

Gaming Controller Use and its Effects on Morphological Characteristics of the Median Nerve

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Gaming Controller Use and its Effects on Morphological Characteristics of the Median Nerve

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Gaming Controller Use and its Effects on Morphological Characteristics of the Median Nerve

ゲームコントローラーの使用と正中神経の
形態学的特性への影響

SEPTEMBER 2024

MARIANO, LIZBETH AMBROCIO

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Table of Contents

Acknowledgement	i
Table of Contents	ii
List of Tables	vi
List of Figures	vii
List of Abbreviations	x
List of Publication	xi
Abstract	xii
Chapter 1 General Introduction	1
1.1 Esports development worldwide.....	2
1.2 The esports environment.....	3
1.2.1 Platforms	3
1.2.2 Game genres	3
1.2.3 Controllers	5
Mouse	5
Keyboard.....	6
Gamepads	7
Smartphones and tablets	10
Special-purpose devices	12
1.2.4 Physical setup	12
1.3 Musculoskeletal disorders in esports	14
1.3.1 Physical stressors	14
1.3.2 Neck and upper back pain	16
1.3.3 Lower back pain	17
1.3.4 Upper limb pain	17
1.4 Esports and carpal tunnel syndrome.....	18
1.4.1 Carpal tunnel syndrome	18
1.4.2 Current evidence of CTS related to esports.....	22
1.5 Prevention of CTS in esports	23
1.6 Research gap and study aims.....	24
1.7 Structure of the dissertation	25
Chapter 2 Musculoskeletal Discomfort in Esports Players.....	27
2.1 Introduction.....	28

2.2 Methods.....	29
2.2.1 Participants	29
2.2.2 Questionnaire construction, pilot testing, and survey proper	30
2.3 Results	33
2.3.1 Demographic characteristics	33
2.3.2 Gaming habits and playing environment.....	33
2.3.3 Self-reported body discomfort, severity, and BCTQ.....	39
2.3.4 Awareness of injury prevention	41
2.3.5 Correlation of pain and playing years, frequency, and hours	42
2.4 Discussion	43
2.4.1 Body pain/discomfort.....	43
2.4.2 Injury prevention awareness among esports players.....	44
2.4.3 Limitations	45
2.5 Conclusions.....	45
Chapter 3 Effects of Gamepads and Button Operations on the Median Nerve.....	46
3.1 Introduction.....	47
3.2 Materials and methods	49
3.2.1 Participants	49
3.2.2 Ultrasound Examination Protocol.....	50
Gamepads	51
Neutral, PS Grip, and SW Grip	53
Simulated gaming	54
Actual gaming	57
3.2.3 Image processing and analysis.....	58
3.2.4 Statistical analysis.....	59
3.3 Results	60
3.3.1 Effects of PS Grip and SW Grip on the median nerve	60
3.3.2 Comparison of the effects of gamepad use on the median nerve.....	61
Differences between Neutral and the PS and SW Grips	61
Differences in using the two types of gamepads	63
3.3.3 Comparison of the effects of button types on the median nerve.....	65
3.3.4 Dynamic changes in the median nerve during actual gaming.....	67
3.4 Discussion.....	71
3.4.1 Effects of PS Grip and SW Grip on the median nerve	71

3.4.2 Comparison of the effects of gamepad use on the median nerve.....	73
Difference between Neutral and the PS and SW Operations	73
Difference between operating the two types of gamepads	74
3.4.3 Comparison of the effects of using different buttons on the median nerve	77
3.4.4 Dynamic changes in the median nerve during actual gaming.....	78
3.5 Limitations of the study.....	80
3.6 Conclusion.....	81
Chapter 4 Acute Effects of Playing Esports on the Median Nerve and Hand Functions.....	82
4.1 Introduction.....	83
4.2 Materials and methods	85
4.2.1 Participants	85
4.2.2 Gaming setup	85
Gamepad	85
Game	86
4.2.3 Experiment setup	87
Finger sensitivity test	89
Dexterity test	90
Grip strength test	90
Subjective evaluation	91
Experiment protocol	92
4.2.1 Ultrasound examination protocol.....	92
4.2.2 Image processing and analysis.....	95
4.2.3 Statistical analysis.....	95
4.3 Results	96
4.3.1 Characteristics of the sample data.....	96
4.3.2 Acute effects of Resting and Gaming Tasks on the median nerve	96
Changes cross-sectional area of the median nerve.....	96
Changes in shape of the median nerve	98
4.3.3 Acute effects of gaming on hand functions and self-perceived pain	101
Dexterity raw scores	101
Grip strength	102
Finger sensitivity test	103
Subjective evaluation	105
4.4 Discussion.....	106

4.4.1 Acute effect of gaming on the cross-sectional area of the median nerve	106
4.4.2 Acute effect of gaming on the shape of the median nerve	108
4.4.3 Acute effects of gaming on hand functions and self-perceived pain	109
4.5 Limitations of the study	109
4.6 Conclusions	110
Chapter 5 General Discussion and Conclusion	111
5.1 Summary	112
5.2 Implications	114
5.2.1 Ergonomic recommendations regarding the musculoskeletal health of esports players	114
5.2.2 Gamepad design to minimize median nerve compression	115
5.2.3 Regular breaks for recovery from biomechanical stresses to the median nerve ...	116
5.2.4 Summary of findings	116
5.3 Recommendations and future studies	118
5.4 Limitations and potential biases	118
5.5 Conclusion	119
References	120

List of Tables

Table 1.1 Game genre, example games, platform played, and controllers used.....	5
Table 1.2 Esports athletes who had injuries and their impact.....	16
Table 2.1 Characteristics of the participants.....	35
Table 2.2 Differences in the characteristics of Filipino and Japanese participants.....	36
Table 2.3 Differences in playing years, frequency, and time between Japanese and Filipino participants.....	36
Table 2.4 Gaming habits and playing environment.....	37
Table 2.5 Differences in playing years, frequency, and time between Japanese competitive and recreational participants.....	38
Table 2.6 Differences in playing years, frequency, and time between Filipino competitive and recreational participants.....	38
Table 2.7 Differences in body pain between Japanese and Filipino participants.....	39
Table 2.8 Percentage of participants who rated their discomfort as at least “Very uncomfortable.”.....	40
Table 3.1 Characteristics of the participants (n = 14).....	50
Table 3.2 Measured travel distances for each button on the gamepads.....	52
Table 3.3 Median nerve data and results of the paired samples t-test for the comparison of the Neutral, PS Grip, and SW Grip positions.....	61
Table 3.4 Mean changes (%) in the median nerve during actual gaming.....	68
Table 4.1 Characteristics of the participants (n = 12).....	85
Table 4.2 Measured travel distances for each button.....	86
Table 4.3 Basic controls of the Switch Pro gamepad.....	87
Table 4.4 Static two-point discrimination scoring.....	89
Table 4.5 Results of the subjective evaluation results of the right and left hands (n = 12).	105
Table 5.1 Summary of findings of the three studies.....	117

List of Figures

Figure 1.1 Forecasted number of esports players by 2026.....	2
Figure 1.2 Mouse controls typically used for gaming.	6
Figure 1.3 Keyboard controls typically used for gaming.....	6
Figure 1.4 (a) NES gamepad (b) Super NES gamepad.	7
Figure 1.5 (a) N64 gamepad (b) GameCube gamepad.	8
Figure 1.6 (a) Nintendo Switch Joycons (b) Switch Pro gamepad.	9
Figure 1.7 (a) PlayStation Gamepad (b) DualSense Gamepad.	10
Figure 1.8 An example of a HUD.	11
Figure 1.9 (a) Typical smartphone grip and (b) tablet grip.	11
Figure 1.10 Arcade stick.....	12
Figure 1.11 A PC gaming setup example.....	13
Figure 1.12 A console gaming setup example.	14
Figure 1.13 Cross section of the carpal tunnel and surrounding structures.	19
Figure 1.14 Risk factors of CTS.	20
Figure 1.15 Conceptual framework of this dissertation.	25
Figure 2.1 Ergonomic features of a chair.	31
Figure 2.2 The 14 body regions rated by the participants.	31
Figure 2.3 Screening process for the survey responses.	32
Figure 2.4 Types of pain or discomfort encountered by the participants.....	40
Figure 2.5 Warm-up activities used by the participants.....	41
Figure 2.6 Cooldown activities used by the participants.	42
Figure 2.7 Sources of information by the participants.	42
Figure 3.1 Hydrogel pad attached to the transducer.	51
Figure 3.2 L-frames used in the study.....	51
Figure 3.3 PS gamepad buttons and dimensions.	52
Figure 3.4 SW gamepad buttons and dimensions.	53
Figure 3.5 Hand positions at (a) Neutral, (b) PS Grip, and (c) SW Grip.....	53
Figure 3.6 Left analog stick (a) Instructions, (b) magnified buttons, and finger positions for (c) PS and (d) SW gamepads.	55
Figure 3.7 Right analog stick (a) instructions, (b) magnified buttons, and finger positions for (c) PS and (d) SW gamepads.	55

Figure 3.8 Trigger and bumper instructions and finger positions for (a) PS and (b) SW gamepads.	56
Figure 3.9 Action buttons instructions and finger positions for (a) PS and (b) SW gamepads..	56
Figure 3.10 Taking ultrasound images during actual gaming.....	57
Figure 3.11 Traced median nerve, D1, and D2.	59
Figure 3.12 (a) Left MNCSA, (b) Right MNCSA, (c) Left circularity, and (d) Right circularity of Neutral vs. Gamepad operations.....	62
Figure 3.13 (a) Left D1, (b) Right D1, (c) Left D2, and (d) Right D2 of Neutral vs. Gamepad operations.....	63
Figure 3.14 (a) MNCSA and (b) Circularity for each operation.	64
Figure 3.15 (a) D1 and (b) D2 for each operation ($*p < 0.05$, $n = 14$).	65
Figure 3.16 (a) MNCSA and (b) circularity when using a PS gamepad.	66
Figure 3.17 (a) D1 and (b) D2 when using a PS gamepad. ($*p < 0.05$, $n = 14$)	66
Figure 3.18 (a) MNCSA and (b) circularity when using SW gamepad.	67
Figure 3.19 (a) D1 and (b) D2 when using SW gamepad.	67
Figure 3.20 Changes in left (a) MNCSA, (b) circularity, (c) D1, and (d) D2 in actual gaming. ..	69
Figure 3.21 Changes in right (a) MNCSA, (b) circularity, (c) D1, and (d) D2 in actual gaming.	70
Figure 3.22 Left median nerve shape sample images from a participant at (a) Neutral, (b) PS Grip (c) SW Grip positions.	72
Figure 3.23 Right median nerve shape at (a) Neutral, (b) PS Grip, (c) SW Grip positions (sample images from a participant).	72
Figure 3.24 Sample median nerve ultrasound images from a participant at (a) PS Trigger, (b) SW Trigger, (c) PS Game L, and (d) SW Game L operations.	75
Figure 3.25 Finger postures using (a) a PS gamepad and (b) a SW gamepad.	75
Figure 3.26 Thumb (a) Initial position and (b) Pushing the analog stick fully.	76
Figure 3.27 Sample median nerve images from a participant observed at (a) PS Action R, (b) PS Analog R, and (c) PS Trigger R.	78
Figure 3.28 Sample median nerve images from a participant observed at (a) SW Action R, (b) SW Analog R, and (c) SW Trigger R.	78
Figure 3.29 Sample median nerve shapes from a participant at (a) Neutral L, (b) PS Game L, and (c) SW Game L.	80
Figure 3.30 Sample median nerve shapes from a participant at (a) Neutral R, (b) PS Game R, and (c) SW Game R.	80
Figure 4.1 Switch Pro gamepad used in the study.....	86

Figure 4.2 Super Smash Bros. Ultimate/Special.	87
Figure 4.3 Layout of the experiment setup.	88
Figure 4.4 Gaming station.	88
Figure 4.5 Finger sensitivity test station.	89
Figure 4.6 O' Connor finger dexterity test.	90
Figure 4.7 The digital grip dynamometer used.	91
Figure 4.8 Right hand areas based on CHDQ.	91
Figure 4.9 The 3D-printed arm support used at the ultrasound station.	93
Figure 4.10 Experiment protocol.	94
Figure 4.11 Traced median nerve, D1, and D2.	95
Figure 4.12 MNCSA for the (a) right and (b) left sides.	97
Figure 4.13 Median nerve circularity for the (a) right and (b) left sides.	99
Figure 4.14 Median nerve D1 for the (a) right and (b) left sides.	100
Figure 4.15 Median nerve D2 for the (a) right and (b) left sides.	100
Figure 4.16 Dexterity raw scores for the (a) right and (b) left hands per hour.	102
Figure 4.17 Grip strength for the (a) right and (b) left hands per hour.	103
Figure 4.18 Sensitivity test results for the (a) right and (b) left hands per hour.	104
Figure 4.19 Wrist posture when holding a gamepad.	108

List of Abbreviations

ANOVA	Analysis of variance
CTS	Carpal tunnel syndrome
CS:GO	Counter-Strike Global Offensive
DotA	Defense of the Ancients
FPS	First-person shooter
FDP	Flexor digitorum profundus
FDS	Flexor digitorum superficialis
FPL	Flexor pollicis longus
LoL	League of Legends
MNCSA	Median nerve cross-sectional area
MOBA	Multiplayer online battle arena
PS	PlayStation
RSI	Repetitive strain injury
RPG	Role-playing game
SSCT	Subsynovial connective tissue
TPS	Third-person shooter

List of Publication

Chapter 2

Mariano L, Loh, PY, Ishihara Y, Choi J, and Muraki S. Evaluating Musculoskeletal Discomfort in Esports: A Focus on Competitive and Recreational Players from the Philippines and Japan. Journal of Electronic Gaming and Esports. 2024; 2(1): 1-10. doi: 10.1123/jege.2023-0035

Abstract

The rising popularity of esports as a profession and a recreational activity has increased the number of players and enthusiasts annually. However, similar to other sports, there are health concerns for players such as musculoskeletal injuries and discomfort. Carpal tunnel syndrome (CTS) is one of the most common injuries experienced by the players. Thus, this dissertation mainly aimed to determine the effects of gaming on the musculoskeletal health of players and investigate its impact on the median nerve. Furthermore, the first study aimed to determine the prevalence and severity of musculoskeletal pain, player characteristics, and gaming conditions in Filipino and Japanese esports players. It was found that Filipino and Japanese players experienced musculoskeletal pain in the upper body, specifically in the back, neck, wrists, hands, and shoulders. Positive correlations were found between the number of playing years and presence of neck, shoulder, and wrist pain among Japanese participants. Increased number of playing hours was also positively correlated with hand pain.

The second study aimed to investigate the dynamic changes in the median nerve at the proximal carpal tunnel, specifically the cross-sectional area, circularity, and longitudinal and transverse diameters, using different buttons and gamepads during simulated and actual gaming. A smaller gamepad size resulted to a smaller median nerve cross-sectional area (MNCSA), indicating compression. Moreover, longer travel distances of the buttons showed greater deformation of the median nerve, as evidenced by a smaller MNCSA. Analog stick design was also found to compress the carpal tunnel when fully pushed by the thumb. Analysis of the dynamic changes in the median nerve revealed a significant increase in the longitudinal diameter compared to the simulated use. These findings indicate that the median nerve undergoes compression and strain during an actual game.

Lastly, the third study aimed to determine the acute changes in the median nerve and hand functions after playing esports for different durations. Playing esports continuously resulted in an

increased MNCSA for both hands after 90 and 120 minutes. The increase in the MNCSA after some time highlights the importance of taking regular breaks. Thus, players should incorporate breaks into their regular gaming schedules to allow for recovery and prevent the development of CTS symptoms.

In summary, this dissertation presents the impact of gaming on the musculoskeletal health of players and on the morphological changes in the median nerve. A thorough analysis of the results provided the insights into the relevant factors affecting median nerve deformation. This study highlights the importance of gamepad design, specifically size and button design, and regular breaks to minimize the stress exerted on the median nerve to prevent CTS.

Chapter 1 General Introduction

1.1 Esports development worldwide

Esports is defined as “sports facilitated by electronic systems and in which players and teams interact in esports activities through human-computer interfaces.” [1] It has increased in popularity since the first competition, a game of *Spacewar!* at Stanford University on October 19, 1972, with a one-year *Rolling Stone* subscription as the prize [2]. Currently, winning esports teams are presented with multimillion-dollar prizes.

Owing to massive markets, such as China and India, and countries actively engaged in gaming, such as Japan and South Korea, more than half of the players worldwide come from the Asia-Pacific region [3]. The number of gamers worldwide was forecasted to reach 3.305 billion in 2023 (Fig. 1.1) and is expected to grow further in the coming years [4]. Apart from the players, esports spectators are also becoming widespread. The global esports audience, which includes enthusiasts and occasional viewers, was 435 million in 2020 and is forecasted to grow to 640 million by 2025 [5].

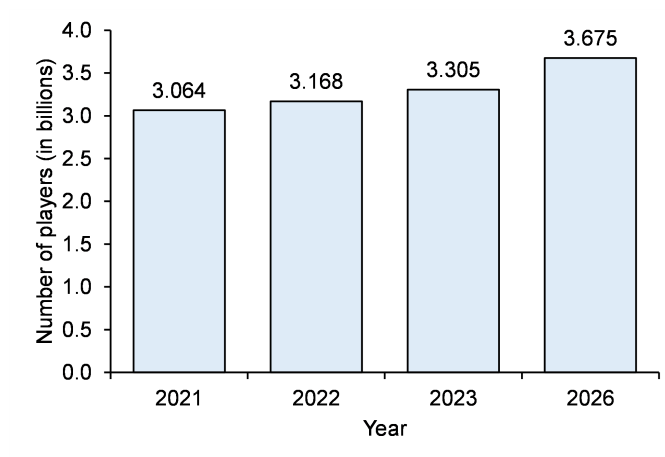


Figure 1.1 Forecasted number of esports players by 2026.
Source: Newzoo

1.2 The esports environment

1.2.1 Platforms

Several platforms can be used in esports, such as personal computers (PCs), consoles, and mobile devices [6]. Players usually pair a computer with a mouse and keyboard in PC gaming. Console gaming uses devices like the Nintendo Switch, PlayStation (PS), or Xbox. Mobile gaming, which includes smartphones and tablets, is considered the future of gaming because of its innovative game availability, portability, and affordability. Over the last decade, the distinction between these platforms has decreased because of the continued growth in cross play, wherein games can be readily played on PCs, consoles, or mobile devices [7].

1.2.2 Game genres

The commonly played esports games fall under the category of action games. Action games usually involve “fast-paced gameplay with a constant focus on movement, quick decision making, hand-eye coordination, combat, and reaction time performance characteristics” [8]. Player movements in these games can reach more than 500 actions per minute, which can be sustained for hours or involve sudden bursts of speed [9,10]. Action games include genres such as multiplayer online battle arena (MOBA), first-person shooter (FPS), third-person shooter (TPS), role-playing game (RPG), fighting games, and real-time strategy (RTS).

MOBA is a team battle-type game with the goal of destroying an opponent's base while defending their own. Each player controls a single character using a unique set of abilities. RPG is similar to MOBA as a team game. Each player takes on a specific role within the team; for example someone takes on enemy hits (tank) or heals other teammates (support). Both FPS and TPS are shooter games that differ in player perspective. In FPS, the player sees through

the eyes of the chosen game character. In TPS, the camera is positioned behind and slightly above the character being controlled. Shooter games require aiming skills.

Fighting games usually have two players controlling characters who will fight in hand-to-hand combat. They may use a combination of kicks, punches, special moves, and combos to defeat the opponent. The goal is to drain the opponent's health or score higher within the time limit. These games require quick reflexes, timing, and strategy. Lastly, RTS is a strategy game wherein players control armies or civilizations in real-time. The game keeps going and players need to manage resources, build bases, and command units to defeat their opponents. Table 1.1 shows the commonly used controllers for each game genre.

Using a keyboard and mouse is preferred for games that require precise aiming and have several key binds easily accessible during games such as shooter games, MOBA, and RTS. Gamepads are typically preferred in fighting games and RPGs. These games commonly require button combinations, and closely placed buttons on gamepads are well-suited. However, the player must still determine the type of controller best suited for their playing style and comfort.

With the advent of technology, mobile gaming has emerged as one of the fastest-growing gaming platforms. Mobile devices, such as smartphones and tablets, make gaming accessible and portable. Some PC and console game publishers have created mobile versions of their games to allow cross-platform play.

Table 1.1 Game genre, example games, platform played, and controllers used.

	Game genre	Platform	Commonly used input devices
1	Shooter games (FPS, TPS)	PC Console Mobile	Keyboard and mouse Gamepad Smartphone or tablet
2	Team battle (MOBA, RPG)	PC Console Mobile	Keyboard and mouse Gamepad Smartphone or tablet
3	Fighting games	Console Arcade	Gamepad Arcade stick
4	Strategy games (RTS)	PC Console Mobile	Keyboard and mouse Gamepad Smartphone or tablet

Note: FPS – First-Person Shooter, TPS – Third-Person Shooter, MOBA – Multiplayer Online Battle Arena, RPG – Role-Playing Game, RTS – Real Time Strategy

1.2.3 Controllers

Controllers are devices that provide input to video game systems. They may include a mouse and keyboard, gamepads, joysticks, motion controllers, and special-purpose devices. Controllers may be utilized across platforms using adapters.

Mouse

Esports players prefer to use a mouse (Fig. 1.2) in FPS, TPS, and MOBA games. These games require quick and precise aiming. Aiming with a mouse is approximately twice as efficient as using a gamepad to hit a target [11]. The mouse is usually operated by the right hand, with the left click used for shooting and the right click for aiming.

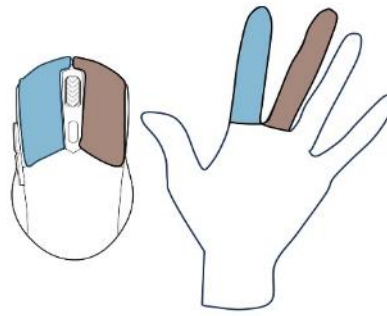


Figure 1.2 Mouse controls typically used for gaming.

Keyboard

A keyboard, partnered with a mouse, is more convenient for games requiring quick access to multiple key binds. Games such as RTS, FPS, TPS, and MOBA are preferable to play using a keyboard. Typically, when using a keyboard in FPS, the “WASD” keys are utilized for in-game movements, “F” or “E” for using game items, “R” for reload, “Shift” for sprinting, “Ctrl” for crouch, space bar for jump, and “Tab,” “Caps Lock,” “Z,” “X,” “C,” or “V” for other functions. Most of the time, the left hand operates the keyboard using the finger nearest each key (Fig. 1.3).

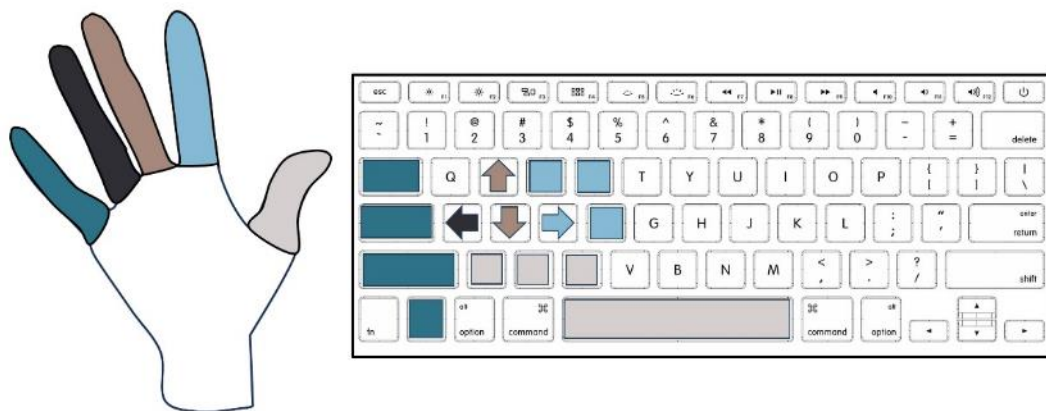


Figure 1.3 Keyboard controls typically used for gaming.

Gamepads

Gamepads are convenient when games involve a single character with limited moves, such as fighting games and RPG. These games require complex combinations of controls for execution, which is easier with the close placement of gamepad buttons. Gamepads also allow for controlled speeds using pressure-sensitive analog sticks, which is advantageous in racing games. Some players consider gamepads more comfortable to hold than other controllers because of their shapes.

Gamepads are held with both hands and involve commonly used in-game controls, such as two analog sticks for movement (left) and aiming (right), a directional pad (d-pad), four action buttons, two triggers, and two bumper buttons. Traditionally, the thumb operates the d-pad, analog sticks, and action buttons, whereas the index and middle fingers operate shoulder buttons (triggers and bumpers). Popular gamepads include the Nintendo and PlayStation gamepads, which have evolved based on the needs of the games and players.

Nintendo gamepads come in various sizes and shapes. The first was the Nintendo Entertainment System (NES) gamepad, which inspired most subsequent gamepads [12]. It was rectangular and had a d-pad and two buttons (Fig. 1.4a). This was followed by a Super NES (SNES) gamepad with a refined design that included a rounded profile, two extra buttons, and two newly introduced shoulder buttons [12] (Fig. 1.4b).



Figure 1.4 (a) NES gamepad (b) Super NES gamepad.
Source: Wikimedia/Evan Amos

In 1995, the Nintendo 64 (N64) gamepad (Fig. 1.5a) was launched to cater to 3D games [12]. It had an “M” shape with an analog stick at the center [12,13]. The back of this gamepad contained rumble and memory slots for games that required them [12]. In 2001, Nintendo released the GameCube gamepad after the N64 (Fig. 1.5b). It had two analog sticks and was an improved version of its predecessor [13]. Users can quickly learn the layout of the buttons in minutes, and some dubbed it the best Nintendo gamepad [12].



Figure 1.5 (a) N64 gamepad (b) GameCube gamepad.

The Nintendo Switch Joy-Con was released in 2017 as the primary gamepad for the Switch console. This gamepad was the culmination of previous gamepads [12]. Joy-Cons were very versatile and could be attached to the console, attached to a comfort grip, or used as two separate individual controllers (Fig. 1.6a-c). They had wireless connectivity, motion control, and a rumble feature. Each Joy-Con came with an analog stick, four buttons, and two trigger/bumper buttons. The Switch Pro gamepad, which was also released with the Switch console (Fig. 1.6d), was the full-controller version of the Joy-Cons.

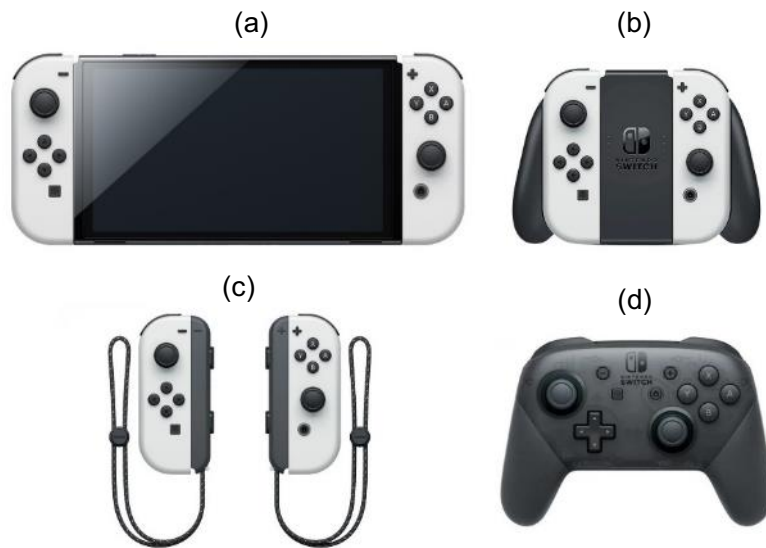


Figure 1.6 (a) Nintendo Switch Joycons (b) Switch Pro gamepad.
Source: Nintendo

The PlayStation gamepad was the first gamepad released by Sony Interactive Entertainment in 1994 (Fig. 1.7a). The company wanted to create a gamepad that felt good and was not too heavy [14]. It was based on the design of the SNES gamepad. The improvements were in the second pair of shoulder buttons for 3D games [15]. Consequently, grip handles were added to ease the transition of the index and middle fingers from L1/R1 to L2/R2 buttons. The in-game movements depended on the d-pad operated by the left thumb. No analog stick was available yet. The action buttons, usually operated by the right thumb, used symbols instead of letters [15]. The cross (X) meant “no,” the circle meant “yes,” the triangle signified point of view, and the square represented menus [14,15]. In 1997, the Dual Analog Controller was released, featuring twin analog sticks with recessed grooves [15]. These were necessary for the increased popularity of 3D games [16]. The Dual Analog Controller also included a rumble feature.

Changes in the succeeding gamepad versions (DualShock, DualShock 2, Sixaxis, DualShock 3, and DualShock 4) were mostly related to rumble features/haptic feedback, textured grips, pressure sensitivity of the analog sticks, wireless connectivity, motion detection, and aesthetic aspects such as color. Including the rumble feature/haptic feedback increased the

gamepad's weight due to the vibration motors included in the handles [15]. Textured grips made it easier to hold the gamepad and prevent slippage. Motion detection reduces the burden of action on the fingers.

The latest generation was the DualSense gamepad (Fig. 1.7b), released in 2020 and included new functions with a refined design. The haptic feedback and adaptive triggers were improved in this gamepad. The latest available gamepad was the DualSense Edge, a high-performance and ultra-customizable gamepad. The stick sensitivity and trigger travel distance were adjustable, and all DualSense standard features were retained.



Figure 1.7 (a) PlayStation Gamepad (b) DualSense Gamepad.
Sources: (a) Wikipedia/Evan-Amos (b) Sony

Smartphones and tablets

Smartphones and tablets are technically not input devices, but they can be used to play esports. These devices utilize a touchscreen as the main game interface. A heads-up display (HUD) shows the character's controls or capabilities, health/lives, weapons/ammunition, game progress, mini-map, compass/quest arrow, timer (for timed events), and menu. Fig. 1.8 shows an example of a HUD for *Call of Duty: Mobile*, an FPS game.



Figure 1.8 An example of a HUD.

Source: Activision Games Blog

Typical smartphone screen sizes used in gaming can vary from 4.7–7 inches, while tablet sizes can be 8–13 inches. Both hands can be used to hold the smartphones and smaller tablets when playing. However, larger tablets need a stand because they are heavier and more challenging to hold. Fig. 1.9 show the typical smartphone and tablet grips. The thumbs and index fingers perform most tasks on the screen.



Figure 1.9 (a) Typical smartphone grip and (b) tablet grip.

Sources: (a) CNBgear.com (b) Pressfarm

Special-purpose devices

Other input devices can be used for specific purposes. Arcade or fight sticks (Fig. 1.10) are mainly used for fighting games such as *Street Fighter* and *Tekken* [17]. Motion controllers use built-in inertial or optical sensors to capture the player's movements and control games [18,19]. Nintendo's Wii Remote is an example of a handheld motion controller, while Microsoft's Kinect is a camera-based motion controller [18,19].



Figure 1.10 Arcade stick.
Source: 8BitDo.com

1.2.4 Physical setup

A dedicated gaming setup is advantageous for players because it can improve their performance, productivity, and game immersion, enhance the setup's customizability, and save money by avoiding redundant device purchases [20]. Each gaming setup varies depending on the platform, budget, and purpose of playing [20,21]. The purpose of the setup may be competitive practice, recreational play, or live streaming.

The PC gaming setup includes a table, chair, gaming PC, monitor, keyboard, mouse, headset, and speakers (Fig. 1.11). Ordinary tables and chairs may be used to play esports. However, with the evolution of esports, gaming chairs, tables, and desks have become available to improve comfort and performance [22]. Gaming chairs are equipped with high backrests to support the upper body while playing video games and usually involve an adjustable seat height,

armrests, lumbar support, and a headrest. Most gaming chairs resemble racecar seats, on which their design is based, and have become a symbol of a legitimate gamer with the popularization of live streaming [23]. In contrast, gaming desks or tables are designed to maximize the playing space and provide a neat location for cables, accessories, and the CPU [24].

A gaming PC is at the heart of a PC gaming setup. It must have a powerful processor, dedicated graphics card, and ample RAM and memory [20]. These ensure that the game does not lag and runs smoothly. The monitor size should be at least 24 inches, with a minimum resolution of 1440p [25]. The proper size and resolution allow the player to see the game clearly and attack with better precision. The refresh rate should be at least 120 Hz to avoid display stutter [25]. A laptop can also be used for this setup to allow gaming portability. The desktop computer setup is replaced with a laptop mounted on a stand, and an external keyboard and mouse are used for more convenient and comfortable control [21].



Figure 1.11 A PC gaming setup example.
Source: bmbhomie via Reddit

A console gaming setup (Fig. 1.12) requires a television (4K UltraHD) or monitor, headset or speakers, a gaming chair or comfortable sofa, console, and gamepad [26–28]. The console may also be set up as in PC gaming by replacing the PC, mouse, and keyboard but keeping the monitor and other elements. Some players even combine their console and PC gaming setups, owing to the rise of cross-platform gaming. The gamepads may also be interchanged on each gaming platform. For example, a gamepad can be used as the controller in PC gaming.



Figure 1.12 A console gaming setup example.
Source: SpawnPoint

Playing for a live-stream audience requires additional devices, such as an extra monitor for controlling the stream, a microphone, a camera, and streaming software [29]. These can be added to the PC, console, or mobile gaming setup to initiate streaming.

1.3 Musculoskeletal disorders in esports

1.3.1 Physical stressors

Several studies have found that esports players, whether playing recreationally or competitively, suffer musculoskeletal pain and discomfort in the back, neck, wrist, and hand, similar to athletes in traditional sports [30–34]. One study found that 86% of 116 competitive video gamers had at least one musculoskeletal injury [35]. Another study found 42.6% of 188 Danish esports athletes reported musculoskeletal pain [31]. Moreover, 77.8% of 522 casual, competitive, and professional players from Canada and 28 other countries experienced upper-body gaming-related pain [33]. Typically, playing esports involves prolonged sitting, screen exposure, and hundreds of repetitive movements [10].

Musculoskeletal issues commonly affect the neck, back, and upper extremities because esports are sedentary activities usually associated with poor posture [36]. Esports players usually spend 5.5–10 hours per day playing [30]. Few players have reported standing up to take

a break after three or more hours of gaming. Scarce breaks are problematic because office workers who sit for two hours have significantly increased discomfort in the lower back and hip/thigh/buttocks area [37]. Changing the position from sitting to standing/walking every hour has also been recommended to reduce the risk of musculoskeletal problems by 30% [38].

Repetitive microtrauma, instead of an acute process, may have caused upper limb injuries [9]. This slow process can occur unnoticed until the symptoms worsen and are perceived by the players [9]. In competitive esports, gameplay highly depends on fast, repetitive wrist, hand, and finger movements that require accuracy [10,39]. Carpal tunnel syndrome (CTS), De Quervain's tenosynovitis, or ulnar tunnel syndrome, causing wrist pain and lateral epicondylitis, causing elbow pain, are frequently reported due to keyboard and gamepad overuse [10].

Esports pain resemble the pain of office workers who use computers frequently and for prolonged periods [10,30]. Higher levels of musculoskeletal pain were found among office workers who exerted higher typing forces on the keyboard [40–42]. The strong relationship between carpal tunnel syndrome (CTS) and keyboard typing was also highlighted in a literature review study [43]. Moreover, long-term computer users were found to have a susceptibility to median nerve damage in the wrist region [44]. Improper wrist posture has also been found to increase carpal tunnel pressure and considered as one of the factors associated with CTS [45]. The median nerve cross-sectional area was found to increase after continuous typing [46,47]. This indicates that there are changes on the median nerve because of keyboard typing. Although it is still unclear if it leads to nerve injury or long-term effects [46]. The use of keyboard for office work has been widely studied because of its negative impacts in the musculoskeletal health of workers.

Table 1.2 presents the injuries reported among esports athletes from 2011 to 2021 [48,49]. These include wrist, hand, and finger injuries and collapsed lungs. More than half of the injuries (56%) affected the wrists. These injuries forced players to undergo treatment, miss competitions, or retire.

Table 1.2 Esports athletes who had injuries and their impact.

Year	Name	Injury	Game	Impact
2011	Flash	RSI in wrist, forearm, shoulder	Starcraft II	Missed competitions
2011	sC	Collapsed lung	Starcraft II	Hospitalized
2011	Sheth	Wrist pain	Starcraft II	Retirement
2012	Mvp	Wrist injury, spine/neck issues	Starcraft II	Missed competitions
2013	iNcontrol	Blood clot in the knee	Starcraft II	Pulmonary embolism
2013	Scarlett	Wrist injury	Starcraft II	Missed competitions
2013	GanZi	Wrist injury	Starcraft II	Retirement at 26
2013	Toyz	CTS	LoL	Initial retirement at 21
2014	Fear	Tennis elbow	DotA 2	Initial retirement at 26
2015	Hai	Wrist injury, collapsed lung	LoL	Initial retirement at 22
2015	Hax	Hand injury	Super Smash Bros. Melee	Multiple retirements
2015	Mylon	Collapsed lung	LoL	Hospitalized
2015	Bjergsen	Wrist injury	LoL	Multiple retirements
2016	Guardian	CTS	CS:GO	Missed competitions
2016	Olofmeister	Hand, CTS	CS:GO	Missed competitions
2016	gla1ve	Collapsed lung	CS:GO	Underwent surgery
2016	Mithy	Wrist injury	LoL	Retirement at 24
2016	Freeze	Wrist tendonitis	LoL	Missed competitions
2017	Janus	Collapsed lung	Overwatch	Missed competitions
2017	miCKe	NTOS	DotA 2	Missed competitions
2018	TheShy	Wrist, hand, arm injury	LoL	Missed competitions
2020	Mantuu	De Quervain's tenosynovitis	CS:GO	Missed competitions
2020	Uzi	Arm, hand injury	LoL	Retirement at 23
2020	Issa	CTS	Fortnite	Retirement at 19
2021	ZooMaa	Thumb injury	Call of Duty	Initial retirement at 25

Note: RSI – repetitive strain injury, CTS – Carpal tunnel syndrome, DotA – Defense of the Ancients, LoL – League of Legends, CS:GO – Counter-Strike Global Offensive, NTOS - Neurogenic thoracic outlet syndrome

1.3.2 Neck and upper back pain

Approximately 11–50% of players worldwide report neck and back pain from playing esports [30–33,35]. Within 30 minutes of gaming, players assume a less vertical and less upright

posture while seated [50]. This postural deviation can lead to forward head posture (FHP), with an excessive distance between the head and the spine [50]. A more forward head position can increase neck pain [51,52]. Over time, the head tilts forward, causing an imbalance in the cervical spine muscles [50,53]. The cervical spine muscles serve as couplings to maintain the balance between the head and neck, which primarily depends on the vertical alignment of the spine [50,54]. For every inch the head deviates from alignment with the spine, the cervical extensor muscles exert an additional ten pounds of force [55]. This imbalance leads to tightness of some muscles and weakness of others in the area [50]. These may affect the activities of daily living (ADL) due to the low mobility of the neck and trigger pain due to muscle strain [50]. The imbalance also promotes a cycle of FHP, added torque, and muscle strain, increasing neck and back pain and headaches [36,50].

1.3.3 Lower back pain

FHP during prolonged sitting may cause players to slump or slouch posture [56]. Slumping increases the forces on the intervertebral disks of the lower back and can cause herniation [36,57], which can cause pain in the lower back, buttocks, thighs, and calves. Approximately 20–64% of players experience lower back pain from playing esports [32,33,35].

Additionally, seats with backrests, such as gaming chairs, increase the risk of flattened lumbar lordosis and posterior pelvic tilt [36,57]. These cause persistent lower back pain owing to muscle strain caused by imbalances, muscle tension, and weakness [36].

1.3.4 Upper limb pain

An aberrant posture when playing esports may also affect the shoulders. One study found that playing for over three hours with poor posture is associated with shoulder pain [58]. Approximately 11–35% of players experience shoulder pain while playing esports [31,32,35].

Finger, hand, and wrist movements in esports typically require fast and exact keystrokes or clicks, and intense games may involve 500 actions per minute [10]. Repetitive movements can cause tendon thickening in the carpal tunnel and increase the median nerve's cross-sectional area and swelling ratio [36,46]. The carpal tunnel pressure noticeably increased after 30–60 minutes of keyboard use and ulnar deviation [36,46]. Approximately 8–45% of esports players reported wrist pain, and 21–45% of them experienced pain in their hands [30,32,33,35].

The use of joysticks in video games may also cause De Quervain's tenosynovitis [34,36,59]. A biomechanical analysis revealed that grasping the joystick produces tension in the thumb's abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons [59]. Additionally, repetitive, and rapid movements of the thumb and wrist increase stress on the APL and EPB [59].

1.4 Esports and carpal tunnel syndrome

1.4.1 Carpal tunnel syndrome

The carpal tunnel, shown in Fig. 1.13, is a narrow osteofibrous opening through which the median nerve, flexor pollicis longus (FPL) tendon, four flexor digitorum superficialis (FDS) tendons, and four flexor digitorum profundus (FDP) tendons pass through the volar wrist [60]. Multilayer viscoelastic subsynovial connective tissue (SSCT) is interspersed between the tendons and the median nerve [61]. The layers allow gliding movement inside the carpal tunnel via stretching the interconnecting collagen fibers and lubrication from the carpal tunnel bursae [62]. The carpal tunnel is enclosed by the scaphoid bone, trapezoid bone, and tendon of the flexor carpi radialis (FCR) muscle in the radial boundary, while the carpal bones, the hamate hook, triquetrum, and pisiform line, the ulnar boundary, with the flexor retinaculum serving as the border [63].

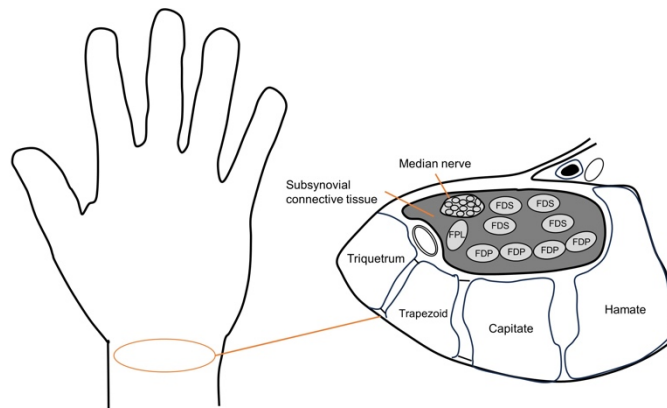


Figure 1.13 Cross section of the carpal tunnel and surrounding structures.

Carpal tunnel syndrome (CTS) is one of the most common peripheral neuropathies of the upper limbs, occurring in approximately 90% of cases [64]. In the general population, 1–5% have CTS [65]. Females have a higher risk of developing CTS than males (3:1 ratio); obesity doubles the risk, and older adults aged 40–60 years are more susceptible [65]. Fig. 1.14 shows the known risk factors of CTS.

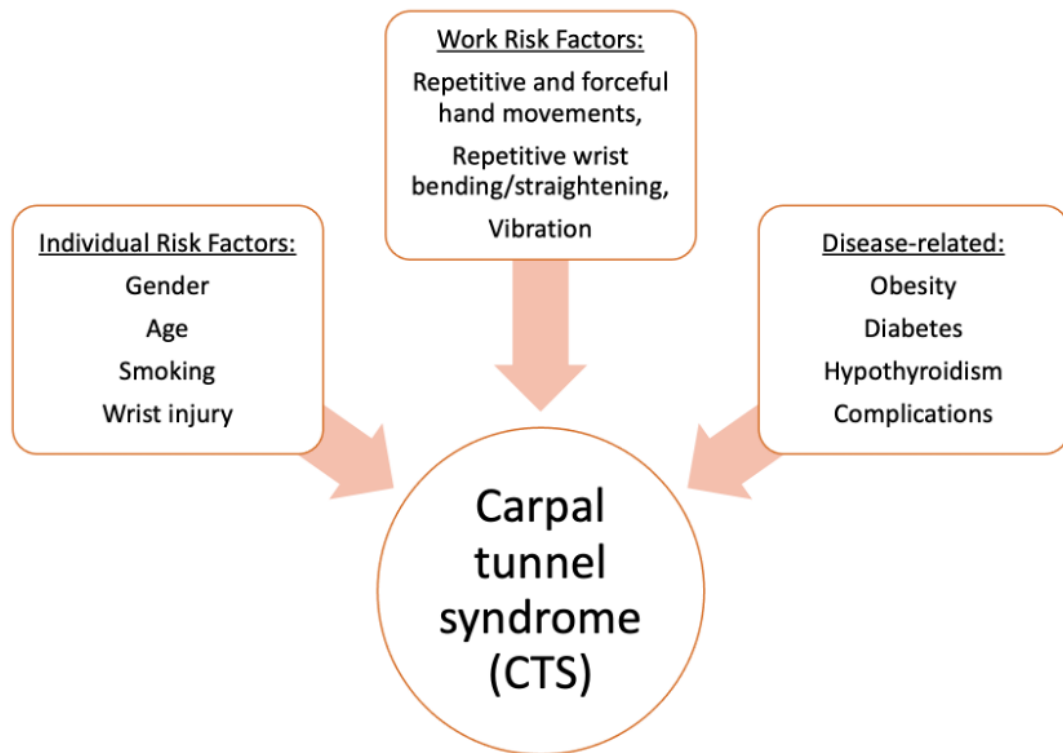


Figure 1.14 Risk factors of CTS.

Sources: [66,67].

CTS occurs when the median nerve is compressed as it travels through the carpal tunnel into the hand [9]. The primary symptoms of CTS are numbness, tingling, and pain in the thumb, forefinger, middle finger, and radial half of the ring finger [68]. Loss of grip strength, pinch strength, and finger coordination may also occur [69]. Occupations involving high pressure, high force, repetitive tasks, and tool vibration have a high risk of CTS [64]. However, intrinsic factors, such as obesity and hormonal changes, that could contribute to the development of CTS should be considered [64,65].

Carpal tunnel pressure and blood supply disruption may sacrifice median nerve conductivity whenever the carpal tunnel is constricted [70]. The pressure may increase due to the narrowing of the tunnel during wrist flexion or extension, crowding inside the tunnel due to

trauma to the median nerve, or abnormal growth [60,70]. Histological studies have found SSCT thickening or fibrosis in cases of CTS [71,72].

Researchers have investigated the risk factors of CTS. It has been associated with deviated wrist postures, repetitive and forceful use of the hands, and the small size and shape of the carpal tunnel [60,68]. When the wrist is in a neutral position in a healthy individual, the average pressure in the carpal tunnel is 2 mmHg; however, it increases to approximately 33 mmHg during extension and approximately 42 mmHg during flexion [73]. The opening narrows during extension due to the lunate pressing toward the tunnel. At the same time, flexion causes the flexor retinaculum to close into the radius and the capitate to glide in the distal and palmar directions [70]. Increased wrist flexion and extension angles increase the shear strain of the SSCT compared with that in the neutral position [74]. However, normal wrist flexion and extension alone are not known to cause CTS.

A previous study found that finger motion in the flexed wrist position can cause SSCT friction, which can increase with differential finger motion [62]. Differential finger motion or single digit motion increases the gliding resistance (friction) in the SSCT since it is shared by the FDS tendons and may stretch in different directions. These movements may increase the risk of SSCT shear injury owing to increased friction.

The development of CTS has been hypothesized to begin with the shear injury of the SSCT in the tunnel [71]. The possibility of shear injury is high, which triggers a wound-healing process that results in thicker collagen fibers of the SSCT [71]. An injured SSCT is also more susceptible to further injury because failure occurs at lower strains than a normal SSCT [61,75]. Furthermore, the injured SSCT becomes stiff, making tendon movement more complex [75]. SSCT stiffness increases the force required to move the tendons and renders the SSCT more vulnerable, creating a vicious cycle [75]. This cycle may cause crowding inside the carpal tunnel, increasing pressure.

1.4.2 Current evidence of CTS related to esports

Players have a history of quitting esports because of CTS pain and symptoms. However, whether playing esports leads to CTS is still being determined. Some potential risk factors are associated with this activity. One of these is the repetitive, rapid, and precise movements of the wrists, hands, and fingers while playing video games. These movements can be sustained for a long time or occur suddenly, depending on the situation in the game [10]. In addition, differential finger movements can occur when each finger operates a separate button or key in controllers. These movements have been proposed as a possible factor leading to CTS [71].

Wrists tend to deviate from neutral postures when holding input devices and using controls in-game. A tall mouse can increase the wrist extension angle and may build up the pressure in the carpal tunnel [76]. Typing on a keyboard can lead to ulnar deviation and wrist extension. Wrist deviations from the neutral position, especially flexion, increase the pressure in the carpal tunnel, which may compress the median nerve. The keyboard must allow for an almost neutral wrist position, such that the extension is at 0–15° and the ulnar deviation is only 0–5°[17]. This position would ensure that the pressure in the carpal tunnel does not increase.

Mechanical keyboards used for gaming typically require a higher key actuation force than membrane keyboards used for typing [77]. Research on the relationship between the actuation force and upper limb discomfort has been conducted among office workers [40,42,78]. The keyboard actuation force represents the force required to reach the actuation point of the keyboard and register a key press [17]. Computer workers with high musculoskeletal symptoms in the upper limbs applied significantly higher key-strike forces than those with lower symptom levels [40]. However, ultralow travel and virtual keyboards that require low activation forces are less preferred than conventional keyboards and increase body discomfort among subjects [42,78]. The discomfort could be due to static loading in the muscles, as the participants cannot rest their hands or fingers during typing to avoid accidental key activation [42]. Players should

have sufficient keyboard activation forces to receive tactile feedback that does not overexert the upper limbs.

Repetitive and differential finger movements, forceful finger movements, and wrist deviation from neutral movements that may occur when using input devices while playing esports may become risk factors for CTS. When combined with intrinsic factors, such as obesity, a known risk factor for CTS, the risk is higher.

1.5 Prevention of CTS in esports

Esports is a long-standing hobby and an emerging occupation for many people. Increased engagement in esports is forecasted in the next few years [5]. However, as a new industry, most esports-related health risk factors remain unknown. Identifying hazards is essential so players, team management, and medical personnel know the risks and learn how to address them. Injuries must be prevented to optimize players' performance throughout their careers. Recreational players could also benefit, as ADL may be adversely affected by musculoskeletal pain or injury. Therefore, determining the playing setup and conditions that protect players from injuries is necessary.

The occurrence of known risk factors should be avoided or minimized to prevent CTS among esports players. The designs of gaming controllers must allow for approximately neutral postures of the wrists and avoid pressing the carpal tunnel. Furthermore, controller buttons must have lower actuation forces and key travel distances without sacrificing tactile feedback. Because of the repetitive movements required to play video games, timely and sufficient breaks are essential. General muscle training, exercises, physical conditioning, and rehabilitation of players are necessary to avoid and recover injuries. Studies found that strength training and exercises can help prevent and manage musculoskeletal disorders and symptoms [79,80].

1.6 Research gap and study aims

Due mainly to its sedentary nature, esports have not been considered an activity where players would be subject to physical injury [30]. However, musculoskeletal injuries among esports players have gained attention in recent years because of their increased occurrence [34]. Therefore, focusing on preventing injuries, specifically CTS, is crucial because it is among the most reported injuries in players. Of the 25 reported injuries, 56% involved the wrist, and 29% were CTS (Table 1.2).

Researchers have conducted several investigations on the prevalence of musculoskeletal pain and injuries among esports players worldwide, including the USA, Canada, Denmark, Korea, and China. Few studies have been conducted on playing conditions in other Asian countries. Many authors have also highlighted the need for conducting studies related to esports epidemiology, risk factors for musculoskeletal discomfort, and the mechanics of injury [1,10,30,36,39]. To date, limited studies have focused on the injuries that occur during esports gameplay. Thus, the main objectives of this dissertation were to determine the effects of gaming on the musculoskeletal health of players, investigate the impact of gaming on the median nerve, and provide design guidelines for gamepads to prevent carpal tunnel syndrome. Fig. 1.15 shows the overall scope of the study. Specific studies have addressed the following objectives.

- Study 1 aimed to explore the gaming habits, environment, and prevalence of wrist and hand pains among Filipino and Japanese esports players.
- Study 2 aimed to investigate morphological changes in the median nerve at the proximal carpal tunnel, specifically the cross-sectional area, circularity, and longitudinal and transverse diameters, while using different buttons and gamepads during simulated and actual gaming.
- Study 3 aimed to determine the acute changes in the median nerve, hand functions, and self-perceived discomfort of players after continuous gaming.

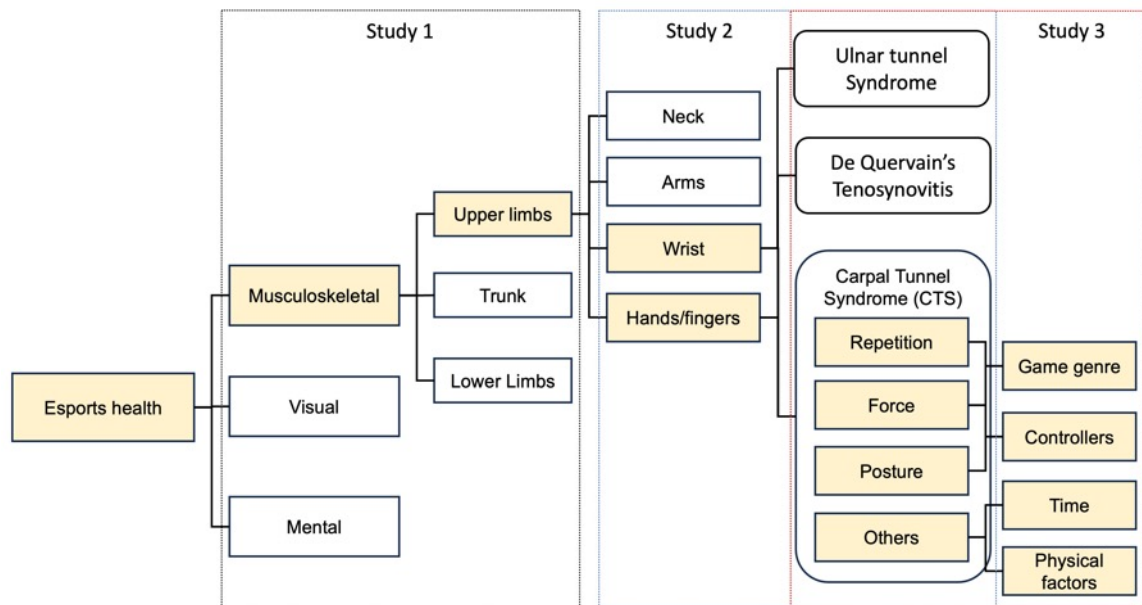


Figure 1.15 Conceptual framework of this dissertation.

1.7 Structure of the dissertation

Chapter 2 explores esports players' characteristics, gaming habits, the prevalence and severity of musculoskeletal pain and discomfort, and the risk factors for pain. An online survey questionnaire was employed to gather information on esports players in the Philippines and Japan. This chapter aims to understand the current playing conditions, verify the prevalence and severity of pain, and determine its risk factors in esports.

Chapter 3 investigates the changes in median nerve morphology (cross-sectional area, circularity, and longitudinal and transverse diameters) using different gamepad buttons and commercially available gamepads. The experiments used a simulated gamepad and actual gaming conditions. This chapter focuses on characterizing the changes in the median nerve when using analog sticks (left/right), triggers and bumpers, action buttons, and different types of gamepads with different sizes, weights, and button layouts.

Chapter 4 examines the acute changes in median nerve morphology (cross-sectional area and longitudinal and transverse diameters) and hand functions when playing esports for different durations (0, 30, 60, 90, and 120 min). This chapter investigates the initial effects of prolonged gaming on the median nerve and hand function.

Chapter 5 discusses the results of chapters 2–4. This chapter synthesizes the results of the previous chapters to provide a holistic analysis of the specific outcomes and their combined implications. It also discussed future research directions.

Chapter 2 Musculoskeletal Discomfort in Esports Players

2.1 Introduction

Esports gained a huge following in recent years. Its audience was 532 million in 2022 and was forecasted to grow to 640.8 million by 2025 [5]. Furthermore, esports is attaining acceptance as a profession and a sporting event worldwide, increasing interest and growing its market exponentially [1]. However, there is an increasing concern about the health issues related to playing esports [1,30,32].

Playing esports involves repetitive movements of fingers, hands, and arms that require speed and accuracy [10]. These movements during intense games can reach more than 500 actions per minute and may be sustained for hours or involve sudden bursts of speed [2,10]. Injuries to the upper extremities, possibly caused by repetitive microtrauma, can occur unknowingly until the players notice and experience the worsening symptoms [9]. Moreover, prolonged sitting, exacerbated by poor posture, usually leads to back and neck pain [10]. A study revealed that neck, shoulder, headache, and back discomfort were the most pronounced after four hours of continuous computer gaming [81].

Epidemiological studies on esports injuries are limited. Researchers have investigated the most common health complaints among competitive players. Danish esports athletes reported that they experience pain in the back (31.3%), neck (11.3%), and shoulders (11.3%) [31]. While a study on collegiate esports athletes from the US and Canada reported eye fatigue (56%), neck and back pain (42%), wrist pain (36%), and hand pain (32%) [30]. Elite mobile esports players from China also reported headache/dizziness (40%), rhinitis (32%), and pain in the scapula (24%) [32]. Furthermore, casual, competitive, and professional gamers from Canada and 28 other countries reported pain in the neck (43.9%), lower back (41.4%), and the distal upper limb (37.9%) [33].

Certain studies have explored the association between esports players' demographics, gaming characteristics, and musculoskeletal pain/discomfort. A strong positive correlation was

found between left elbow pain intensity and the total number of years spent gaming [33]. However, only a weak association between the number of hours played per week and musculoskeletal pain in several body regions was found. No significant association between career duration and the total number of confirmed injuries was found in another study [32]. Considering these findings, the study aimed to verify the associations between the number of playing years, playing frequency, playing hours, and musculoskeletal pain among players. These variables were hypothesized to be correlated positively with musculoskeletal pain.

Previous research has predominantly focused on esports athletes' characteristics and musculoskeletal complaints in other countries. These complaints could also be prevalent among Filipino and Japanese esports players. Currently, there are limited studies conducted on these specific populations. Thus, determining the differences in the gaming habits of players from different gaming landscapes could reveal further insights. Therefore, this study aimed to gain insights into the gaming habits, environment, and prevalence of wrist and hand pain among competitive and recreational players in the Philippines and Japan.

2.2 Methods

2.2.1 Participants

A convenience sampling method was used to recruit the participants. Filipino and Japanese esports players aged 14 to 26 participated in the survey. The Filipino participants were recruited from August to October 2021. Six professional and one collegiate team, eight university or school representatives, one tournament organizer, and around 50 individuals received the invitation via Facebook and email. They were requested to participate and to share the online questionnaire with other players. The participation rate was approximately 41%, wherein 159 out of around 386 invited players completed the survey.

The Japanese participants were recruited between September 2021 and April 2022. Postal mails were sent to 109 high schools and collegiate teams (approximately three members each).

The mail included the QR codes of the survey questionnaire that participants could access online. Additionally, messages containing a link to the online survey were sent to the Twitter accounts of 123 esports teams. The participation rate was approximately 27%, wherein 120 out of 450 invited players participated.

All participants were required to provide informed consent before answering the survey voluntarily and anonymously. Those under 18 years old were required to ask for permission from a parent or guardian to participate in the survey. This study was approved by the Research Ethics Committee of the Faculty of Design of Kyushu University (Approval number 403).

2.2.2 Questionnaire construction, pilot testing, and survey proper

Two questionnaire versions were created, one in English and one in Japanese. The English language was chosen to survey Filipino esports players, considering the high proficiency of Filipinos in the language. The questionnaire was prepared in English, which subsequently underwent double translation to produce the Japanese version [82].

The questionnaire consisted of six parts. Part I was the introduction of the survey and participant or parental informed consent. Part II included demographic questions such as age, gender, team membership, number of playing years, and injury history. Part III contained gaming-related questions such as devices used, game genres played, reason for playing, playing frequency and hours, types of gaming gears used (e.g., wrist brace, gaming gloves, muscle tape, gaming sleeve), and ergonomic features of the chair that they use (Figure 2.1). Part IV included questions on injury prevention, frequency and length of breaks, warm-up and cooldown habits, and training attendance. In Part V, for the past seven days and six months, the participants rated their esports-related discomfort of the 14 body regions shown in Figure 2.2 from the lowest rating of “1- not uncomfortable” to the highest rating of “5 - extremely uncomfortable”. Lastly, Part VI included the English version of the Boston Carpal Tunnel Syndrome Questionnaire (BCTQ) to assess hand and wrist pain or discomfort among

participants conveniently. The Japanese questionnaire adopted the CTSI-JSSH (validated BCTQ in Japanese) for Part VI [83,84]. The online surveys were designed using SurveyMonkey (Momentive, San Mateo, CA).

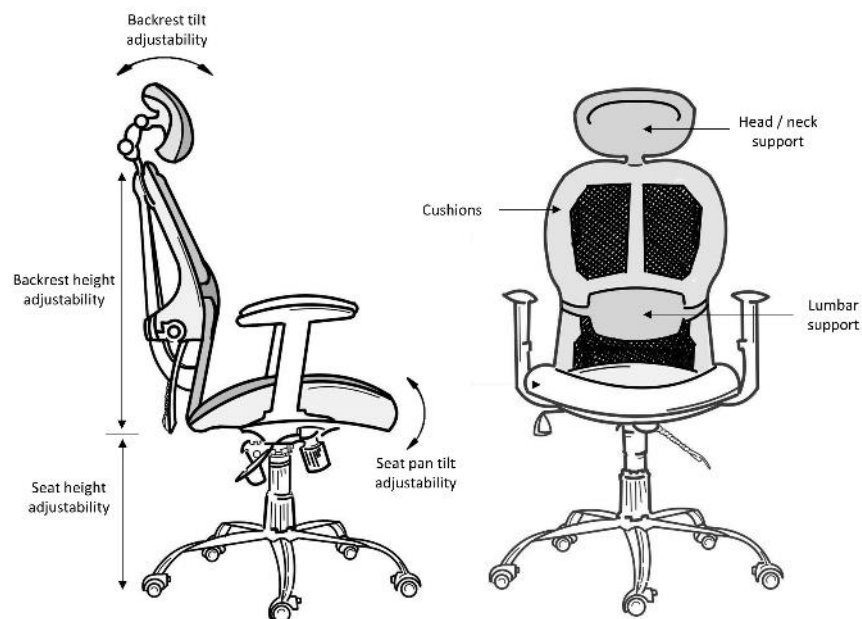


Figure 2.1 Ergonomic features of a chair.

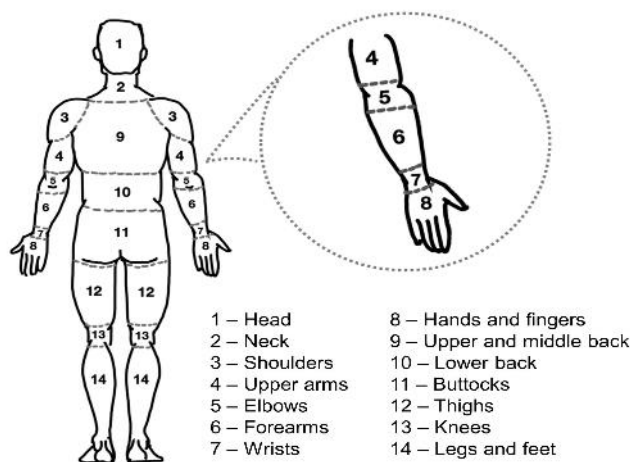


Figure 2.2 The 14 body regions rated by the participants.

A pilot survey was conducted and included 105 Filipino and 57 Japanese participants. The typical completion time was 10 minutes for the English version and 5 minutes for the Japanese version. Feedback from several participants was reviewed and used to improve the questionnaires to produce the final versions. The final questionnaire consisted of 84 items that the participants could answer within 10–15 minutes.

After the survey, the data was exported from SurveyMonkey in CSV file format and then converted to an Excel file for postprocessing. Figure 2.3 summarizes the screening process for the responses included in the analysis. The data was stratified according to population (Japanese or Filipino) and type of player (competitive or recreational). Participants were categorized as competitive or recreational players based on their reasons for playing esports (Table 2.1). Those who responded that they were playing for recreation were classified as recreational players, whereas the rest were considered competitive players.

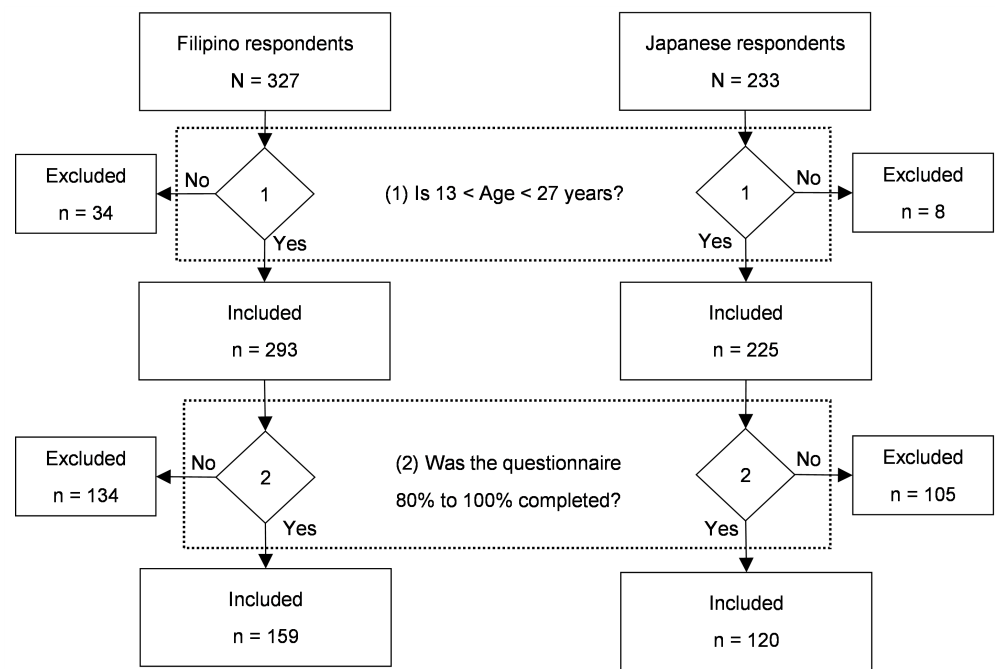


Figure 2.3 Screening process for the survey responses.

SPSS version 28 (IBM Corp., Armonk, NY, USA) was used for statistical tests and analysis. The chi-square homogeneity test was applied to determine the differences between the Filipino and Japanese participants regarding demographic data, such as age, gender, and esports team membership. The Mann–Whitney U Test was used for ordinal data, such as the number of playing years, playing frequency, and playing hours, to determine the differences in gaming habits. Spearman's correlation was used to assess the association of playing years, frequency, and hours with musculoskeletal pain. All statistical tests used a 5% significance level.

2.3 Results

2.3.1 Demographic characteristics

Table 2.1 presents a summary of the demographic characteristics of the participants. As shown in Table 2.2, the Japanese participants were significantly younger than the Filipino participants ($p < 0.001$). Most participants were male; however, more Filipino participants were female than Japanese participants ($p = 0.003$). A significantly higher number of Japanese participants were members of an esports team ($p < 0.001$). Table 2.3 shows that Filipino participants had significantly more playing years than Japanese participants ($p < 0.001$).

2.3.2 Gaming habits and playing environment

Table 2.4 presents the gaming-related data. On average, about 83% of Filipino and Japanese participants typically played using one to three types of gaming devices. Most of them (80%) also play multiple game genres. Filipino participants normally alternated among one to five kinds of games, while Japanese participants typically played one to three game genres.

Those who use a chair were asked about its features, and approximately 35% of Filipino and 53% of Japanese participants reported using a chair with at least height adjustment and a cushioned seat pan and backrest. About 80% of the players used no additional playing gear to improve their comfort or performance during a game.

Table 2.3 shows no significant difference in playing frequency between Filipino and Japanese participants ($p = 0.418$). However, in terms of average playing time, Filipino participants reported a significantly higher number of hours than Japanese participants ($p < 0.05$). Moreover, Japanese competitive players played significantly more frequently ($p = 0.011$) than Japanese recreational players (Table 2.5). Filipino competitive players were found to play for significantly longer hours ($p < 0.001$) than Filipino recreational players (Table 2.6).

Table 2.1 Characteristics of the participants.

Characteristic	Filipino, n = 159 (%)		Japanese, n = 120 (%)	
	Competitive	Recreational	Competitive	Recreational
Age				
14 to 17 years old	1 (2.5)	5 (4.2)	17 (36.2)	32 (43.8)
18 to 21 years old	27 (67.5)	59 (49.6)	15 (31.9)	36 (49.3)
22 to 26 years old	12 (30.0)	55 (46.2)	15 (31.9)	5 (6.9)
Gender				
Male	37 (92.5)	85 (71.4)	42 (89.4)	65 (89.0)
Female	3 (7.5)	31 (26.1)	5 (10.6)	5 (6.9)
Non-binary	0	2 (1.7)	0	2 (2.7)
Prefer not to say	0	1(0.8)	0	1(1.4)
With esports team/club				
Yes	12 (30.0)	4 (3.4)	40 (85.1)	55 (75.3)
No	28 (70.0)	115 (96.6)	7 (14.9)	18 (24.7)
No. of years played				
0 to 3	18 (45.0)	52 (43.7)	29 (61.7)	52 (71.2)
4 to 7	5 (12.5)	25 (21.0)	13 (27.7)	17 (23.3)
8 and above	17 (42.5)	42 (35.3)	5 (10.6)	4 (5.5)
Reason for playing				
School varsity	14 (35.0)	0	16 (34.0)	0
Profession	11 (27.5)	0	9 (19.2)	0
Tournament practice	15 (37.5)	0	21 (44.7)	0
Recreation	0	119 (100)	0	73 (100)
Others	0	0	1 (2.1)	0
Total	40 (100)	119 (100)	47 (100)	73 (100)

Table 2.2 Differences in the characteristics of Filipino and Japanese participants.

Proportion	Age		Gender		Esports Team Member	
	<18years	>18years	Male	Female	Yes	No
Japanese	0.408	0.592	0.915	0.085	0.792	0.208
Filipino	0.038	0.962	0.782	0.218	0.101	0.899
Chi-square (two- tailed)	$p < 0.001$		$p = 0.003$		$p < 0.001$	

Table 2.3 Differences in playing years, frequency, and time between Japanese and Filipino participants.

Participants	Playing years			Playing frequency			Playing time (hours)		
	U	z	Mean rank	U	z	Mean rank	U	z	Mean rank
Japanese	12529.5	4.96	115.09	8932.5	-0.81	143.06	11166.5	2.57	126.45
Filipino			158.80			135.89			150.23
Asymptotic sig. (2-sided test)		$p < 0.001$			$p = 0.418$			$p = 0.010$	

Table 2.4 Gaming habits and playing environment.

	Filipino, n = 159 (%)		Japanese, n = 120 (%)	
	Competitive	Recreational	Competitive	Recreational
Device used*				
Desktop Computer	32 (30.8)	74 (25.6)	34 (31.2)	43 (27.7)
Smartphone	29 (27.9)	89 (30.8)	20 (18.3)	28 (18.1)
Laptop	22 (21.1)	74 (25.6)	12 (11.0)	12 (7.7)
Nintendo Switch	4 (3.8)	10 (3.5)	18 (16.5)	29 (18.7)
PlayStation	10 (9.6)	16 (5.5)	16 (14.7)	34 (21.9)
XBOX	1 (1.0)	5 (1.7)	3 (2.8)	0 (0.0)
Tablet/lpad	5 (4.8)	19 (6.6)	2 (1.8)	6 (3.9)
Wii	1 (1.0)	1 (0.35)	2 (1.8)	2 (1.3)
Others	0 (0.0)	1 (0.35)	2 (1.8)	1 (0.7)
Factors (Device choice)*				
Comfort	29 (25.2)	86 (23.6)	36 (30.8)	58 (31.0)
Reliability	36 (31.3)	99 (27.1)	27 (23.1)	43 (23.0)
Price	24 (20.9)	93 (25.5)	34 (29.0)	48 (25.7)
Familiarity	15 (13.0)	52 (14.2)	6 (5.1)	21 (11.2)
Aesthetics	9 (7.8)	28 (7.7)	9 (7.7)	14 (7.5)
Others	2 (1.8)	7 (1.9)	5 (4.3)	3 (1.6)
Game genres played*				
FPS	31 (20.7)	84 (19.5)	27 (22.9)	46 (23.0)
MOBA	35 (23.3)	96 (22.3)	21 (17.8)	23 (11.5)
RPG	13 (8.7)	55 (12.8)	11 (9.3)	31 (15.5)
Sports	12 (8.0)	34 (7.9)	15 (12.7)	17 (8.5)
Fighting	15 (10.0)	41 (9.5)	14 (11.9)	25 (12.5)
TPS	17 (11.3)	42 (9.7)	10 (8.5)	16 (8.0)
Social Simulation	7 (4.7)	29 (6.7)	9 (7.6)	20 (10.0)
Real-time Strategy	10 (6.7)	24 (5.6)	3 (2.5)	4 (2.0)
Racing	7 (4.7)	23 (5.3)	5 (4.2)	9 (4.5)
Others	3 (2.0)	3 (0.7)	3 (2.5)	9 (4.5)
Playing Frequency				
Everyday	23 (57.5)	57 (48.7)	33 (70.2)	34 (46.6)
4 to 6 times a week	13 (32.5)	28 (23.9)	8 (17.0)	23 (31.5)
2 to 3 times a week	4 (10.0)	25 (21.4)	6 (12.8)	7 (9.6)
Once a week	0 (0.0)	3 (2.6)	0 (0.0)	5 (6.8)
2 to 3 times a month	0 (0.0)	2 (1.7)	0 (0.0)	3 (4.1)
Once every 2 months	0 (0.0)	2 (1.7)	0 (0.0)	1 (1.4)
Average playing time				
< 1 hour	0 (0.0)	1 (0.8)	1 (2.1)	2 (2.7)
1 to 2 hours	2 (5.0)	29 (24.4)	14 (29.8)	21 (28.8)
3 to 4 hours	11 (27.5)	61 (51.3)	17 (36.2)	33 (45.2)
5 to 6 hours	14 (35.0)	11 (9.2)	12 (25.5)	13 (17.8)
7 to 8 hours	9 (22.5)	9 (7.6)	2 (4.3)	2 (2.7)
9 to 10 hours	3 (7.5)	7 (5.9)	0 (0.0)	1 (1.4)
11 to 12 hours	1 (2.5)	1 (0.8)	0 (0.0)	0 (0.0)
More than 12 hours	0 (0.0)	0 (0.0)	1 (2.1)	1 (1.4)

* Multiple responses

Table 2.5 Differences in playing years, frequency, and time between Japanese competitive and recreational participants.

Japanese	Playing years			Playing frequency			Playing time (hours)		
	U	z	Mean rank	U	z	Mean rank	U	z	Mean rank
Competitive	1535.5	-1.18	64.33	1288.0	-2.56	69.60	1621.0	-0.54	62.51
Recreational			58.03			54.64			59.21
Asymptotic sig. (2-sided test)		$p = 0.239$			$p = 0.011$			$p = 0.591$	

Table 2.6 Differences in playing years, frequency, and time between Filipino competitive and recreational participants.

Filipino	Playing years			Playing frequency			Playing time (hours)		
	U	z	Mean rank	U	z	Mean rank	U	z	Mean rank
Competitive	2303.5	-0.33	81.91	1968.5	-1.63	88.29	1292.0	-4.57	107.20
Recreational			79.36			75.82			70.86
Asymptotic sig. (2-sided test)		$p = 0.743$			$p = 0.103$			$p < 0.001$	

2.3.3 Self-reported body discomfort, severity, and BCTQ

Figure 2.4 presents the types of pain or discomfort the participants have encountered. Most esports-related pain and discomfort reported by the participants affected the upper body regions. At least one upper-body pain or discomfort was reported by 55.4% of Filipino and 39.2% of Japanese participants, as shown in Table 2.7. Filipino participants reported a significantly higher prevalence of back pain ($p < 0.001$), hand pain ($p < 0.001$), neck pain ($p < 0.05$), wrist pain ($p < 0.001$), and eye discomfort ($p < 0.05$). Shoulder pain ($p = 0.107$) and other injuries ($p = 0.144$) were not significantly different between the Filipino and Japanese participants. Most of these participants (85%) healed by resting from playing esports. Table 2.8 summarizes the self-perceived discomfort ratings of the participants. Filipino participants reported higher discomfort ratings for all the body regions than Japanese participants.

Table 2.7 Differences in body pain between Japanese and Filipino participants.

Proportion	Back pain		Hand pain		Neck pain		Wrist pain	
	Yes	No	Yes	No	Yes	No	Yes	No
Japanese	0.117	0.883	0.075	0.925	0.150	0.850	0.125	0.875
Filipino	0.371	0.629	0.302	0.698	0.296	0.704	0.371	0.629
Chi-square (two- tailed)	$p < 0.001$		$p < 0.001$		$p < 0.05$		$p < 0.001$	

Proportion	Eye discomfort		Shoulder pain		Others	
	Yes	No	Yes	No	Yes	No
Japanese	0.208	0.792	0.125	0.875	0.042	0.958
Filipino	0.377	0.623	0.201	0.799	0.013	0.987
Chi-square (two- tailed)	$p < 0.05$		$p = 0.107$		$p = 0.144$	

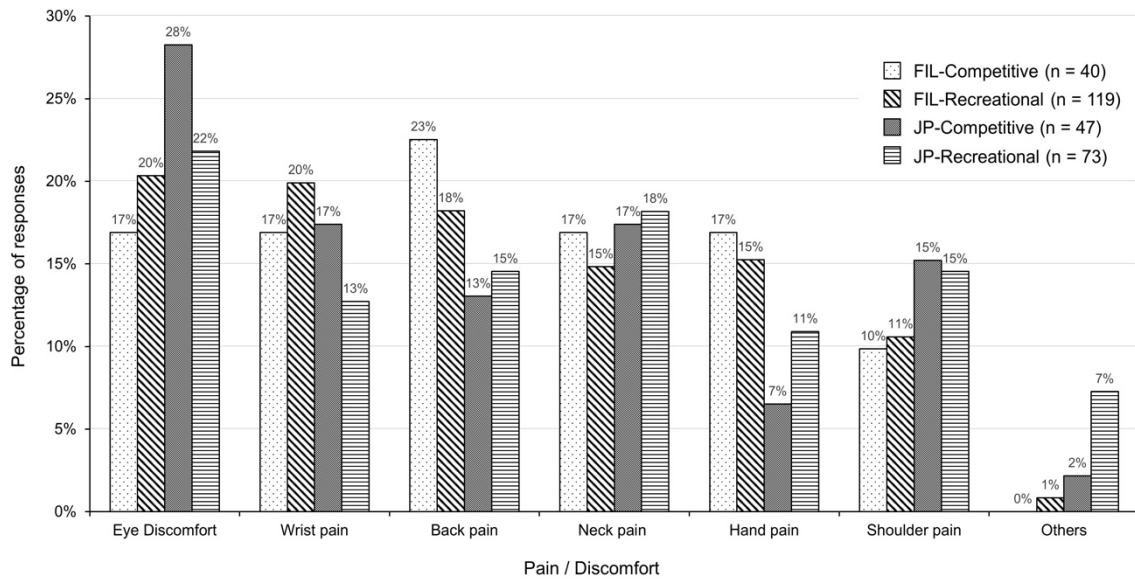


Figure 2.4 Types of pain or discomfort encountered by the participants.

Table 2.8 Percentage of participants who rated their discomfort as at least “Very uncomfortable.”

Body regions	Last 7 days		Last 6 months	
	Filipino n=159	Japanese n=120	Filipino n=159	Japanese n=120
Lower back	25.8	8.8	20.8	3.8
Hand and fingers	20.8	5.7	15.1	2.5
Upper and middle back	19.5	5.0	17.0	3.8
Wrist	17.0	4.4	13.2	4.4
Neck	13.8	4.4	11.9	5.0
Shoulders	11.9	3.8	10.1	5.7
Buttock	11.3	3.1	10.7	0.6
Upper arm	8.2	1.3	6.3	0.6
Thigh	6.3	1.3	5.7	0.0
Elbow	5.0	1.3	5.7	0.0
Head	4.4	1.3	6.3	3.1
Forearm	4.4	0.6	6.3	1.9
Leg and foot	4.4	0.6	5.0	0.6
Knee	3.1	0.0	3.8	0.6

The resulting BCTQ scores to assess the hand and wrist pain severities were low. Filipino participants showed an average symptom severity scale (SSS) score of 1.4 ± 0.5 and a functional

status scale (FSS) score of 1.2 ± 0.4 . Japanese participants had average scores of 1.1 ± 0.2 and 1.0 ± 0.1 for SSS and FSS, respectively. Based on these results, the hand and wrist conditions may be considered normal, without difficulty performing functions.

2.3.4 Awareness of injury prevention

The proportion of participants who performed warm-up ($p = 0.510$) or cooldown activities ($p = 0.195$) between Filipinos and Japanese had no significant difference. However, the proportion of competitive players who warmed up was significantly higher ($p < 0.05$) than that of recreational players. The proportion of players who cooled down after playing a game had no significant difference between competitive and recreational players. Figures 2.5 and 2.6 show the types of warm-up and cooldown activities performed by the participants.

Notably, some participants reported using the game or aiming software, such as Aim Lab, as a warm-up activity. Less than 5% of participants received training on injury prevention related to esports. However, about half of the participants were aware of some safety precautions when playing esports. Figure 2.7 shows the popular sources of information for preventing esports injuries among the participants.

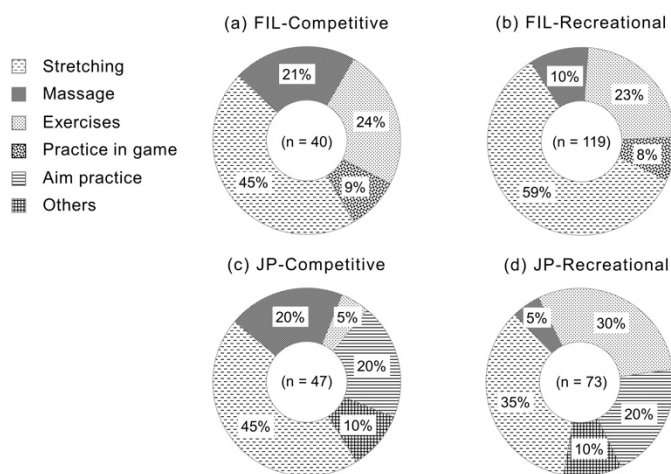


Figure 2.5 Warm-up activities used by the participants.

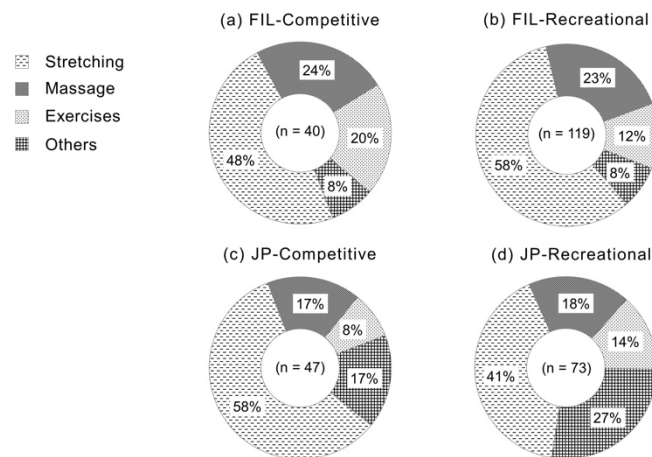


Figure 2.6 Cooldown activities used by the participants.

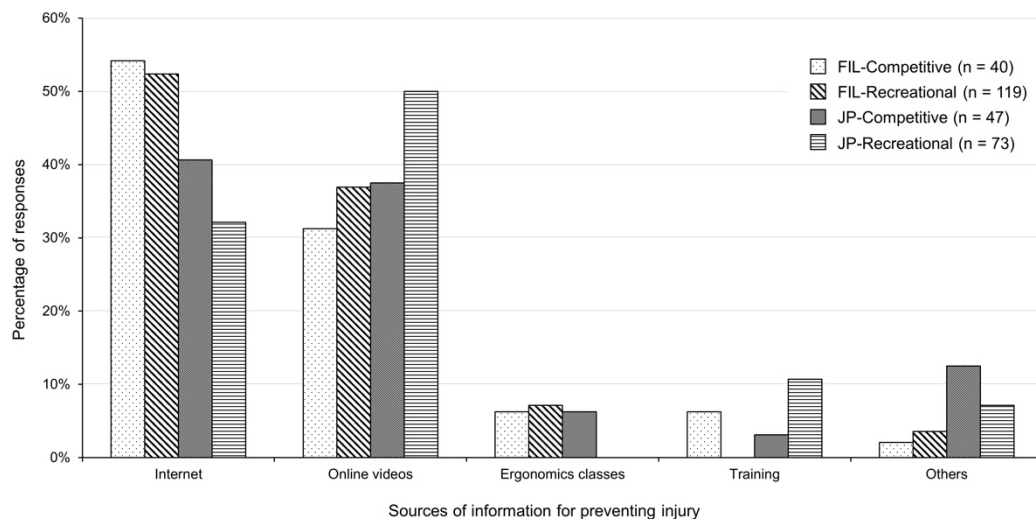


Figure 2.7 Sources of information by the participants.

2.3.5 Correlation of pain and playing years, frequency, and hours

From the Japanese participants' data, the number of playing years correlated positively with the presence of neck pain ($r_s = 0.229$, $p = 0.012$), shoulder pain ($r_s = 0.183$, $p = 0.045$), and wrist pain ($r_s = 0.350$, $p < 0.001$). The number of playing hours also correlated positively with

hand pain ($r_s = 0.194$, $p = 0.034$). The Filipino participants' data on the number of playing years, playing frequency, and playing hours had no significant correlation with body pain.

2.4 Discussion

2.4.1 Body pain/discomfort

Filipino participants reported a higher prevalence of musculoskeletal pain and discomfort than Japanese participants. This difference could be attributed to the age and playing years discrepancy between Filipino and Japanese participants. A similar trend of an increased incidence of gaming-related pain with increasing age was observed [33]. Filipino participants also reported a lower percentage of ergonomic chair use which could have increased the back and neck pain prevalences compared to Japanese participants. Another possible reason for this discrepancy is that pain perception is complex and subjective [33,85]. Some individuals may perceive mild pain as severe, while others may perceive it differently. This difference in perception poses a challenge for epidemiological studies.

Our findings on the body regions experiencing discomfort in esports participants were similar to those of previous studies. Collegiate esports players reported a higher prevalence of body discomfort [30]. The most frequent complaints were neck and back (42%), wrist (36%), and hand (32%) pain. The higher prevalence rates may be attributed to more intense practice for more extended hours (5.5–10 compared to the 3–4 hours of daily practice for half of our participants). Another study on Danish esports athletes [31] found similar prevalence rates of neck and shoulder pain compared to our study (11% vs. 15%), although their study found a higher prevalence of back pain. Their study involved players with a similar practice time of 3–3.8 hours daily. These patterns indicate that more extended and more intensive play increases the possibility of developing musculoskeletal pain.

Esports health risks were considered similar to those of office workers owing to being a screen-based activity and its sedentary nature [30,86] except that esports require rapid, accurate movements. One study found that if office workers perform typing at very high speeds, they may subject their neck and shoulder muscles to more significant strain, which results in increased discomfort [41]. Studies on computer users have found that the number of hours spent using a computer is significantly associated with musculoskeletal discomfort [87,88]. Furthermore, a significant relationship was found between the time spent using a smartphone or laptop daily and the intensity of musculoskeletal pain in the neck, shoulder, and back [89]. These findings suggest the need to implement a time limit for using these devices in esports or office work by including micro-breaks within the session or implementing a daily limit set to facilitate body recovery.

The positive correlation between the number of playing years and pain (in the wrist, neck, and shoulders) agreed with the findings of study among office workers [90]. The researchers found that the number of years doing office work was a crucial occupational factor associated with neck or lower back pain. Another study found that elbow pain was more frequently reported among computer workers who had worked for more than five years [88]. These findings suggest that the number of playing years (or career duration for office workers) signifies the physical strain accumulating over time.

2.4.2 Injury prevention awareness among esports players

The turnout of participants in injury prevention programs and those who performed warm-up and cooldown activities for esports could have been higher, considering that approximately 40% were members of esports teams. Formal workstation ergonomics training reduces musculoskeletal complaints and stress due to increased awareness of workplace risks, improving the workers' postures, practices, and behavior [91]. This ergonomic training may also improve player gaming conditions.

2.4.3 Limitations

A potential limitation of the study includes sampling bias, such as the expansive intake of participants ranging from recreational to professional players aged 14–26 years. The turnout in responses was higher for Japanese participants aged 14–17 years, which might have made the prevalence and severity ratings of the body regions lower for this group. Due to the limited number of professional players who participated in the survey, the author could not draw any conclusions regarding the population. BCTQ was used for assessing hand and wrist pain or discomfort for convenience in the online questionnaire and may be insufficient for measuring hand symptom severity.

Additionally, there was a potential recall bias among participants, such as when they were asked about their body discomfort status six months prior to the questionnaire. Those who have played esports for less than six months were also allowed to skip questions on discomfort in the last six months. Esports is also a rapidly growing industry, and new devices, games, and software can soon appear; therefore, newer trends might not fall under the scope of this study.

Future research should explore gaming-related factors to understand better the multiple variables influencing self-reported body discomfort in esports. Studying the effects of a specific playing setup could help prevent musculoskeletal pain in players.

2.5 Conclusions

It was found that Filipino and Japanese esports players experienced musculoskeletal pain in the back, neck, wrists, hands, and shoulders. The number of playing years was associated positively with neck, shoulder, and wrist pain among the Japanese participants. Additionally, an increased number of playing hours correlated positively with hand pain.

Chapter 3 Effects of Gamepads and Button Operations on the Median Nerve

3.1 Introduction

Active finger flexion causes gliding of the flexor tendons and the median nerve [92]. The subsynovial connective tissue (SSCT) allows for this type of movement due to its multilayered structure that can stretch during gliding [61]. The gliding of flexor tendons inside the carpal tunnel due to single-digit movements can compress and deform the median nerve [93,94]. During isolated flexion of the middle finger, the flexor digitorum superficialis (FDS) tendon moves toward the flexor retinaculum; however, given that the median nerve slightly blocks this movement, it remains compressed between the FDS and the flexor retinaculum [94]. Remarkably, in healthy individuals or when the fingers move together (to form a fist), the median nerve can avoid maximum compression from the tendons by gliding in the radial or ulnar direction [93,94].

Playing esports involves rapid and repetitive movements of the hands, wrists, and fingers are involved. Differential finger movements occur and deviated wrist postures may also be required depending on how the player holds the gamepad. A combination of these movements and postures could increase the risk of carpal tunnel syndrome (CTS). However, there are only a few studies on the effects of using gaming controllers on the median nerve have been conducted to date. Notably, relevant studies on the effects of use of smartphones and computer keyboards have been published [43,95–97]. Some studies have been conducted to determine the effects of general smartphone use on the median nerve and other CTS symptoms [95,96]. One study revealed that students who use smartphones frequently for texting, emailing, scheduling, playing, and internet browsing show a significantly increased the cross-sectional area of the median nerve and the flexor pollicis longus (FPL) tendon [95]. Similarly, another study found that intensive use of electronic devices (≥ 5 hours per day), such as tablets and smartphones, significantly increases the cross-sectional area of the median nerve [96]. Moreover, a study that included healthy individuals and patients with CTS indicated that the risk of CTS increases with excessive daily smartphone use [97]. The researchers hypothesized that the

repetitive wrist flexion-extension and loading of the thumb increases the cross-sectional area of the median nerve and the risk of CTS.

Other related studies were focused on keyboard typing and its effects on the median nerve. Although the results of these studies regarding the correlation between computer typing and the development of CTS are contradictory, most studies identified relationships between these factors [43]. Researchers found that typing with a wrist posture closer to the neutral position can minimize the morphological median nerve changes that occur during typing [47,96]. Another study demonstrated that increased typing force increases the risk of CTS because the flexor tendon forces are 4 to 7 times higher than the actual fingertip force observed [98]. Additionally, faster typing speeds and longer key travel distance can impede the recovery of the SSCT and increase the risk of injury because it naturally has a slower response to the gliding of tendons [61]. These previous studies indicate that wrist posture, typing force, and typing speed are associated with the changes in the median nerve when typing with a computer keyboard.

Currently, there are no studies on the use of gamepads and its dynamic effects on the median nerve. Therefore, this study was conducted to determine whether the use of gamepads affects the median nerve. The first hypothesis of this study is that the repetitive fast and differential finger movements involved in the use of gamepads for esports compress the median nerve. Gamepads used for console gaming come in various sizes. However, only two sizes of gamepads were used in this study: the Nintendo Switch Joy-cons mounted on a comfort grip and the PS5 DualSense gamepad. These gamepads were selected for this study because the use of consoles, such as Switch and PlayStation, is a popular gaming mode among esports players. The second hypothesis of this study is that using a bigger gamepad would cause more compression to the median nerve than using a smaller gamepad because the bigger gamepad has larger buttons with farther travel distances than the smaller gamepad. Therefore, the main objective of this study was to evaluate the changes in median nerve morphology, including cross-

sectional area (MNCSA), circularity, longitudinal diameter (D1), and transverse diameter (D2), that occur while using two sizes of gamepad for simulated and actual gaming. In addition, the study analyzed whether there is a difference in these metrics between holding versus using a gamepad.

3.2 Materials and methods

3.2.1 Participants

Seven healthy male and seven healthy female participants were recruited for this study (Table 3.1). The inclusion criteria were as follows: no injury of the upper limbs, must be right-handed, must have played video games before, and provided informed consent to participate in the study. The Flinders Handedness survey (FLANDERS) [99] was used to determine the handedness of the participants. Anthropometric measurements of the hands, such as hand, thumb, index, and middle finger lengths and widths, were taken. This study was approved by the Ethics Committee of the Faculty of Design, Kyushu University (Approval number: 403).

Table 3.1 Characteristics of the participants (n = 14).

	Male (n = 7)		Female (n =7)	
Age (years)	23.0 ± 1.5		27.0 ± 4.4	
Height (cm)	175.7 ± 5.1		158.1 ± 3.6	
Handedness Score	9.4 ± 1.0		9.4 ± 1.0	
	Right	Left	Right	Left
Hand length (mm)	18.6 ± 0.4	18.6 ± 0.4	16.4 ± 0.5	16.4 ± 0.5
Hand width (mm)	8.7 ± 0.4	8.7 ± 0.5	7.9 ± 0.4	7.8 ± 0.4
Thumb length (mm)	6.5 ± 0.4	6.5 ± 0.4	5.8 ± 0.2	5.7 ± 0.2
Thumb width (mm)	1.4 ± 0.1	1.4 ± 0.1	1.1 ± 0.1	1.1 ± 0.1
Index finger length (mm)	6.5 ± 0.4	6.6 ± 0.3	5.8 ± 0.2	5.7 ± 0.3
Index finger width (mm)	0.9 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
Middle finger length (mm)	7.3 ± 0.3	7.3 ± 0.3	6.4 ± 0.1	6.4 ± 0.2
Middle finger width (mm)	1.0 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1

3.2.2 Ultrasound Examination Protocol

The LOGIQ e ultrasound system (GE Healthcare, USA), equipped with a 12L-RS transducer (imaging frequency bandwidth of 5–13 MHz) and a depth of 40 mm, was used for the assessment of changes in median nerve morphology. The coupling agent used was a 3.0 mm thick hydrogel pad (Kikgel, Ujazd, Poland), which was attached to the ultrasound transducer using a plastic wrap (Fig. 3.1). This prevented the hydrogel pad from dropping while in use. The transducer was carefully placed on the wrists of the participants during the examination to avoid exerting pressure on the median nerve.

Two plastic L-frames were used to guide proper placement of the transducer on the wrists of the participants (Fig. 3.2). The longer end of the L-frame was attached to the ulnar bone of each participant, while the perpendicular shorter end was aligned to the crease of the wrist. The transducer was kept perpendicular to the wrist by following the shorter end of the L-frame. The transducer was placed on the crease of the wrist to examine the median nerve in the transverse

plane at the proximal end of the carpal tunnel. The hyper-echogenic rim encapsulating the hypo-echogenic nerve fascicles was used as a guide for recognizing the median nerve at the superficial level [92].



Figure 3.1 Hydrogel pad attached to the transducer.



Figure 3.2 L-frames used in the study.

Gamepads

The two gamepads used in this study were the DualSense gamepad (PS) (Sony Interactive Entertainment LLC, California, USA) and the Switch Joy-cons (SW) attached to a comfort grip (Nintendo Co., Ltd., Kyoto, Japan). The PS gamepad (Fig. 3.3) is bigger and heavier than the SW gamepad (Fig. 3.4). In addition, their button layouts differ slightly, specifically in the

placement of the analog sticks. The PS analog sticks are aligned to each other in the middle of the gamepad, whereas the SW analog sticks are placed diagonal to each other. Table 3.2 shows the travel distance for each button when pressed or tilted. The measurements were taken by the author using a ruler and a manual goniometer (Nihon Medix, Co. Ltd., Chiba, Japan). The maximum travel distance for the analog sticks (L) was computed in mm using the following formula (based on the arclength formula) [100].

$$L = r \times \theta$$

where r is the length of the analog stick (mm)
 θ is the tilt angle from the original position (radians)

Table 3.2 Measured travel distances for each button on the gamepads.

Button	Travel distance (mm)	
	DualSense (PS)	Joy-cons (SW)
Action buttons	1.0	0.5
Triggers	10.0	1.0
Bumpers	1.0	0.5
Analog stick	3.05	1.05
Analog stick (max. tilt angle)	25°	10°
Analog stick (height)	7.0	6.0



Figure 3.3 PS gamepad buttons and dimensions.

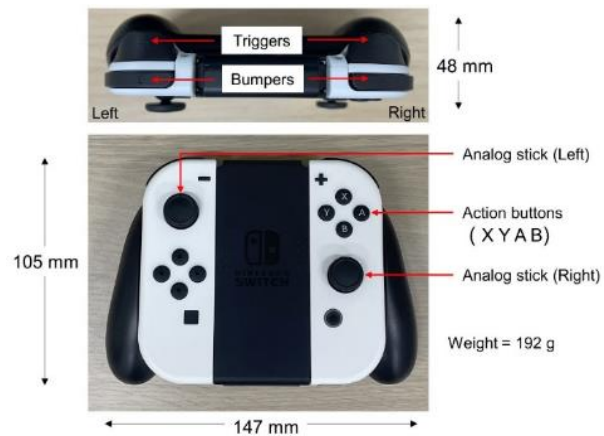


Figure 3.4 SW gamepad buttons and dimensions.

Neutral, PS Grip, and SW Grip

Each participant was seated with his/her feet placed flat on the floor and knees positioned at 90°. Fig. 3.5a shows the Neutral hand position used in this study. In this position, the participant's forearm was placed supinated on a towel draped on a table. In the PS Grip position, the participant's forearms were positioned laterally while holding a PS gamepad (Fig. 3.5b). Similarly, in the SW Grip position, the participant's forearms were positioned laterally while holding a Switch gamepad (Fig. 3.5c). Two 16-second ultrasound videos of each wrist were recorded with the arms of the participants in the three abovementioned positions.

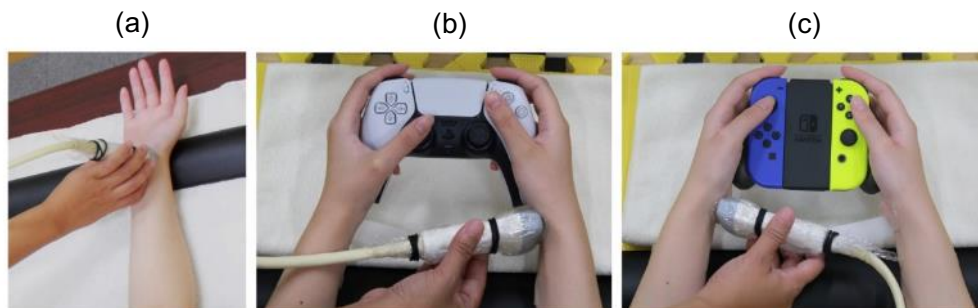


Figure 3.5 Hand positions at (a) Neutral, (b) PS Grip, and (c) SW Grip.

Simulated gaming

During the simulated gaming, eight sets of instructions were alternately posted in front of each participant to follow. The instructions were used to simulate the use of buttons or the execution of operations available in the gamepads. Each gamepad had one set of instructions for the analog stick L (left), analog stick R (right), trigger and bumper (right only), action buttons (right) (Figs. 3.6 to 3.9). Only one wrist was observed at a time. For example, if the participant was using the right hand to operate the action buttons, the left hand served as support only for the left side of the gamepad.

These instructions were initially discussed with the participants, and they were instructed to practice them for five minutes. The speed of executing the instructions was timed at 200 bpm using a digital quartz metronome (Yamaha Corp., Shizuoka, Japan). Each tile on the instruction sheet represented a beat on the metronome. Several tiles denoted prolonged press or rotation of a button. For the analog sticks (Figs. 3.6 and 3.7), the arrows represented the direction of the push or rotation. The instructions showed the participants the exact buttons to press (Figs. 3.8 and 3.9).

Once the participant was ready, he/she was requested to follow the instructions for approximately two minutes. Meanwhile, three 16-second ultrasound video clips were recorded during the examination. A five-minute break was taken after the fourth set of instructions was completed. The procedure was repeated until all the eight instructions were completed.

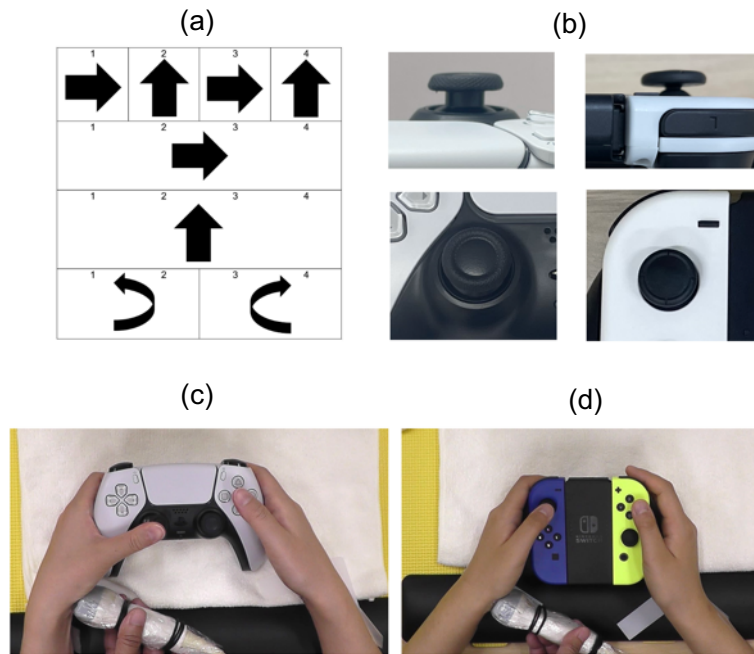


Figure 3.6 Left analog stick (a) Instructions, (b) magnified buttons, and finger positions for (c) PS and (d) SW gamepads.

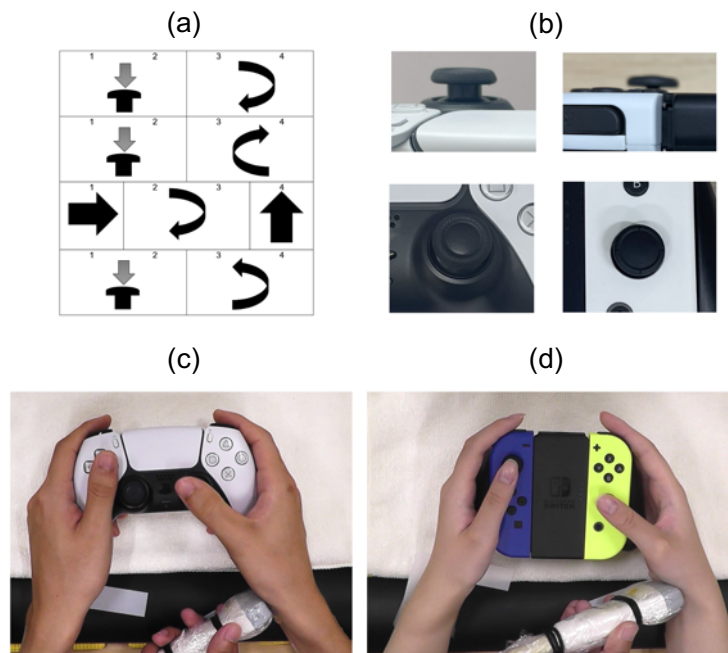


Figure 3.7 Right analog stick (a) instructions, (b) magnified buttons, and finger positions for (c) PS and (d) SW gamepads.



Figure 3.8 Trigger and bumper instructions and finger positions for (a) PS and (b) SW gamepads.

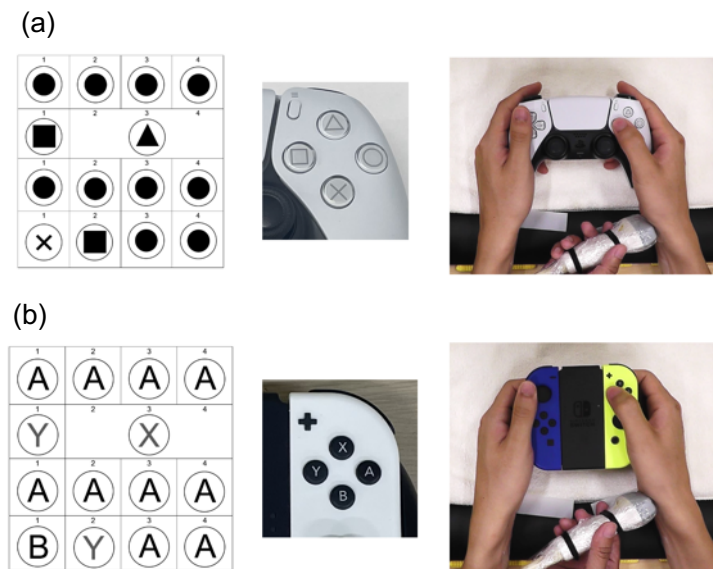


Figure 3.9 Action buttons instructions and finger positions for (a) PS and (b) SW gamepads.

Actual gaming

The console used for the actual gaming was a Switch OLED (Nintendo Co., Ltd., Kyoto, Japan) in TV mode. A USB wireless gamepad adapter (Mayflash Ltd., Guangdong, China) was used to connect the DualSense gamepad to the console. Each participant was asked to practice the game, Pokémon Unite (The Pokémon Company, Tokyo, Japan). This game is a multiplayer online battle arena (MOBA) game and requires simple and straightforward use of the gamepad buttons compared to fighting games. Movements of the hands and fingers during gameplay are highly repetitive.

The participants completed a 15-minute tutorial and a 10-minute practice game and were allowed to rest for 5 minutes before playing the actual game. Each participant was given the goals of scoring at least 60 points and defeating the enemy twice during the gaming session. This was to ensure that the participant played actively during the experiment. Each participant played the game for 10 minutes while the examiner was recorded three 16-second ultrasound videos of the left and right wrists (Fig. 3.10).



Figure 3.10 Taking ultrasound images during actual gaming.

3.2.3 Image processing and analysis

The ultrasound video clips were converted to images using VLC media player (VideoLAN, Paris, France). The recording ratio used was 10, resulting in two images per second of the video. Thirty images, corresponding to 30 seconds of video, were taken for each condition in the experiment. The median nerve images were analyzed using Image J software (Schneider, Rasband, and Eliceiri, 2012). The tracing method [101] was used to identify the median nerve, then the minimum bounding rectangle method was used for approximate measurement of the MNCSA, D1, D2, and circularity. The median nerve was traced along the hyperechogenic rim, and the Multi Measure plugin of the Image J software was used to conveniently trace five images at a time. The MNCSA, circularity, D1, and D2 were measured using the Measure function.

MNCSA is the “primary sonographic parameter for assessing and diagnosing median nerve pathology, such as CTS” [102]. Increased MNCSA is associated with degradation of nerve conductivity [103,104] and hand/wrist pain [96]. Studies of similar populations revealed that normal MNCSA at the proximal carpal tunnel ranges from 8.60 to 9.33 mm² [105,106]. A normal upper limit of 10 mm² has been recommended in previous studies [106,107].

Circularity is a value calculated using the cross-sectional area (CSA) and perimeter of the median nerve as illustrated by the equation below [108,109]. It is used to indicate how close the shape of the median nerve is to a circle. A rounder than a flattened shape is better because flattening of the nerve indicates compression [108]. Moreover, more flattened median nerve is related to wrist/hand pain [96]. However, the use of circularity as a measure is limited in that it cannot indicate the direction of the compression. Thus, the longitudinal (D1) and transverse diameters (D2) of the median nerve were also measured in this study (Figure 3.11). A lower D1 indicates compression stress in the vertical directions, while a lower D2 indicates compression stress in the horizontal directions.

$$Circularity = \frac{4\pi CSA}{perimeter^2}$$

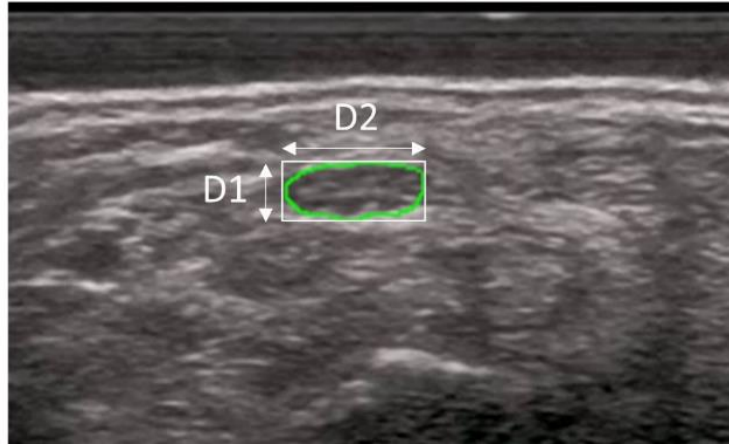


Figure 3.11 Traced median nerve, D1, and D2.

The data obtained from the experiments were collated and saved in an MS Excel file. The mean values of MNCSA, circularity, D1, and D2 were computed from the 30 images measured. The change in the median nerve at time i was characterized using $\%Change_i$. The median nerve measurement recorded at time i (MNCSA, circularity, D1, and D2) was compared with that obtained at time $i - 1$. The percentage change per second was computed using the following formula:

$$\%Change_i = \frac{|Measurement_i - Measurement_{i-1}|}{Measurement_{i-1}} \times 100\%$$

where i is the time in seconds
 $Measurement_i$ is the value at time i
 $Measurement_{i-1}$ is the previous value at $i - 1$

3.2.4 Statistical analysis

All statistical analyses were performed using SPSS version 28.0 (IBM Corp., Armonk NY, USA). The Shapiro-Wilk test and visual inspection of histograms and normal Q-Q plots were

used to test the normality of the MNCSA, D1, D2, and circularity data. Given that the statistical tests used were robust with the presence of outliers or violations in normality, outliers were included in the analysis [110,111].

The paired-samples t-test was used to compare differences in median nerve data between the two gamepads, and the difference between each gamepad operation and neutral. Cohen's D was used as the indicator of effect size. One-way repeated measures analysis of variance (ANOVA) was used to compare the effects of the button operations (Analog R, Action, and Trigger R). All statistical tests were conducted at a 0.05 level of significance. Data are presented as mean $\pm$ standard deviation, unless otherwise stated.

3.3 Results

3.3.1 Effects of PS Grip and SW Grip on the median nerve

The Shapiro-Wilk test, histograms, and normal Q-Q plots showed that the MNCSA, circularity, D1, and D2 data were approximately normally distributed. The mean MNCSA, circularity, D1, and D2 when holding no gamepad (Neutral), holding a PS gamepad (PS Grip), and holding a Switch gamepad (SW Grip) in the left and right sides are summarized in Table 3.3.

The paired samples t-test revealed a statistically significant decrease in MNCSA in the SW Grip position compared to Neutral for both the left and right sides. However, no significant change in circularity, D1, and D2 in this position was observed. No significant change in MNCSA, circularity, D1, and D2 in the PS Grip position was observed. Table 3.3 presents the results of the paired samples t-test with the corresponding effect sizes.

Table 3.3 Median nerve data and results of the paired samples t-test for the comparison of the Neutral, PS Grip, and SW Grip positions.

		Mean $\pm$ SD			PS Grip vs. Neutral		SW Grip vs. Neutral	
		Neutral	PS Grip	SW Grip	<i>p</i> value	Effect Size	<i>p</i> value	Effect Size
MNCSA	Left	8.79 $\pm$ 0.57	8.66 $\pm$ 0.35	8.63 $\pm$ 0.48	0.101	-0.472	0.024*	-0.684
	Right	8.9 $\pm$ 0.55	8.72 $\pm$ 0.34	8.66 $\pm$ 0.52	0.067	-0.533	0.004*	-0.924
Circularity	Left	0.59 $\pm$ 0.08	0.56 $\pm$ 0.12	0.57 $\pm$ 0.11	0.313	-0.281	0.303	-0.287
	Right	0.55 $\pm$ 0.06	0.52 $\pm$ 0.09	0.56 $\pm$ 0.09	0.361	-0.253	0.701	0.105
D1	Left	2.18 $\pm$ 0.32	2.14 $\pm$ 0.38	2.29 $\pm$ 0.39	0.742	-0.090	0.432	0.217
	Right	1.99 $\pm$ 0.20	2.07 $\pm$ 0.35	2.09 $\pm$ 0.35	0.456	0.205	0.316	0.279
D2	Left	6.07 $\pm$ 0.50	6.30 $\pm$ 1.02	6.20 $\pm$ 0.91	0.412	0.227	0.303	0.141
	Right	6.47 $\pm$ 0.60	6.59 $\pm$ 0.73	6.32 $\pm$ 0.73	0.251	0.185	0.243	-0.191

*Statistically significant

L, Left; R, Right; Neutral, no gamepad; PS Grip, holding a PS gamepad; SW Grip; holding a Switch gamepad

3.3.2 Comparison of the effects of gamepad use on the median nerve

Differences between Neutral and the PS and SW Grips

Figs. 3.12a and b present the mean of MNCSA for the Neutral position and all gamepad operations (PS Analog, SW Analog, PS Action, SW Action, PS Trigger, SW Trigger, PS Game, and SW Game) for the left and right sides, respectively. The paired samples t-test showed the MNCSAs recorded during all gamepad operations were significantly smaller than that recorded in Neutral.

For the left side, the median nerve circularity recorded in Neutral L was not significantly different from those recorded during all gamepad operations (Fig. 3.12c). The paired samples t-test revealed that the circularity recorded while using PS Analog R was significantly higher than that recorded in Neutral R (Fig. 3.12d). For the right side, the circularity values recorded during the other gamepad operations were not significantly different from those recorded in Neutral R.

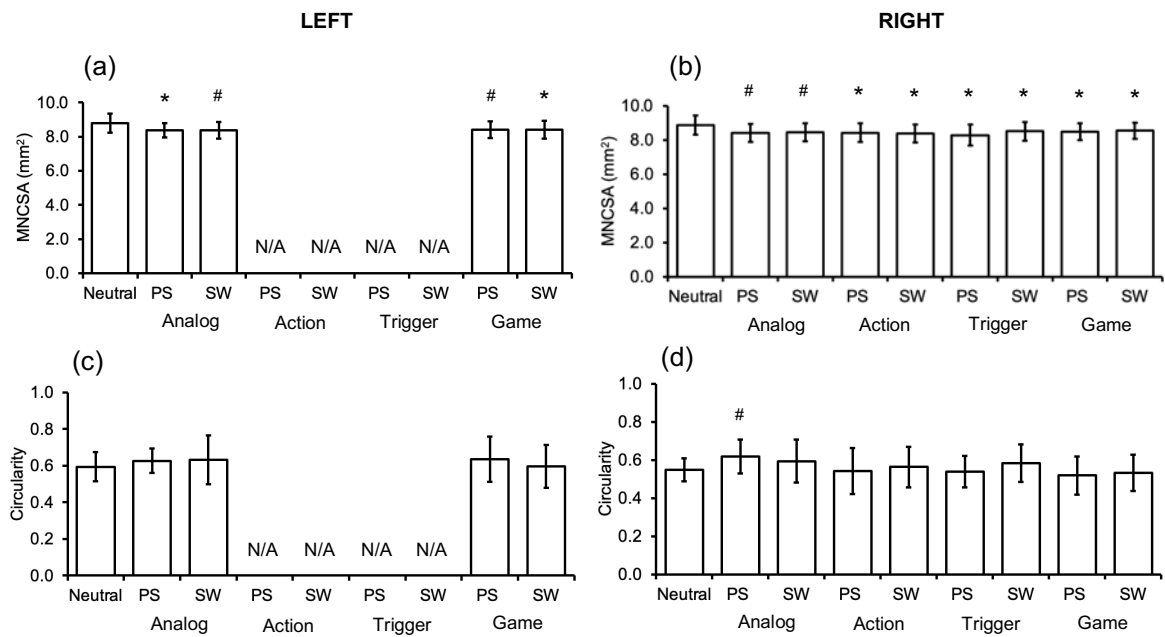


Figure 3.12 (a) Left MNCSA, (b) Right MNCSA, (c) Left circularity, and (d) Right circularity of Neutral vs. Gamepad operations.

(* $p < 0.001$, # $p < 0.01$, $n = 14$).

Note: Neutral – no gamepad, PS – PS gamepad, SW – Switch gamepad, N/A – Not applicable.

The median nerve longitudinal diameter (D1) data are presented in Figs. 3.13a and b. All D1 data for the left side were not significantly different from those recorded in Neutral (Fig. 3.13a). For the right side, the mean D1 for PS Analog, SW Analog, SW Action, and SW Trigger were significantly higher than that for Neutral (Fig. 3.13b).

Figs. 3.13c and d present the median nerve transverse diameter (D2) for Neutral and all gamepad operations. For the left side, the paired samples t-test indicated that the D2 recorded while using PS Analog was significantly narrower than that recorded in Neutral by 0.45 mm (Fig. 3.13c). Similarly, the right D2 recorded while using PS Analog, SW Analog, and SW Trigger were significantly narrower than that recorded in Neutral (Fig. 3.13d).

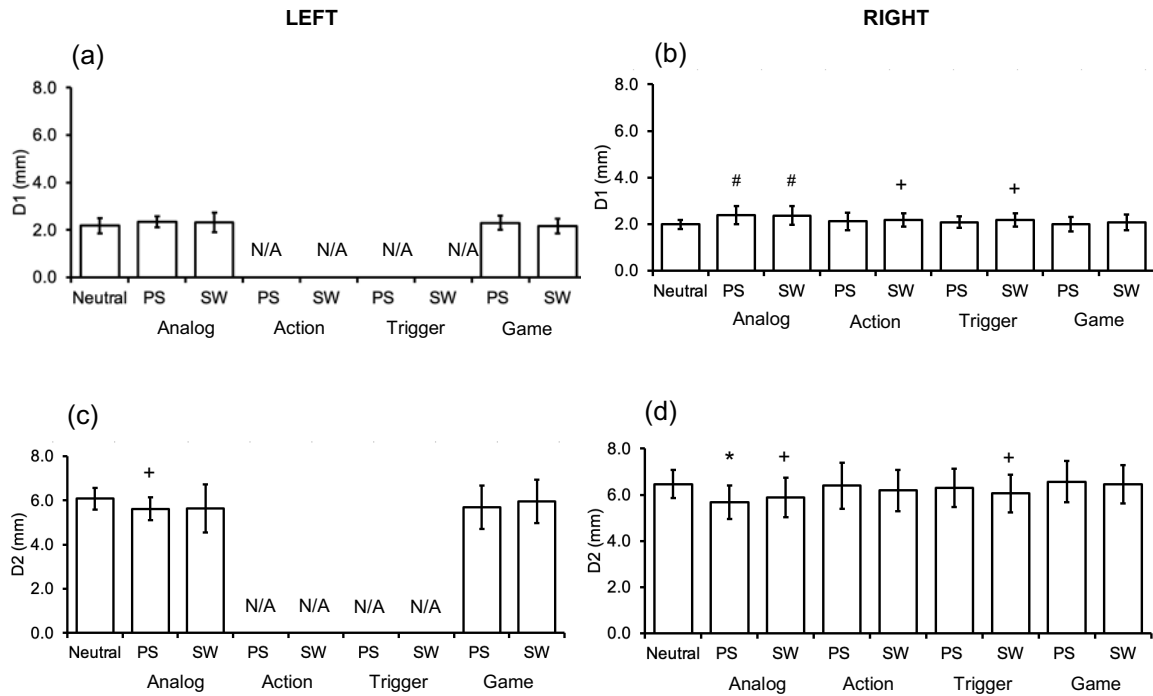


Figure 3.13 (a) Left D1, (b) Right D1, (c) Left D2, and (d) Right D2 of Neutral vs. Gamepad operations.

(* $p < 0.001$, # $p < 0.01$, + $p < 0.05$, $n = 14$)

Note: Neutral – no gamepad, PS – PS gamepad, SW – Switch gamepad, N/A – Not applicable.

Differences in using the two types of gamepads

The results of the paired samples t-test showed that the MNCSA recorded while using SW trigger R was significantly larger than that recorded while using PS trigger R by 0.23 mm² (Fig. 3.14a). There were no significant differences in other gamepad operations between the PS and SW gamepads. Median nerve circularity (Fig. 3.14b) measured while using SW Trigger R was significantly higher than that measured while using PS Trigger R by approximately 0.04 mm. In addition, the circularity measured while using PS Game L was significantly higher than that measured while using SW Game L by 0.04 mm. The paired samples t-test showed that the longitudinal diameter (D1) for PS Game L was significantly longer than that for SW Game L (Fig.

3.15a). Correspondingly, the transverse diameter (D2) measured while using PS Game L was significantly narrower than that measured while using SW Game L (Fig. 3.15b).

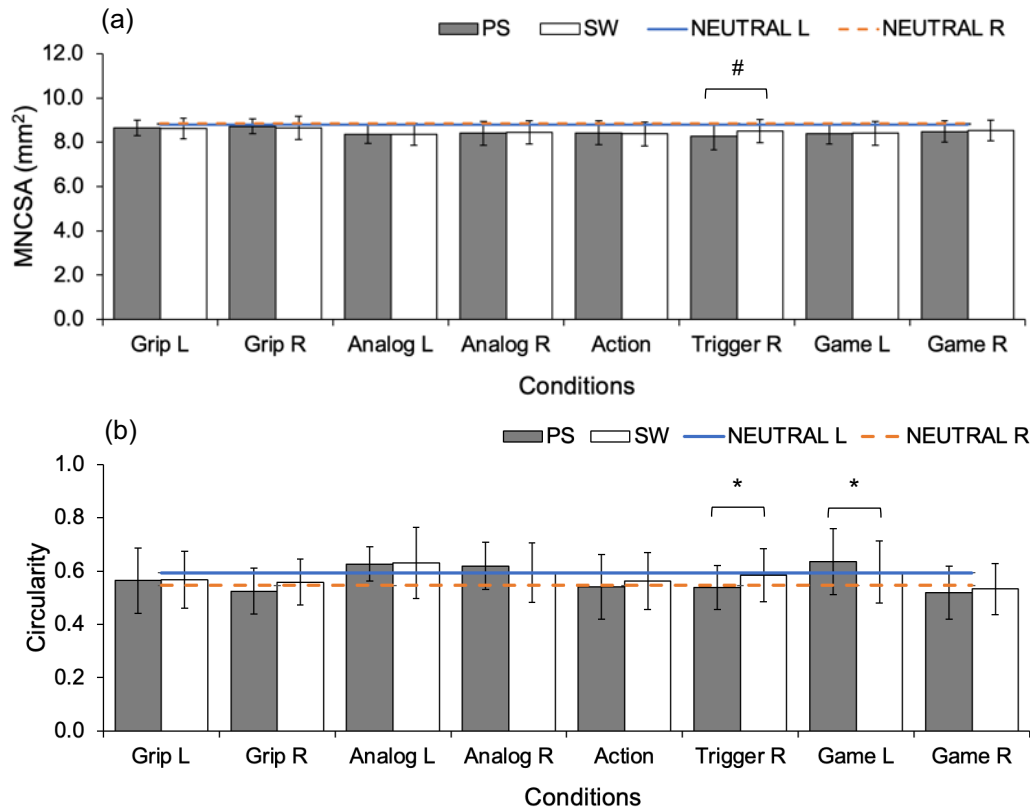


Figure 3.14 (a) MNCSA and (b) Circularity for each operation.
 (# $p < 0.01$, * $p < 0.05$, $n = 14$).

Note: PS – DualSense gamepad, SW – Switch gamepad, L – Left, R – Right, Neutral – no gamepad, Grip – holding a gamepad, Analog – analog stick, Action – action buttons, Trigger – trigger and bumper, Game – an actual game

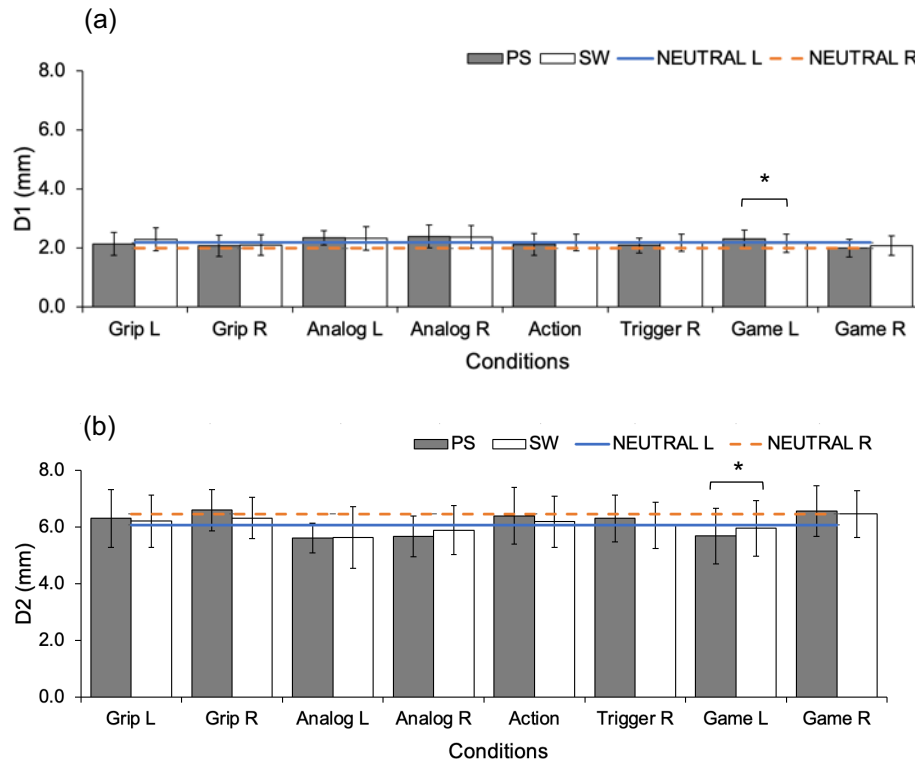


Figure 3.15 (a) D1 and (b) D2 for each operation ($*p < 0.05$, $n = 14$).

Note: PS – DualSense gamepad, SW – Switch gamepad, L – Left, R – Right, Neutral – no gamepad, Grip – holding a gamepad, Analog – analog stick, Action – action buttons, Trigger – trigger and bumper, Game – an actual game

3.3.3 Comparison of the effects of button types on the median nerve

The one-way repeated measures ANOVA post-hoc test revealed that for the PS gamepad, the MNCSA measured when using Trigger R was significantly smaller than that measured when using the Analog R button by 0.139 mm^2 (Fig. 3.16a). Similarly, the circularity of the median nerve measured while using Trigger R was significantly lower than measured while using Analog R by 0.079 (Fig. 3.16b). There was no significant difference in D1 among the three buttons (Fig. 3.17a). However, D2 measured while using Trigger R were significantly wider than that measured while using the Analog R button by 0.626 mm (Fig. 3.17b).

For the SW gamepad, the results of the one-way repeated measures ANOVA post-hoc test showed that the MNCSAs measured while using the Action and Trigger R buttons were

significantly different (Fig. 3.18a). Specifically, the MNCSA measured while using the Action button was higher by 0.12 mm². There was no significant difference in circularity, D1, and D2 among the three buttons (Figs. 3.18b, 3.19a and b).

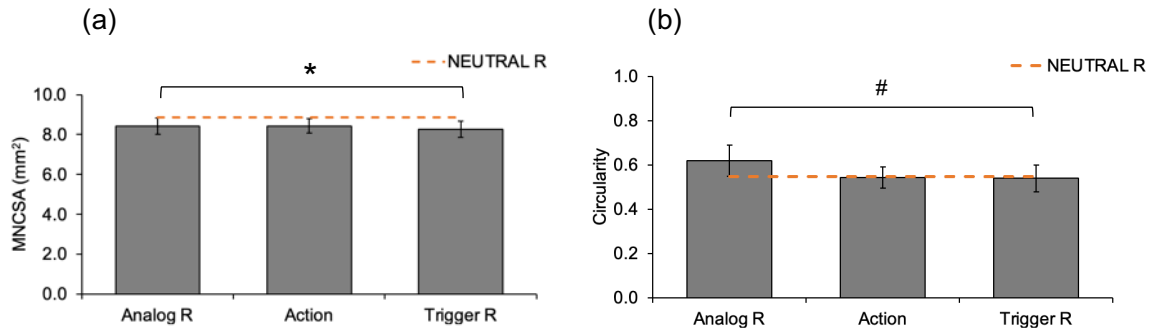


Figure 3.16 (a) MNCSA and (b) circularity when using a PS gamepad.
(* $p < 0.05$, # $p < 0.01$, $n = 14$)

Note: Neutral – no gamepad, PS – DualSense gamepad, R – Right, Analog – analog stick, Action – action buttons, Trigger – trigger and bumper

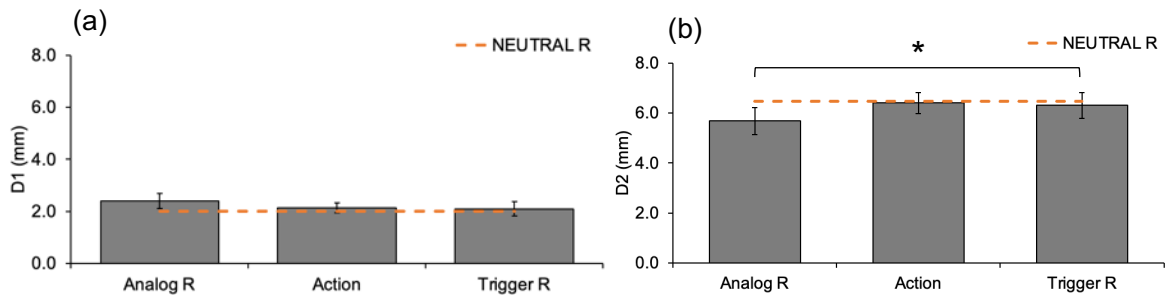


Figure 3.17 (a) D1 and (b) D2 when using a PS gamepad. (* $p < 0.05$, $n = 14$)

Note: Neutral – no gamepad, PS – DualSense gamepad, R – Right, Analog – analog stick, Action – action buttons, Trigger – trigger and bumper

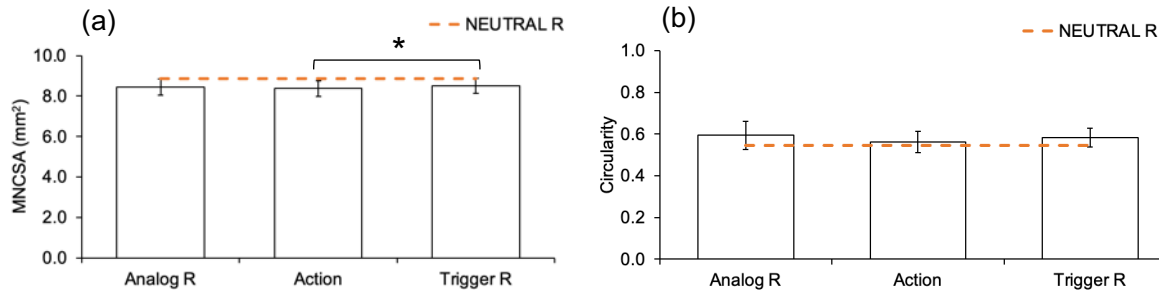


Figure 3.18 (a) MNCSA and (b) circularity when using SW gamepad.
(* $p < 0.05$, $n = 14$)

Note: Neutral – no gamepad, R – Right, Analog – analog stick, Action – action buttons, Trigger – trigger and bumper, SW – Switch gamepad

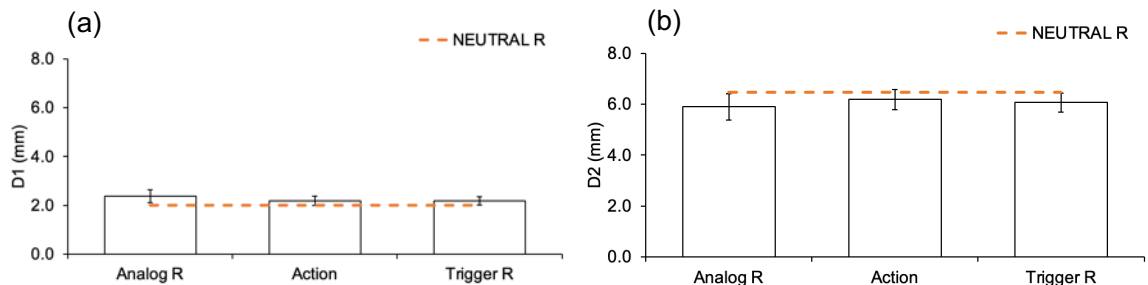


Figure 3.19 (a) D1 and (b) D2 when using SW gamepad.

Note: Neutral – no gamepad, SW – Switch gamepad, R – Right, Analog – analog stick, Action – action buttons, Trigger – trigger and bumper

3.3.4 Dynamic changes in the median nerve during actual gaming

The MNCSA, circularity, D1, and D2 data recorded per second were largely normally distributed. The one-way repeated measures ANOVA showed that the use of the gamepads did not lead to significant dynamic change in MNCSA, circularity, and D2 (Table 3.4). Although the main effect of gamepad use on MNCSA was not significant, the largest change in MNCSA was observed while using the SW gamepad with the left hand (SW Game L), followed by using the PS gamepad (PS Game L); the smallest change in MNCSA was observed in Neutral L. For the right side, the largest MNCSA change was observed while using the PS gamepad (PS Game R), followed by using the SW gamepad (SW Game R); the smallest change was observed in Neutral R. There was no significant difference in MNCSA change between the gamepads.

The effects of gamepad use on the dynamic change in D1 was significant for the left ($p = 0.015$) and right ($p = 0.015$) sides. Post-hoc analysis with a Bonferroni adjustment revealed that compared to Neutral L, the use of the left side of the PS gamepad (PS Game L) significantly increased the change in D1 by 0.9% ($p = 0.037$), whereas the use of the right side of the PS gamepad (PS Game R) significantly increased the change in D1 by 1.5% compared to Neutral R ($p = 0.025$). However, the use of the SW gamepad did not significantly affect the change in D1 compared to Neutral. Figs. 3.20 and 3.21 show the dynamic changes in each median nerve parameter for the left and right sides, respectively.

Table 3.4 Mean changes (%) in the median nerve during actual gaming.

<i>Parameter</i>	<i>Side</i>	%Change; (n = 30)		
		<i>Neutral</i>	<i>PS Gamepad</i>	<i>SW Gamepad</i>
MNCSA	Left	0.95 ± 0.65	1.15 ± 0.82	1.44 ± 0.85
	Right	1.05 ± 0.69	1.27 ± 1.05	1.13 ± 0.74
Circularity	Left	1.68 ± 1.15	2.12 ± 1.59	2.07 ± 1.18
	Right	2.38 ± 1.63	2.64 ± 1.92	2.27 ± 2.11
D1	Left	1.51 ± 1.11	2.43 ± 1.67 *	1.42 ± 1.22
	Right	1.88 ± 1.44	3.42 ± 2.16 *	2.23 ± 2.10
D2	Left	1.49 ± 1.15	1.51 ± 1.20	1.55 ± 1.20
	Right	1.82 ± 1.15	2.08 ± 1.67	1.65 ± 1.50

*Significant result of the post hoc analysis with Bonferroni adjustment, $p < 0.05$

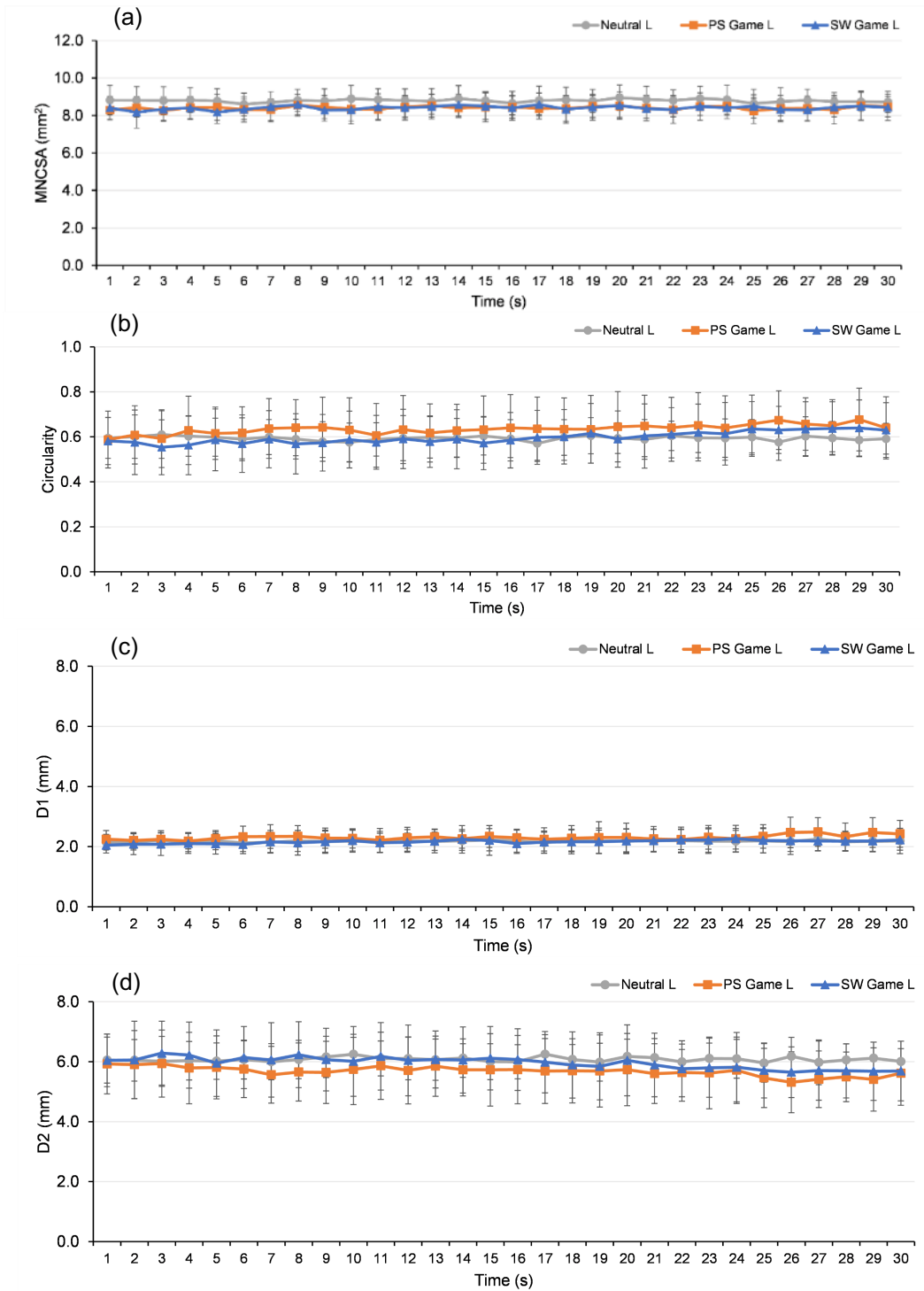


Figure 3.20 Changes in left (a) MNCSA, (b) circularity, (c) D1, and (d) D2 in actual gaming.

Note: L – left side, Neutral L – no gamepad, PS Game L – gaming with PS gamepad, SW Game L – gaming with Switch gamepad.

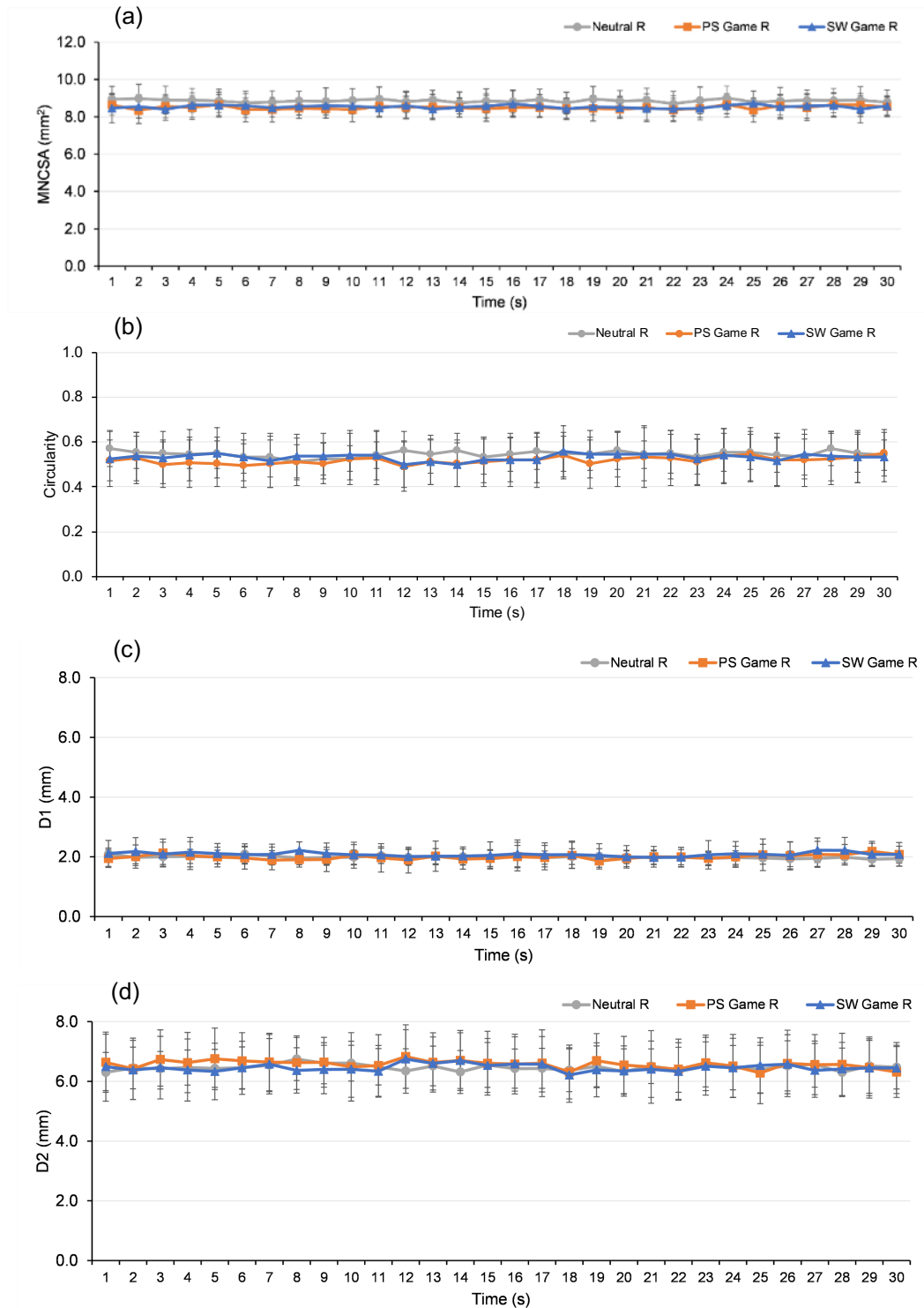


Figure 3.21 Changes in right (a) MNCSA, (b) circularity, (c) D1, and (d) D2 in actual

Note: R – right side, Neutral R – no gamepad, PS Game R – gaming with PS gamepad, SW Game R – gaming with Switch gamepad.

3.4 Discussion

The widespread popularity of esports has led to increased interest in playing video games. However, musculoskeletal injuries such as CTS, are one of the concerns associated with playing esports. Currently, there are only a few studies on the effect of gamepad use on the wrists of esports players. This study involved the analysis of dynamic changes in the cross-sectional area (MNCSA), circularity, longitudinal diameter (D1), and transverse diameter (D2) of the median nerve while using two sizes of gamepads for simulated and actual gaming.

3.4.1 Effects of PS Grip and SW Grip on the median nerve

The smallest MNCSA was observed when the participants were holding the SW gamepad (Table 3.3). This change could be due to the smaller size of the gamepad and the positioning of the fingers while holding it. Studies have shown that the MNCSA decreases when the fingers flexed and gripped because the tendons and flexor retinaculum compress the median nerve [93,96]. The handle of the SW gamepad has a circumference of approximately 110 mm, whereas that of the PS gamepad is approximately 130 mm. A smaller gamepad causes more finger flexion because the hand posture required to hold it is similar to the full fist posture. Researchers have found that this posture results in the smallest MNCSA compared to other finger postures studied [92,96].

Gripping the SW gamepad involves flexing the third to fifth digits around its handle while the index fingers are positioned on the triggers, left thumb on the analog stick, and right thumb on the action buttons (Fig. 3.5c). In contrast, gripping the PS gamepad (Fig. 3.5b) involves flexing only the fourth and fifth digits around the handles while the middle and index fingers are on the trigger and bumper buttons, respectively. Similarly, the left thumb is also positioned on the analog stick and the right thumb on the action buttons. Given that positioning the middle finger

on the PS gamepad involves less flexion, less compression of the median nerve may occur, resulting in a slightly larger MNCSA than that recorded while holding the SW gamepad. Figs. 3.22 and 3.23 show the ultrasound images of the median nerve for each grip position for the left and right wrists, respectively.

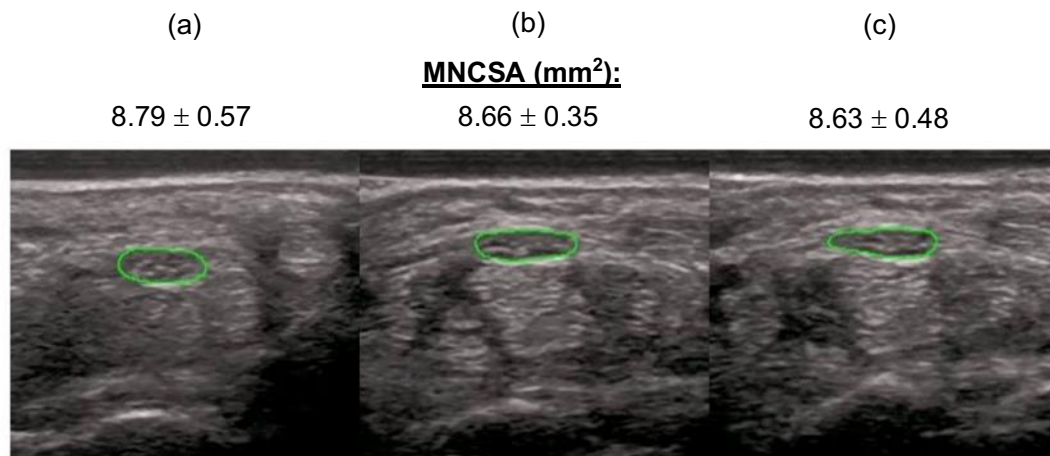


Figure 3.22 Left median nerve shape sample images from a participant at (a) Neutral, (b) PS Grip (c) SW Grip positions.

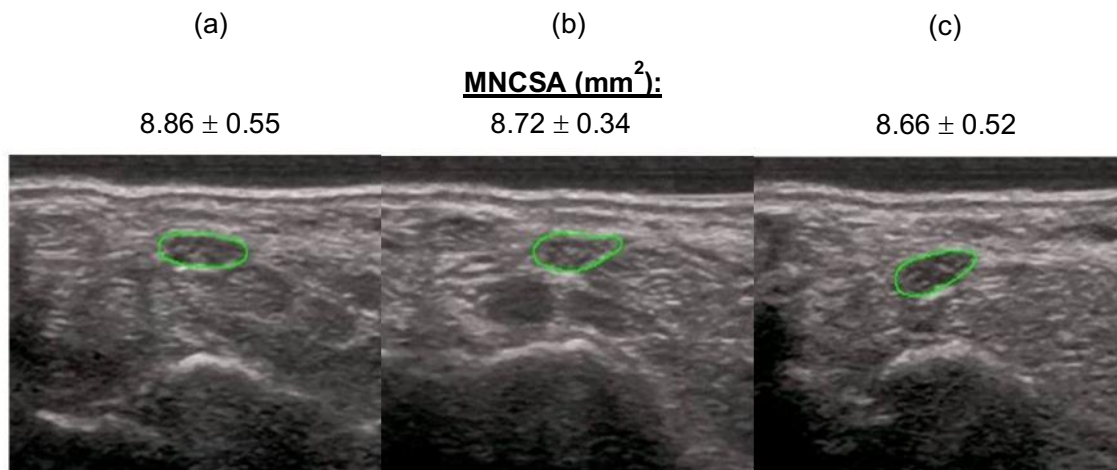


Figure 3.23 Right median nerve shape at (a) Neutral, (b) PS Grip, (c) SW Grip positions (sample images from a participant).

3.4.2 Comparison of the effects of gamepad use on the median nerve

Difference between Neutral and the PS and SW Operations

The MNCSAs recorded while using the two gamepads were significantly smaller than that measured in Neutral (Figs. 3.12a and b). This finding is in line with the hypothesis that use of gamepads affect the median nerve. The reduction in MNCSA could be due to the repetitive flexion-extension of the fingers that occurs while using the gamepads. These results are similar to the findings of a study that demonstrated that flexion of the thumb and fingers reduces the MNCSA [112]. These finger movements lead to the compression of the median nerve by the flexor tendons and flexor retinaculum [93,96].

PS Gamepad. The changes in circularity, D1, and D2 observed while using the PS gamepad were caused by operating the Analog sticks in both the left and right hands. For the left side, only the D2 measured while using Analog L was significantly narrower than that measured in Neutral (Fig. 3.13c). For the right side, the circularity and D1 measured while using Analog R were higher than those measured in Neutral, while the D2 for Analog R was narrower than that for Neutral (Figs. 3.12a, 3.13b, and 3.13d). These results indicate that the median nerve may be compressed from the side due to the rapid repetitive flexion-extension of the thumb while operating the analog stick. Studies have shown that thumb and finger flexion causes corresponding movements of the tendons and the median nerve, which can lead to the compression and distortion of the nerve [47,92,113,114]. Thus, the median nerve may have been compressed between the flexor tendons and the surrounding structures within the carpal tunnel.

SW Gamepad. Only the right-side buttons had significant changes in shape compared to Neutral (Figs. 3.12d, 3.13b and d). Taller D1 than Neutral was encountered due to the individual use of Analog R, Action, and Trigger R buttons (Fig. 3.13b). While D2 was narrower compared to Neutral because of using Analog R and Trigger R separately (Fig. 3.13d). Similar to the PS

gamepad, the thumb was used for the Analog R and Action buttons. It could also be the movement of the tendons and the median nerve that caused its side compressions.

For the Trigger R, the index finger is used for operating the trigger and bumper buttons. While the index finger is performing rapid repetitive flexion-extension, the middle, ring, and little fingers are flexed around the SW gamepad (Fig. 3.25b). These finger postures and index finger movements result in a 'side-compressed' shape of the median nerve similar to that observed during thumb operations. The Trigger R posture resembles the finger postures and movements studied by other researchers [94,113]. One study showed that the full fist motion and index finger flexion cause considerable median nerve and tendon displacement and disturbance in the carpal tunnel [113]. However, studies on the effects of a combination of the full fist posture and single finger repetitive flexion on the median nerve are limited.

Difference between operating the two types of gamepads

The MNCSA measured while using PS Trigger R was smaller than that measured while using SW Trigger R (Fig.3.14a); however, there was no significant difference in shape between the two gamepad operations (Fig. 3.24a and b). This could be attributed to the fact that the design of the gamepad makes it easier to operate the PS trigger and bumper buttons using two fingers (Fig. 3.25a). Unlike the SW gamepad, the index finger can operate the two buttons on the PS gamepad with ease (Fig. 3.25b). A study found that middle finger flexion causes the highest median nerve and tendon displacement, followed by index finger flexion and thumb flexion [113]. This displacement leads to disturbances in the carpal tunnel, thereby providing more opportunities for deformation and possible nerve compression.

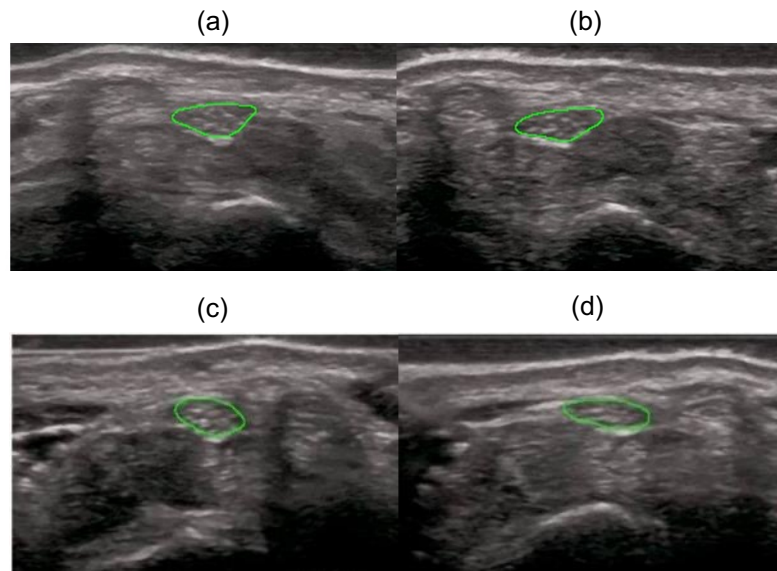


Figure 3.24 Sample median nerve ultrasound images from a participant at (a) PS Trigger, (b) SW Trigger, (c) PS Game L, and (d) SW Game L operations.



Figure 3.25 Finger postures using (a) a PS gamepad and (b) a SW gamepad.

The longer travel distance of the trigger and bumper buttons on the PS gamepad may have contributed to the smaller MNCSA measured during gameplay. The travel distances of the PS trigger and bumper buttons are 10.0 mm and 1.0 mm, respectively (Table 3.2), whereas those of the SW trigger and bumper buttons are 1.0 mm and 0.5 mm, respectively. This could indicate greater compression of the median nerve when using a PS trigger button. Previous studies have indicated that the full fist posture results in the highest deformation of the median

nerve [92,113]. This action causes longer excursion of finger flexor tendons than other finger postures, probably resulting in greater deformation of the median nerve [92]. Therefore, the longer travel distances of the PS trigger and bumper buttons may be responsible for the smaller MNCSA measured during use.

Different left median nerve shapes were observed for each gamepad during actual gaming (Figs. 3.14b, 3.15a and b). In the Game L operation, the cross-section of the median nerve observed while using the PS gamepad was taller and narrower than that observed while using the SW gamepad (Fig. 3.15a and b). Most of the finger motions of the left hands involved using the thumb to operate the analog stick for the movement of characters in the game. While playing, the left thumb muscle tends to fold towards the wrist whenever the analog stick is pushed fully to the right or downwards (Fig. 3.26b). This motion may compress the side of the carpal tunnel. Given that the PS analog stick can move up to approximately 25° in each direction, compared to the 10° only for the SW analog stick, its use contributes further to the compression of the median nerve from the side owing to the longer movement of the FPL tendon [93], thus, resulting in a taller and narrower median nerve cross-section for the left PS gamepad use.



Figure 3.26 Thumb (a) Initial position and (b) Pushing the analog stick fully.

3.4.3 Comparison of the effects of using different buttons on the median nerve

The smallest MNCSA was observed while using PS Trigger R compared with PS Action and PS Analog R (Fig. 3.27c). This may be attributed to the long travel distances of the trigger and bumper buttons, which contribute to further movement of the flexor tendons to compress the median nerve. Moreover, the index and middle fingers are used for the trigger and bumper operations. Flexion of the middle finger causes the highest displacement and deformation of the median nerve, followed by index finger flexion; the lowest values are observed during thumb flexion [113–115].

The most apparent change in the shape of the median nerve observed in this study was during the use of the PS Analog R button. Its use produced the narrowest and most circular median nerve compared to the other buttons (Fig. 3.16b and 3.17b). Similar to PS Analog L, use of the PS Analog R could compress the right median nerve from the side due to the movement of the abductor pollicis brevis muscle and the FPL tendon, resulting in a taller and narrower shape. Previous studies have indicated that the circularity of the median nerve increases when the finger moves from extension to flexion [108,116]. The alternate extension and flexion of the thumb that occurs when pushing and pulling the analog stick could be the reason for the higher circularity observed with the use of the button compared with the other buttons.

The use of SW Action R produced the smallest MNCSA for the SW gamepad (Fig. 3.28a). However, there was no difference among the SW gamepad buttons with respect to the shape of the median nerve during gameplay. This could be due to the long travel distances of the thumb when pressing the four action buttons (ABXY) [92,113]. The thumb successively presses and moves back and forth on these buttons. The distance (center to center) from button A to Y is 8 mm and that from A to X or B is 5 mm. These were the longest travel distances observed among the three types of buttons, especially given that the distance from the trigger to bumper buttons

is approximately 5 mm and that the analog stick can travel approximately 1.05 mm from its original position.



Figure 3.27 Sample median nerve images from a participant observed at (a) PS Action R, (b) PS Analog R, and (c) PS Trigger R.

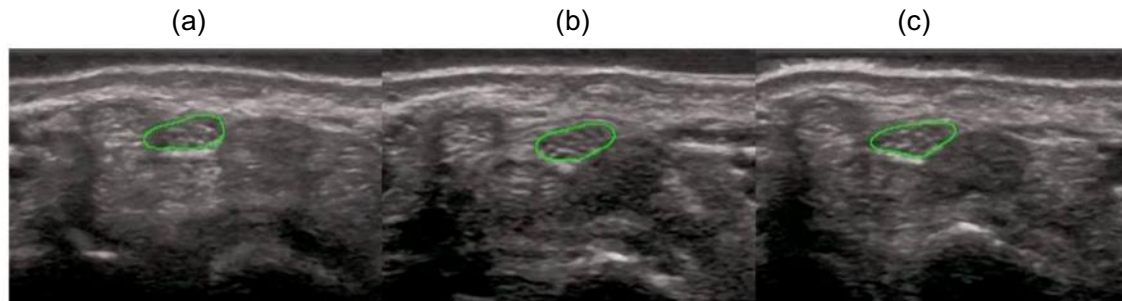


Figure 3.28 Sample median nerve images from a participant observed at (a) SW Action R, (b) SW Analog R, and (c) SW Trigger R.

3.4.4 Dynamic changes in the median nerve during actual gaming

MNCSA. The changes in the MNCSA for the Neutral, PS Grip, and SW Grips were similar (Table 3.4). Interestingly, only a small percentage of the measured MNCsAs changed from their initial values. The percentage change in MNCsA observed in the present study is smaller than those reported in other studies [92,113]. This could be due to the difference in the finger postures required to hold the gamepads. The postures used in the present study were relatively more relaxed than those used in a previous study [92]. Notably, another study involved the execution of full, individual finger flexions, which are unlikely to be used in gaming [113].

Shape. The greatest change in the shape of the median nerve was observed in the D1 recorded in the PS Game. This significant change in shape could be because of the travel distances of the buttons on the PS gamepad are longer than those of the buttons on the SW gamepad. Actions such as full fist motion, wherein the fingers were fully flexed, create the greatest excursion of the flexor tendons, resulting to increased deformation of the median nerve [92,113]. This may have affected the shape of the median nerve.

The shape of the median nerve was predominantly more circular when the left side was used for gameplay than when the right side was used (Figs. 3.29b and 3.30b). Remarkably, the left median nerve was mostly compressed from the sides (radial-ulnar directions). The analog stick is predominantly used for gaming while using the left hand. The stick is operated using the thumb while the index finger was flexed on the trigger area and the rest of the fingers flexed on the handle (Fig. 3.26). Thumb movements can cause displacement of the FPL tendon and the median nerve. However, the findings of previous studies regarding the movement of the flexor tendons and the median nerve due to finger flexion are inconsistent [113]. The findings of the present study align with those of a study on normal and CTS-affected wrists [114]. The previous study showed that thumb flexion leads to the movement of the FPL tendon and median nerve in the volar-ulnar direction [114]. Index finger flexion varies the most with volar-ulnar and volar-radial movements of the nerve, FDS2, and FDP2 tendons [113,114]. Middle finger flexion was predominantly causes dorsal-radial displacement of the FDS3 [94,113,114]. It seems that the movement of the FPL tendon and median nerve during thumb flexion may be opposed by the FDS2, FDP2, and FDS3 tendons. The median nerve may have been compressed-decompressed in between these flexor tendons from the sides, which may have increased-decreased its longitudinal diameter, D1.

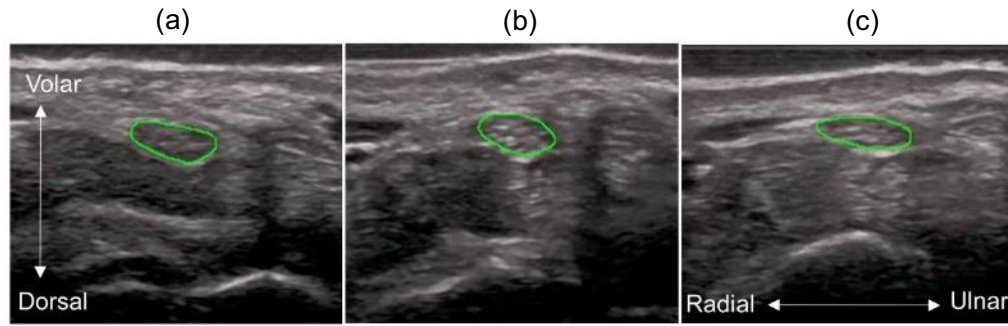


Figure 3.29 Sample median nerve shapes from a participant at (a) Neutral L, (b) PS Game L, and (c) SW Game L.



Figure 3.30 Sample median nerve shapes from a participant at (a) Neutral R, (b) PS Game R, and (c) SW Game R.

The buttons used while gaming with the right side include the analog stick, the action buttons, and the trigger and bumper buttons. The thumb operates the analog stick and the action buttons (Fig. 3.26). Then, the index finger controls the bumper, and the middle finger operates the trigger. Similar to the left hand, majority of the movements are performed by the thumb, with some performed by the index and middle fingers. These movements may have compressed-decompressed the median nerve, resulting in the increased change in its D1.

3.5 Limitations of the study

First, this study was conducted using only two commercially available gamepads. There are several other gamepads with different designs that could be studied in the future. Second,

movements of the participants during the simulated gaming use were based on a MOBA game. Playing a different game may influence the findings obtained in the present study. To the best of the researcher's knowledge, no study has been conducted to clearly establish the differences in the kinematics of playing the different game genres.

3.6 Conclusion

This study demonstrated that using a smaller gamepad result in greater compression of the median nerve due to its smaller profile. Using a bigger gamepad would most likely mimic the more relaxed posture of the hands. However, the smaller travel distances of smaller gamepads cause less deformation of the median nerve. Notably, the design of the gamepad buttons may lead to compression of the carpal tunnel. Using a combination of the three types of buttons would generally reflect the effects that using them individually will have on the median nerve, especially those that are frequently used during gaming. Analysis of the dynamic changes in the median nerve revealed more significant changes in the D1 of the median nerve in both hands during actual gaming than that observed during simulated gaming. These findings signify the compression and strain exerted on the median nerve during actual gaming.

Chapter 4 Acute Effects of Playing Esports on the Median Nerve and Hand Functions

4.1 Introduction

Advancements in technology have been steadily propelling digital entertainment such as esports into the realm of mainstream entertainment and sports. However, research on the identification and management of the adverse health effects of playing esports is still at an early stage. Global data on the extent and prevalence of injuries related to playing esports is still insufficiently documented. Early reports have indicated that carpal tunnel syndrome (CTS) is a common issue among players [49]. CTS is characterized by feeling pain, numbness, and tingling sensations in the hands and fingers [65,117]. It can also cause weakness of the thumb, index finger, middle finger, and half of the ring finger [65].

Playing esports is highly dependent on fine motor skills [118]. CTS is known to impair these capabilities in the hands. Patients with CTS show interrupted kinematics of the thumb in opposition and circumduction movements, even with normal pinch strength [119]. Thumb opposition and circumduction movements are typically employed by esports players when using gamepads. Patients with CTS generally presented a smaller range of motion (ROM) than normal subjects [119]. A smaller ROM would greatly affect the fine motor skills needed when playing esports. In a previous study, the severity of CTS was identified using the Functional Dexterity Test and comparing the results obtained with those from nerve conduction studies [120]. The researchers concluded that the sensorimotor impairments that occur due to CTS can influence hand dexterity. This impaired capability can make playing games and engaging in other activities challenging.

A study found that patients with CTS have significantly weaker grip and pinch strengths than normal individuals without CTS [121]. Grip strength is a common indicator of physical fitness [122]. In another study, a four-week intervention that included exercises and using splints was administered to patients with CTS and they showed improved grip strength, albeit not to normal

levels [121]. This finding indicates that it is essential to prevent the development of CTS because its effects could be irreversible.

Related studies on use of computer keyboards revealed that the cross-sectional area of the median nerve significantly increases after keyboard typing tasks [47,123]. This signifies the impact of prolonged repetitive activities, such as typing, on the median nerve [123]. Additionally, a nerve conduction study of computer users indicated that the sensory conduction velocity of the median nerve is significantly delayed in the extremities of the dominant hand compared to that in extremities of the non-dominant hand [44]. Computer use is very closely related to esports gaming activities and these reported effects of typing on the median nerve may also be present among players of esports. Most esports players typically spend 3 to 4 hours per day playing games, with only 5% of them taking the necessary breaks in between sessions. Prolonged repetitive gaming and improper wrist postures may increase the risk of developing CTS.

CTS can reduce the quality of life and playing performance of gamers. Thus, evidence-based musculoskeletal health guidelines are needed to help prevent pain and injuries among esports players. Therefore, the aim of this study was to investigate the acute changes in the median nerve (cross-sectional area, circularity, longitudinal, and transverse diameters) and the finger sensitivity, dexterity, grip strength, and self-perceived discomfort of esports players after continuous gaming.

4.2 Materials and methods

4.2.1 Participants

Six healthy male and six healthy female participants were recruited for this study (Table 4.1). Each participant met the following inclusion criteria: no injury of the upper limbs, right-handed, knows how to play “Super Smash Brothers Ultimate” (“Special” in Japanese), and provide informed consent to participate in the study. The Flinders Handedness survey (FLANDERS) [11] was used to determine the handedness of the participants [99]. Phalen’s Test and Tinel’s Sign Test were performed to ensure that none of the participants had pre-existing CTS. This study was approved by the Ethics Committee of the Faculty of Design, Kyushu University (Approval number: 403).

Table 4.1 Characteristics of the participants (n = 12).

	Male (n = 6)	Female (n = 6)
Age (years)	23.8 ± 2.6	28.3 ± 3.8
Height (cm)	174.0 ± 5.5	159.7 ± 3.8
Handedness score	9.7 ± 0.8	9.7 ± 0.8
Sitting eye height (cm)	120.8 ± 1.8	111.5 ± 7.1
Grip Level	6.0 ± 0.6	4.0 ± 0.0
Game Level	8.3 ± 1.2	3.3 ± 2.3
Days between sessions	3.2 ± 3.9	3.8 ± 1.8

4.2.2 Gaming setup

Gamepad

The gamepad used in this study was a Nintendo Switch Pro gamepad (Nintendo Co., Ltd., Kyoto, Japan) paired with the Switch OLED console (Fig. 4.1). It is a medium-sized gamepad with similar to those on the Switch Joy-cons. It was used wirelessly during the study. The approximate travel distances for the buttons on the gamepad are summarized in Table 4.2

summarizes. The measurements were taken by the author using a ruler and a manual goniometer (Nihon Medix, Co. Ltd., Chiba, Japan).



Figure 4.1 Switch Pro gamepad used in the study.

Table 4.2 Measured travel distances for each button.

Button	Travel distance (mm)
Action buttons (ABXY)	1.0
Triggers (ZL, ZR)	2.0
Bumpers (L, R)	1.0
Analog stick (max. tilt angle)	15°

Note: These are approximate measurements; there may be an ± 0.05 mm or $\pm 1^\circ$ error margin.

Game

The game used in this study was “Super Smash Bros. Ultimate” (English name) or “Super Smash Bros. Special” (Japanese name). Fig. 4.2 shows a screenshot of the game during gameplay. The game is a fighting game wherein the player controls one character who battles an enemy. It is a fast-paced game from start to finish. In addition, the game has a short respawn

(reappearance) time of about 2 seconds if the character is killed by the enemy (short game break). The player uses various button combinations to generate different attacks/movements in game. The basic controls of the game are shown in Table 4.3. Numerous other button combinations can be used in the game. The button mapping was not changed during the experiment.

Table 4.3 Basic controls of the Switch Pro gamepad.

Button	Function
Analog stick - left (L)	Directional movements
ZL or ZR	Shield
L or R	Grab
X or Y	Jump
A	Attack
B	Special attacks
Analog stick - right (R) + A	Tilt attack



Figure 4.2 Super Smash Bros. Ultimate/Special.
Source: Nintendo.com

4.2.3 Experiment setup

The experiment setup consisted of a pre-experiment area, the hand tests area, the gaming station, and the ultrasound and subjective evaluation area. The setup is displayed in Fig. 4.3. The gaming station consisted of a gaming chair (GXTRACE, Saitama, Japan) and a 138.5-cm television (Fig. 4.4). A video camera was mounted on a side table to capture top view of the hand movements and wrist flexion/extension of each participant.

Finger sensitivity test

Finger sensitivity was evaluated using a static two-point discriminator test, which was performed using an Exacta Touch Test two-point discriminator (North Coast Medical, Inc., California, USA) (Fig. 4.5). During the test, the participant's hand was positioned fully supinated on a soft cloth while his/her eyes were occluded [125]. The initial distance setting used for the two points was 5 mm. One or two points were applied randomly on each fingertip for about three seconds. The pressure was applied consistently on the participant's fingertips. In cases of inaccurate response from the participant, the distance was increased to 6 mm for the specific finger being tested. All fingers of the left and right hands were tested, and six out of the 10 responses (per hand) must be accurate for the hand to be scored. Table 4.4 shows the scoring of the static two-point discrimination test. The percentage accuracy per hand was computed using the following equation:

$$\% \text{ accuracy} = \frac{\text{Number of accurate responses}}{\text{Number of trials}} \times 100$$

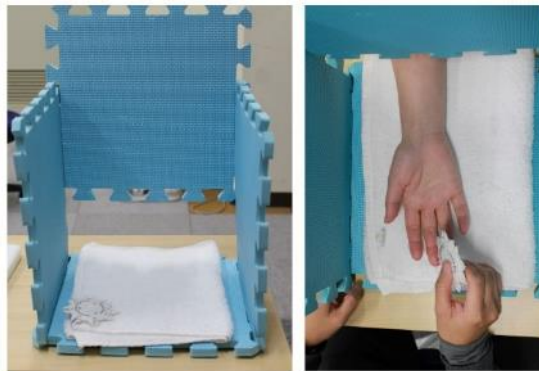


Figure 4.5 Finger sensitivity test station.

Table 4.4 Static two-point discrimination scoring.

Score	Distance
Normal	less than 6 mm
Fair	6 to 10 mm
Poor	11 to 15 mm
Protective	One point perceived
Anesthetic	No point perceived

Dexterity test

The O'Connor Finger Dexterity Test (Lafayette Instrument Company, Indiana, USA) was used to test the finger dexterity of the participants (Fig. 4.6). Only 20 holes in the board were used to avoid lengthy testing. Each participant was instructed to take three pins from the pile and put them in each hole as fast as possible [126]. For both hands, the participant was made to practice putting three pins each in a total of 10 holes. The dominant hand was tested first. The participants were instructed not to pick up any pin they drop, but to take a replacement pin from the pile instead. A stopwatch was used to record the test time for each hand. The score was computed using the following equation [126]:

$$\text{Raw score} = \frac{\text{First half time} + (1.1 \times \text{Second half time})}{2}$$

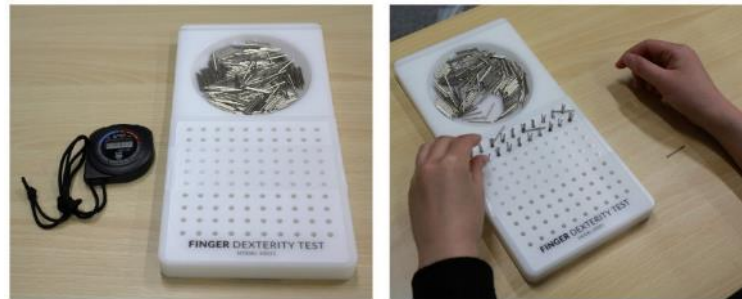


Figure 4.6 O' Connor finger dexterity test.

Grip strength test

A digital grip dynamometer (Takei Scientific Instruments Co., Ltd., Niigata, Japan) was used for the measurement of grip strength in this study (Fig. 4.7). The grip handle was adjusted such that the initial position of the metacarpophalangeal joints in the fingers of the participant were at 90°. The participant was instructed to grip the handle twice using his/her maximum power. The dominant hand was tested first, and the highest measurement was considered per hand.



Figure 4.7 The digital grip dynamometer used.

Subjective evaluation

The discomfort felt in the left and right hands of the participants before the experiment and after each task was evaluated using modified the Cornell Hand Discomfort Questionnaires (CHDQ) [127]. Three questions were asked, and the first question was “In which hand area do you experience any ache, pain, or discomfort right now?”. Fig. 4.8 shows the six areas of the right hand presented to the participant based on the CHDQ. For the left hand, the same areas were labeled but in a mirror image of Fig. 4.8.

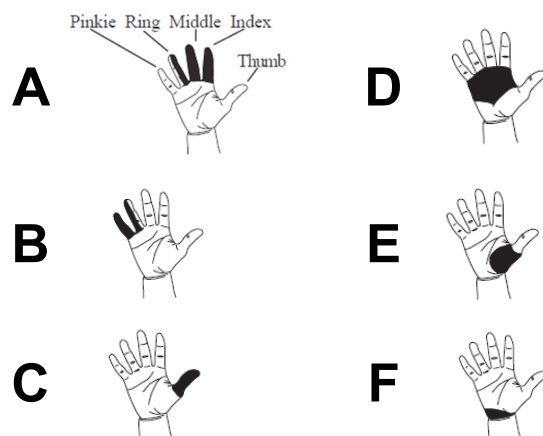


Figure 4.8 Right hand areas based on CHDQ.

The second question, which was focused on the severity of the pain, was as follows: “If you experienced ache, pain, or discomfort, how uncomfortable was it?”. The possible responses to question were graded on a Likert scale: “1 – Slightly uncomfortable”, “2 – Moderately uncomfortable”, and “3 – Very uncomfortable”. The last question was “If you experienced ache, pain, or discomfort, did it interfere with your ability to play?” and it had the following possible responses: “1 – Not at all,” “2 – Slightly interfered,” and “3 – Substantially interfered”. The second and third questions were not asked if the participant’s response to question 1 was that he/she experienced no pain, ache, or discomfort.

Experiment protocol

The pre-experiment procedure (Block 0) included orientation of the participant, obtaining informed consent, FLANDERS, and initial hand tests (subjective evaluation, wrist ultrasound and sensitivity, dexterity, and grip strength tests). The experiment protocol consisted of two types of tasks. The first was the Resting Task wherein the participant sat and performed no hand activities. The second was the Gaming Task, in which the participant played esports. The Resting Task included four time blocks, while the Gaming Task included five time blocks. Each time block involved a 30-minute task and post-task tests. Blocks 1 and 3 included only wrist ultrasound and subjective evaluation. Blocks 2, 4, and 5 included all the hand tests. The Resting Task was 2.7 hours long, whereas the Gaming Task lasted 3.3 hours. Each task was performed on a different day and was counterbalanced for the 12 participants. Fig. 4.10 illustrates the duration of each activity in the experiment.

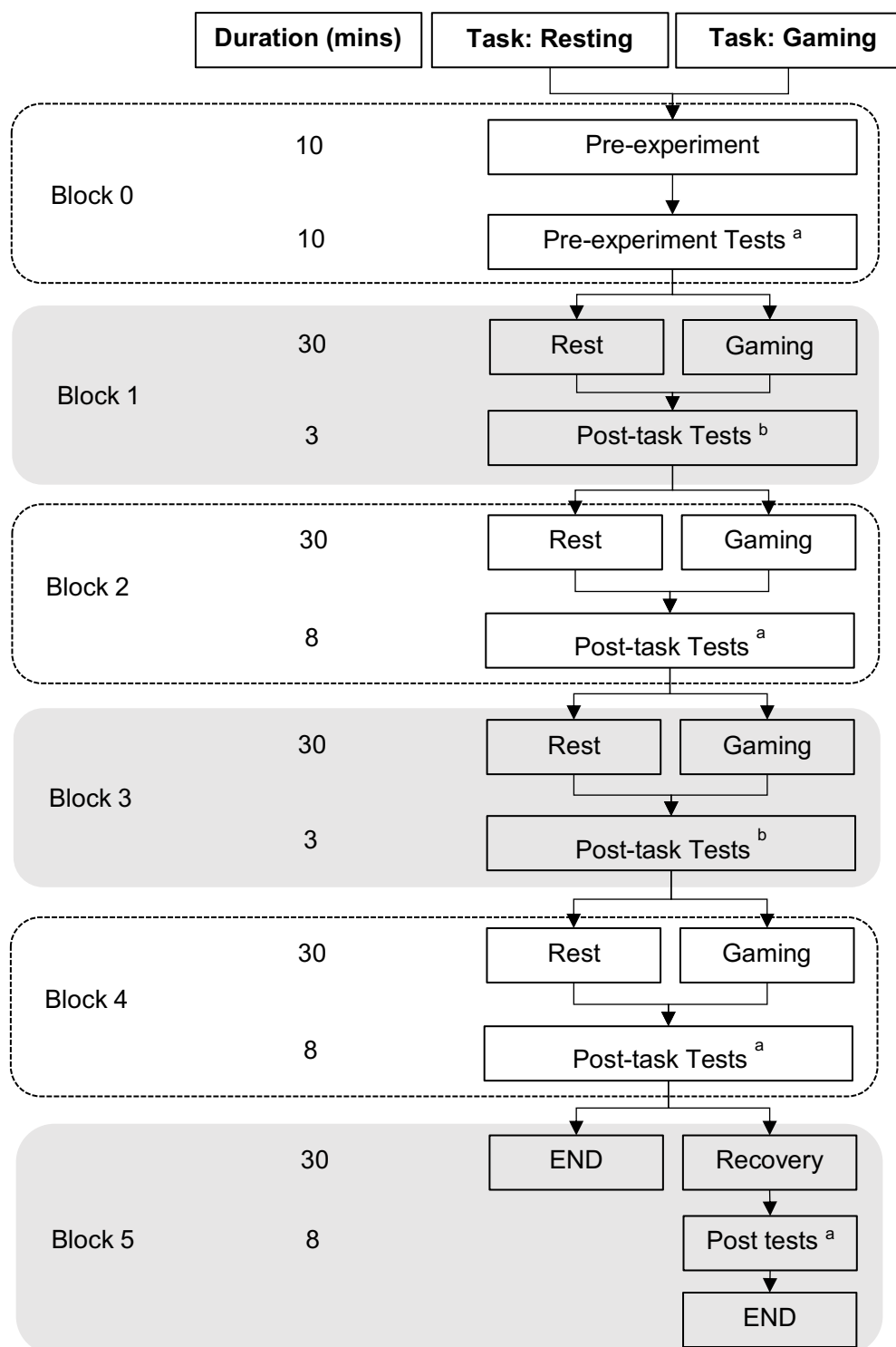
4.2.1 Ultrasound examination protocol

The LOGIQ e ultrasound system (GE Healthcare, USA) with a 12L-RS transducer (imaging frequency bandwidth of 5–13 MHz) and a depth of 40 mm was used for the assessment of

changes in the median nerve. The coupling agent used was a 7.0 mm thick ultrasound gel pad (Nippon BXI Inc., Tokyo, Japan). The transducer was carefully placed on the wrists of the participant during the examination to avoid exerting pressure on the median nerve. A 3D-printed arm support with a towel placed on top was used to properly position the participant's wrist for ultrasound (Fig. 4.9). The wrist crease was aligned to the front guide bar of the arm to ensure that the transducer was placed perpendicular to the wrist. The transducer was placed on the wrist crease to examine the median nerve in the transverse plane at the proximal end of the carpal tunnel. The hyper-echogenic rim encapsulating the hypo-echogenic nerve fascicles was used as a guide in recognizing the median nerve at the superficial level [92].



Figure 4.9 The 3D-printed arm support used at the ultrasound station.



Note:

^a All tests (ultrasound, subjective, sensitivity, dexterity, and grip strength tests)

^b Ultrasound and subjective only

Figure 4.10 Experiment protocol.

4.2.2 Image processing and analysis

The images of the median nerve were analyzed using Image J software (Schneider, Rasband, and Eliceiri, 2012). The tracing method [101] was used to identify the median nerve, whereas the minimum bounding rectangle method was used to measure the cross-sectional area (MNCSA), longitudinal diameter (D1), transverse diameter (D2), and circularity of the median nerve (Figure 4.11). The median nerve was traced along the hyperechogenic rim. The Multi Measure plugin of the Image J software was used to conveniently trace five images at a time. The MNCSA, D1, D2, and circularity measurements were taken using the Measure function of the software. The data were collated and saved in an MS Excel file.

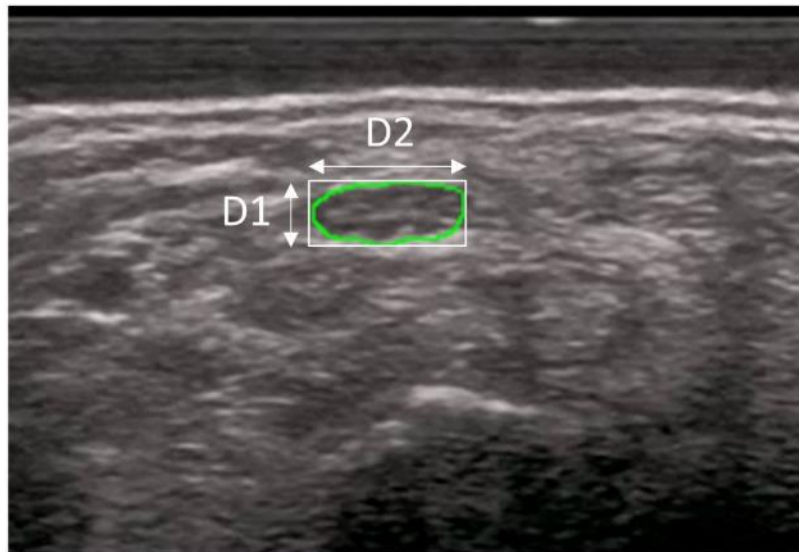


Figure 4.11 Traced median nerve, D1, and D2.

4.2.3 Statistical analysis

All statistical analyses were performed using SPSS version 28.0 (IBM Corp., Armonk NY, USA). The Shapiro-Wilk Test and visual inspection of histograms and normal Q-Q plots were used to test for the normality of the MNCSA, D1, D2, and circularity data, dexterity raw scores, and grip strength data. Given that the statistical test used is robust with the presence of outliers

or violations in normality, minimal outliers were detected and included in the analysis [110]. Two-way repeated measures ANOVA (2 x 5 factorial design) with simple main effects comparison of the two tasks (Resting and Gaming) and the five time blocks (0, 30, 60, 90, and 120 minutes) was performed. Post-hoc analysis using Dunnett's test was performed to compare the MNCSA, circularity, D1, D2, dexterity, and grip strength data for the Resting and Gaming Tasks in time block 0 vs. the other time blocks. All statistical tests were conducted at a 0.05 level of significance. Data are presented as mean $\pm$ standard deviation, unless otherwise stated.

4.3 Results

4.3.1 Characteristics of the sample data

The Shapiro-Wilk Test and the visual inspection of histograms and normal Q-Q plots showed that the MNCSA, circularity, D1, and D2 data were approximately normally distributed ($p > 0.05$), skewed, and kurtotic. Dexterity raw scores and grip strength data were also approximately normally distributed ($p > 0.05$). The sensitivity data were not normally distributed ($p < 0.05$).

4.3.2 Acute effects of Resting and Gaming Tasks on the median nerve

Changes cross-sectional area of the median nerve

Right. Two-way repeated measures ANOVA revealed that there was a statistically significant two-way interaction between task (Resting or Gaming) and time on MNCSA ($F[4,44] = 67.09$, $p < 0.001$, partial $\eta^2 = 0.859$). The main effect of task on MNCSA was also found statistically significant ($F[1,11] = 70.90$, $p < 0.001$, partial $\eta^2 = 0.866$). Similarly, the main effect of time ($F[1,11] = 64.43$, $p < 0.001$, partial $\eta^2 = 0.854$) on MNCSA was also found statistically significant. Pairwise comparisons revealed that compared to the MNCSA recorded during the

Resting Task, the MNCSA recorded during the Gaming task significantly increased by 0.604 mm² and 0.879 mm² in time blocks 90 ($F[1,11] = 44.28$, $p < 0.001$, partial $\eta^2 = 0.801$) and 120 ($F[1,11] = 101.65$, $p < 0.001$, partial $\eta^2 = 0.902$), respectively.

Post-hoc tests (Dunnett) revealed no significant difference in the MNCSAs recorded in all time blocks during the Resting Task ($F[4,55] = 0.00$, $p = 1.00$). In the Gaming Task, MNCSA was significantly increased in time block 120 ($F[4,66] = 2.702$, $p < 0.045$, partial $\eta^2 = 0.170$) (Fig. 4.12a).

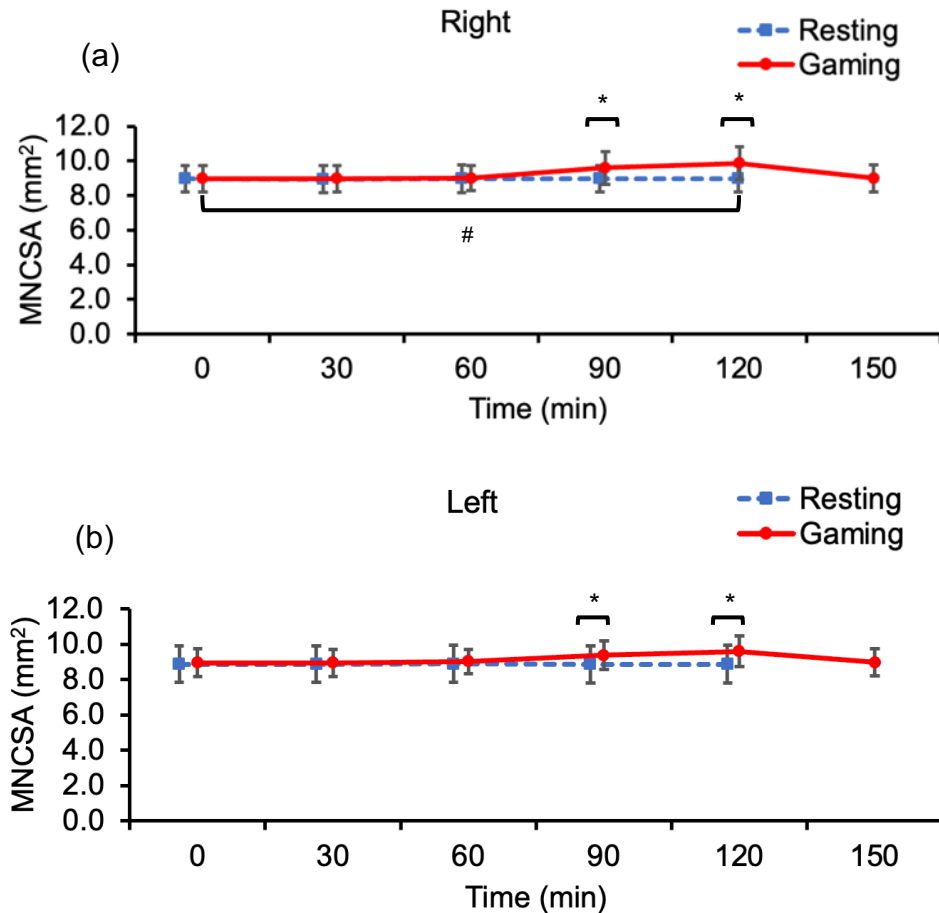


Figure 4.12 MNCSA for the (a) right and (b) left sides.
(* $p < 0.001$, # $p < 0.05$, $n = 12$)

Left. Two-way repeated measures ANOVA showed that the main effects of tasks ($F[1,11] = 96.50, p < 0.001$, partial $\eta^2 = 0.898$), time blocks ($F[4,44] = 32.75, p < 0.001$, partial $\eta^2 = 0.749$), and their two-way interactions ($F[4,44] = 37.71, p < 0.001$, partial $\eta^2 = 0.774$) on the MNCSA were all statistically significant. The MNCSAs recorded during the Gaming Task were significantly higher than those recorded during Resting Task in time blocks 90 ($F[1,11] = 57.86, p < 0.001$, partial $\eta^2 = 0.840$) and 120 ($F[1,11] = 105.77, p < 0.001$, partial $\eta^2 = 0.906$). Post-hoc tests (Dunnett) showed no significant change in MNCSA in all time blocks of the Resting Task ($F[4,55] = 0.001, p = 1.00$). Similarly, post-hoc tests confirmed that compared to time block 0, there was no significant change in MNCSA in all time blocks of the Gaming Task $F(4,8) = 51.22, p < 0.001$, partial $\eta^2 = 0.962$] (Fig. 4.12b).

Changes in shape of the median nerve

Right. The main effects of task ($F[1,11] = 2.17, p = 0.169$), time ($F[4,44] = 0.65, p = 0.630$), and their interaction ($F[4,44] = 0.64, p = 0.637$) on the circularity of the median nerve were not significant. Likewise, the main effects of task ($F[1,11] = 0.083, p = 0.778$), time ($F[4,44] = 1.704, p = 0.166$), and their interaction ($F[4,44] = 0.551, p = 0.699$) on the D1 of the median nerve were not significant. The main effects of task ($F[1,11] = 3.44, p = 0.091$), time ($F[4,44] = 2.21, p = 0.084$), and their interaction ($F[4,44] = 0.72, p = 0.585$) on the D2 of the median nerve were also not significant. These results are illustrated in Figs. 4.13a – 4.15a. There was a noticeable increase in the D2 of the right median nerve in time block 120 (Fig. 4.15a) of the Gaming Task; however, the result was not statistically significant compared to that obtained during the Resting Task.

Left. The main effects of task ($F[1,11] = 0.12, p = 0.733$), time ($F[4,44] = 0.82, p = 0.518$), and their interaction ($F[4,44] = 0.54, p = 0.710$) on the circularity of the median nerve were not significant. Similarly, the main effects of task ($F[1,11] = 0.11, p = 0.750$), time ($F[4,44] = 0.34, p$

= 0.849), and their interaction ($F[4,44] = 2.01$, $p = 0.110$) on the D1 of the median nerve were not significant. Lastly, the main effects of task ($F[1,11] = 0.84$, $p = 0.378$), time ($F[4,44] = 1.76$, $p = 0.155$), and their interaction ($F[4,44] = 1.24$, $p = 0.307$) on the D2 of the median nerve were not significant. These results are also presented in Figs. 4.13b - 4.15b.

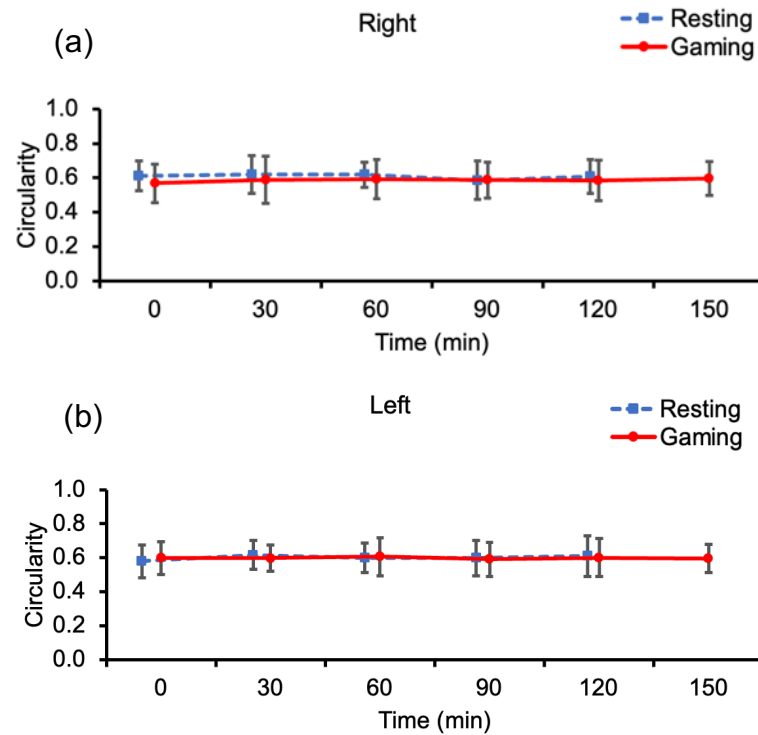


Figure 4.13 Median nerve circularity for the (a) right and (b) left sides.

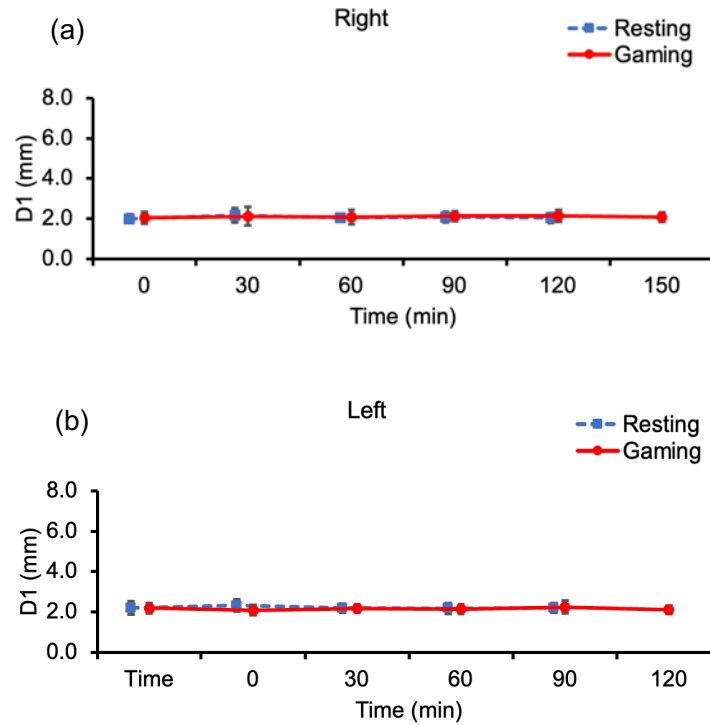


Figure 4.14 Median nerve D1 for the (a) right and (b) left sides.

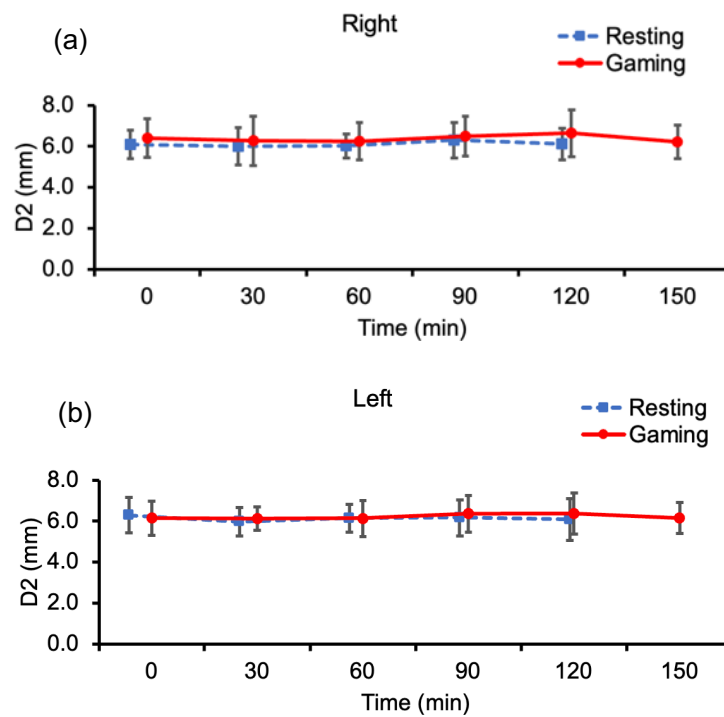


Figure 4.15 Median nerve D2 for the (a) right and (b) left sides.

4.3.3 Acute effects of gaming on hand functions and self-perceived pain

Dexterity raw scores

The dexterity raw score is the number of seconds it takes to finish placing pins into the 20 holes in the O'Connor Finger Dexterity Test. Lower values indicate better dexterity. Only the raw scores were used in this study to show the changes in dexterity in each time block.

Right hand. Two-way repeated measures ANOVA showed that the interaction between task and time was not statistically significant ($F[2,22] = 2.24, p = 0.130$). Moreover, the main effect of task on dexterity scores was not significant ($F[1,11] = 1.09, p = 0.319$). The main effect of time (0, 60, 120 minutes) on the dexterity raw scores was statistically significant ($F[2,22] = 4.00, p = 0.033$, partial $\eta^2 = 0.267$). However, pairwise comparisons showed no significant difference.

Post-hoc tests (Dunnett) revealed that in the Resting Task, there was no significant difference in dexterity raw scores among the time blocks ($F[2,33] = 0.187, p = 0.830$). In addition, the dexterity raw scores recorded during the Gaming Task did not change significantly compared to that recorded in time block 0 ($F[3,44] = 0.927, p = 0.436$) (Fig. 4.16a).

Left hand. The main effect of the interaction between task and time on dexterity scores was not statistically significant ($F[2,22] = 1.68, p = 0.209$) (Fig. 4.16b). Likewise, the main effects of task ($F[1,11] = 0.64, p = 0.440$) and time ($F[2,22] = 2.88, p = 0.078$) were not significant.

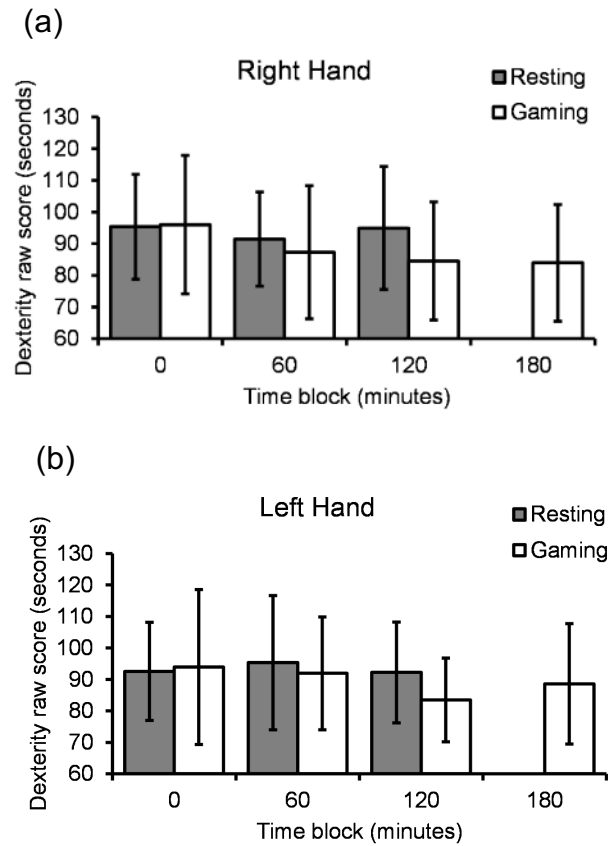


Figure 4.16 Dexterity raw scores for the (a) right and (b) left hands per hour. (* $p < 0.05$ vs. time 0, $n = 12$).

Grip strength

Right hand. Two-way repeated measures ANOVA revealed that the interaction between task and time on grip strength was not statistically significant ($F[2,22] = 0.64$, $p = 0.537$, partial $\eta^2 = 0.055$) (Fig. 4.17a). Moreover, the main effect of task was not significant ($F[1,11] = 0.04$, $p = 0.842$, partial $\eta^2 = 0.004$). However, the main effect of time on grip strength was statistically significant ($F[2,22] = 5.73$, $p = 0.010$, partial $\eta^2 = 0.342$). Notably, pairwise comparisons revealed no significant differences. Additionally, Dunnett post-hoc tests showed no significant differences in the grip strength recorded in each time block during both the Resting Task ($F[2,33] = 0.099$, $p = 0.906$) and the Gaming Task ($F[3,44] = 0.066$, $p = 0.978$).

Left hand. The interaction between task and time on the grip strength was not statistically significant ($F[2,22] = 0.69, p = 0.510$) (Fig. 4.17b). Furthermore, the main effects of task ($F[1,11] = 1.17, p = 0.303$) and time ($F[2,22] = 0.04, p = 0.966$) on grip strength were not significant.

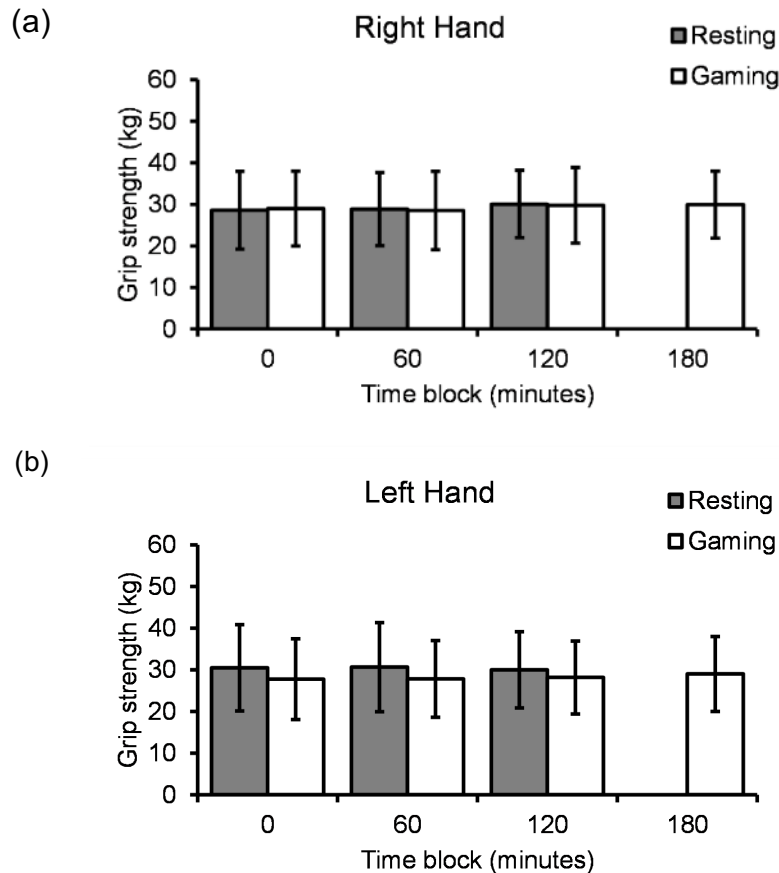


Figure 4.17 Grip strength for the (a) right and (b) left hands per hour.

Finger sensitivity test

Right hand. Two-way repeated measures ANOVA showed that the interaction between task and time on finger sensitivity was not statistically significant ($F[1.35,14.88] = 0.23, p = 0.707$). Also, the main effects of task ($F[1,11] = 1.00, p = 0.339$) and time ($F[1.35,14.88] = 0.23, p = 0.707$) on sensitivity were not statistically significant. Fig. 4.18a shows the results of the

sensitivity tests. The distances used ranged from 5 mm to 6 mm, which fall under the “Normal” and “Fair” sensitivity categories, respectively.

Left hand. Two-way repeated measures ANOVA indicated that the effects of the interaction between task and time on finger sensitivity was not statistically significant ($F[1,11] = 1.00$, $p = 0.339$). The main effects of task ($F[1,11] = 3.01$, $p = 0.111$) and time ($F[1,11] = 1.00$, $p = 0.339$) on sensitivity were not statistically significant. The results of the sensitivity tests are shown in Fig 4.18b. The distances used ranged from 5 mm to 6 mm, which fall under the “Normal” and “Fair” sensitivity categories, respectively.

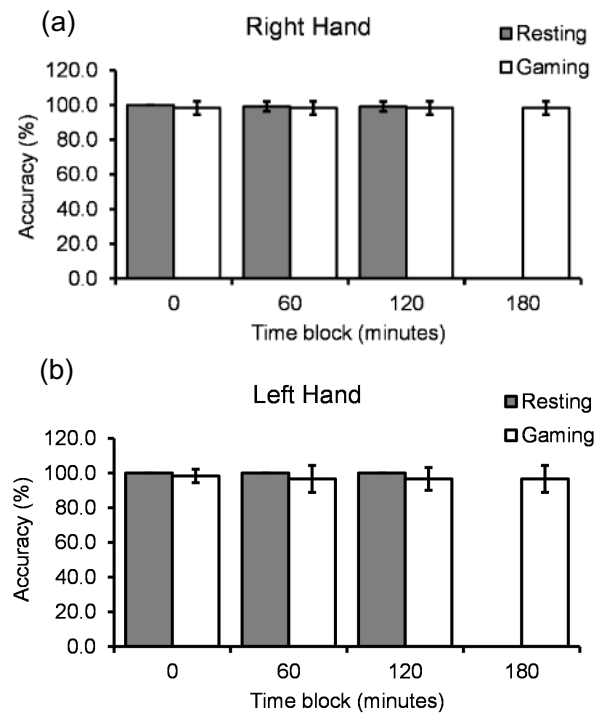


Figure 4.18 Sensitivity test results for the (a) right and (b) left hands per hour.

Subjective evaluation

Table 4.5 shows the results of the subjective evaluation for each time block. For the Resting Task, all participants answered that they experienced no pain or discomfort (Normal) in all time blocks. However, some participants experienced pain or discomfort during the Gaming Task.

Table 4.5 Results of the subjective evaluation results of the right and left hands (n = 12).

<i>Tasks</i>		<i>Time blocks</i>				
Right Hand	0	30	60	90	120	180
Resting	N	N	N	N	N	N
Gaming	N	1*	1*	3*	2*	1*
Left Hand						
Resting	N	N	N	N	N	N
Gaming	N	N	N	2*	1*	1*

Note: N, Normal

*Number of participants who experienced pain or discomfort

Right hand. The common complaint was slight discomfort that did not interfere with playing, and the commonly affected areas were Areas B (pinky and ulnar half of the ring finger) and C (thumb). One participant experienced moderate discomfort of the thumb that slightly interfered with playing in time blocks 90 and 120. Another participant experienced slight discomfort in Area B from time block 30 to time block 60; the discomfort disappeared when the participant adjusted the hand posture used in holding the gamepad.

Left hand. The affected areas were Areas B, C, and E (muscles of the thumb). Only one participant experienced the moderate discomfort from time block 90 and reported slight discomfort after recovery in time block 180.

4.4 Discussion

Prolonged repetitive activity of the upper limbs is typically associated with repetitive strain injuries such as CTS. The present study was conducted to investigate the changes in the median nerve (cross-sectional area, circularity, longitudinal, and transverse diameters) and the finger sensitivity, dexterity, grip strength, and self-perceived discomfort of players after continuous gaming.

4.4.1 Acute effect of gaming on the cross-sectional area of the median nerve

The MNCSA in both hands of the participants increased significantly after 90 minutes of gaming and continued to increase until 120 minutes of gaming. However, it returned to its original size after 30 minutes of recovery. The reason for the increased MNCSA could be endoneurial edema or swelling due to repetitive compression stress on the median nerve. The contents of the nerve tend to move in different directions during compression. The normal fluid pressure inside the carpal tunnel ranges from 2 to 5 mm Hg [73,128]. However, activities similar to gaming, such as active use of a computer mouse, increase it to at least 28 mm Hg [128] which is enough to impair nerve blood flow [129]. Low magnitude compression stress exerted for a short period may cause minor structural changes and reversible biological effects [128]. In addition, it may cause significant physical changes in the nerve when applied over a long period, resulting in reduced blood flow and ischemia [128].

Differential finger movements can increase the gliding resistance of the subsynovial connective tissue (SSCT) in the carpal tunnel [62]. This may cause friction among the SSCT, median nerve, and flexor tendons inside the tunnel, possibly leading to swelling. The movement of the SSCT in response to tendon movements is delayed [61,72]. Therefore, faster differential finger movements would mean less chance for the SSCT to recover [72]. Fighting games, such

as the one used in the present study, require rapid movements for competitive performance. This fast movement speed may increase the risk of shear injury in the SSCT, which is linked to CTS [61].

The results reported in the previous chapter indicated that analog stick operations in gamepads tend to compress the carpal tunnel, where the median nerve passes through, whenever the stick is pushed towards the farthest right or left direction, especially for sticks with a wider tilt angle (Fig. 3.33). This compression of the carpal tunnel may reduce its volume and increase the likelihood of deformation and compression of the median nerve during tendon movements [61].

The results of the present study indicate that the effect of gaming on the MNCSA takes a longer time to manifest than that observed after continuous keyboard typing, wherein the effect is apparent after 30 minutes [46,47,123]. This could be due to the differences in wrist posture while using gamepads versus typing on a keyboard. The results of a previous study suggested that the wrists of keyboard users are usually in extension and ulnar deviation [46]. The authors found that the participants with increased wrist ulnar deviation angles showed greater changes in MNCSA. In another study, typing on a keyboard with a high slope resulted in larger changes in the MNCSA than typing on a keyboard without a slope [47]. Deviation of the wrist from the neutral posture reduces the volume and increases the fluid pressure in the carpal tunnel [45,130]. The results of these previous studies indicate that keyboard typing changes the MNCSA faster than gaming. However, unlike keyboard typing, holding a gamepad allows for minimal wrist deviation from the neutral position (Fig. 4.19). This may lessen the effects of gaming on the volume and pressure of the carpal tunnel.

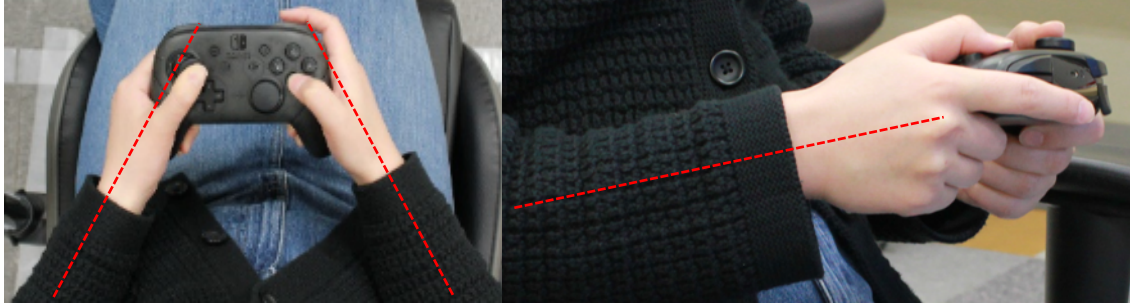


Figure 4.19 Wrist posture when holding a gamepad.

The findings of the present study indicate that it is essential for esports players to take regular breaks after one hour of gaming. Given that the MNCSA of the participants started to increase after 90 minutes of playing, resting in between 30- to 60-minute sessions would aid the recovery of the median nerve, tendons, and SSCT.

4.4.2 Acute effect of gaming on the shape of the median nerve

No statistically significant change in the shape parameters of the median nerve were observed in this study. However, a slightly decreasing trend in the circularity of the median nerve was observed during the Gaming Task (Figs. 4.13a and b). The D1 seemed unchanged, whereas an increasing trend in D2 was observed (Figs. 4.15a and b). These changes could signify the possible tendency of the median nerve to slightly widen its transverse diameter starting from 90 minutes of gaming. Although the changes in the D1 were unclear, these results are similar to the findings of some previous studies [44,46,47,123]. The hypothesis of the present study was that the circularity, D1, and D2 of the median nerve will increase with the MNCSA. However, it seems that the findings support the idea that increase in the longitudinal and transverse diameters of the median nerve is limited to counter the occurrence of intraneural edema [47].

4.4.3 Acute effects of gaming on hand functions and self-perceived pain

No significant changes in dexterity, grip strength, and finger sensitivity were observed in this study. It is possible that these effects were not immediate in the Gaming Task so these could be unsuitable tests for the study. In some previous studies, the manual dexterity of videogame players were improved compared to that of non-players [131–133]. Further studies on the effect of playing esports on player dexterity are warranted.

Regarding self-perceived pain among participants, only a few of them responded that they felt slight discomfort during the gaming sessions. However, given that gaming injuries are expected to develop slowly and inadvertently [2], it is important for esports players to incorporate regular breaks into their gaming habits.

4.5 Limitations of the study

The main limitation of this study is the shortening of the finger dexterity and sensitivity tests in the experiment protocol as it was necessary to minimize the time between gaming sessions. However, it should be noted that the tests were conducted consistently in each session. Another limitation is that the subjective evaluation of self-perceived pain or discomfort among the participants may have varied because everyone has a different own level of tolerance to pain.

The duration of the gaming sessions, which lasted for 120 minutes only, may have affected the results of the hand function tests. This is because esports players typically play games for longer periods. Thus, future studies on the effects of longer gaming sessions on hand functions are warranted. Finally, the researcher cannot recommend a specific duration for regular breaks during gaming as it was not included in the scope of this study. This would be an interesting topic for further research.

4.6 Conclusions

This study demonstrated that playing esports continuously using a gamepad leads to an increase in the MNCSA in both hands after 90 and 120 minutes. The increased MNCSA highlights the importance of taking regular breaks while playing esports with a gamepad. Thus, players should incorporate breaks into their gaming schedule to allow for recovery and prevent the development of injuries.

Chapter 5 General Discussion and Conclusion

5.1 Summary

Esports and video gaming have been in existence since the 1970s. Advancements in technology and increased social media usage have considerably boosted their popularity recently, with players even participating in competitions. Notably, the increasing interest in esports have led to increased concerns regarding injuries related to playing video games. The fast, repetitive movements required for playing esports increase the risk of repetitive strain injuries such as carpal tunnel syndrome (CTS). Moreover, esports are usually played for long hours and players tend to overlook taking breaks in between sessions. Initial injury of the subsynovial connective tissues inside the carpal tunnel triggers an irreversible cycle that could possibly lead to CTS. Thus, it is of utmost importance to avoid such injuries as they may be irreversible.

Previous studies have indicated the effects of gaming on the musculoskeletal health of players [30–33,35]. However, only a few studies have been conducted to investigate the risk factors for injuries commonly associated with playing esports. Thus, this dissertation was conducted to analyze gaming habits and conditions, commonly played games and commonly used gaming devices, and the dynamic effects of gamepad use and prolonged gaming on the median nerve. Two types of gamepads were used in investigating the dynamic effects of gaming on the median nerve. The main objective of this dissertation was to determine the musculoskeletal effects of gaming on esports players and to investigate the mechanics of CTS.

The study reported in Chapter 2 was conducted to investigate the gaming habits and the prevalence and self-perceived severity of musculoskeletal pain when playing esports among competitive and recreational esports players in the Philippines and Japan. The study verified the associations between the number of playing years, playing frequency, playing hours, and musculoskeletal pain among players. The main findings were that Filipino and Japanese esports players experience musculoskeletal pain in the back, neck, wrists, hands, and shoulders. The

number of playing years was positively associated with neck, shoulder, and wrist pain among the Japanese participants. Additionally, an increased number of playing hours was positively correlated with hand pain. These findings gave insights on the presence of musculoskeletal concerns and the dose-related nature of musculoskeletal pain among esports players.

The study reported in Chapter 3 was focused on the changes in median nerve morphology when using two sizes of gamepads for simulated and actual gaming. The difference between holding and using a gamepad was also analyzed in the study. The results showed that holding a bigger gamepad result in less median nerve compression than holding a smaller one. However, the longer button travel distances on the bigger gamepad result in greater nerve deformation. Moreover, the design of the gamepad buttons may contribute to compression of the carpal tunnel. Analysis of the dynamic changes in the median nerve showed the strain that the median nerve undergoes during gaming. The findings of the study verified the importance of gamepad design in avoiding CTS.

The study outlined in Chapter 4 was conducted to investigate the morphological changes in the median nerve, finger sensitivity, dexterity, and grip strength, and self-perceived discomfort of players after continuous gaming. The primary finding of the study was that playing esports continuously leads to an increase in MNCSA in both hands after 90 and 120 minutes of gameplay. The increased MNCSA after prolonged gaming highlights the importance of taking regular breaks while playing esports.

5.2 Implications

The major findings of this dissertation can be summarized into four key points: the effects of gaming, gamepad design, gamepad operations, and prolonged gaming.

5.2.1 Ergonomic recommendations regarding the musculoskeletal health of esports players

One of the aims of this dissertation was to determine the presence of wrist and hand pain caused by playing esports. The results reported in Chapters 2 and 4 indicate that esports players mostly experience pain in their hands, wrists, and upper body. The presence of neck, shoulder, and wrist pain was positively correlated with the number of playing years. In addition, the presence of hand pain was positively correlated with the number of playing hours. These preliminary findings verified the existence of musculoskeletal discomfort among esports players. They also indicated the dose-related nature of developing musculoskeletal pain and injuries from playing esports. These findings signify that bodily trauma accumulates over years of playing esports and increases the risk of injury over time.

Approximately 39 – 45% of musculoskeletal pain cases progress into a chronic and long-lasting problem [134]. Players who develop musculoskeletal discomfort resulting from long-term playing of esports experience substantial degradation in their quality of life because of functional disability. In a study of patients of musculoskeletal disorders, appreciable limitations in activities of daily living, family and social relationships, and sleep disturbances were observed [135]. Moreover, esports athletes who experience musculoskeletal pain participate significantly less in esports training [31]. These adverse effects highlight the importance of using ergonomic devices and engaging in suitable exercises while playing esports to minimize the risks of the musculoskeletal effects of gaming. Use of ergonomic chairs and tables, playing with the right

size of controllers, performing strengthening exercises, warming up and cooling down before and after a game, and taking regular session breaks are necessary for preventing short- and long-term injuries related to playing esports. Player education can also help increase awareness in identifying hazards and lead to the improvement of conditions.

5.2.2 Gamepad design to minimize median nerve compression

This dissertation demonstrated the effects of different gamepad designs on the median nerve. The results reported in Chapters 3 and 4 indicated that gamepad size has an effect on the median nerve. Holding a smaller gamepad leads to increased deformation of the median nerve as evidenced by the smaller MNCSA measured. This deformation can irritate of the nerve if the gamepad is used for a long period. The study outlined in Chapter 4 indicated that the participants reported minimal self-perceived pain because the size of the gamepad they used while playing allowed for a neutral position of the wrist and hands.

A bigger gamepad allows for the adoption of a more relaxed posture for the hands and fingers. However, bigger gamepads often have bigger buttons with longer travel distances, which cause longer displacements of the flexor tendons that lead to greater deformation in the median nerve [92,113]. A bigger gamepad with shorter button travel distances would be preferable for minimizing median nerve deformation. Button travel distances may be shortened with the use of tactile feedback, as in the Switch Joy-cons.

Increased button travel distance can also increase carpal tunnel pressure. For analog sticks with a wider range of motion (degrees of rotation), pushing the stick to the farthest side using the thumb will increase the pressure in the carpal tunnel. This reduces the volume of the carpal tunnel, leaving a smaller space for movement of the median nerve, flexor tendons, and other structures, thereby increasing the risk of nerve compression, which is one of the causes of CTS.

5.2.3 Regular breaks for recovery from biomechanical stresses to the median nerve

This dissertation presents the acute effects of continuous gaming on the median nerve. Chapters 3 and 4 indicate that the movements of the hands and fingers during gaming are highly repetitive and subject the median nerve to compressive stress. As reported in Chapter 4, the results of the study showed that the MNCSA increases after 90 minutes of gaming and continues to increase after 120 minutes gaming; however, it reduces to its original size after recovery for 30 minutes. This finding indicates the cumulative effects of continuous gaming on the median nerve. Notably, the participants reported minimal to no hand discomfort after the two-hour gaming session. This signifies that the early effects of gaming may not be apparent, resulting in players playing continuously for a long time. Moreover, it should be noted that CTS develops slowly, and could manifest any time from several days to several years [65,117]. Thus, the minimal to inapparent short-term physical effects of playing esports can lure players to continue gaming for long hours without knowing that a wrist injury is already developing. Considering these findings, it is recommended for players to take a break after playing for a one-hour session. This can facilitate the recovery of the median nerve and other structures subjected to biomechanical stresses while playing.

5.2.4 Summary of findings

The findings of the three studies are summarized Table 5.1. These studies verified the presence of musculoskeletal concerns in among esports players and highlighted the risk factors for CTS among the gamers, which include number of years played, size of the gamepad, button travel distance, manipulation of buttons, and duration of the gaming session.

Table 5.1 Summary of findings of the three studies.

Study	Conditions	Conclusions
Musculoskeletal Discomfort among Esports Players ($n_{FIL} = 159$ and $n_{JP} = 120$)	Playing esports in general	Resulted to upper body pain (back, neck, wrists, hands, and shoulders)
	Increased number of years played	Resulted to neck, shoulder, and wrist pain
	Increased hours played	Resulted to hand pain
Effects of gamepads and button operations on the median nerve (n = 14)	Holding gamepads (PS and SW vs. Neutral)	<i>MNCSA</i> : Significantly reduced; <i>Circularity</i> , <i>D1</i> , and <i>D2</i> : NSD
	Simulated use of two gamepads (PS and SW vs. Neutral)	<i>MNCSA</i> : Significant reduction for all gamepad operations; <i>Circularity</i> : Significant increase in for PS Analog R; <i>D1</i> : Significant increase for PS and SW Analog R, SW Action and Trigger; <i>D2</i> : Significant decrease in PS Analog L and R, SW Analog R and Trigger
	Gamepad comparison	Significant comparisons: <i>MNCSA</i> : SW Trigger R > PS Trigger <i>Circularity</i> : SW Trigger R > PS Trigger, PS Game L > SW Game L; <i>D1</i> : PS Game L > SW Game L; <i>D2</i> : PS Game L < SW Game L
	Simulated use of three buttons (Analog, Action, Trigger)	PS Gamepad : <i>MNCSA</i> & <i>Circularity</i> : Trigger < Analog R; <i>D1</i> : NSD; <i>D2</i> : Trigger > Analog R SW Gamepad : <i>MNCSA</i> : Trigger < Action; <i>Circularity</i> , <i>D1</i> , and <i>D2</i> : NSD
	Dynamic changes in gaming	<i>MNCSA</i> : NSD in change for Neutral, PS, and SW operations
Effects of playing esports on the median nerve and hand functions (n = 12)	Resting (time blocks)	<i>MNCSA</i> , <i>circularity</i> , <i>D1</i> , and <i>D2</i> : NSD <i>Hand functions</i> : NSD No hand discomfort experienced
	Continuous gaming (time blocks)	<i>MNCSA</i> : Significantly increased at time 90 and 120 minutes; <i>Circularity</i> , <i>D1</i> , and <i>D2</i> : NSD; <i>Hand functions</i> : NSD

Note: n_{FIL} – Filipino participants, n_{JP} – Japanese participants, PS – PlayStation gamepad, SW – Switch gamepad, L – left, R – Right, NSD – No significant difference.

5.3 Recommendations and future studies

Regarding controller designs, a controller with a size and shape that allows for a neutral position of the wrist and hands is recommended. The buttons should be designed in such a manner that their positions would not lead to carpal tunnel compression. Furthermore, the travel distances of the buttons should be minimized, and tactile feedback should be included so that the players do not need to press the buttons too hard. Considering the findings of these studies, future studies on whether less dynamic buttons will reduce gaming satisfaction among players will be interesting.

Regarding gaming habits, the results of these studies indicate that players should take a break after every hour of gaming. This will allow the SSCT, median nerve, and flexor tendons to recover from the rapid repetitive hand movements used during gaming. The break should last for least 30 minutes, if possible. Future studies may determine the optimal length of breaks that would allow for recovery. The longest gaming session used in these studies was 120 minutes. Given that players usually play esports for three or more, future studies on the effects of longer sessions on the median nerve are warranted.

Lastly, the findings of these studies indicate that players should be strengthened through physical and awareness trainings. Upper limb strengthening, warm up, and cooldown exercises are recommended. Players should also undergo awareness trainings on the proper and improper wrist and hand postures.

5.4 Limitations and potential biases

The main limitation of this dissertation is the use of gamepads only as the input device in the experiments. Moreover, the sequence of tasks may have had some effects. To manage this, counterbalancing of the order of tasks per participant was performed. Additionally, the

participants were all recreational players; no professional esports player was included. This could be a research topic for future studies.

Regarding the first study (Chapter 2), the possibility of recall bias regarding the pain and discomfort of the participants in the past six months cannot be eliminated. The participants were also asked if they had experienced similar pain in the past seven days to verify recurrence and allow for better recall.

5.5 Conclusion

This dissertation demonstrated the effects and implications of playing esports, gamepad design, and prolonged gaming on the morphology of the median nerve. The effects of gaming on the musculoskeletal health of the players were apparent in the significant deformations of the median nerve that occurred during and after the sessions. Interestingly, the participants reported minimal discomfort after playing. However, this could be due to the gradual manifestation of CTS symptoms during these types of activities. Thus, improved controller designs, taking regular breaks, and engaging in strengthening exercises are necessary to mitigate the risks of injuries caused by prolonged gaming.

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