice among all participants presented by the percentage of subjects that chose each mouse as their favorite.

shoulder muscle activities in this study could reflect the precision demand acting on the shoulder, caused by the accelerations of the hand. Also, in a previous study, the peak grip force was found to coincide with the peak wrist acceleration, rather than the peak total load (Werremeyer and Cole, 1997). Therefore, the lower peak accelerations observed in the very light mice could indicate that a lower peak grip force was required when using the lighter mouse.

The popularity of the very light wireless mouse is consistent with our previous study, which included more gamers of varying skill level, where the very light (80g) wireless mouse was preferred by professional gamers compared to the heavier one (Li et al., 2022). When considering the subjective ratings, it is clear that being wireless versus being 7g lighter was the key characteristic that drove the preferences. In fact, preferences based on mouse weight was close to a 50/50% split indicating that since both mice were quite light, the 7g difference was too small to impact subjective ratings. Interestingly, although 7-g was a rather small difference to compare, professional gamers could still tell this subtle difference during the blind experiment. It is possible that professional gamers are highly sensitive to mouse weight, explaining their consistent preference for the wireless very light mouse when objective data showed no statistically significant differences.

Chen et al. compared wrist motion and forearm muscle activity during a fast speed task when using 5 different mice (70g, 100g, 130g, 160g, 190g). According to their results in fast speed tasks, the ECR, ECU, and ED muscle activities were lowest in the 130g mouse trial (Chen et al., 2012). Given that the mice in our study weighed 80g and 87g, the muscle activity measured were very similar. It is likely that a larger weight difference would show clearer changes in forearm muscle activity. During their fast speed tasks, the mean wrist movement range in the 70g mouse was the highest (Chen et al., 2012); similar results were achieved in the current study where the movement area was slightly larger when using the very light mouse compared to the light one. More research should be conducted with larger differences in mouse weight to determine the optimal mouse weight for gaming, given that movement patterns are considerably different and mousing times are considerably longer for esports players compared to their office worker counterparts.

4.3. Potential risk for musculoskeletal disorders

Jonsson (1982) recommended that static muscle load levels if applied for an hour or more, should not exceed 2% MVC and must not exceed 5% MVC (Jonsson, 1982). Although these thresholods have not been validated, six out of ten static muscle activity levels exceeded 2% MVC while gaming; ED and ECR static muscle activity levels were even above 5% MVC. As reported, esports athletes trained 7 hours on a daily basis, which may make them vulnerable to MSDs and muscle fatigue. Previous research has found that carpal tunnel pressure was significantly greater during dragging and pointing tasks (Keir et al., 1999). Further, dragging activities increased carpal tunnel force compared to simple point-and-click activities. During the Overwatch game, dragging the mouse to follow the target was the professional gamers' main task. Dennerlein and Johnson observed an increase in the median wrist flexor EMG activity during a GRAPH task which is somewhat similar to our gaming task; both tasks required a lot of dragging activity and precision. Dennerlein and Johnson proposed that the increase of wrist flexor EMG activity was most likely due to the increased force applied to the mouse (Dennerlein and Johnson, 2006). Further, compared to a WEB task that did not require precision motor control, muscle activity during the GRAPH task required higher muscle activity and force (Visser et al., 2004). The negative effect of these small differences in muscle activity could be magnified over long durations of gaming that professional gamers engage in. For professional gamers who game an average of 7–8 hours per day, the long duration of hand exertion may increase their risk of pain and injury. Hence, the specific exposure-response relationships between exposures while gaming and musculoskeletal disorders for esport athletes should be studied to maintain optimal performance and reduce risk of injury.

4.4. Overall preference for the wireless mouse

Although there were no statistically significant differences between connection types for hand kinematics and most muscle activity levels, the wireless mice achieved significantly higher scores in subjective usability ratings related to being "light and effortless", better for "long time use", and increased "ease of use". As for the weight comparison, there were no significant differences between the two mouse weights when compared subjectively or objectively. This may have been due to the weights of the mice being very similar (only 7g different) making differences negligible.

As shown in Table 2, the "error rate" was significantly different ($p < 0.05$) during the Fitts test when comparing connection types with the wired mice having a higher error rate. This may have contributed to the user's preference for the wireless mice. The wired mice had small but significantly higher muscle activities than wireless ones in Tricep ($p < 0.05$, static of Fitts' task), UT ($p < 0.05$, peak of Fitts' task, median and peak of gaming task), ED ($p < 0.05$, median and peak of gaming task) and FCU ($p < 0.05$, peak of gaming task). According to Emara et al. (2020) and Park et al. (2021), high-intensity games may require up to hundreds of actions per minute by gamers in bursts or lasting over hours. Therefore, the levels of muscle activity (Gustafsson and Hagberg, 2003; Li et al., 2019; McGee, 2021) and "muscle memory" built by FPS players (Park et al., 2021) may have contributed to their preference for the very light wireless mouse, even though the objective differences were too subtle to be captured by EMG.

4.4. Limitations

This study was a simulated experiment with a rather small sample size. Although the whole experiment took about 180 minutes, the total time of mouse use was only about 50 minutes. The esport athletes spend 49.4 hours training in games per week, with an additional 16.4 hours of other mouse-based computer work averaging 9.4 hours of mousing per day, seven days per week. Given the long exposure duration, the small reductions in outcome variables in the wireless and very light mice could be more significant. Another limitation is that some subjects may have used the experimental mouse before which may have affected their performance and preference. The evaluation of mouse weight and connection type may have been confounded by random differences in the variability of game play. However, the error would be non-differential biasing the results for the gaming task toward the null. The inclusion of the Fitts task was intentional to evaluate the mice characteristics in a controlled task. Finally, 7-g was a small yet detectable difference to Professional gamers. Evaluating a broader range of mouse weights may provide larger differences in outcome variables.

4.5. Overall recommendations

Based on the study's findings, a reduction of 7 g of weight had a minimal impact on muscle activity, hand kinematics, accuracy, or preferences. However, the wireless mouse did show small reductions in muscle activity during both the Fitts and gaming task. Further the error rate was lower when using the wireless mouse and participants had a clear preference for the wireless mouse. It is possible that the freedom of movement and accuracy contributed to their selection of the wireless mouse. Although our instrumentation found small differences in muscle activity, professional gamers perceived the subtle differences in comfort and performance when using the lighter mouse. The results of this study recommend that gamers use a wireless mouse. Further research should evaluate a broader range of mouse weights to fully understand the impact of mouse weight.

5. Conclusions

Generally, the wireless mice achieved better results than wired ones in terms of error rate, muscle activity while gaming and hand kinematics. The wireless mouse got significantly higher subjective ratings than the wired mouse. Despite no statistically significant differences were found between the very light and light mice, the very light mouse was perceived as the top choice by professional esport gamers compared to the light mouse, however, the 7-g difference was likely too small to capture differences in muscle activity and hand kinematics. While gaming, six out of ten static muscle activity levels exceeded the recommended 2% MVC level indicating that surveillance for musculoskeletal disorders may be important in this population.

Ethical approval

The study was approved by the Institutional Review Board of the University of California at Berkeley and carried out in accordance with The Code of Ethics of the World Medical Association for experiments involving humans. The protocol of current study conformed to the principles outlined by the Declaration of Helsinki.

Relevance to the industry

Findings of current study could provide some guidance to the design of gaming mouse and reference to preventing work-related musculoskeletal disorders for Esports players.

Author statement

Wang contributed to the data collection, the data analysis, and drafted the manuscript; Li contributed to the data collection and process; Arippa and Barr contributed to the data collection and manuscript editing; Xue contributed to manuscript editing. Harris Adamson contributed to experimental design, data analysis, data interpretation and manuscript editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2023.103493.

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