

Examining the effects of computer mouse sensitivity on upper extremity muscle activity and
kinematics in video game players

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Computer mice are a primary component of human-computer interfaces in both office and video game settings, with video game players adjusting their mouse sensitivity to optimize performance. Limited data exists on how mouse sensitivity affects muscle activity and kinematic during video gaming. Differing movement strategies are associated with changes in mouse sensitivity, as lower sensitivity requires larger mouse movements for the same cursor movements. Therefore, the purpose of this investigation was to assess mouse sensitivity's effects on muscle activity, arm kinematics, while investigating skill level and game difficulty effects.

Thirty-four participants, classified as experienced or casual players, played a rhythm-based target acquisition game called *osu!* (ppy Pty Ltd), while using a mouse set at three sensitivities. Mouse sensitivity was set at low (400 DPI), high (1600 DPI) and preferred (mean=921 DPI). Participants played 7 trials per mouse sensitivity; 3 with the closest accuracy were analyzed. Experienced participants completed both easy- and hard-difficulty beatmaps. Kinematics and EMG data from the right upper limb and torso were compared across mouse sensitivities and between participant skill level or game difficulty.

Main effects of sensitivity revealed a consistent relationship in muscle activity levels, where muscle activation was 40+% higher in the upper trapezius, supraspinatus, infraspinatus, and extensor carpi ulnaris while using the mouse at a low sensitivity compared to high or preferred. Mean muscle activity was within ranges of 1-6 %MVC across sensitivities, while peaking up to 23 %MVC in extensor carpi ulnaris, which combined with long play times may result in signs of muscle fatigue (Jørgensen et al., 1987, Jonsson et al., 1978). Sensitivity effects in kinematics only emerged in wrist radial deviation across mouse sensitivities, with low sensitivity revealing 6° more wrist deviation than high sensitivity. Shoulder kinematics differed

between skill groups, as experienced players demonstrated more shoulder abduction and internal rotation, with mean postures differing by 10° and 4° , respectively. Lastly, more difficult gameplay resulted in significantly higher muscle activation across most muscles. This thesis offers novel insights into how the effects of mouse sensitivity on muscle activity and posture, which can assist clinicians with further understanding potential causes of injury prevalence in computer mouse users.

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1.0 Introduction

Video games can be played on various gaming consoles and are categorized into different genres, with some genres requiring high precision and accuracy. 70% of adults in the United States played video games on mobile devices, gaming consoles, virtual reality, and computer (Vorhaus, 2022). Video games have vast amounts of genres and sub-genres, ranging from puzzle and strategy to role playing or sports, with many others, to tailor to many audiences. Some games require high precision and aiming (example include Multiplayer Online Battle Arenas (MOBAs), First-person shooters), whereas some are story based which require minimal precision (such as adventure games, puzzle games). Some genres have competitive rankings where players compete against other players to receive a rank that increases with their game skill. Performance is difficult to measure in esports as some specific and quantifiable measurements, such as accuracy and in-game score, are not consistently tied to high level performance (Sharpe et al., 2022), considering there are additional cognitive decisions associated with varying game genres. Despite varying definitions of performance, casual and high-ranked players enjoy video games, as shown in the number of adults incorporating video games into their lives.

Computer mice are input devices that vary in size, shape and weight and are used by video game players and office workers. Most existing computer mouse research focused on office workers and the workplace, investigating the influence of mouse weight (Chen et al., 2012, Li et al., 2019, Toth et al., 2023) and mouse shape on physical demands, cognitive demands on physical exposures (Visser et al., 2004, Laursen et al., 2002) and how postural changes affect mouse use and productivity (Gustafsson & Hagberg, 2003). Computer mouse sensitivity is rarely assessed, as most office related studies assess other computer mouse variables with mouse sensitivity set to a default setting. Mouse sensitivity is measured in dots per inch (DPI),

measuring how far a computer mouse cursor moves relative to an inch of mouse movement. Computer mice are commonly used with a pronated forearm and wrist, however, alternative mouse designs such as neutral hand position has elicited lower forearm extensor muscle activity in office workers, though it decreased user comfort (Gustafsson & Hagberg, 2003). Office work tasks require lower precision and allow break intervals (Toth et al., 2023) to achieve high levels of performance. Currently, there is extensive research on office worker tasks and physical demands, contrasting the scarce task knowledge for video game players. Further understanding of kinematic differences following changes in mouse sensitivity will assist in understanding the joint movements and demands in mouse control tasks.

1.1 Research Objectives

The goal of this thesis was to examine how computer mouse sensitivity impacts muscle recruitment and arm movement strategy to understand potential contributors to injury precipitation. This was assessed by comparing muscle activity, upper extremity kinematics across computer mouse sensitivity settings. The secondary purpose was to explore the differences in upper extremity kinematics between low-level players and high-level players. This was done by comparing hand velocities and accelerations between skill levels. The tertiary purpose was to explore the differences in upper extremity muscle activation between game difficulties.

Specific research questions included:

- 1) Does mouse sensitivity influence upper extremity movement strategies inosu! players?
- 2) Does computer mouse sensitivity setting modify upper extremity muscle activity?
- 3) Does player skill level affect upper extremity kinematics?
- 4) Doesosu! game difficulty affect upper extremity muscle activity?

1.2 Hypotheses

It is hypothesized that:

1. Lower mouse sensitivity will result in lower wrist range of motion compared to higher mouse sensitivity, with higher elbow and shoulder range of motion.
2. Lower mouse sensitivity will result in lower wrist muscle activity and higher elbow and shoulder muscle activity compared to high mouse sensitivity.
3. Experienced players will have higher hand velocities and accelerations compared to casual players.
4. More difficult gameplay will increase muscle activity in experienced players across all muscles.

1.2 Significance of research

This work aims to quantify the effects of computer mouse sensitivity on muscle activity and arm kinematics, while considering player skill and game difficulty. This will provide fundamental knowledge related to movement strategies and muscle activation in computer mouse video games and office ergonomics. Quantifying muscle activity and postural demands between different mouse sensitivities can assist clinicians in individualizing gaming-related injury assessment and treatments based on a patient's preferred mouse sensitivity. Currently, clinicians use case studies and functional anatomy knowledge to assess patients. If lower mouse sensitivity reduces muscle activity in forearm muscles and reduces wrist deviation, clinicians can suggest lower mouse sensitivities in patients with forearm tendinopathies to offload their injured tissues. Overall, this study can add valuable knowledge of physical exposures on a larger muscle sample than previously reported, and with gaming-relevant populations. As video games are a growing hobby, this investigation aims to relate findings to casual populations and compare them

to high-level players. Office workers use a computer mouse to perform work tasks, therefore, the information may also apply to populations exposed to computer use and potentially help to direct ergonomic interventions.

2.0 Literature Review

2.1 Upper Extremity Functional Anatomy

2.1.1 Shoulder Complex

The shoulder complex consists of the clavicle, scapula, thorax, and sternum. These bones articulate to form the glenohumeral (GH) joint, acromioclavicular (AC) joint, and sternoclavicular (SC). The scapulothoracic (ST) articulation is an additional joint in the shoulder complex, though it is not considered a true joint since it lacks bony or ligamentous attachments (Culham, 1993; Terry & Chopp, 2000). Instead, it comprises of axioscapular muscles allowing increased shoulder range of motion, compared to sole GH joint motion (Terry & Chopp, 2000).

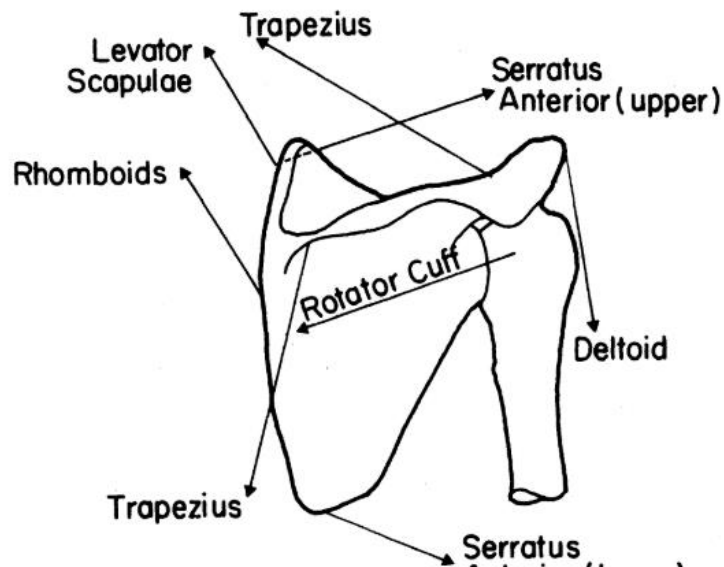


Figure 1: Muscle forces of scapular muscles (Peat, 1986).

The SC joint is the only attachment point of the upper extremity to the axial skeleton. The shoulder girdle is supported by muscles attaching the scapula to the axial skeleton. **Figure 1** (Peat, 1986) illustrates the lines of action of the muscles responsible for assisting the motion of the scapula. The trapezius is a broad muscle segmented into upper, middle, and lower. The three sections work in unison to rotate the scapula to assist in full shoulder range of motion. The upper trapezius originates from the superior nuchal line and insert on the lateral third of the clavicle and spine of the scapula, performing shoulder elevation (Criswell & Cram, 2011).

The GH joint is the articulation between the humeral head and the glenoid fossa of the scapula capable of large ranges of motion in abduction, adduction, external rotation, internal rotation, flexion, and extension. The prime movers performing these movements are pectoralis major, latissimus dorsi, and deltoids. The pectoralis major originates on the medial clavicle, sternum and fifth and sixth ribs, extending to the insertion site on the lateral lip of the bicipital groove (Criswell & Cram, 2011). The primary function is to adduct and internally rotate the humerus. The deltoid originates on the lateral third of the clavicle (anterior), acromion (middle), and lower border of the spine of the scapula (posterior) and converge to insert on the deltoid tuberosity of the humerus (Criswell & Cram, 2011). The three portions of the deltoid activate to perform arm abduction, though perform individual movements when activated independently. The anterior deltoid flexes, medial rotates and abducts the arm, whereas the posterior deltoid extends, externally rotates, and abducts the arm.

Due to the shallow osteomorphology of the glenoid fossa, the GH joint relies heavily on muscles and ligaments surrounding the joint to maintain stability (Peat, 1986). The deepest muscles around the GH joint comprise the rotator cuff, consisting of subscapularis, supraspinatus, infraspinatus, and teres minor. All four rotator cuff muscles originate on the head

of the humerus and insert on the scapula. Supraspinatus, infraspinatus, and teres minor are most frequently external rotators of the humerus, whereas subscapularis is an internal rotator (Terry & Chopp, 2000). The small moment arms of the rotator cuff muscles are advantageous in maintaining GH stabilization due to their muscular arrangement around the humeral head (Veeger & van der Helm, 2007).

2.1.2 Elbow Joint

The elbow joint is a modified hinge joint with four muscle groups that allow for elbow flexion and extension as well as forearm supination and pronation. Normal range of motion is from 0-150 degrees of flexion-extension, with most activities of daily living within 30-130 degrees (Fornalski et al., 2003). The elbow performs pronation and supination at the forearm, with averages of 75 degrees of pronation and 85 degrees of supination (Fornalski et al., 2003). To perform these movements, there are 4 muscle groups: elbow flexors, elbow extensors, flexor-pronator group, and extensor-supinator group. The flexor group contains the biceps brachii, brachioradialis and brachialis. The biceps brachii also functions as a supinator, with its highest torque generated with the forearm is supinated (Stroyan & Wilk, 1993). The two elbow extensors are the triceps brachii and the anconeus. The flexor-pronator group consists of forearm muscles, containing pronator teres (PT), flexor carpi radialis (FCR), palmaris longus (PL), flexor carpi ulnaris (FCU) and flexor digitorum superficialis (FDS). Their primary function is associated with wrist or finger flexion. Though, these muscles originate on the medial epicondyle of the humerus, thus assisting with elbow flexion (Stroyan & Wilk, 1993). Lastly, the extensor-supinator group includes the brachioradialis, extensor carpi radialis brevis (ECRB), extensor carpi radialis longus (ECRL), supinator, extensor digitorum (ED), extensor carpi ulnaris (ECU), and extensor digiti minimi (EDI) (Stroyan & Wilk, 1993). The extensor-supinator group's

primary function lies in moving the wrist or fingers. Their common origin site is the lateral epicondyle (Fornalski et al., 2003), and all except brachioradialis insert distal to the wrist allowing them to perform assist in elbow extension and supination.

2.1.3 Wrist

The wrist consists of 8 uniquely shaped carpal bones, metacarpals, ulna, radius, ligaments, and muscles that cross the joint, which together accomplish a wide range of motions and force transfer. Though, articulation of the wrist joint is between the distal radius and the scaphoid, lunate, and triquetrum (Erwin & Varacallo, 2018). There are multiple biomechanical models and theories of the wrist joint, such as, row-theory, column-theory, row-column-theory, and ring-model (Eschweiler et al., 2022). In the context of these competing wrist movement theories, this paper will treat the wrist as a static segment and will thus focus discussion on the function of the muscles acting at the wrist.

Wrist movement is generated by forearm muscles crossing the wrist joint to produce wrist flexion, extension, abduction, and adduction. Six superficial forearm muscles (**Figure 2**) facilitate different wrist movements, based on their location relative to the radius and ulna (Eschweiler et al., 2022). The superficial forearm flexors group contains flexor carpi radialis (FCR), palmaris longus (PL), and flexor carpi ulnaris (FCU). These three muscles perform wrist flexion. FCR and FCU perform radial deviation or abduction and ulnar deviation or adduction, respectively. On the posterior side of the forearm, the extensor group consists of extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB), and extensor carpi ulnaris (ECU). Not shown in this diagram is the extensor digitorum (ED), which is a primary wrist extensor. ECRB and ECRL assist in wrist abduction, whereas ECU assists in wrist adduction. These wrist

abductors and adductors work in unison to allow stable movements through multiple axes (MacLean et al., 2022).

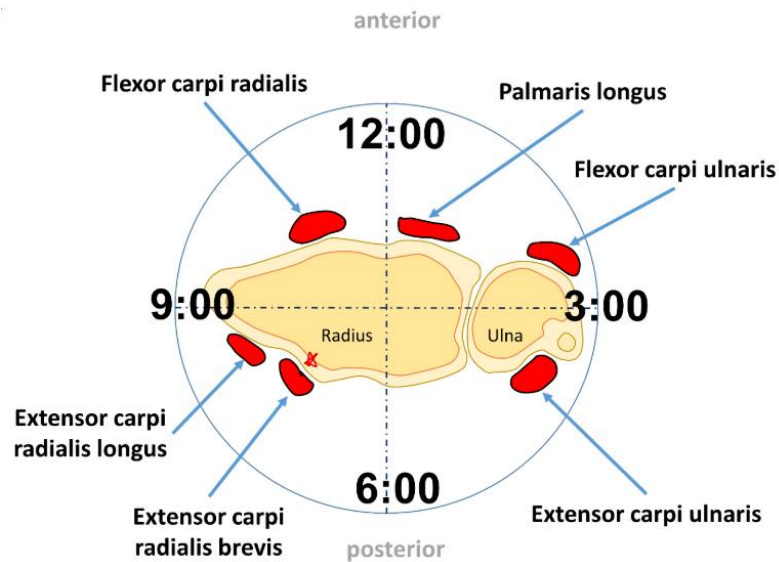


Figure 2: Superficial wrist muscle position on the radius and ulna (Eschweiler et al., 2022)

2.2 Computer Mouse Studies

Office ergonomics includes consideration of workstation adjustments to better fit the worker's needs. Workstations consist of computer monitors, computer mice, keyboards, desks, and chairs, amongst other task specific objects, consistent with video game set ups. Primary research areas on mouse use in office ergonomics are modified mouse designs, physical exposures, mental demands, and injury prevalence.

2.2.1 Modified mouse design and physical exposures

Variation in computer mouse design has been evaluated to understand the impact of mouse components on physical exposures. Computer mice typically incorporate two buttons, a scroll wheel and require users to use a pronated forearm posture to perform computer inputs. Though, new mouse designs are being assessed for user comfort, productivity, and physical exposures. One common alternative to the pronated mouse position is a neutral mouse that

allows for a neutral forearm position when used, due to the mouse's vertical design. Neutral mouse designs elicited decreased muscle activity in extensor digitorum and extensor carpi ulnaris, though effects on upper trapezius were inconclusive due to variance across participants (Gustafsson & Hagberg, 2003). Despite lower muscle activity while using a neutral mouse, productivity decreased, and participants reported lower discomfort scores. Another study looked at 3 new mouse designs with the aim of reducing finger and wrist extensor muscle activity in different mouse tasks. These mouse designs achieved lower extensor muscle activity values, at the cost of higher flexor loading and lower task performance (Lee et al., 2007). Another mouse modification is altering the weight of the mouse to investigate the muscle activity and kinematic changes. Chen et al., 2012 measured ECR, ECU, EDC, and UT during repetitive point-and-click tasks. Mouse weight was adjusted to 70g, 100g, 130g, 160g, and 190g. Maximal wrist deviation did not differ amongst mouse weights. However, wrist range of motion and muscle activity were lowest for the 130g mouse during the high-speed task. One explanation for lower muscular costs is other arm muscles were activated to move the mice. Therefore, collecting electromyography of muscles acting at the elbow and shoulder joint could provide more conclusive results. Overall, altering the mouse design can modulate muscle activity and physical exposures, however, it may concomitantly reduce user comfort and productivity which is important in a workplace environment.

2.2.2 Mental demands on physical exposures

Workplaces may include a variety of stressors that can influence the way workers interact with their environment, equipment, and thus their performance of job tasks. One area of computer mouse research investigates the impact of mental demands on muscle activity. Replicating a stressful work environment in a laboratory setting was attempted through verbal

feedback and instructions regarding the participant's task performance. Increasing mental demands during computer tasks increased muscle activity in the upper extremity (Birch et al., 2000; Laursen et al., 2002; Visser et al., 2004). Visser et al. (2004) assessed the effects of precision and mental pressure on upper extremity muscles in computer mouse tasks. Participants performed a tracking task and aiming task, where they used their mouse to follow a dot with their cursor and were asked to click on a dot on the computer screen at random intervals, respectively. Mental pressure was exhibited through verbal instruction to perform well while being provided performance feedback, or to make correct clicks as quickly as possible. Mental pressure increased upper trapezius activation in the tracking task, whereas all muscles had higher muscle activity in the aiming task. Flexor digitorum superficialis (FDS), extensor digitorum (ED), and upper trapezius muscle activity significantly increased by 142%, 45%, and 41%, respectively, in response to mental demands during the aiming task. Precision demands only caused small increases in muscle activation in extensor digitorum and flexor digitorum superficialis, with FDS amplitude significantly increasing by 21%. Though, this could be due to increased co-contraction to increase precision by reducing excess movement of the wrist. These increases in muscle activity show higher physical exposures in mouse users exposed to higher stress environments. Tracking and aiming tasks are performed by video game players, and with the required high precision needed as well as the mental pressure to win a game and perform well for their team or themselves, they would likely also elicit increased muscle activity while playing games. These tasks are most closely related to video games, however, expanding on these selected muscles would be valuable. Additional muscle activity data of muscles at the elbow joint and shoulder will improve the understanding of physical exposures of mouse use, thus improving knowledge of injury mechanisms in computer mouse users. Due to the inconsistencies in measured muscles

and task types, it is difficult to compare results between studies. However, there appears to be a consensus that forearm muscle EMG increases with increased mental demands or precision (Birch et al., 2000b; Laursen et al., 2002).

2.2.3 Computer mouse use and injury prevalence

With computer use becoming a more common job task in the 1990s, ergonomists and researchers investigated the relationship between physical exposures and musculoskeletal disorders (MSD). Out of the cumulative trauma disorders of the upper extremities, wrist and hand were the highest percentage of claims. When analysing the cause of these claims, computer related injuries had a higher proportion of claims in the wrist, compared to computer mouse related claims with higher proportion of claims in hand, fingers and arm (Fogleman & Brogmus, 1995). As these injuries made up a high percentage of claims, studies in the early 2000s aimed to further assess the physical exposures potentially precipitating these injuries. As workers spent more time on computers, connections between hours of computer use and musculoskeletal symptoms were analysed. However, there was no relationship between hours of mouse use and symptoms, instead, different mouse positions influenced prevalence of symptoms. When office workers used their mouse with their arm in an abducted position, there was a higher prevalence of neck symptoms with 73.9% reporting neck pain compared to 60% with their arm in an optimal position. Computer mouse users have 15.8° greater ulnar deviation of their wrist than non-computer mouse users (Karlqvist et al. 1994), which can explain higher prevalence of wrist symptoms with increased computer use (Cook et al., 2000, Jensen et al., 2002). To better understand the varying work capacities and symptom occurrence, Richter et al., 2012 conducted a 2-year longitudinal study with questionnaires and measurements of computer input use. Peak usage days were defined as >4 hours of computer use or >2.5 hours of mouse use, which is less

than the average reported session length (2.9 ± 1.6 hr) of casual video game players (Forman & Holmes, 2023). Overall, they did not find an indication that high peaks in computer use were related to the occurrence of neck-shoulder and arm-wrist-hand symptoms (Richter et al., 2012).

Due to the nature of repetitive office work tasks, upper extremity injuries are common injury claims. With carpal tunnel syndrome (CTS) appearing to have a high incidence and prevalence in computer-based occupations, meta-analyses have attempted to assess and validate these relationships (Shiri & Falah-Hassani, 2015; Thomsen et al., 2008). One common weakness in CTS and computer work studies, is neglecting to use nerve conduction (NC) tests, which are the gold standard for measuring CTS symptoms and progression (Aroori & Spence, 2008). Thomsen et al 2008 assessed the methods and results of eight epidemiological studies to investigate the association between computer work and CTS, though each study exhibited limitations. Inclusion criteria for this meta-analysis required the CTS definition to include symptoms of CTS in combination with NC testing or symptoms confirmed with an interview. Of the eight studies, one study had a large population with a short follow-up period and found some positive associations. However, it did not involve NC tests making it difficult to confirm the prevalence of CTS. Overall, Thomsen et al. 2008's meta-analysis determined the evidence of association between computer use and CTS to be conflicting due to the inconsistencies in CTS symptom confirmation. Shiri & Falah-Hassani (2015) conducted a meta-analysis of six studies comparing computer workers with the general population to assess whether computer use causes CTS, determining a weak-positive association between computer mouse use and CTS. CTS was positively associated with mouse use for ≥ 4 hours (OR = 1.93, 95% CI 1.43-2.61) and frequent mouse use (OR = 1.84, 95% CI 1.18-2.87). The weak-positive association is potentially meaningful, suggesting excessive computer use, particularly mouse use, might be associated with

symptoms of CTS. Though, not all studies included in their review performed NC tests on their participants. Without consistent measurements across these studies, it is difficult to determine whether computer mouse use and office work are direct risk factors for CTS development.

Further research examines alternate upper extremity disorders, specifically tendinopathies. With limited quantitative data on muscle activity and kinematic data on computer mouse users, health professionals are constrained to experiences, expert opinions, and relevant research to accurately diagnose disorders (McGee & Ho, 2021). Questionnaires conducted by DiFrancisco-Donoghue et al 2019 on collegiate esports athletes showed similar injury patterns as office workers in previous prevalence studies. Hands and wrist pain are the highest reported pain in these athletes at 30% and 36%, respectively, similar to Cook et al., 2000 reporting wrist/hand pain in 39.3% of office workers. A deeper investigation into type of upper extremity disorder (UED) in esports players shows a pattern of repetitive strain injuries (RSI) such as tendinopathies in the shoulder and wrists, lateral epicondylitis, and medial epicondylitis (Difrancisco-Donoghue et al., 2019; McGee & Ho, 2021; Sant & Micallef Stafrace, 2021), though additional research establishing a relationship between mouse movement and specific UEDs is needed. This thesis will observe changes in muscle activity and arm movement between computer mouse movement patterns in video game players. Connecting mouse sensitivity to joint range of motion while performing the task will provide insights into the occurrence of specific tendinopathies.

2.3 Gaming-specific computer mouse studies

Computer mouse variation allows for users to optimize user comfort and performance. Computer mice range in shape, size, weight, and connection type. Video game players prefer specific components of their computer mouse to achieve the highest level of performance. Office-related-studies initiated investigations of mouse weight and design on muscle activity and

user comfort. Subsequent gaming-focused studies further specified mouse weight, mouse type and user performance.

Video game performance is multifaceted and difficult to assess, leading researchers to seek metrics that measure specific components. Gaming performance can be measured by cognitive psychology (reaction time, response time), skill (mouse control), strategy, awareness (environmental awareness), and game-specific knowledge (economy) (Sharpe et al., 2022). Some of these performance metrics can be measured quantitatively in time (reaction or response time) or success rate (strategy successes), but other variables are difficult to measure without quantitative values associated with them (game-specific knowledge or awareness). Therefore, to reduce confusion, the primary performance metric reviewed is mouse control. Fitt's law consists of multiple tests to compute information capacity of the human motor system (Fitts, 1954). One test called "reciprocal tapping" has been adapted to computer use, which requires participants to tap two targets as fast as they can.

Target acquisition is an important skill in video gaming, as it is a key performance indicator in genres that require high mouse cursor precision, though different computer mouse factors can influence player performance. The repeatability of the Fitt's test provides a consistent metric for measuring a computer user's ability to move their mouse cursor to a target. Accessing performance in the Fitt's test between a heavy wired, light wireless and heavy wireless computer mice did not show statistically significant differences in mean time, error rate and throughput (Li et al., 2019b). These computer mice were within 7 grams of each other with weights of 86 grams, 80 grams, and 87 grams, respectively. However, another study further assessed the impact of mouse weight on performance in the Fitt's test and noticed that lighter mice (40 grams) had a higher error rate and higher number of target re-entries (Yan et al., 2022). Both experiments

considered user preference, with the 60-gram mouse scoring the highest in overall preference (Yan et al., 2022) and the light-wireless mouse was easiest to use (Li et al., 2019b). A comparison between professional video game players and high-level players performing a Fitt's test and 10 minutes of video gaming at 3 different computer mice weights (87g, 80g, 86g) showed higher wrist muscle activity (ED and ECR) in high-level players compared to professional players (Li et al., 2022). Though, professional players showed higher UT and shoulder muscle activity level compared to high-level players, potentially indicating different techniques in skill level. Furthermore, static muscle activity was higher than recommended threshold limits for MSD prevention. Additionally, professional players had higher velocities and accelerations of the hand. This study appears to be the first to examine arm (triceps brachii, biceps brachii) and shoulder (middle deltoid, anterior deltoid) muscles during mouse use. One limitation is movements in the games were not identical across trials, thus making it difficult to assume the differences in muscle activation were due to player skill rather than the intensity of their games. Lastly, Toth et al., 2023 explored kinematic phases of aiming tasks in first person shooters to understand target acquisition in esports. Kinematic phases were classified as recognition phase, response phase and verification stage. The recognition phase consists of recognizing the target and the neural planning to acquire it; the response phase is the ballistic movement towards the target; the verification phase is the time to verify that the target has been acquired. Amongst 3 skill-levels of participants (Elite, Low Skill, Non Gamers), gamers recognized targets and moved to targets more quickly, with fewer movements to verify their accuracy than non-gamers. Elite gamers took less time than low skilled gamers, and low skilled gamers took less time than non-gamers. This study primarily assessed practice effects on the groups, however, they suggested investigating movement strategies at different skill levels.

2.4 Literature Review Summary

Computer mouse use is a common task in workplace environments and a key component in video gaming, although there has been minimal investigation into how computer mouse sensitivity influences movement strategies and muscle activity. Existing research focuses on the physical design of a computer mouse, the impact of mental demands and pressure on muscle activity, and injury prevalence in mouse users. The assessment of varied mouse designs showed that some designs can elicit desired decreased muscle activity changes, with the risk of lower user comfort, performance, and productivity. Creating a high-stress environment elicited increased muscle activity in the upper trap and forearm muscles, although it is unknown if this influences other muscles due to the scarce data on shoulder muscles. Lastly, office workers and video game players had similar injury incidence rates, indicating tendon-related upper extremity musculoskeletal disorders in both populations. Overall, existing office literature provides a framework for gaming-related studies, though it cannot relate to gaming populations who deviate from default mouse sensitivities observed in office-related studies. Currently, clinicians must resort to existing biomechanical literature to diagnose and treat patients with computer-mouse-related injuries, despite this knowledge gap related to mouse user preference. This thesis aimed to address the existing limited shoulder muscle literature and arm kinematics during mouse use to further understand another aspect of potential injury.

3.0 Methodology

3.1 Participants

Thirty-four participants (**Table 1**), free of any upper extremity, neck, or back injuries in the last year were recruited, with 17 participants in the casual group and 17 in the experienced group. A casual participant was required to have a minimum 3 hours of osu! experience. An experienced participant had a minimum 10 hours of osu! experience and could complete the selected hard difficulty level in osu!. The easy difficulty beatmap's song was titled '*Soufuu (TV Size)*' by Tomofumi Tanizawa, mapped by osu! user nante, with a Star Rating of 1.80, while the hard difficulty beatmap's song was titled '*quaver*' by dj TAKA, mapped by osu! user *Shunao* with a Star Rating of 3.53. To contextualize the difficulty, a Star Rating of 1.80 would be too challenging for someone with minimal video gaming experience, whereas a Star Rating of 3.53 would require players to have approximately 30 hours of osu! experience or substantial experience in video games that demand precise mouse movements.

Table 1: Participant demographics (means $\pm$ standard deviations). F indicated female participants; M indicated male participants.

Group	Sex	Age (years)	Height (cm)	Weight (kg)
Casual (n = 17)	3F, 14M	21.3 $\pm$ 1.6	170.3 $\pm$ 7.8	69.4 $\pm$ 16.9
Experienced (n = 17)	2F, 15M	20.8 $\pm$ 1.6	173.5 $\pm$ 7.8	71.8 $\pm$ 13.3

3.2 Experimental Protocol

Participants spent approximately two and a half to three hours in the lab, including the pre-experimental protocol and 1 of the 2 experimental protocols (**Figure 3**).

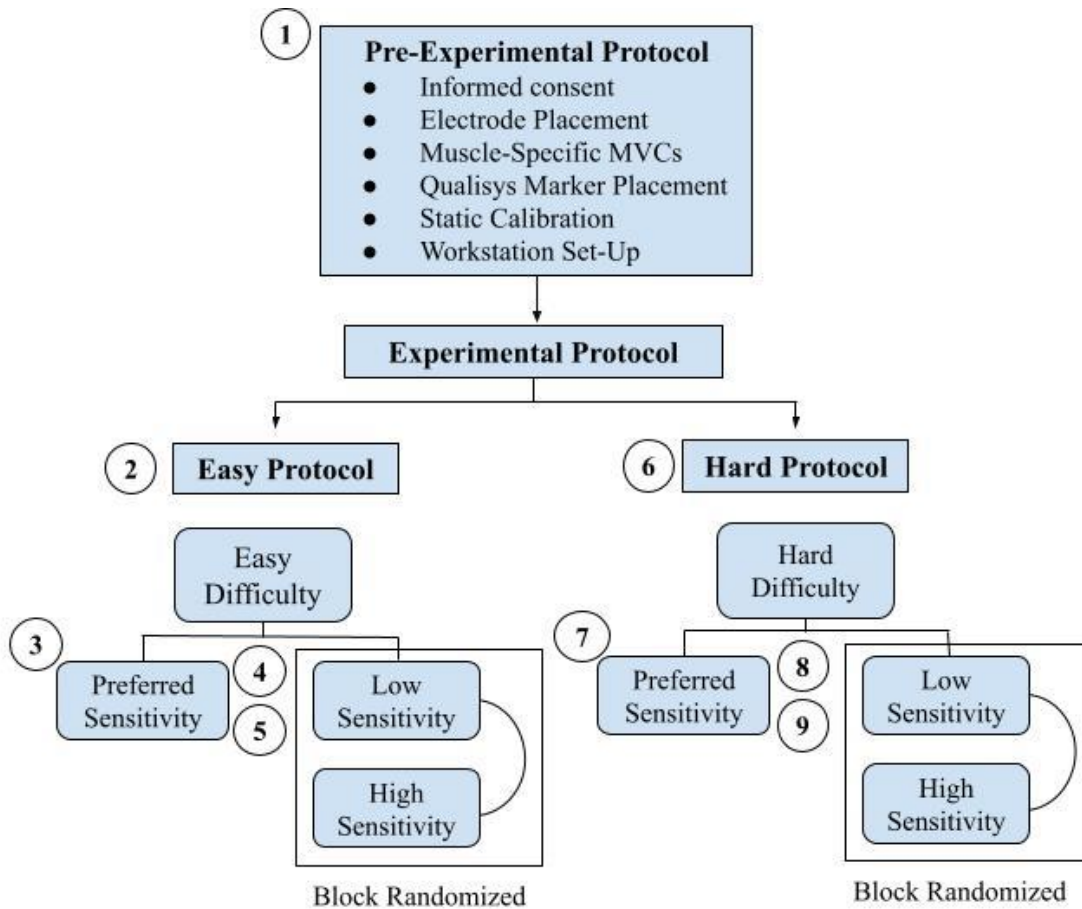


Figure 3: Overview of experimental collection protocol. All participants began with the same pre-experimental protocol (1). Participants were classified as casual or experienced players. Casual players completed the easy protocol (2), while experienced players completed both the easy protocol (2) and hard protocol (6).

3.2.1 Collection Protocol

Upon arrival, participants reviewed information regarding the collection protocol and provided informed consent prior to participation. Prior to instrumentation set-up, participants performed a right-hand task of the Purdue Pegboard Test (Lafayette Instruments, Indiana, USA) for a parallel investigation, outside the scope of this thesis. Participant demographics (*i.e.* age, sex, height, weight) and information about their gaming history were taken before instrumentation. Instrumentation began with prepping the skin for electrode placement, then electrodes were placed over muscle sites on the right upper extremity and torso (**Figure 4**). Sub-maximal voluntary contractions were done to verify electrode placement, then participants performed two 5 second Maximal Voluntary Contractions (MVC) for each muscle (**Table 2**). Participants had at least 2 minutes of rest between MVC trials, and MVCs were performed in an order to avoid recruiting muscle groups in consecutive MVCs.

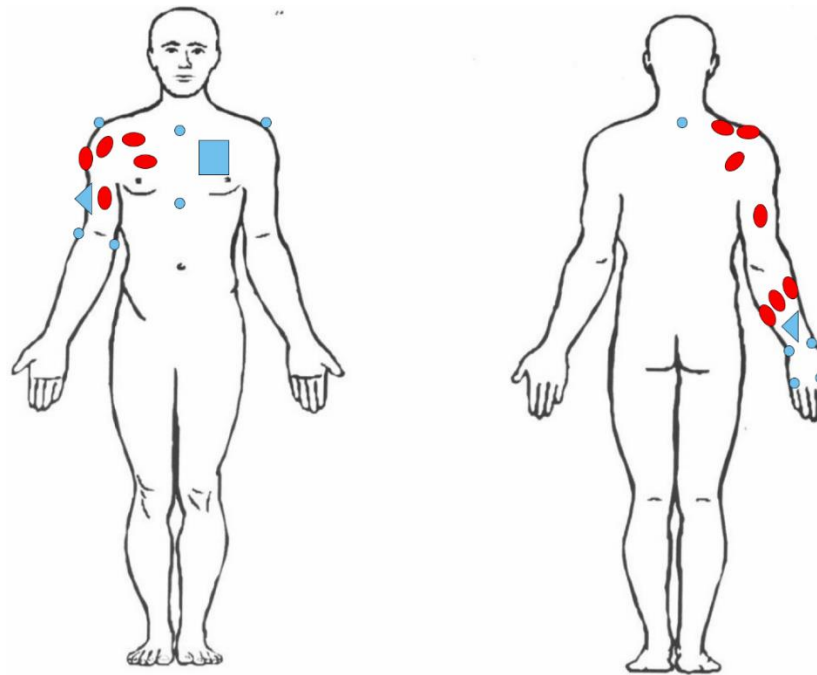


Figure 4: Surface electromyography electrode placements (red), reflective markers for Qualisys (blue). Circles represent individual markers, square and triangles represent clusters.

Table 2: A description of MVC postures for the 12 muscles in this experiment. Postures are based on Daniels and Worthingham (1986)^a Cram and Kasman (1998)^b and Perotto (2011)^c

Muscle	Description of Posture
Upper Trapezius ^a	Participant will sit over end of table with hands in their lap. Participant will shrug their shoulders.
Anterior Deltoid ^b	Participant will be seated with shoulder flexed to 90 degrees with thumb pointing medially.
Middle Deltoid ^b	Participant will be seated with their arm abducted to 90 degrees.
Supraspinatus ^b	Participant will be seated with arm abducted to 5 degrees.
Infraspinatus ^b	Participant will be seated with elbow flexed to 90 degrees, while externally rotating their arm.
Pectoralis Major (Sternal) ^a	Participant will be seated with shoulder abducted to 90 degrees, while elbow is flexed to 90 degrees with hand facing anteriorly. Participant will horizontally adduct their arm.
Pectoralis Major (Clavicular) ^a	Participant will be seated with shoulder abducted to 60 degrees, while elbow is flexed at 90 degrees with hand pointing anteriorly. Participant will horizontally adduct their arm against resistance.
Biceps Brachii ^c	Participant will be seated with arm at 90 degrees and forearm supinated. Participant will flex their elbow against resistance.
Triceps Brachii ^c	Participant will be seated with elbow at 90 degrees and forearm pronated. Participant will extend their elbow against resistance.
Extensor Digitorum Communis ^c	Extend the metacarpophalangeal joints with the forearm fully pronated
Extensor Carpi Radialis ^c	Dorsiflexion of wrist in radial deviation. Resistance will be applied on the dorsal surface of the 2 nd and 3 rd metacarpals in the direction of flexion and ulnar deviation.
Extensor Carpi Ulnaris ^c	Participant seated with elbow flexed and forearm fully pronated. Resistance will be applied on the dorsal surface of the 5 th metacarpal in the direction of flexion and radial deviation.

Following EMG setup, reflective passive markers and rigid clusters were placed over bony landmarks and segments, respectively (**Figure 4**). Prior to any experimental trials, a five second static calibration trial was collected. To prevent obstruction of markers during the calibration trial, the workspace was moved into the collection space following calibration. Following instrumentation set-up, participants were instructed to adjust the workspace to match their home set up as closely as possible (**Figure 5**). Participants were shown how to adjust the

chair height, back support, and arm rests on a Herman Miller Aeron chair, along with the desk height and monitor height.



Figure 5: Experiment set up highlight workstation and participant position.

Once the workspace was adjusted, participants performed a series of reaction time tests for a parallel investigation outside the scope of this investigation. Participants were familiarized with the Rating of Perceived Performance (RPP) (**Table 6**) and Rating of Perceived Exertion (RPE) ratings (**Table 5**), the Logitech G Pro Wireless mouse, then were instructed to indicate their preferred mouse sensitivity. Following the familiarization period with the protocol, participants began the novel procedure, which was specifically designed to encourage movement strategies using extreme low (400 DPI) and high (1600 DPI) mouse sensitivity. Initially, each participant's mouse sensitivity was adjusted to their preferred setting, and they completed 7 trials of the beatmap at that sensitivity, with 2 minutes of rest between trials. After each trial, participants reported RPP and RPE. Following the first 7 trials, mouse sensitivity was randomized between 400DPI (LOW) or 1600 DPI (HIGH). In cases where the participant's preferred sensitivity was

the same as the pre-defined low or high sensitivities, the participant performed 7 trials at 800 DPI; however, this extra condition was not included in data analysis. Following the preferred condition, participants performed 7 trials at the first sensitivity, then 7 trials at the second sensitivity. Participants classified as experienced also performed the game task at the high difficulty with the same mouse sensitivities for a total of 42 trials.

3.3 Instrumentation

3.3.1 Electromyography

Surface electromyography (EMG) signals were measured from 12 sites over muscles of the right shoulder, arm, and forearm. EMG was recorded from 6 shoulder muscles: deltoid (anterior, middle), infraspinatus, supraspinatus, and pectoralis major (sternal and clavicular); 1 scapulothoracic muscle: trapezius (upper); 2 muscles that cross the elbow joint: biceps brachii and triceps brachii; and 3 muscles that cross the wrist: extensor digitorum, extensor carpi radialis and extensor carpi ulnaris. Electrode placements followed previous work (Criswell, 2011; A. Perotto, 2011). Bipolar Ag-AgCL dual surface electrodes (Noraxon, Arizona, USA) with fixed 2.0 cm inter-electrode distances were used to detect EMG signals. Prior to electrode placement, the skin overlying the muscles was shaved and wiped with an alcohol swab to reduce electrical impedance. EMG data was collected using a Noraxon Ultium EMG system (Noraxon Inc., Arizona, USA). EMG signals were sampled at 2000 Hz then converted from analog to digital using a 24-bit A/D card. This system includes bypass filtering from 10-500 Hz and differential amplification using a common-mode rejection ratio > 100 dB with input resistance of $100\text{M}\Omega$.

Table 3: A description of electrode placements used to measure electromyography of the 12 muscles studied in this experiment. Placements are suggested from Criswell & Cram, 2011 and Perotto, 2011.

Muscle	Electrode Placement
Upper Trapezius	2cm lateral to the midpoint between the spine and the acromion along the muscle belly of trapezius
Anterior Deltoid	4cm below the lateral edge of the clavicle on the anterior aspect of the arm, running obliquely from clavicle to deltoid tuberosity running parallel to the muscle belly
Middle Deltoid	3 cm below the acromion, placed on the lateral aspect of the arm angled from acromion to the deltoid tuberosity
Supraspinatus	1cm above the midpoint of the spine of the scapula
Infraspinatus	4cm below the midpoint of the scapular spine, over the infraspinatus fossa, angled obliquely toward the inferior aspect of the humeral head
Pectoralis Major (Sternocostal)	2cm medial to the anterior axillary fold, placed horizontally on the chest over the muscle mass
Pectoralis Major (Clavicular)	2cm below the lateral edge of the clavicle, just medial to the axillary fold angled obliquely toward the clavicle
Biceps Brachii	Positioned on the centre of the muscle belly at the midpoint between the acromion and forearm when the elbow is flexed at 90 degrees.
Triceps Brachii	2cm medial from the midline of the arm at the midpoint between acromion and olecranon, with elbow flexed at 90 degrees
Extensor Digitorum Communis	Positioned between proximal and middle third of the forearm angled from lateral epicondyle to midpoint of the wrist
Extensor Carpi Radialis	2 fingerbreadths (4cm) distal to the lateral epicondyle
Extensor Carpi Ulnaris	1cm above the midpoint of the shaft of ulna

3.3.2 Motion Capture

Three-dimensional kinematic data of the right upper extremity and torso was collected at 100 Hz using a Qualisys passive motion capture system (Qualisys, Gothenburg, Sweden). The collection space was calibrated prior to the participants' arrival, with the origin set to ensure that movements were performed in the positive axes during the experiment. The global coordinate system (GCS) was set to International Society of Biomechanics (ISB) standards, where +Y represents up, +X represents forward and +Z represents to the right of the origin (Wu et al., 2005). Eleven reflective markers were placed on the right arm and torso over palpable bony landmarks following ISB recommendations (Table 4) (Wu et al., 2005). Additional clusters

containing at least 3 markers each were placed on the chest, upper arm, and forearm. A five second static calibration trial, with the participant standing in a “T-pose”, was taken prior to the beginning of the experimental trials.

Kinematic data was used to calculate joint angles of the wrist, elbow, and shoulder. Joint angles were compared between different mouse sensitivities to identify differences in movement strategies. There were 3 markers on the mouse to measure hand-mouse movement differences, which would be attributable to the fingers, which for logistical reasons were not monitored. Indeed, specific finger movements were not captured in this study due to the variety of computer mouse grip types. Standardizing grip for this study could lead to differences in participant comfort and gaming performance, and thus less applicable to real life scenarios.

Table 4: Motion capture marker placement based on recommendations by Wu et al. (2005).

Body Segment	Anatomical Landmark
Thorax	Spinous Process of the the 7 th Cervical Vertebra (C7)
	Supra Sternal Notch (SS)
	Xiphoid Process (XP)
	Left and Right Acromion Process (LACR, RACR)
	Chest Cluster (CHEST1, CHEST2, CHEST3, CHEST4, CHEST5)
Right Humerus	Upper Arm Cluster (UA1, UA2, UA3)
	Medial Epicondyle (ME)
	Lateral Epicondyle (LE)
Right Forearm	Forearm Cluster (FA1, FA2, FA3)
	Radial Styloid Process (RS)
	Ulnar Styloid Process (US)
Right Hand	2 nd Metacarpal Joint (MCP2)
	5 th Metacarpal Joint (MCP5)
Computer Mouse	Computer Mouse (MOUSE1, MOUSE2, MOUSE3)

3.3.3 Game task

Osu! (ppy Pty Ltd) is a rhythm game where players are rewarded for clicking on circles at specific timings to the beat of a song. The game consists of beatmaps, which are unique game modes where the targets are shown at the same time and same location in the play area throughout the song. Each song has multiple beatmaps and multiple levels of difficulty.

In this protocol, participants played either the low-difficulty or both the easy- and hard-difficulty beatmaps. These beatmaps were identical each time a participant completed it, thus performing tasks with identical outputs. Following each trial, osu! provides a score of accuracy out of 100%. The three trials with the closest accuracy to each other were used for statistical analysis to reduce kinematic variance within participants.

3.3.4 Ratings of perceived exertion

Participants provided a rating of perceived exertion (RPE) using modified BORG CR-10 scales (Borg, 1998). Participants verbally indicated their level of exertion with visual reminders of the scale, providing a rating between 0-10 in the context of defined anchors (**Table 5**).

Table 5: Rating of perceived exertion chart. Borg CR10 scale (Borg, 1998).

BORG CR-10 Scale Rating of Perceived Exertion	
Rating	Description
0	Nothing at all
0.5	Very, very light
1	Very light
2	Light
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	Very, very hard
10	Maximal

3.3.5 Rating of perceived performance

Participants provided a rating of perceived performance (RPP) using a 1-5 scale (Table 6). Participants verbally indicated how they felt they played theirosu! beatmap trial with visual reminders of the scale from 1 to 5. This scale was used to monitor how participants perceived their performance following the gaming task when using different DPI.

Table 6: Rating of perceived performance chart.

Rating of Perceived Performance	
1	Very poor performance compared to normal
2	Poor performance compared to normal
3	Same as normal performance
4	Very good performance compared to normal
5	Excellent performance compared to normal

3.3.6 Gaming History Demographics

Participants reported their gaming history upon arrival to characterize their gaming history and at-home gaming set-up. The information collected consisted of hours of gaming per week, length of sessions, type of games played, which games they play the most, their competitive ranks in their highest played games, and if they have competed on a professional team (*i.e.* collegiate esports). This information assisted in determining if participants could complete the hard difficulty beatmap.

3.4 Analysis

3.4.1 Kinematic Data Processing

Kinematic analysis consisted of data filtering, marker reconstruction and local segment coordinate system reconstruction to obtain joint angles and positional data. Raw three-dimensional kinematic data was visually inspected and labeled using the Qualisys Track Manager (QTM) 2023.6 software (Qualisys, Gothenburg, Sweden). If gaps (100 frames or less, or 1 second worth of data) were found in a marker's trajectory, they were gap-filled using a relational gap-fill trajectory in the QTM software. The relational gap-fill trajectory function requires the selection of at least 1 other marker on the segment without gaps and continues the trajectory with the same movement pattern. In cases where gaps were larger than 100 frames, markers were recreated using clusters in post-processing. The raw kinematic data was filtered with a dual-pass, second order, low-pass Butterworth filter with a cutoff frequency set to 10 Hz (McDonald et al., 2019; Tung et al., 2015).

The static calibration trial was used to develop rotation matrices between the anatomical axis system and the clusters of the torso, upper arm, and forearm to recreate anatomical markers. Segmental local coordinate systems (LCS) were defined using the anatomical markers following ISB recommendations (**Table 7**) (Wu et al., 2005) to decrease skin motion artifact (Leardini et al., 2005). An alternative LCS approach was used for the thorax, where the Y-axis was assumed to be in line with the laboratory (global) and ISB Y axis, and in line with gravity since the calibration trial is taken standing and the participants are seated throughout the trials. Due to the protocol omitting a hand cluster to reduce participant comfort and performance, there is only an anatomical LCS for the hand segment, thus using individual markers to determine joint movement. Segment rotation matrices between the anatomical and cluster LCS systems were

calculated using the segment cluster system relative to the anatomical LCS. This relationship was assumed to remain constant during all trials.

Upper extremity joint centre positions and joint angles were calculated at each time point during the gaming trials. The shoulder joint centre was calculated by subtracting 60 mm along the Y-axis of the torso segment from the right acromion marker (Nussbaum & Zhang, 2000), which coincides with the Y-axis of the global coordinate system. The joint centre of the elbow was defined as the midpoint between the lateral and medial epicondyles, and the joint centre of the wrist was defined as the midpoint between the radial styloid and the ulnar styloid. Joint angles were computed for the torso (thorax to global), thoracohumeral (humerus to torso), elbow (forearm to humerus) and wrist (hand to forearm) segments using a time varying rotation matrix constructed between the Global Coordinate System and the cluster Local Coordinate System. Direction cosine matrices were calculated between each segment at each time point to decompose and extract appropriate Euler angles. Direction cosine matrices were calculated by multiplying the transpose of the distal segment by the proximal segment, then joint angles were decomposed using the recommended Euler rotation sequences for clinical interpretations (**Table 8**) (Wu et al., 2005). The thorax, elbow, and wrist used the ZXY rotation sequence (**Equation 1**). An XZ'Y'' rotation sequence (**Equation 2**) was used to calculate the thoracohumeral (shoulder) joint angles since participants were within the first 20° of shoulder elevation for majority the task (Rundquist et al., 2003, Phadke et al, 2011).

Table 7: Local coordinate systems for the thorax, upper arm, forearm, and hand as recommended by Wu et al. (2005).

Segment	Origin	Local Coordinate System
Thorax	Suprasternal Notch	Y _t - In line with the global +Y, pointing superiorly. Z _t - The common line perpendicular to the line created between C7 and SS, pointing to the right X _t - The common line perpendicular to the Z _t and Y _t axes, pointing anteriorly.
Upper Arm	Adjusted Acromion (GHJ)	Y _{ua} - The line connecting GHJ and the midpoint of LE and ME, pointing toward GHJ. X _{ua} - The line perpendicular to the plane formed by LE, ME and GHJ, pointing forward. Z _{ua} - The common line perpendicular to the Y _h and X _h axes, pointing to the right.
Forearm	Ulnar Styloid	Y _{fa} - The line connecting US to the midpoint of LE and ME, pointing proximally. X _{fa} - The line perpendicular to plane through US, RS, and the midpoint between ME and LE, pointing anteriorly. Z _{fa} - The common line perpendicular to Y _f and X _f axes, pointing to the right.
Hand	Metacarpal Center	Oh - The midpoint between US and RS, and MCP2 and MCP5 Y _h - The line connecting Oh to the midpoint of US and RS, pointing proximally. X _h - The line perpendicular to the plane created by Y _h and the line connecting Oh to MCP2, pointing palmar. Z _h - The common line perpendicular to Y _h and X _h axes, pointing right (ulnarly).

$$\begin{bmatrix} \cos(\gamma) \cos(\alpha) - \sin(\beta) \cos(\alpha) & \cos(\gamma) \sin(\alpha) + \sin(\gamma) \sin(\beta) \cos(\alpha) & -\sin(\gamma) \cos(\beta) \\ -\cos(\beta) \sin(\alpha) & \cos(\beta) \cos(\alpha) & \sin(\beta) \\ \sin(\gamma) \cos(\alpha) + \cos(\gamma) \sin(\beta) \sin(\alpha) & \sin(\gamma) \sin(\alpha) - \cos(\gamma) \sin(\beta) \cos(\alpha) & \cos(\gamma) \cos(\beta) \end{bmatrix} \quad (Eq.1)$$

$$\begin{bmatrix} \cos(\gamma) \cos(\alpha) & \cos(\gamma) \sin(\alpha) + \sin(\gamma) \sin(\beta) & \cos(\gamma) \sin(\alpha) \sin(\beta) \\ -\sin(\alpha) & \cos(\alpha) \cos(\beta) & \cos(\alpha) \sin(\beta) \\ \sin(\gamma) \cos(\alpha) & \sin(\gamma) \sin(\alpha) \cos(\beta) - \cos(\gamma) \sin(\beta) & \sin(\gamma) \sin(\alpha) \sin(\beta) + \cos(\gamma) \cos(\beta) \end{bmatrix} \quad (Eq.2)$$

All calculations for joint angles were completed using a custom Python script. Joint angles were calculated for the three trials with the closest accuracy at each condition for data analysis. Mean joint angles were obtained by taking the mean of the means of the three trials, to represent the ‘neutral’ or average posture of each participant. The maximum and minimum values at each of the three Euler angles of the wrist, elbow, and glenohumeral joint were obtained.

Table 8: Rotation sequences and clinical interpretations for joint angle calculations as recommended by Wu et al., 2005.

Joint	Rotation and Clinical Interpretation
Thorax to Upper Arm	Rotation Sequence: X-Z-Y <i>e2</i>: Rotation around the Z-axis of the upper arm. Rotation (α_{TU}): GH flexion (+) and extension (-) <i>e1</i>: Rotation around the rotated X-axis. Rotation (β_{TU}) GH abduction (-) and adduction (+) <i>e3</i>: Rotation around the twice rotated Y-axis of the humerus. Rotation(γ_{TU}) GH-axial rotation, internal rotation (-) and external rotation (+)
Upper Arm to Forearm	Rotation Sequence: Z-X-Y <i>e1</i>: Rotation around the Z-axis of the upper arm coordinate system. Rotation (α_{UF}): flexion (+) and hyperextension (-) <i>e3</i>: Rotation around the axis coincident with the Y-axis of the forearm coordinate system. Rotation (γ_{UF}): axial rotation of the forearm, pronation (+) and supination (-). <i>e2</i>: The floating axis, perpendicular to <i>e1</i> and <i>e3</i>, the rotated X-axis of the forearm coordinate system. Rotation (β_{UF}): carrying angle.
Forearm to Hand	Rotation Sequence: Z-X-Y <i>e1</i>: The axis coincident with the Z-axis of the forearm coordinate system. Rotation (α_{FH}): flexion (+) and extension (-). <i>e3</i>: The axis coincident with the Y-axis of the hand coordinate system. Rotation (γ_{FH}): pronation (+) and supination (-). <i>e2</i>: The common axis perpendicular to <i>e1</i> and <i>e3</i>. Rotation (β_{FH}): radial deviation (-) and ulnar deviation (+)

3.4.2 Electromyography data processing

Electromyographic signals were filtered, normalized, and analyzed with respect to amplitude. DC bias was removed from the raw signal. Three trials with the closest game-monitored accuracy during the gaming trials for each condition were chosen for data analysis. Maximal voluntary contraction (MVC) trials and gaming trials were filtered using a high-pass, 2nd order Butterworth filter with a cutoff frequency of 30 Hz applied to the signal of all 12 muscles to remove noise and heart rate contamination from the raw signal (Drake & Callaghan, 2006). The signals were then linear enveloped using full-wave rectification followed by low-pass, 2nd order Butterworth filter at 500 Hz (Winter, 2009). Following filtering, the gaming trial was clipped to remove the first 4.5 seconds and the last 4.5 seconds of each trial to account for filtering noise and exclude transitional periods preceding and succeeding the segment of the gaming task, leaving approximately 47 seconds worth of data left for analysis. To normalize the EMG signals, linear enveloped signals were divided by the peak amplitude during the MVC, which represented the muscle's maximum activation, and were reported as percent maximum voluntary contraction (%MVC). To obtain the mean values of each muscle during each condition, the mean of the mean of three trials was used. The peak and amplitude across the three trials of each condition was used for peak EMG analysis.

3.5 Statistical Analysis

All statistical analyses were completed within JMP software (SAS Institute, North Carolina, USA). Shapiro-Wilk Tests for normality were conducted on the data. Data was transformed as needed to satisfy normality assumptions. Due to lack of non-parametric test equivalents to answer the research questions, if data could not be transformed to pass Shapiro-Wilk test for normality, the transformations that resulted in data with the most normal skewness

and kurtosis values were chosen. The EMG data was divided into 4 independent variable outputs to test for normality (mean and peak values for the mixed and repeated measures ANOVAs). The following metrics in each analysis did not pass the Shapiro-Wilk tests: mean muscle activity in repeated measures ANOVA (infraspinatus); peak muscle activity in repeated measures ANOVA (supraspinatus, infraspinatus, triceps brachii, pectoralis major (sternal), anterior deltoid, extensor digitorum); mean muscle activity in mixed ANOVA (supraspinatus, infraspinatus, extensor carpi ulnaris); peak muscle activity in mixed ANOVA (infraspinatus). Regarding the kinematics data, the following joint angle values did not pass the Shapiro-Wilk test: shoulder mean γ (axial rotation of humerus), elbow minimum α (flexion-extension). Statistical significance was considered at $\alpha = 0.05$. Tukey HSD post-hoc analysis was conducted if statistically significant differences existed, and when a main effect emerged between 2 factors then a t-test was conducted.

3.5.1 ANOVAS

Two-way mixed ANOVAs were used to assess the effect of mouse sensitivity and skill level on kinematics and muscle activity (**Table 9**). Skill level was a between subjects' factor and mouse sensitivity was a repeated measure. Hypothesis #1 compared the range (minimum and maximum) and means of joint angles at the wrist, elbow, and shoulder between mouse sensitivities. Hypothesis #2 was tested by comparing the %MVC peak and mean of each individual muscle of the right upper extremity between skill groups and mouse sensitivities. Hypothesis #3 entailed comparison of means and peak hand velocities and accelerations between mouse sensitivities and skill level.

Table 9: Hypotheses, dependent variables, statistical tests, factors, and levels included in this thesis. Tested main effects and interactions are outlined. Repeated measures are underlined.

Hypothesis	Dependent Variable	Statistical Test	Factors	Levels	Main effects and interactions
#1	Shoulder, elbow, wrist mean joint angles (α,β,γ)	Two-Way ANOVA	Sensitivity	PREF, LOW, HIGH	Sensitivity Skill Sensitivity*Skill
	Shoulder, elbow, wrist minimum joint angles (α,β,γ)				
	Shoulder, elbow, wrist maximum joint angles (α,β,γ)				
#2	Mean Muscle Activation (%MVC)		Skill	CASUAL, EXPERIENCED	
	Peak Muscle Activation (%MVC)				
#3	Hand velocities Hand accelerations				
#4	Mean Muscle Activation (%MVC)	Two-way Repeated Measures ANOVA	<u>Sensitivity</u>	PREF, LOW, HIGH	Sensitivity Difficulty Sensitivity*Difficulty
	Peak Muscle Activation (%MVC)		Difficulty	EASY, HARD	

Two-way repeated measures ANOVAs were used to assess the effect of game difficulty on muscle activity level at different mouse sensitivities (**Table 9**). Game difficulty and mouse sensitivity were repeated measures. Hypothesis #4 was tested by comparing %MVC maximum and mean of each individual muscle of the right upper extremity within the high-level players between the low and high-difficulty gaming task.

4.0 Results

The results of this study were presented in order of stated hypotheses. Significant interaction effects are interpreted first, followed by main effects. Prior to interpretation of sensitivity main effects, and interaction effects, it is important to understand the distribution of participant preferred sensitivity (**Figure 6**). The mean of the distribution was 921, with 13 participants choosing 800 DPI, and 4 participants outside the 400-1600 DPI range. The results revealed patterns in muscle activation and hand kinematics following changes to mouse sensitivity, and participant skill highlighted differences in shoulder movement strategies. Shoulder musculature and rotator cuff had significantly higher muscle activation when using low sensitivity compared to high and preferred sensitivity. Additionally, hand velocities and accelerations were the highest while using low mouse sensitivity. Lastly, experienced and casual players were inclined to use different shoulder postures while performing gaming tasks.

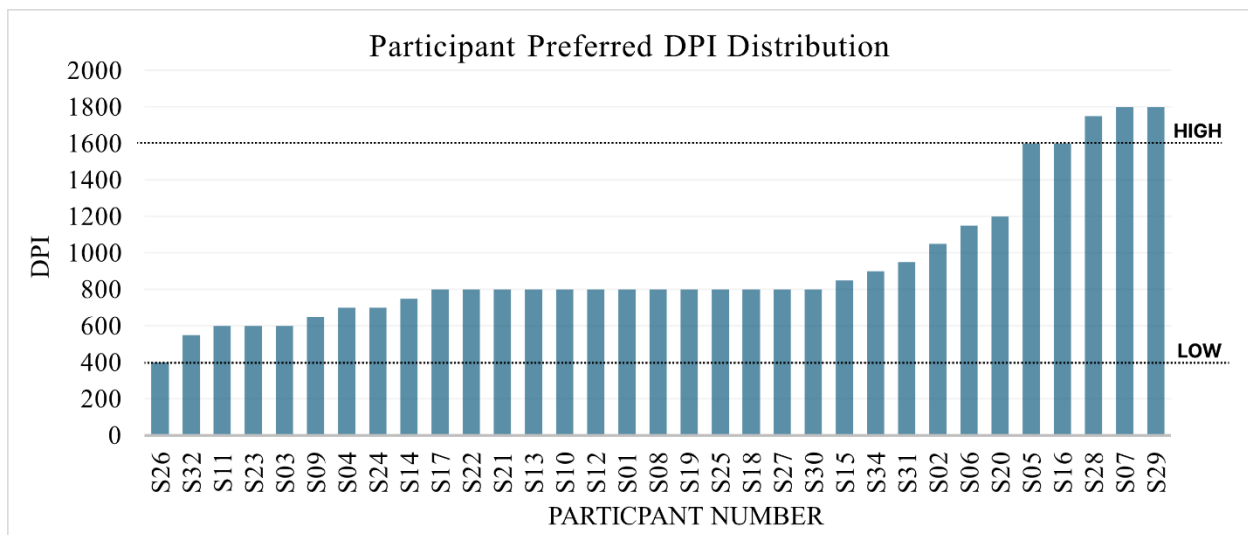


Figure 6: Distribution of participant selected mouse sensitivity (DPI), low and high sensitivity highlighted by dotted lines at 400 DPI and 1600 DPI.

4.1 Hypothesis 1: 3D-Kinematic movement strategies across mouse sensitivity influenced by skill level.

Main effects of skill were significant during shoulder abduction-adduction (β) (**Table 12**).

Differences between experienced and casual were most noticeable in abduction (negative degrees) and adduction (positive degrees), where experienced players were within -4 and -6° of abduction while casual players favoured an upper arm posture between $4 - 8^\circ$ of adduction (**Figure 7**). Shoulder internal-external rotation between the skills groups had more overlap than in abduction-adduction, though there was a 6.5° difference between the average postures of the two groups, with experienced in more internally rotated postures (**Figure 8**).

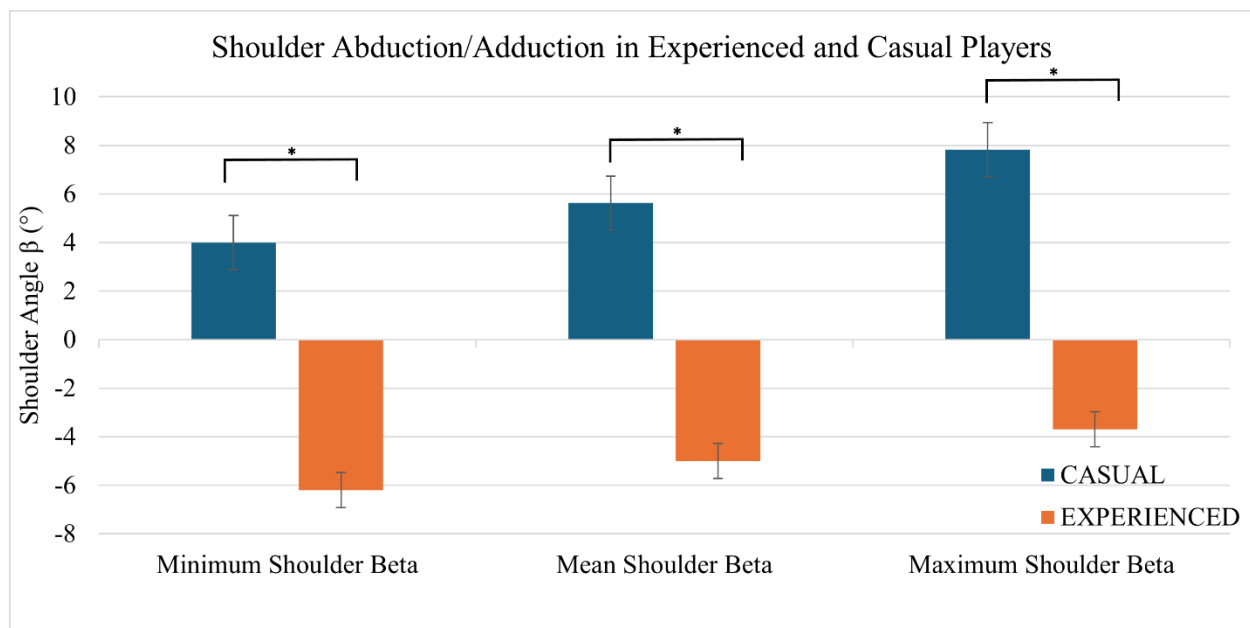


Figure 7: Shoulder abduction (-) – adduction (+) minimum, mean, and maximum angles compared between experienced and casual players. Casual (blue), experienced (orange). Error bars: standard error (SE). Asterisk (*) indicates significance ($p < 0.05$).

Table 10: Skill main effects of wrist joint angles from the two-way mixed ANOVA (Sensitivity*Skill), outlining standard deviations (SD), degrees of freedom (DF), F ratio, p-values, and Cohen's d effect sizes. Significant p-values (<0.05) are **bolded**.

Euler Angle	Skill	Angle	SD	DF	F Ratio	p-Value	Effect Size
Wrist Alpha Min	CASUAL	29	11	87	4.33	0.04	0.59
	EXPERIENCED	28	15				
Wrist Alpha Mean	CASUAL	31	10	87	4.62	0.03	0.58
	EXPERIENCED	29	15				
Wrist Alpha Max	CASUAL	33	10	87	4.89	0.03	0.59
	EXPERIENCED	30	15				
Wrist Beta Min	CASUAL	4	13	87	0.02	0.90	0.12
	EXPERIENCED	-6	17				
Wrist Beta Mean	CASUAL	6	13	87	0.02	0.88	0.07
	EXPERIENCED	-5	17				
Wrist Beta Max	CASUAL	8	13	87	0.18	0.68	0.01
	EXPERIENCED	-4	17				
Wrist Gamma Min	CASUAL	-23	21	87	1.78	0.19	0.02
	EXPERIENCED	-26	13				
Wrist Gamma Mean	CASUAL	-21	21	87	2.01	0.16	0.04
	EXPERIENCED	-24	13				
Wrist Gamma Max	CASUAL	-18	21	87	1.60	0.21	0.04
	EXPERIENCED	-22	13				

Table 11: Skill main effects of elbow joint angles from the two-way mixed ANOVA (Sensitivity*Skill), outlining SD, DF, F ratio, p-values, and Cohen's d effect sizes. Significant p-values (<0.05) are **bolded**.

Euler Angle	Skill	Angle	SD	DF	F Ratio	p-Value	Effect Size
Elbow Alpha Min	CASUAL	73	16	87	0.002	0.96	0.15
	EXPERIENCED	73	14				
Elbow Alpha Mean	CASUAL	76	16	87	0.09	0.76	0.16
	EXPERIENCED	76	14				
Elbow Alpha Max	CASUAL	79	16	87	0.30	0.59	0.11
	EXPERIENCED	78	14				
Elbow Beta Min	CASUAL	10	12	87	3.99	0.05	0.34
	EXPERIENCED	4	17				
Elbow Beta Mean	CASUAL	12	12	87	4.21	0.04	0.32
	EXPERIENCED	6	16				
Elbow Beta Max	CASUAL	15	12	87	4.70	0.03	0.27
	EXPERIENCED	8	16				
Elbow Gamma Min	CASUAL	149	13	87	0.15	0.70	0.14
	EXPERIENCED	150	15				
Elbow Gamma Mean	CASUAL	152	13	87	0.00	0.99	0.11
	EXPERIENCED	152	15				
Elbow Gamma Max	CASUAL	155	14	87	0.07	0.80	0.05
	EXPERIENCED	155	14				

Table 12: Skill main effects of shoulder joint angles from the two-way mixed ANOVA (Sensitivity*Skill), outlining SD, DF, F ratio, p-values, and Cohen's d effect sizes. Significant p-values ($p < 0.05$) are **bolded**.

Euler Angle	Skill	Angle	SD	DF	F Ratio	p-Value	Effect Size
Shoulder Alpha Min	CASUAL	29	10	87	0.22	0.64	0.36
	EXPERIENCED	28	5				
Shoulder Alpha Mean	CASUAL	31	10	87	0.44	0.51	0.39
	EXPERIENCED	29	5				
Shoulder Alpha Max	CASUAL	33	10	87	0.85	0.36	0.43
	EXPERIENCED	30	5				
Shoulder Beta Min	CASUAL	4	8	87	9.98	<0.01	0.28
	EXPERIENCED	-6	9				
Shoulder Beta Mean	CASUAL	6	9	87	11.04	<0.01	0.26
	EXPERIENCED	-5	10				
Shoulder Beta Max	CASUAL	8	10	87	12.30	<0.01	0.23
	EXPERIENCED	-4	10				
Shoulder Gamma Min	CASUAL	-23	9	87	2.66	0.11	0.46
	EXPERIENCED	-26	10				
Shoulder Gamma Mean	CASUAL	-21	10	87	4.04	0.05	0.46
	EXPERIENCED	-24	10				
Shoulder Gamma Max	CASUAL	-18	10	87	5.35	0.02	0.45
	EXPERIENCED	-22	11				

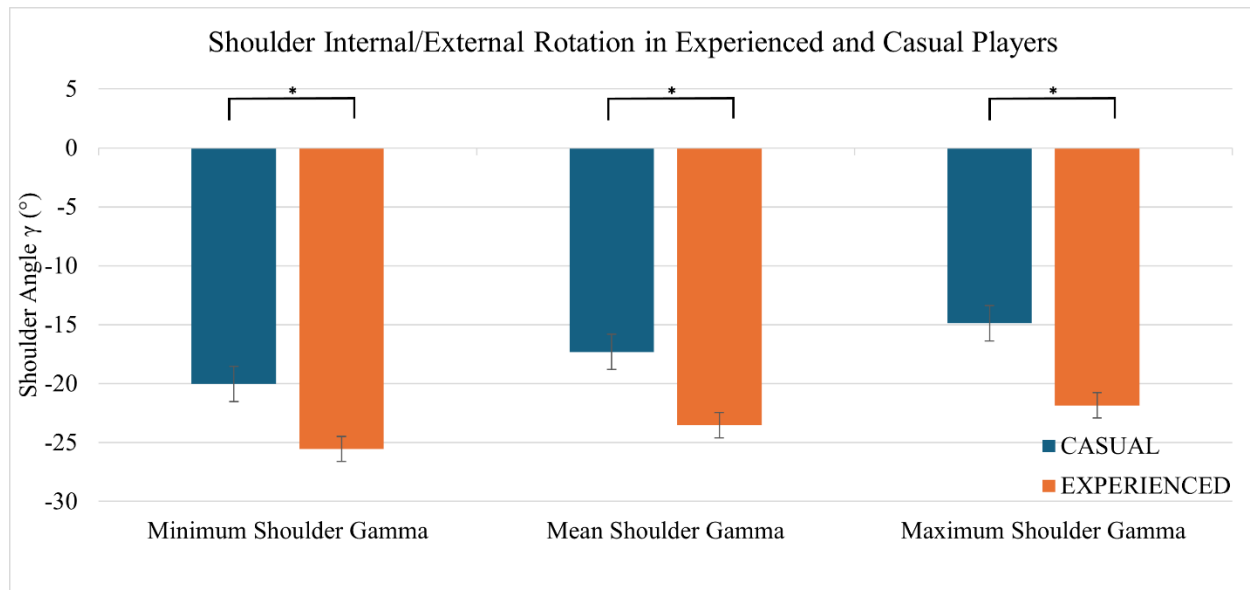


Figure 8: Shoulder internal (-) – external (+) minimum, mean, and maximum angles compared between Casual and Experienced players. Casual (blue) and experienced (orange). Error bars: standard error. Asterisk (*) indicates significance ($p < 0.05$)

Wrist radial-ulnar deviation (β) was the sole joint movement that had sensitivity main effects. A Tukey's post hoc test revealed that maximal wrist deviation was more ulnarly deviated by 6° while using low sensitivity compared to high sensitivity ($p = 0.0173$). Though the value for low sensitivity appears smaller, since maximal wrist deviation was within $24.58 - 31.17^\circ$ of radial deviation across sensitivities, there was the most variance towards ulnar deviation (**Table 13**). **Figure 9** displays the minimum, mean, and maximum values to highlight sensitivity driving the differences in maximal wrist deviation.

Table 13: Sensitivity main effects of wrist joint angles from the two-way mixed ANOVA (Sensitivity*Skill), outlining minimum, mean, and maximum angles, SD, DF, and p-values. Significant p-values ($p < 0.05$) are **bolded**.

Euler Angle	Sensitivity	Angle	SD	DF	F Ratio	p-Value
Wrist Alpha Min	HIGH	11	7.6	87	2.42	0.09
	LOW	12	7.7			
	PREF	12	7.8			
Wrist Alpha Mean	HIGH	9	7.8	87	0.28	0.76
	LOW	8	8.1			
	PREF	9	8.2			
Wrist Alpha Max	HIGH	7	7.5	87	0.25	0.78
	LOW	5	8.3			
	PREF	6	8.3			
Wrist Beta Min	HIGH	-31	8.6	87	0.03	0.97
	LOW	-25	9.3			
	PREF	-29	9.4			
Wrist Beta Mean	HIGH	-33	9.0	87	1.22	0.30
	LOW	-30	10.0			
	PREF	-33	9.5			
Wrist Beta Max	HIGH	-35	10.0	87	3.46	0.04
	LOW	-35	10.3			
	PREF	-35	9.7			
Wrist Gamma Min	HIGH	22	8.6	87	1.99	0.14
	LOW	27	9.3			
	PREF	24	10.3			
Wrist Gamma Mean	HIGH	19	9.6	87	0.04	0.96
	LOW	18	10.2			
	PREF	19	10.8			
Wrist Gamma Max	HIGH	16	9.9	87	0.04	0.96
	LOW	11	10.5			
	PREF	14	11.2			

Table 14: Sensitivity main effects of elbow joint angles from the two-way mixed ANOVA (Sensitivity*Skill), outlining minimum, mean, and maximum angles, SD, DF, and p-values. Significant p-values ($p < 0.05$) are **bolded**.

Euler Angle	Sensitivity	Angle	SD	DF	F Ratio	P Value
Elbow Alpha Min	LOW	77	14.2	87	0.16	0.85
	PREF	80	14.9			
	HIGH	77	15.3			
Elbow Alpha Mean	LOW	76	14.4	87	0.06	0.94
	PREF	77	14.8			
	HIGH	76	15.3			
Elbow Alpha Max	LOW	74	14.6	87	0.51	0.60
	PREF	72	14.7			
	HIGH	73	14.8			
Elbow Beta Min	LOW	10	15.3	87	0.08	0.92
	PREF	12	14.9			
	HIGH	11	14.8			
Elbow Beta Mean	LOW	9	15.0	87	0.01	0.99
	PREF	9	14.9			
	HIGH	9	14.9			
Elbow Beta Max	LOW	7	15.0	87	0.17	0.84
	PREF	6	15.1			
	HIGH	7	15.1			
Elbow Gamma Min	LOW	154	13.4	87	1.17	0.32
	PREF	155	15.0			
	HIGH	156	14.8			
Elbow Gamma Mean	LOW	153	13.3	87	0.39	0.68
	PREF	150	14.6			
	HIGH	154	15.1			
Elbow Gamma Max	LOW	151	12.8	87	0.06	0.94
	PREF	146	14.4			
	HIGH	152	15.2			

Table 15: Summary of sensitivity main effects of shoulder joint angles from the two-way mixed ANOVA (Sensitivity*Skill), outlining minimum, mean, and maximum angles, SD, DF and p-values. Significant p-values ($p < 0.05$) are **bolded**.

Euler Angle	Sensitivity	Angle	SD	DF	F Ratio	P Value
Shoulder Alpha Min	LOW	28.9	12.4	87	0.06	0.94
	PREF	27.7	13.6			
	HIGH	28.3	14.0			
Shoulder Alpha Mean	LOW	30.8	12.5	87	0.18	0.83
	PREF	28.9	13.5			
	HIGH	29.4	13.7			
Shoulder Alpha Max	LOW	32.8	12.6	87	0.38	0.68
	PREF	30.1	13.4			
	HIGH	30.6	13.4			
Shoulder Beta Min	LOW	-1.6	15.0	87	0.00	1.00
	PREF	-1.5	16.7			
	HIGH	-1.7	16.2			
Shoulder Beta Mean	LOW	0.3	15.1	87	0.03	0.97
	PREF	-0.5	16.6			
	HIGH	-0.3	16.4			
Shoulder Beta Max	LOW	2.6	15.3	87	0.16	0.85
	PREF	0.7	16.7			
	HIGH	0.8	16.6			
Shoulder Gamma Min	LOW	-24.7	17.2	87	0.17	0.84
	PREF	-24.4	16.7			
	HIGH	-24.6	18.5			
Shoulder Gamma Mean	LOW	-21.0	17.4	87	0.74	0.48
	PREF	-22.6	16.6			
	HIGH	-23.0	18.3			
Shoulder Gamma Max	LOW	-17.6	17.7	87	2.20	0.12
	PREF	-21.2	16.7			
	HIGH	-21.6	18.3			

Table 16: Tukey post hoc results for Euler angles across sensitivity from the two-way mixed ANOVA (Sensitivity*Skill). Significant p-values ($p < 0.05$) are **bolded**.

Euler Angle	Sensitivity	p-Value	effect size
Wrist Beta Min	LOW-PREF	0.98	0.07
	LOW-HIGH	0.95	0.05
	HIGH-PREF	0.99	0.02
Wrist Beta Mean	LOW-PREF	0.51	0.3
	LOW-HIGH	0.21	0.4
	HIGH-PREF	0.82	0.09
Wrist Beta Max	LOW-PREF	0.17	0.48
	LOW-HIGH	0.02	0.67
	HIGH-PREF	0.63	0.17

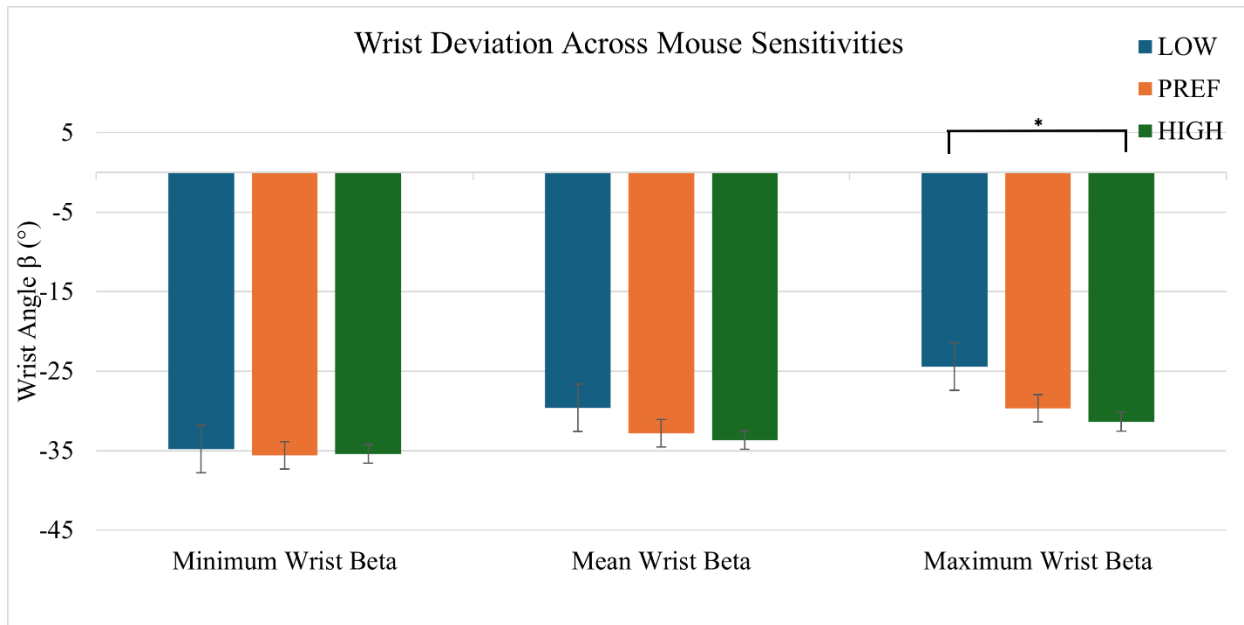


Figure 9: Wrist deviation (radial deviation (-), ulnar deviation (+)) minimum, mean, and maximum angles compared across mouse sensitivities. Low (blue), preferred (orange), and high (green) sensitivity. Asterisk (*) indicated significance ($p < 0.05$).

4.2 Hypothesis 2: Mouse sensitivity and muscle activity

The ANOVA did not reveal significant interaction effects between sensitivity and skill in mean muscle activity. However, many shoulder and rotator cuff muscles revealed significant sensitivity main effects and a couple muscles had skill main effects. Sensitivity main effects were revealed in shoulder muscles, with muscle activity means higher during the low sensitivity condition compared to high and preferred (**Figure 10, Table 17**). There were no significant sensitivity main effects in the forearm muscles, however, the highest mean muscle activation was in extensor carpi ulnaris with all conditions resulting in 6 %MVC. Focusing on the rotator cuff, supraspinatus and infraspinatus had significantly lower mean muscle activation by 2 and 1 %MVC during the high sensitivity condition compared to low, respectively; though the magnitudes appear small, this was a 40% decrease in activation. Tukey post hoc tests further confirmed that low sensitivity resulted in significantly higher mean muscle activation compared to high and preferred sensitivity, while there were no significant relationships between preferred and high sensitivity (**Table 18**).

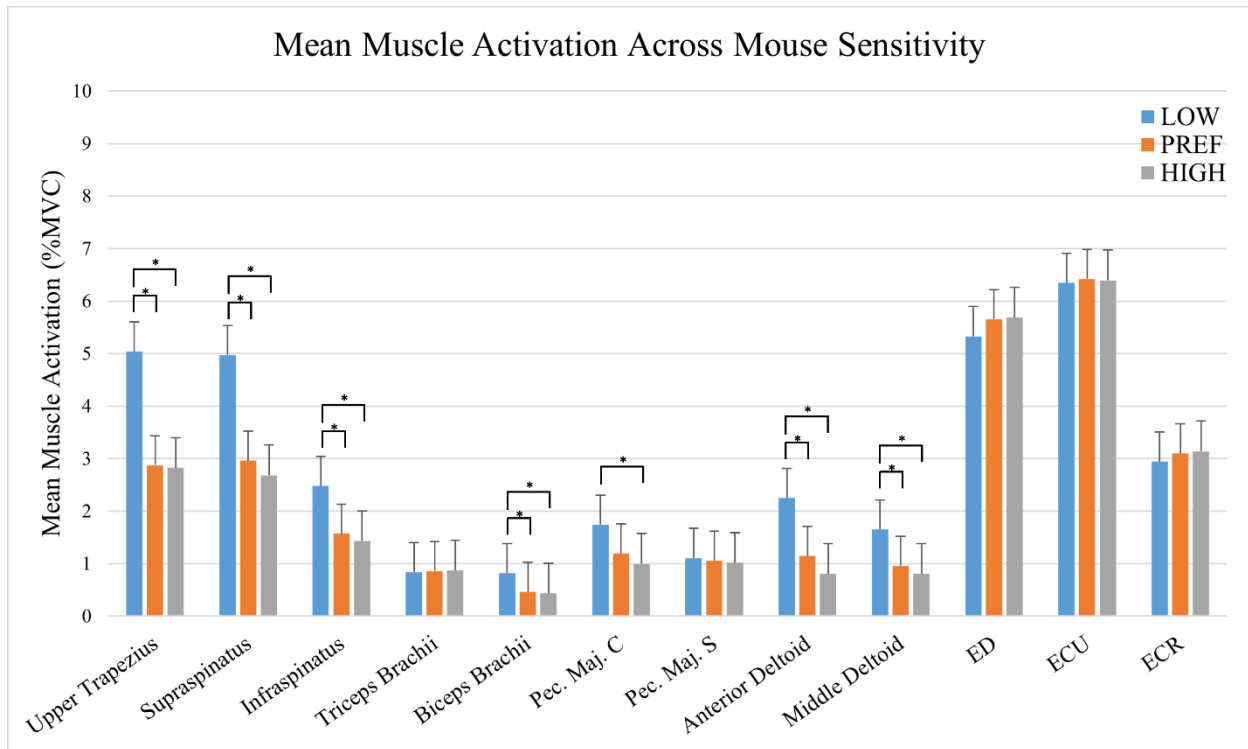


Figure 10: Mean muscle activity (%MVC) across mouse sensitivity: low (blue), preferred (orange), high (grey). Asterisk (*) indicate significant differences (Tukey's post hoc, $p < 0.05$). Error bars: standard error.

Table 17: Summary of sensitivity main effects and Tukey post-hoc tests for mean muscle activation from the two-way mixed ANOVA (Sensitivity*Skill). Significant p-values are **bolded**.

Muscle	Sensitivity	Muscle Activity Means	SD	DF	F Ratio	p- Value
Upper Trapezius	LOW	5.0	4.2	96	5.51	<0.01
	PREF	2.9	2.4			
	HIGH	2.8	2.5			
Supraspinatus	LOW	5.0	2.8	96	12.05	<0.01
	PREF	3.0	1.6			
	HIGH	2.7	1.7			
Infraspinatus	LOW	2.5	1.2	96	10.63	<0.01
	PREF	1.6	0.9			
	HIGH	1.4	0.8			
Triceps Brachii	LOW	0.8	0.5	96	0.04	0.96
	PREF	0.9	0.5			
	HIGH	0.9	0.4			
Biceps Brachii	LOW	0.8	0.8	96	3.99	0.02
	PREF	0.5	0.5			
	HIGH	0.4	0.5			
Pectoralis Major Clavicular	LOW	1.7	1.5	96	4.18	0.01
	PREF	1.2	0.9			
	HIGH	1.0	0.7			
Pectoralis Major Sternal	LOW	1.1	0.9	96	0.09	0.90
	PREF	1.1	0.8			
	HIGH	1.0	0.8			
Anterior Deltoid	LOW	2.3	2.0	96	8.68	<0.01
	PREF	1.1	1.4			
	HIGH	0.8	0.9			
Middle Deltoid	LOW	1.6	1.1	96	7.93	<0.01
	PREF	1.0	0.9			
	HIGH	0.8	0.8			
Extensor Digitorum	LOW	5.3	2.8	96	0.16	0.85
	PREF	5.7	3.0			
	HIGH	5.7	2.9			
Extensor Carpi Ulnaris	LOW	6.3	2.2	96	0.01	0.98
	PREF	6.4	2.2			
	HIGH	6.4	2.5			
Extensor Carpi Radialis	LOW	2.9	1.9	96	0.08	0.92
	PREF	3.1	1.9			
	HIGH	3.1	2.1			

Table 18: Tukey post hoc results for mean muscle activity (%MVC) across sensitivity levels. P-values and Cohen's d effect sizes from the two-way mixed ANOVA (Sensitivity*Skill) are shown. Bold: significant p-values.

Muscle	Comparison	Tukey Post Hoc p -Values	Effect Size (Cohen's d)
Upper Trapezius	LOW-HIGH	0.01	0.65
	LOW-PREF	0.01	0.64
	HIGH-PREF	0.99	0.02
Supraspinatus	LOW-HIGH	<0.01	1.00
	LOW-PREF	<0.01	0.88
	HIGH-PREF	0.85	0.17
Infraspinatus	LOW-HIGH	<0.01	1.00
	LOW-PREF	<0.01	0.84
	HIGH-PREF	0.83	0.16
Triceps Brachii	LOW-HIGH	0.96	0.07
	LOW-PREF	0.99	0.04
	HIGH-PREF	0.99	0.03
Biceps Brachii	LOW-HIGH	0.03	0.56
	LOW-PREF	0.05	0.53
	HIGH-PREF	0.98	0.06
Pectoralis Major Clavicular	LOW-HIGH	0.02	0.64
	LOW-PREF	0.10	0.44
	HIGH-PREF	0.74	0.24
Pectoralis Major Sternal	LOW-HIGH	0.90	0.10
	LOW-PREF	0.97	0.06
	HIGH-PREF	0.98	0.05
Anterior Deltoid	LOW-HIGH	<0.01	0.94
	LOW-PREF	0.01	0.65
	HIGH-PREF	0.62	0.29
Middle Deltoid	LOW-HIGH	<0.01	0.90
	LOW-PREF	0.01	0.70
	HIGH-PREF	0.79	0.18
Extensor Digitorum	LOW-HIGH	0.86	0.13
	LOW-PREF	0.88	0.11
	HIGH-PREF	0.99	0.01
Extensor Carpi Ulnaris	LOW-HIGH	0.99	0.02
	LOW-PREF	0.99	0.04
	HIGH-PREF	0.99	0.01
Extensor Carpi Radialis	LOW-HIGH	0.92	0.10
	LOW-PREF	0.95	0.08
	HIGH-PREF	0.99	0.02

Main effects of skill were significant in the mean muscle activation of pectoralis major (sternal), extensor digitorum and extensor carpi ulnaris (**Table 19, Figure 11**). The casual group had significantly higher mean muscle activity in extensor carpi ulnaris and extensor digitorum than the experienced group, however, the difference was only 1 %MVC with small-medium effect sizes.

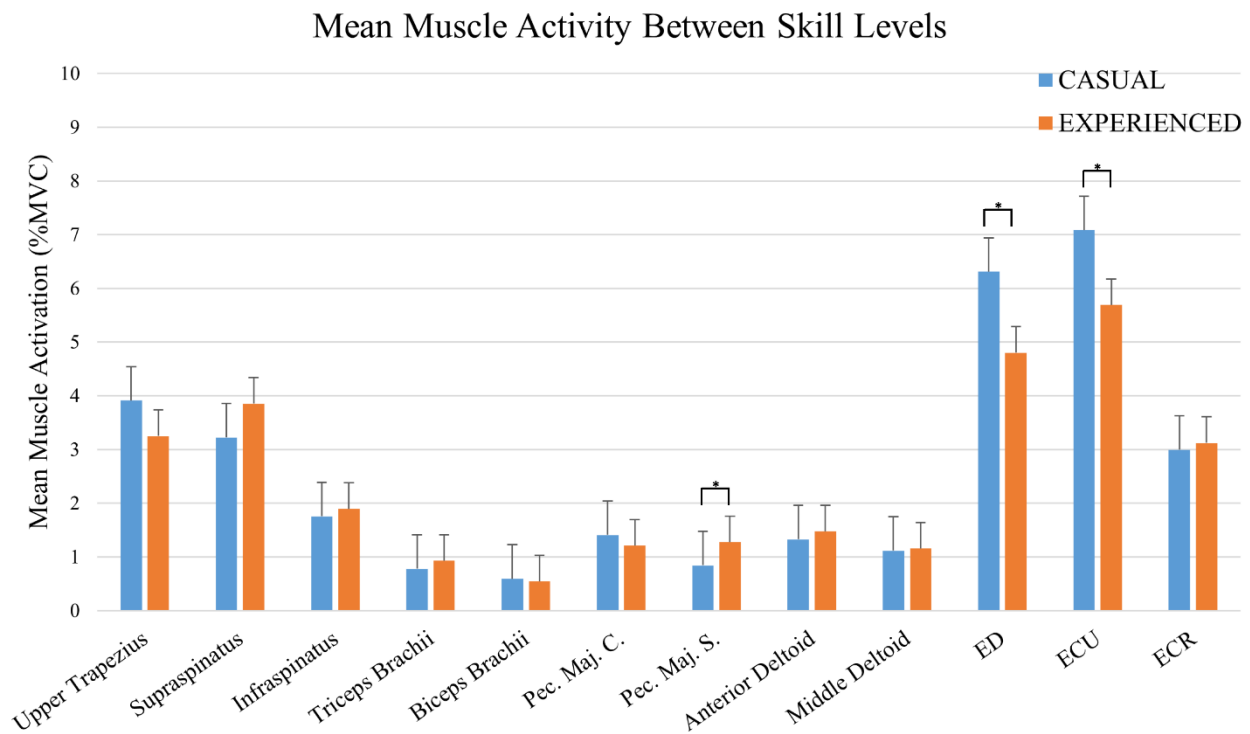


Figure 11: Mean muscle activity (%MVC) between skill levels: casual (blue), experienced (orange). Asterisk (*) indicate significant differences (Tukey's post hoc, $p < 0.05$). Error bars: standard error.

Table 19: Summary of skill main effects for mean muscle activation (%MVC) from the two-way mixed ANOVA (Sensitivity*Skill), outlining means, SD, and p-values. Significant p-values are **bolded**.

Muscle	Skill	Muscle Activity Means	SD	DF	F Ratio	P Value	Effect Size
Upper Trapezius	CAS	3.9	4.1	96	1.12	0.29	-0.64
	EXP	3.3	2.1				
Supraspinatus	CAS	3.2	2.0	96	2.28	0.13	0.23
	EXP	3.9	2.6				
Infraspinatus	CAS	1.8	0.9	96	0.48	0.48	0.36
	EXP	1.9	1.3				
Triceps Brachii	CAS	0.8	0.4	96	2.88	0.09	0.04
	EXP	0.9	0.5				
Biceps Brachii	CAS	0.6	0.6	96	0.14	0.70	0.05
	EXP	0.5	0.7				
Pectoralis Major Clavicular	CAS	1.4	1.1	96	0.77	0.37	0.11
	EXP	1.2	1.2				
Pectoralis Major Sternal	CAS	0.8	0.7	96	6.70	0.01	0.33
	EXP	1.3	1.0				
Anterior Deltoid	CAS	1.3	1.7	96	0.26	0.61	-0.16
	EXP	1.5	1.5				
Middle Deltoid	CAS	1.1	0.9	96	0.05	0.81	0.21
	EXP	1.2	1.1				
Extensor Digitorum	CAS	6.3	3.0	96	7.16	<0.01	-0.18
	EXP	4.8	2.5				
Extensor Carpi Ulnaris	CAS	7.1	2.4	96	10.32	<0.01	-0.27
	EXP	5.7	1.8				
Extensor Carpi Radialis	CAS	3.0	2.0	96	0.10	0.74	0.01
	EXP	3.1	2.0				

The mixed Two-Way ANOVA comparing muscle activity peak values did not reveal significant interaction effects, therefore, only sensitivity and skill main effects will be discussed. Main effects of sensitivity were significant in shoulder and rotator cuff peak muscle activation (**Figure 11, Table 20**). Similar patterns found in mean muscle activation were also noticeable with peak muscle activation, though the differences in muscle activation between mouse sensitivity settings are more pronounced in the peak activation comparisons. Tukey's post hoc tests revealed that peak muscle activity was significantly higher when participants used low mouse sensitivity compared to high sensitivity in all muscles. Upper trapezius, supraspinatus, and infraspinatus showed noticeable differences in muscle activation, where peak muscle activation during the low sensitivity task resulted in activation 6%, 5% and 6 %MVC higher than the high sensitivity condition. One interesting relationship between sensitivities is within the muscle activation of extensor carpi ulnaris compared to other forearm muscles. Between all sensitivity conditions, extensor digitorum and extensor carpi radialis were exhibiting consistent activation within 1 %MVC, however, extensor carpi ulnaris had a difference of 9 %MVC between low and high sensitivity with a medium effect size (**Table 21**). Furthermore, extensor carpi ulnaris showed the largest peak muscle activation compared to all muscles with 23%, 19% 14% MVC at low, preferred, and high, respectively.

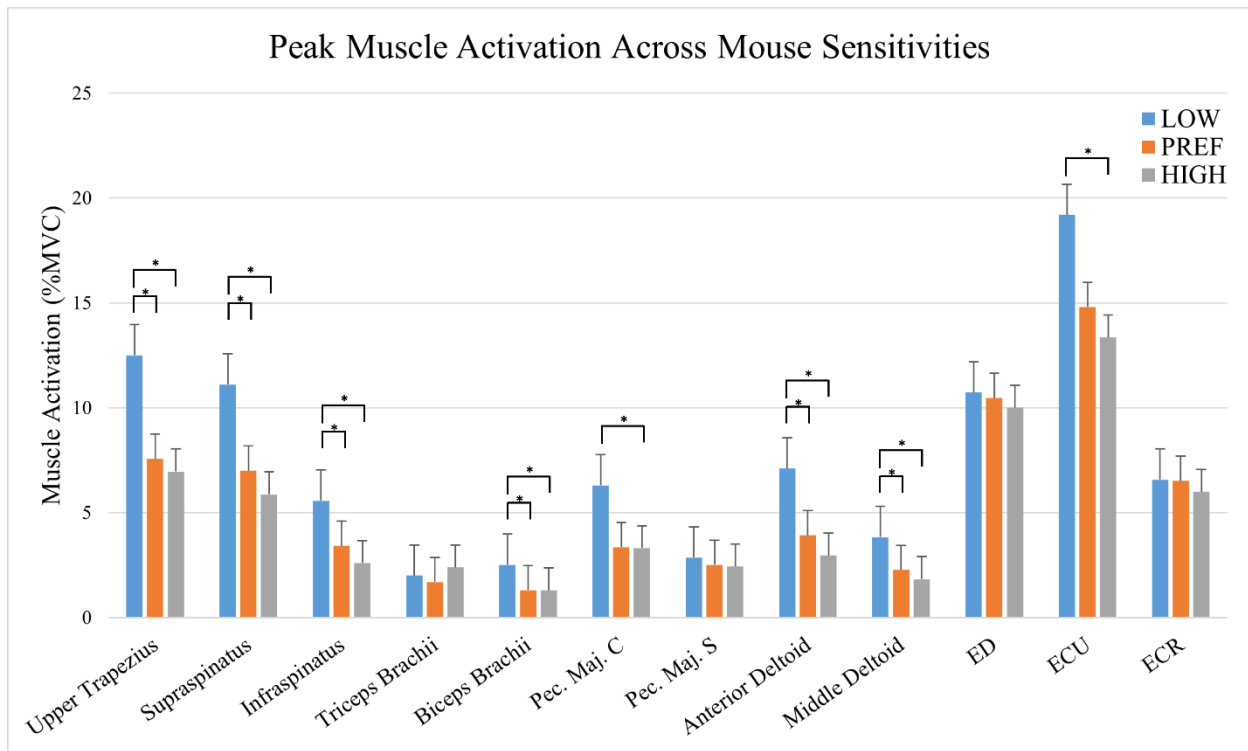


Figure 12: Peak muscle activity (%MVC) across mouse sensitivity: low (blue), preferred (orange), high (grey). Asterisk (*) indicate significant differences (Tukey's post hoc, $p < 0.05$). Error bars: standard error.

Table 20: Sensitivity main effects of peak muscle activation (%MVC). Peaks, standard deviation, degrees of freedom, F ratio and p-values from the two-way mixed ANOVA (Sensitivity*Skill) shown. Significant p-values ($p < 0.05$) are **bolded**.

Muscle	Sensitivity	Muscle Activity Peaks	SD	DF	F Ratio	p-Value
Upper Trapezius	LOW	13.3	8.2	93.1	6.9	<0.01
	PREF	8.4	7.6			
	HIGH	7.2	5.6			
Supraspinatus	LOW	13.2	5.7	109.7	11.7	<0.01
	PREF	8.8	5.9			
	HIGH	8.0	5.3			
Infraspinatus	LOW	10.3	15.3	106.9	13.9	<0.01
	PREF	4.5	2.7			
	HIGH	3.6	3.3			
Triceps Brachii	LOW	4.3	8.9	101.3	0.5	0.621
	PREF	2.5	1.8			
	HIGH	2.7	2.4			
Biceps Brachii	LOW	3.5	3.5	100.6	5.3	<0.01
	PREF	2.0	2.8			
	HIGH	1.9	2.6			
Pectoralis Major Clavicular	LOW	8.4	8.1	105.9	5.3	<0.01
	PREF	4.3	3.4			
	HIGH	4.2	4.4			
Pectoralis Major Sternal	LOW	4.3	3.4	98.6	1.2	0.297
	PREF	3.4	2.6			
	HIGH	3.2	2.7			
Anterior Deltoid	LOW	8.3	5.8	92	11.3	<0.01
	PREF	4.7	3.2			
	HIGH	3.4	2.8			
Middle Deltoid	LOW	4.2	2.2	97.9	10.6	<0.01
	PREF	2.9	2.2			
	HIGH	2.1	1.6			
Extensor Digitorum	LOW	10.7	5.5	96.3	0.1	0.91
	PREF	10.5	5.4			
	HIGH	9.7	4.6			
Extensor Carpi Ulnaris	LOW	23.4	11.5	103.6	4.3	0.02
	PREF	18.7	12.7			
	HIGH	13.5	5.6			
Extensor Carpi Radialis	LOW	7.9	5.5	111.5	0.1	0.881
	PREF	7.8	5.4			
	HIGH	8.9	4.2			

Table 21: Tukey post hoc results for peak muscle activity (%MVC) across sensitivity levels. P-values and Cohen's d effect sizes from the two-way mixed ANOVA (Sensitivity*Skill) are shown. Significant p-values ($p < 0.05$) are **bolded**.

Muscle	Comparison	Tukey Post Hoc p -Values	Effect Size (Cohen's d)
Upper Trapezius	LOW-HIGH	<0.01	0.61
	LOW-PREF	0.01	0.55
	HIGH-PREF	0.92	0.07
Supraspinatus	LOW-HIGH	<0.01	1.07
	LOW-PREF	<0.01	0.70
	HIGH-PREF	0.78	0.23
Infraspinatus	LOW-HIGH	<0.01	1.43
	LOW-PREF	<0.01	0.95
	HIGH-PREF	0.35	0.45
Triceps Brachii	LOW-HIGH	0.67	0.15
	LOW-PREF	0.68	0.27
	HIGH-PREF	0.99	0.27
Biceps Brachii	LOW-HIGH	0.01	0.62
	LOW-PREF	0.02	0.63
	HIGH-PREF	0.95	0.01
Pectoralis Major Clavicular	LOW-HIGH	0.01	0.52
	LOW-PREF	0.09	0.11
	HIGH-PREF	0.55	0.24
Pectoralis Major Sternal	LOW-HIGH	0.29	0.19
	LOW-PREF	0.51	0.16
	HIGH-PREF	0.92	0.04
Anterior Deltoid	LOW-HIGH	<0.01	0.87
	LOW-PREF	0.01	0.63
	HIGH-PREF	0.29	0.29
Middle Deltoid	LOW-HIGH	<0.01	0.99
	LOW-PREF	<0.01	0.72
	HIGH-PREF	0.67	0.25
Extensor Digitorum	LOW-HIGH	0.90	0.14
	LOW-PREF	0.97	0.05
	HIGH-PREF	0.98	0.09
Extensor Carpi Ulnaris	LOW-HIGH	0.01	0.67
	LOW-PREF	0.18	0.50
	HIGH-PREF	0.51	0.25
Extensor Carpi Radialis	LOW-HIGH	0.88	0.16
	LOW-PREF	0.93	0.01
	HIGH-PREF	0.99	0.17

Main effects of skill in peak muscle activation were revealed in supraspinatus, infraspinatus, triceps brachii, pectoralis major (sternal and clavicular), and anterior deltoid (**Table 22**). The relationship between skill level and peak activation varied across muscles. In most muscles, casual players had lower or similar peak muscle activation than experienced players, except for the extensor digitorum and extensor carpi ulnaris. Although not statistically significant, the largest difference was found in extensor digitorum, with casual players reaching 12% MVC compared to 9 %MVC in experienced players.

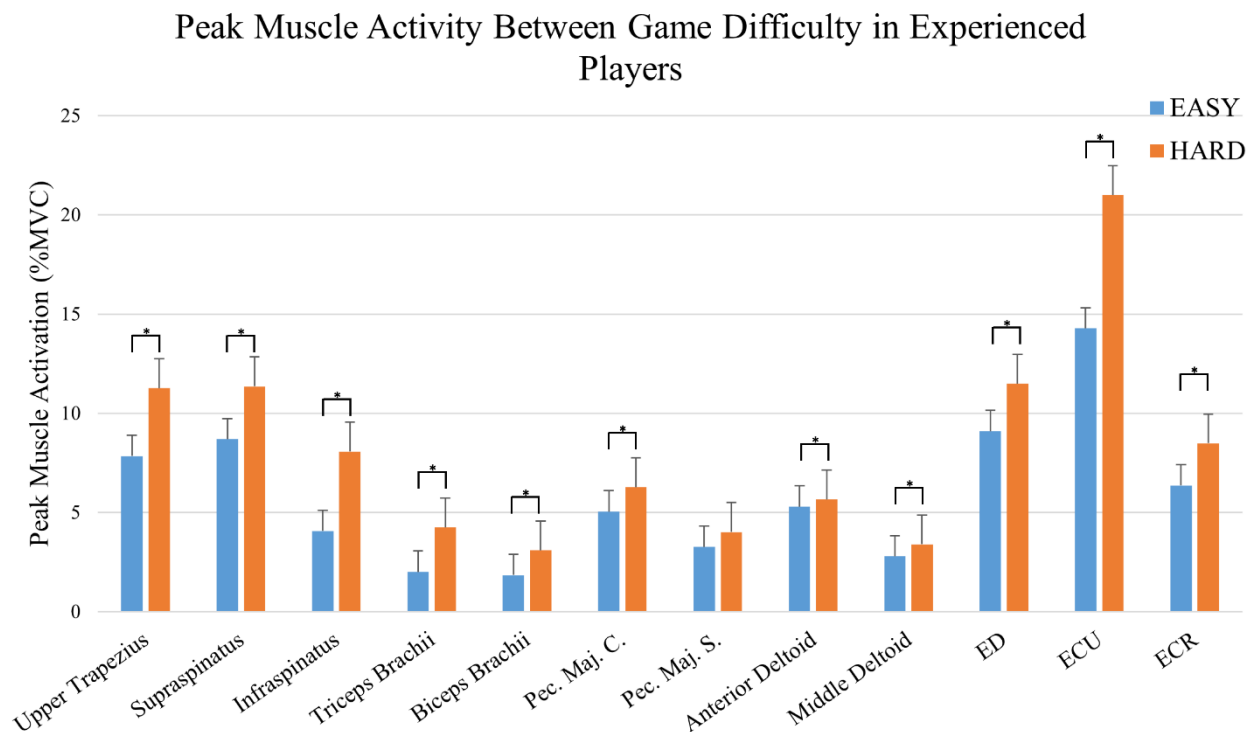


Figure 13: Mean muscle activity (%MVC) between skill levels: casual (blue), experienced (orange). Asterisk (*) indicate significant differences (Tukey's post hoc, $p < 0.05$). Error bars: standard error.

Table 22: Skill main effects on peak muscle activation. Means, standard deviation, degrees of freedom, F ratio and p-values from the two-way mixed ANOVA (Sensitivity*Skill) shown.

Muscle	Skill	Muscle Activity Peaks	SD	DF	F Ratio	P Value	Effect Size (Cohen's d)
Upper Trapezius	CAS	9	10.7	93	2.78	0.09	0.41
	EXP	9	7.0				
Supraspinatus	CAS	6	4.1	109.67	15.23	<0.01	0.45
	EXP	9	6.5				
Infraspinatus	CAS	4	2.1	106.86	4.072	0.04	0.25
	EXP	4	2.7				
Triceps Brachii	CAS	2	2.9	101.29	9.1	<0.01	0.80
	EXP	2	1.2				
Biceps Brachii	CAS	2	1.5	100.59	2.28	0.13	0.34
	EXP	2	2.1				
Pectoralis Major Clavicular	CAS	4	3.0	105.85	4.13	0.04	1.25
	EXP	5	6.5				
Pectoralis Major Sternal	CAS	2	1.4	98.58	19.7	<0.01	0.56
	EXP	3	2.5				
Anterior Deltoid	CAS	4	4.5	92.02	10.17	<0.01	0.07
	EXP	5	4.9				
Middle Deltoid	CAS	3	2.2	97.87	3.28	0.07	0.02
	EXP	3	2.2				
Extensor Digitorum	CAS	12	5.8	96.34	2.25	0.13	0.35
	EXP	9	4.0				
Extensor Carpi Ulnaris	CAS	17	8.3	103.55	0.02	0.86	0.05
	EXP	15	7.9				
Extensor Carpi Radialis	CAS	6	3.6	111.53	1.59	0.21	0.95
	EXP	7	4.7				

4.3 Hypothesis 3: Skill level and kinematics

There were no significant interaction effects between skill and mouse sensitivity, or any skill effects, though it revealed significant sensitivity effects across all measurements. Sensitivity main effects are displayed in **Table 23**, highlighting values and their corresponding Tukey HSD groupings. Since sensitivity main effects in hand kinematics were not a focus in any hypothesis, the contrasting relationships to muscle activation as seen in earlier ANOVAs will be touched upon briefly to assist in further discussion. In each dependent variable, low sensitivity resulted in the highest hand kinematic values, compared to high and preferred sensitivity. However, in cases where Tukey post hoc tests revealed that preferred and high sensitivity resulted in significantly different means, means were higher in the high sensitivity condition than the preferred sensitivity condition as shown in x-velocity max, z-velocity max, x-acceleration max, and z-acceleration max.

Table 23: Summary of sensitivity main effects of hand velocities (m/s) and accelerations (m/s²) outlining means, SD, p-Value and Tukey HSD groupings.

Sensitivity	X Velocity Mean	SD	DF	F Ratio	P Value	Tukey HSD
LOW	0.038	0.022	89	50.4075	<0.0001	A
PREF	0.007	0.005				B
HIGH	0.012	0.010				B
Sensitivity	X Velocity Max	SD	DF	F Ratio	P Value	Tukey HSD
LOW	1.141	0.416	89	94.51	<0.0001	A
PREF	0.223	0.117				B
HIGH	0.352	0.222				C
Sensitivity	Z Velocity Mean	SD	DF	F Ratio	P Value	Tukey HSD
LOW	0.016	0.014	89	16.03	<0.0001	A
PREF	0.005	0.003				B
HIGH	0.006	0.006				B
Sensitivity	Z Velocity Max	SD	DF	F Ratio	P Value	Tukey HSD
LOW	1.210	0.267	89	164.763	<0.0001	A
PREF	0.197	0.119				B
HIGH	0.358	0.220				C
Sensitivity	X Acceleration Mean	SD	DF	F Ratio	P Value	Tukey HSD
LOW	0.005	0.002	89	122.008	<0.0001	A
PREF	0.001	0.001				B
HIGH	0.002	0.001				C
Sensitivity	X Acceleration Max	SD	DF	F Ratio	P Value	Tukey HSD
PREF	5.851	3.135	89	100.137	<0.0001	A
LOW	31.522	10.455				B
HIGH	9.877	6.381				C
Sensitivity	Z Acceleration Mean	SD	DF	F Ratio	P Value	Tukey HSD
LOW	0.003	0.001	89	56.1634	<0.0001	A
PREF	0.0005	0.0004				B
HIGH	0.001	0.001				B
Sensitivity	Z Acceleration Max	SD	DF	F Ratio	P Value	Tukey HSD
LOW	26.237	9.508	89	101.487	<0.0001	A
PREF	4.497	2.969				B
HIGH	7.402	4.621				C

4.4 Hypothesis 4: Game difficulty and muscle activity

There were no significant interaction effects in mean muscle activation between sensitivity and difficulty. Difficulty main effects were revealed in all except two muscles (**Figure 14, Table 24**), with the hard difficulty resulting in higher mean muscle activation. The differences in mean activation between the difficulties were within 2 %MVC for all muscles, with largest differences in extensor digitorum and extensor carpi ulnaris with increases of 1.1% and 2% MVC between easy and hard difficulty.

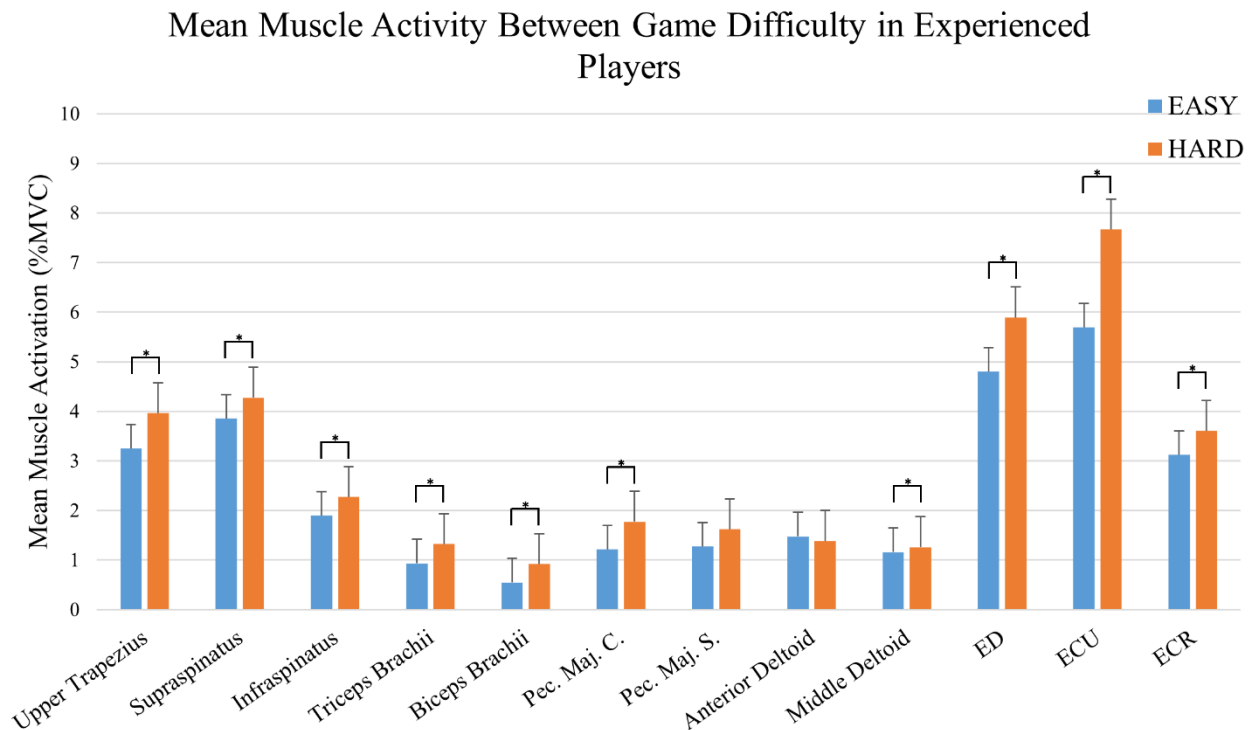


Figure 14: Mean muscle activity (%MVC) between difficulty levels: easy (blue), hard (orange). Asterisk (*) indicate significant differences (Tukey's post hoc, $p < 0.05$). Error bars: standard error.

Table 24: Difficulty main effects on peak muscle activation (%MVC). Peaks, SD, DF, F ratio, p-values from two-way repeated measures ANOVA (Sensitivity*Difficulty). Significant p-values ($p < 0.05$) are **bolded**.

Muscle	Difficulty	Muscle Activity Means	SD	DF	F Ratio	p-Value	Effect Size
Upper Trapezius	EASY	7.8	5.4	46.6	13.70	<0.01	0.48
	HARD	11.3	9.0				
Supraspinatus	EASY	8.7	5.0	47.6	11.18	<0.01	0.28
	HARD	11.4	6.7				
Infraspinatus	EASY	4.1	2.6	48.6	5.20	0.03	1.1
	HARD	8.1	12.9				
Triceps Brachii	EASY	2.0	1.1	48.1	4.90	<0.01	1.19
	HARD	4.2	7.5				
Biceps Brachii	EASY	1.8	2.2	48.0	10.79	0.04	0.48
	HARD	3.1	3.6				
Pectoralis Major Clavicular	EASY	5.0	6.7	47.0	4.44	<0.01	0.24
	HARD	6.3	5.2				
Pectoralis Major Sternal	EASY	3.3	2.5	48.0	15.92	0.40	0.25
	HARD	4.0	3.3				
Anterior Deltoid	EASY	5.3	5.0	48.0	0.69	<0.01	0.15
	HARD	5.7	4.3				
Middle Deltoid	EASY	2.8	2.2	48.0	8.76	<0.01	0.06
	HARD	3.4	2.1				
Extensor Digitorum	EASY	9.1	4.1	48.0	37.45	<0.01	0.34
	HARD	11.5	5.8				
Extensor Carpi Ulnaris	EASY	14.3	7.8	48.0	24.76	<0.01	0.73
	HARD	22.8	17.9				
Extensor Carpi Radialis	EASY	8.0	12.0	48.1	0.10	0.75	0.66
	HARD	8.5	5.8				

There were no significant interaction effects between sensitivity and difficulty in peak muscle activation, therefore, difficulty main effects will be focused on. Compared to mean muscle activation, difficulty main effects in peak muscle activation were more noticeable, revealing larger differences and bigger effect sizes. Overall, the hard difficulty condition resulted in higher peak muscle activation than the easy difficulty task. The largest increases in peak activation were found in upper trapezius, supraspinatus, infraspinatus, extensor digitorum and extensor carpi ulnaris, with 32%, 20%, 50%, 20%, and 49%, respectively, from the easy to hard difficulty condition (**Table 25**). Of these muscles, extensor carpi ulnaris had the highest peak muscle activation with 14 % MVC at the easy difficulty and 23% MVC at the hard difficulties.

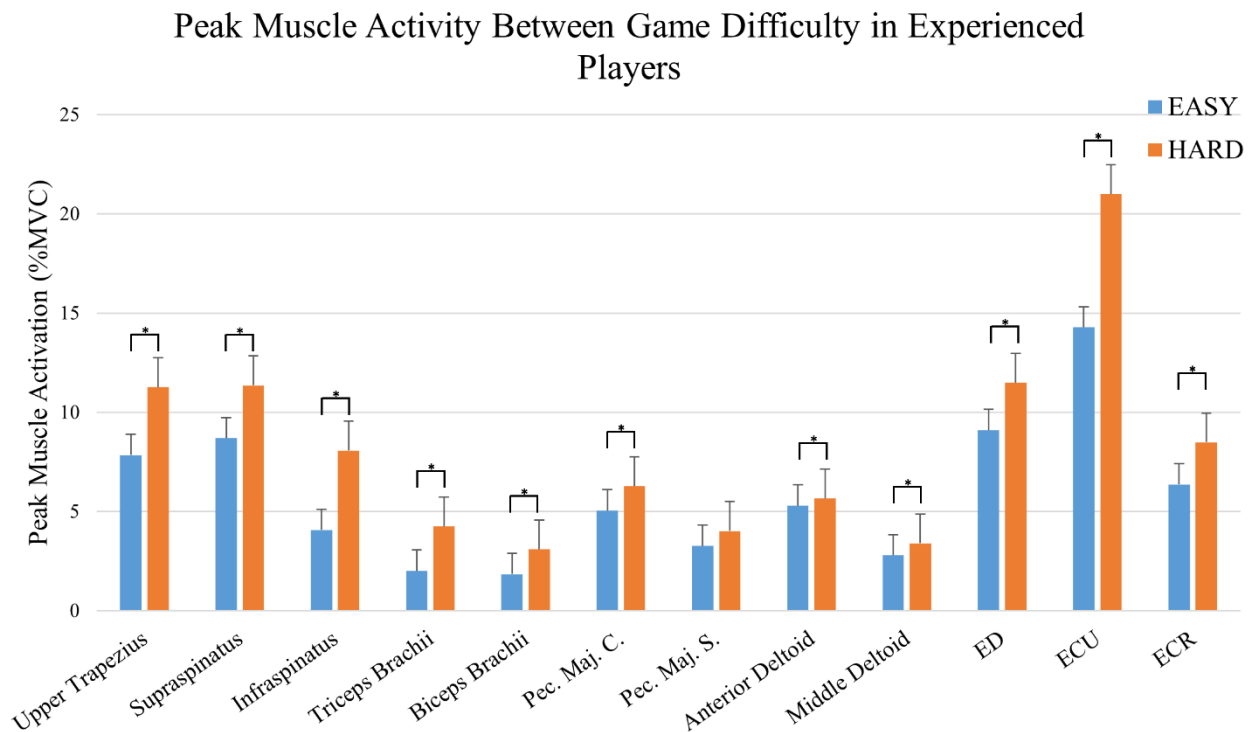


Figure 15: Peak muscle activity (%MVC) between difficulty levels: easy (blue), hard (orange). Asterisk (*) indicate significant differences (Tukey's post hoc, $p < 0.05$). Error bars: standard error.

Table 25: Difficulty main effects on peak muscle activation. Peaks, SD, DF, F ratio, p-values from two-way repeated measures ANOVA (Sensitivity*Difficulty). Significant p-values are **bolded**.

Muscle	Difficulty	Muscle Activity Means	SD	DF	F Ratio	P Value	Effect Size (Cohen's d)
Upper Trapezius	EASY	8	5	46.6	13.70	<0.01	0.48
	HARD	11	9				
Supraspinatus	EASY	9	5	47.6	11.18	<0.01	0.28
	HARD	11	7				
Infraspinatus	EASY	4	3	48.6	5.20	0.03	1.1
	HARD	8	13				
Triceps Brachii	EASY	2	1	48.1	4.90	<0.01	1.19
	HARD	4	7				
Biceps Brachii	EASY	2	2	48.0	10.79	0.04	0.48
	HARD	3	4				
Pectoralis Major Clavicular	EASY	5	7	47.0	4.44	<0.01	0.24
	HARD	6	5				
Pectoralis Major Sternal	EASY	3	3	48.0	15.92	0.40	0.25
	HARD	4	3				
Anterior Deltoid	EASY	5	5	48.0	0.69	<0.01	0.15
	HARD	6	4				
Middle Deltoid	EASY	3	2	48.0	8.76	<0.01	0.06
	HARD	3	2				
Extensor Digitorum	EASY	9	4	48.0	37.45	<0.01	0.34
	HARD	11	6				
Extensor Carpi Ulnaris	EASY	14	8	48.0	24.76	<0.01	0.73
	HARD	23	18				
Extensor Carpi Radialis	EASY	8	12	48.1	0.10	0.75	0.66
	HARD	8	6				

5.0 Discussion

The discussion first summarizes the key findings of the research, then directly addresses each hypothesis in order.

The aim of this thesis was to determine the effects of computer mouse sensitivity on muscle activation, joint angles and posture, while investigating skill and difficulty differences. The results suggest low mouse sensitivity increases muscle activation across the upper extremity muscle activity. In contrast, the relationship between joint posture and sensitivity was less pronounced, as only the wrist was influenced by mouse sensitivity. Skill differences were less noticeable in muscle activity, however, there were significantly different arm abduction and axial rotation postures between the two skill groups. Lastly, difficulty main effects occurred in muscle activity of 10 of 12 muscles, resulting in higher activation during the hard difficulty condition compared to the easy condition. The secondary aim of this thesis was to assess skill effects on hand velocity and accelerations, which revealed no significant differences.

5.1 Hypothesis #1

Hypothesis #1 stated lower mouse sensitivity would result in decreased wrist range of motion compared to higher mouse sensitivity, while increasing elbow and shoulder range of motion. However, since there were significant skill effects on joint range of motion, this hypothesis considered the differences between experienced and casual players. Hypothesis #1 was rejected, as the wrist had an increased range of radial deviation during the low sensitivity condition (**Table 13**). Additionally, there were no significant sensitivity main effects at the shoulder or elbow.

One potential confounding factor contributing to the lack of significance in shoulder postures following sensitivity changes could be the noticeable postural differences between skill levels. Both skill levels maintained ranges of motion of less than 4 degrees of abduction-adduction, with the casual group at 4° and experienced group at 2 degrees° (**Table 12**). However, the mean of the two groups had a difference of 10 °, with experienced group more abducted than the casual group. Similarly, there were significant differences in humeral axial rotation, where experienced players played with more internally rotated shoulders compared to casual players by 3°. Though these values appear small, the SE bars in **Figure 7** and **Figure 8** show the variation in participants in both groups, which highlights some extreme postures in both groups. These differences clarify fundamental postural differences between skill level, and further sub-analyses could identify if there are differences based on participant preferred game.

Range of motion differences, and postural preference between the experienced and casual players can provide clinically relevant information. A previous study compared mouse and non-mouse users' shoulder and wrist postures and noted that mouse users were in postures with greater shoulder abduction, shoulder axial rotation and wrist ulnar deviation (Karlqvist et al. 1994). The same study compared discomfort ratings between the groups and noted that non-mouse users, who sat with internally rotated shoulders and used less wrist deviation, reported higher discomfort scores compared to mouse users at both neck/shoulder and forearm/wrist. Interestingly, the experienced participants seemed to be a hybrid between the 'mouse' and 'non-mouse' users. This experimental protocol had participants playing games for 21 or 42 minutes with rest, depending on skill, and video game players reported their sessions to last 1.3 - 6.8 hours (Forman & Holmes, 2023). This postural information paired with available survey data can

assist clinicians by providing quantitative data about the extreme postures that video game players are likely spending long hours in.

5.2 Hypothesis #2

Hypothesis #2 stated that low mouse sensitivity will result in lower muscle activity at the wrist and higher muscle activity at muscles acting at the elbow and shoulder. This hypothesis was partially accepted. Muscles acting at the shoulder and elbow joint exhibited significantly higher muscle activation levels, both in mean (1-3 %MVC) and peak (1-9 %MVC) values, for low mouse sensitivity compared to high sensitivity. The mean activation of the forearm extensors differed by only 1 %MVC between sensitivities. However, the extensor carpi ulnaris revealed significant sensitivity main effects in peak activation with a 9 %MVC difference between low and high sensitivity.

Using low mouse sensitivity compared to other sensitivities increased mean and peak muscle activation in upper trapezius, infraspinatus, supraspinatus, anterior deltoid and middle deltoid, triceps brachii, and extensor carpi ulnaris. Muscle activation was significantly higher while using low sensitivity compared to high and preferred sensitivity, while high and preferred sensitivities were not significantly different. This may seem like low sensitivity will inherently increase injury risk. However, one consideration with these values is the magnitude of % MVC is relatively small, with 8/12 muscles experiencing mean muscle activation at or below 3%MVC in all conditions. Assessing the values within peak muscle activation, 8/12 muscles reached values above 5%MVC. Previous literature has indicated that sustained contractions as low as 5 %MVC for 1-hour results in signs of muscle fatigue (Jørgensen et al., 1987), with recommendations that continuous work should not exceed 2-5 %MVC (Jonsson, 1978). To draw conclusions related to injury risk, further studies should assess amount of time at each of these

contraction levels or determine how frequently video game players are surpassing this 5% MVC threshold. Therefore, to obtain clinically relevant results, future analyses of this data or future mouse sensitivity comparisons should incorporate amplitude analyses, such as amplitude probability distribution frequency (APDF) to determine amount of time at low static, median or peak loads for easier comparisons to occupational loads (Jonsson, 1982).

Combining postural data with muscle activity can assist in understanding the relationship between mouse sensitivity, movement, and muscle activity. It is interesting that the wrist extensor-deviators (ECU, ECR) had few significant muscle activity differences across sensitivity levels despite the significant wrist deviation differences (**Table 13, Figure 9**). The peak muscle activation was highest in extensor carpi ulnaris, which may be related to the 7° difference in wrist deviation between sensitivity conditions. Given that the players maintained a radially deviated wrist posture throughout the task, as indicated by the mean wrist deviation angles, the lower sensitivity condition, which resulted in less radially deviated postures, may explain the increased activation of the extensor carpi ulnaris. Due to the constraints of using inferential statistics methods to analyse high variable outcomes of muscle activity and kinematics throughout this thesis, it is possible that there were individuals who had larger wrist deviation movements or significantly increased muscle activity between sensitivities that would not be detected in this analysis.

A higher prevalence of lower mouse sensitivity choices with increase in video game skill level could partially explain muscle activity patterns in previous literature. Professional gamers demonstrated 2.8% and 1% higher median muscle activity in the middle and anterior deltoid, respectively, compared to high-level gamers, along with higher activation in the upper trapezius (1.8%), biceps brachii (1.1%), and extensor carpi radialis (1.9%) (Li et al, 2022). In that

experiment, participants chose their own sensitivity, with professionals choosing slightly lower mouse sensitivity than the high-level players. The relationship between mouse sensitivity and muscle activity on muscles at the shoulder could explain their skill related results, considering this thesis saw more difference between low and preferred sensitivity than preferred and high sensitivity, suggesting that lower sensitivity responses drive the sensitivity effects.

Mouse sensitivity may have been a missing piece for identifying preferred mouse settings to optimize performance and reduce muscular load. Previous work investigated an optimal sensitivity range regarding target acquisition and video game genre, demonstrating competitive players preferred an optimal range of 20 – 80 cm/360° (Boudaoud et al. 2022), which converted to the present study is approximately 180 DPI – 600 DPI. A mouse weight study found no significant differences in muscle activity between incrementally weighted computer mice between 40 g - 140 g (Yan et al., 2002). They surveyed participants on mouse preference between the mice and identified that a 60 g mouse had the highest performance score, with the lightest mouse receiving the lowest discomfort score. Overall, it appears video game players prefer mouse sensitivity or mouse weight within a middle range to optimize for comfort and performance, which can explain the mean preferred mouse sensitivity in this study (941 DPI).

5.3 Hypothesis #3

Hypothesis #3 stems from the research question “Does player skill level affect upper extremity kinematics?”, with a focus on hand velocities and accelerations, and stated that experienced players will have significantly higher values than casual players. This hypothesis is rejected since there were no significant skill differences in hand kinematics. It is surprising that no significant skill related hand kinematic results were observed, considering a previous study identified significantly higher hand velocities and accelerations in professional players compared

to high level players (Li et al., 2022). One possible explanation is the skill difference between the casual group and experienced was not enough to elicit differences. Additionally, considering both groups were performing the same easy difficulty task for this analysis, the high-level players may have not needed to resort to more ‘expert’ higher velocities and accelerations to successfully complete the task. The beatmaps in this experiment were chosen to replicate large movements while maintaining a range of difficulty that would allow participants to be eligible. However, due to the constraints of the game, specifically the predetermined repeatable task output, these results may not extrapolate to open ended task-based games that require varying cursor movements during each session for successful task completion. Therefore, future comparisons of these dependent variables can be investigated to assess if the experienced group performs differently depending on difficulty level in less constrained gaming tasks.

5.4 Hypothesis #4

The last research question aimed to investigate the influence of game difficulty on muscle activity, with hypothesis #4 stating that high difficulty will increase mean and peak muscle activity across the muscles. This hypothesis was accepted. The high difficulty task resulted in significantly higher mean and peak muscle activation in 10 of 12 measured muscles, with largest differences between difficulties in the peak values. Previous literature noted significant increases in muscle activity amplitudes of upper trapezius during tracking tasks and increases in wrist extensors during aiming tasks when mental pressure was added to both tasks (Visser et al., 2004), along with overall increases in muscle activity with precision demands (Laursen et al., 2001). One suggestion for the increases, is co-contraction related to the mental demands and the additional precision needed to perform aiming and tracking tasks. This thesis observed similar trends, though they were not as pronounced in the mean muscle activation. Since the gaming task

in this thesis required tracking, aiming and altered precision with modified sensitivity, paired with two difficulty levels, it was expected to see larger differences. However, participants may have been co-contracting across all conditions to manage the mental and precision demands required to learn a new sensitivity within a short period of time, thus reducing the differences in muscle activity between tasks.

5.5 Limitations

The work reported in this thesis should be considered within the context of experimental and practical limitations. All data analysis assumed the three trials with the closest game-reported accuracy would result in the least movement variability. Trials were visually inspected to insure there was not excess movements between analysed trials, however, there are slight differences in joint position, partially based on the starting position during each trial and participant postural adjustments. Future work should investigate variability to better understand the influence of computer mouse sensitivity on physical exposures.

Due to the skill groupings in these sample size, the group sizes for statistical analysis may not enable detection of some important differences, specifically when considering skill. Additional participants in both groups would likely improve sensitivity and reduce normality related assumptions. Though both skill groups had similar demographics, other factors such as age differences, sex differences, handedness, and preferred video game genre were not considered. With a larger sample size, these variables could be considered. One consideration regarding sample size is the exclusion of those with injury. As highlighted in the literature review, 30+% of video game players report injuries (Donoghue et al., 2019), which may have influenced participant recruitment.

The preferred sensitivity factor is a composite value containing a range of sensitivities, which limits the meaningfulness of the participant-selected value. Considering the significant muscle activity and kinematic differences between low and high sensitivity, the range in DPI within the preferred factor may not appropriately assess the effects of sensitivities outside the two pre-set sensitivities. Future work should consider analysing mouse sensitivity across a wider spectrum at each DPI setting to understand the scale that DPI is influencing movement strategy and muscle activity.

The results of this thesis did not consider the time-series data collected, instead, compared minimums, maximums, and means in both muscle activity and kinematics data. This thesis showed that there are main and interaction effects with these values, however, future work should consider additional time-series related data analysis to better understand length of time in specific postures and whether those postures paired with meaningful EMG outputs can help to explain injury prevalences in computer mouse users.

5.5 Future Directions

This thesis adds to current computer mouse literature by investigating mouse sensitivity, however, there are many parts that need further exploration. Identifying postural variability within trials, further analysis of skill based postural variability and potentially grouping participants based on their preferred mouse sensitivities and movement strategies could help understand video gaming tasks and their exposures. This thesis identified patterns in the overall population and did not assess participants at an individual level. One interesting approach to individualizing the analysis could be using probabilistic methods to reveal distribution of muscle activation and postural strategies responses based on an individual's preferred sensitivity. These models have been previously used to predict fatigue-related subacromial geometric variability

(Chopp-Hurley et al., 2016), and would provide insights into fatigue patterns in video game players depending on their movement strategies and preferred mouse sensitivity. Additionally, using analyses that consider time to further explore injury prevalence, or using fatigue specific EMG analyses such as APDF to analyse the muscular loads throughout a gaming session, which have been used in ergonomic fatigue prevention assessment in the past (Jørgensen et al., 1987, Jonsson et al., 1978).

5.6 Practical Implications

Computer mouse sensitivity and muscle activation or posture revealed trends within the context of this thesis, which can be used to provide guidance for ergonomists, clinicians and video game players. The primary trend demonstrated that lower mouse sensitivity influenced muscle activation, with increases compared to higher mouse sensitivities. This trend may deter ergonomists or clinicians from suggesting use of low mouse sensitivity; however, the defined low sensitivity at 400 DPI was typically lower than what individuals prefer (Figure 4). Instead, for example, lowering to 800 DPI from the commonly used 1600 DPI could slightly increase muscle activation, while improving postural variability. Increased posture and exposure variability is beneficial for health and recommended in workplaces to assist in repetitive strain injury reduction (Mathiassen 2006). However, with the knowledge emergent from this thesis, adjusting a computer mouse to low sensitivity may allow some task and posture variation for working populations with a high proportion of desk tasks.

6.0 Conclusions

This thesis explored the novelty of mouse sensitivity in computer mouse use, specifically applied to video gaming populations.

The main findings in this thesis are:

- 1) Mouse sensitivity influenced muscle activation (upper trapezius, infraspinatus, supraspinatus, anterior deltoid, middle deltoid, extensor carpi ulnaris), with higher levels in lower DPI ranges.
- 2) There were skill-based postural shoulder differences, with experienced players favouring greater shoulder abduction and internal rotation than casual players.
- 3) Mouse sensitivity had the largest effect on wrist movement, with more deviation at lower sensitivities.
- 4) Game difficulty affected muscle activation across all muscle groups, with higher levels in the harder difficulty gaming task.

This thesis builds on previous ergonomic and video gaming literature, by examining the influences of the overlooked variable of mouse sensitivity. Though the results do not conclusively identify an optimal sensitivity for user preference, performance and productivity, while reducing injury risk. With the assistance of future research to further investigate muscle activity levels at different mouse sensitivities, intentionally altering mouse sensitivity may be a plausible intervention to offload some muscles while providing postural variability in other joints.

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