# Quantifying Finger Strain in Video Gaming

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**Abstract**

This study aims to provide a quantitative inventory of the strain in finger joints due to a video gaming activity- in terms of joint kinematics, and muscle activation. Ten subjects played a video game on a PSIII gaming console using a sequenced (predefined movements) and a natural (random movements) gaming protocol. Joint angles, velocities and accelerations of the metacarpophalangeal (MCP) and the interphalangeal (IP) joints of the index finger and thumb were captured, using a Vicon system, and modelled in Visual 3D. At the same time, electromyography (EMG) signals were collected from the first dorsal interosseous (FDI) and the extensor digitorum (ED) muscles. The results showed that, at the thumb, flexion-extension of the interphalangeal joint attained very high velocities and accelerations; and, at the index finger, higher velocities and accelerations were attained by the distal interphalangeal joint. For both gaming scenarios, the proximal interphalangeal joint of the index finger attained high flexion-extension angles, which may be attributed to the shape of the game controller. The natural gaming protocol required higher levels of kinematic and muscular efforts. For both gaming protocols, the ED muscle showed greater muscular activity than the FDI muscle. The information acquired from this study is novel and provides a description of finger kinematics that may be useful for design improvements of game controllers to mitigate the risks for overuse injuries.

**Keywords:** Video Gaming, Joint Kinematics, Electromyography (EMG) Muscle Activity.

## 1. INTRODUCTION

Video games have been a source of recreation for nearly half a century. Playing video games at home, on gaming consoles, has been particularly popular among young adults. According to Entertainment Software Association data [1], 58% of the US population plays video games and 51% of the households have at least one gaming console. Lenhart et al. [2] reported that 81% of game players are between the ages 18 and 29. According to demographic and epidemiological information on small hand-held device use among college students [3], more than fifteen percent of an eight-hour workday is spent on gaming for an 'average' youth.

Playing video games may seem to be a ubiquitous mundane recreational activity with harmless consequences to one's health. However, players do suffer from cumulative traumas to the hand from repetitive motions of the fingers and sustained muscular contractions in gripping game equipment. Repetitive thumb motion for pushing or pressing buttons is associated with discomfort and disorders in the thumb ([4],[5]). Bending of the wrist, along with repetitive hand motions, is also a significant contributing factor to ailments like tendinitis, synovitis, tenosynovitis, deQuervain's disease, epicondylitis, etc. [6]. A case of tendinitis was reported [7] from overuse of the thumb during playing games with a Nintendo, and then Brasington coined the term “Nintendinitis”. Later, the term “Wiiitis” was used for repetitive strain injuries of the upper extremities due to excessive use of another gaming console, the Wii ([8], [9]). One of the most common complaints among video game players is pain and numbness on the tip of the thumb, often known as “PlayStation thumb”[10]. Berolo et al. [3] found a significant statistical association between any pain reported in the middle joint of the thumb of the dominant hand and the time spent on gaming in a typical day. In addition, time spent on computer activities, especially game playing, has been reported to be a predictor of low back pain and neck pain among adolescents [11]. Epidemiological evidence shows that among compulsive gamers, severe aches, pains and discomforts, including tendinitis of the hand, have occurred at the base of the thumb ([7], [10]).

Despite the risk for cumulative traumas to the hand, the potential health risks from video game playing has yet not received enough attention in ergonomics research. Motion related (kinematic) and muscle activation (electromyographic) variables are not available in the published literature, and it is not known exactly which joints are exposed to maximum risk.

The effects of video game playing have been studied mainly from physiological (energy expenditure), psychological (psychosocial and emotional), and demographics perspectives. Ravaja et al. [12] studied facial muscle eletromyography signals, heartbeat, and skin conduction of gamers to understand the enjoyment level in different phases of the game. Surprisingly, negative events often triggered positive psychophysiological response and vice versa. Energy expenditure and oxygen consumption for active console video games was studied by Maddison et al. [13], in which players played with a realistic opponent in a three-dimensional arena. Due to high movements of upper extremity limbs, the energy expenditure was comparable with daily light to moderate exercises. In a similar study, Graves et al. [14], using heart rate measurements, found that energy expenditure was not the same for different Nintendo Wii games; it was greater for boxing than for tennis or bowling, and was greater from games played with both hands instead of only one. Wang [15] measured blood pressure, echocardiogram, blood glucose, heart rate and oxygen consumption among children before and after playing a video game. All of these physiological responses increased after playing the game. In almost all cases, physiological responses during or after playing video games showed an increased energy expenditure and upper extremity movement. Psychological and psychosocial studies also established the game playing as both a source of escape from mental stress ([16], [17]).

The published literature is lacking in studies on the kinematics of the fingers, muscle strain, or upper extremity strain assessment from video game playing. Angular motion, velocity and acceleration of the joints, and muscular activity, are all important attributes of any motion-intensive activity, and indicators of the level of strain (the body’s response to the stress), imposed by the demands (speed, accuracy, and competitiveness) of playing the game. The closest study on kinematics that was found was based on recording head and torso motion to predict motion sickness, while playing games on a head-mounted display [18]. The present study, therefore, aims to evaluate joint motion characteristics and muscle activation levels from video game playing.

Kinematics of finger intensive activities have been studied for non-gaming activities, such as using computer keyboards, small mobile phones, and musical instruments. Baker et al. [19] investigated joint angles, velocity, acceleration, and translational movement of the wrist when using a computer keyboard in an effort to understand the associated risks for musculoskeletal problems; Kuo et al. [20] measured muscle activation and joint angles when striking keys on a computer keyboard; and [21] reported a non-consistent relationship between the velocity of typing and other kinematic variables. Furuya et al. [22] investigated the kinematic variables of the fingers and hands of expert piano players, while Goeble and Palmer [23] investigated the joint angle trajectories of the hand for fast tempo piano playing. The latter concluded that the metacarpophalangeal joints contributed more than other joints to fingertip striking motion. Bella and Palmer [24] later reported that finger kinematics at keystroke was unique for each individual and could be used as an identification variable for pianists.

## 2. METHODOLOGY

The objectives of this study were to:

i. Identify and analyze joint motion variables (angular displacement, velocity, and acceleration) of the index finger and thumb of the dominant hand while playing a video game.
ii. Identify and analyze muscle activation patterns obtained from EMG (electromyography) signals from two muscles of the dominant hand during the video game.
iii. Evaluate the kinematic and EMG data as measures of strain in the hand from playing the video game

For simplicity, the kinematic measurements were made on only two fingers – the thumb and index finger of the dominant hand. All the subjects were right handed; therefore dexterity was not a factor of study. A specific game and a specific controller were used, so the type of device was also not a factor. The study protocol was approved by the Institutional Review Board (IRB) of the university.

### 2.1 Subjects

Ten students, eight males (mean age 27.5 ± 4.2 years) and two females (mean age 27± 3 years) participated in the study voluntarily, from posted advertisements on a university campus. They were not paid, nor rewarded, in any way, for their efforts. The participants were all acquainted with the game controller used in the study. Hand measurements (length of joints) of each subject were recorded for descriptive purposes (Table 1). Digit 1 indicates thumb and digit 2 indicates index finger.

| **Width at knuckles** | **Fingertip to root digit 1** | **Fingertip to root digit 3** | **Fingertip to root digit 5** | **Fingertip to IP1** | **IP1 to MCP1** | **Fingertip to DIP2** | **DIP2 to PIP2** | **PIP2 to MCP2** |
|---|---|---|---|---|---|---|---|---|
| 83.3 (5.77) | 63.06 (3.8) | 80.8 (5.26) | 60.37 (5.01) | 33.38 (2.4) | 32.27 (2.42) | 25.62 (2.03) | 21.86 (2.34) | 24.88 (2.47) |
| *44.54 (54.83)* | *33.43 (41.91)* | *43.03 (53.42)* | *32.69 (39.15)* | *17.89 (21.91)* | *17.35 (21.11)* | *13.83 (16.69)* | *12.1 (13.81)* | *13.68 (15.85)* |

*DIP= Distal interphalangeal joint, MCP= Metacarpophalangeal joint, PIP = Proximal interphalangeal joint, and IP = Interphalangeal joint.

**TABLE 1:** Hand measurements (mm) of the male (middle row) and *female* (top row) participants: mean (SD).

### 2.2 Task Description

The experimental task involved participants playing a video game on a Sony PlayStation III (PSIII) gaming console. The game used for this experiment was "Facebreaker" (Electronic Arts, CA, 2008), a relatively basic 2-player boxing game. The reason for selecting this game was that it was a relatively simple game with a limited number of boxing motions. The motions could easily be identified and a sequence could be established to standardize the task. Two gaming protocols were used in the experiment: a sequenced protocol, in which the gamer pressed a predefined sequence of buttons; and a natural protocol, in which the gamer played the game realistically.

a) The Sequenced Protocol (Standardized)

In this protocol, the player (avatar in the game) and the opponent (computer) were pre- chosen. In this scenario, a predefined set of attacks (punches, high punches, low punches, throws, etc.) was performed by the player. The exact sequence played or the buttons pressed on the game controller are shown in Table 2.

| Sequence | Move | Representation in game |
|---|---|---|
| 1 | Press "□" 8 times | Punch (up) |
| 2 | Press "X" 8 times | Punch (down) |
| 3 | Press "O" 8 times | High punch |
| 4 | Press "Δ" 8 times | Throw |
| 5 | Press and hold "□" | High parry |
| 6 | Press and hold "O" | High punch |
| 7 | Press and hold "Δ" | High throw |
| 8 | Press and hold "X" | Low parry |
| 9 | Press R1 twice | Block |
| 10 | Press R1 and "□" together | Block + High parry |
| 11 | Press R1 and "X" together | Blocko + low parry |
| 12 | Move joystick in left, right, up, down and counterclockwise. | None |

**TABLE 2:** Sequenced Gaming Protocol .

The sequenced protocol was defined in such a way that all possible buttons in the controller would be used. Figure 1 shows the button positions in the PSIII controller.


**FIGURE 1:** Operating the PS III Controller.

The subjects were asked to practice the sequence properly before the experiment. When they confirmed that the sequence was well practiced, the subsequent performance was recorded.

b) The Natural (real game) Protocol

In the natural protocol, the opponent of the game was placed in an "offensive mode". In this situation, the subjects were asked to do whatever was needed to win the game In Figure 2, a subject is performing the game; a glimpse of the game can be seen on the TV screen. Gaming protocols were randomly assigned to avoid effects of adaptation.

**FIGURE 2:** Playing Video Game.

## 2.3 Data Collection

*2.3.1 Joints and Muscles of the Hand*

The thumb and index fingers are used predominantly when operating the game controllers, and were the focus of this research. The motions of the two joints in the thumb (the metacarpophlangeal, MCP1, and the interphalangeal, IP1) and three joints in the index finger (metacarpophalangeal, MCP2; proximal interphalangeal, PIP2; and distal interphalangeal, DIP2) were measured. The activation levels of Extensor Digitorum (ED) and First Dorsal Interosseous (FDI) muscles were also measured. The extensor digitorum is a large muscle located on the posterior surface of the arm. It extends the four digits of the hand other than the thumb. Particularly, it extends the proximal phalanges. It also assists in abduction of the index, ring, and little finger, and abduction and extension of the wrist [25]. The FDI muscle is an intrinsic (within hand) muscle of the hand, and its primary function is to conduct abduction/adduction of the index finger. The reflective markers on the hand, and the video game controller held by the hands, limited the space available for the attachment of more electrodes on the hand and, thus, the extent of the EMG measurements.

2.3.2 Hand Preparation

Subjects' hands were wiped thoroughly with alcohol before placing the markers and electrodes on specific points of the dominant hand. Thirteen (three on thumb, four on index finger, three on hand and three on wrist area) reflective markers of 4 mm diameter were placed on the right hand of the subject . Prior to electrode placement, the selected area of the hand was thoroughly cleaned by shaving the hair and rubbing with alcohol. Two sets of EMG surface electrodes were placed on hand and arm as shown in Figure 3.

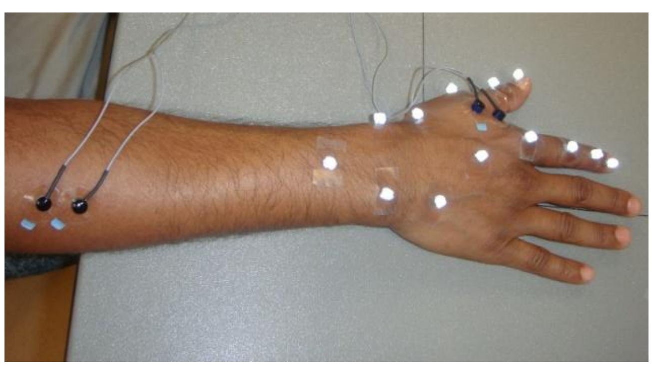


**FIGURE 3:** Marker and EMG Electrode Positions On Hand.

### 2.3.3 Motion Data Collection on VICON

The Vicon 460 motion capture system comprising six cameras (Vicon Motion Systems, 2002) was used to perform (hand) motion capture. Vicon camera positions and focii were selected by trial and error until a steady and reliable image with all thirteen markers was clearly captured. Marker placement on hand was adopted from [19], with slight modification for our two-fingered tasks. Markers were placed so that the index finger could be represented by three links, and the thumb could be represented by two links. The wrist was represented by a triangle and the dorsal surface of the palm was represented by another triangle. The symbols FR1, FR2, FR3 and FR4 represent the markers on the index finger (Table 3), while TR1, TR2 and TR3 represent the markers on the thumb. The markers HRAD, HULN and MHAND complete a triangle on hand and WRAD, WULN and FARM complete a triangle on the wrist. The positions of the markers are described with the figure in Table 3.

| Symbol | Position on hand |
|---|---|
| FR1 | MCP joint of Index finger |
| FR2 | PIP joint of index finger |
| FR3 | DIP joint of index finger |
| FR4 | Tip of the index finger |
| TR1 | MCP joint of thumb |
| TR2 | IP joint of the thumb |
| TR3 | Tip of the thumb |
| HRAD | Proximal second metacarpal |
| HULN | Proximal fourth metacarpal |
| MHAND | Second metacarpal (approximately) |
| WRAD | Radial styloid |
| WULN | Ulnar styloid |
| FARM | A point in forearm between radius and ulna |

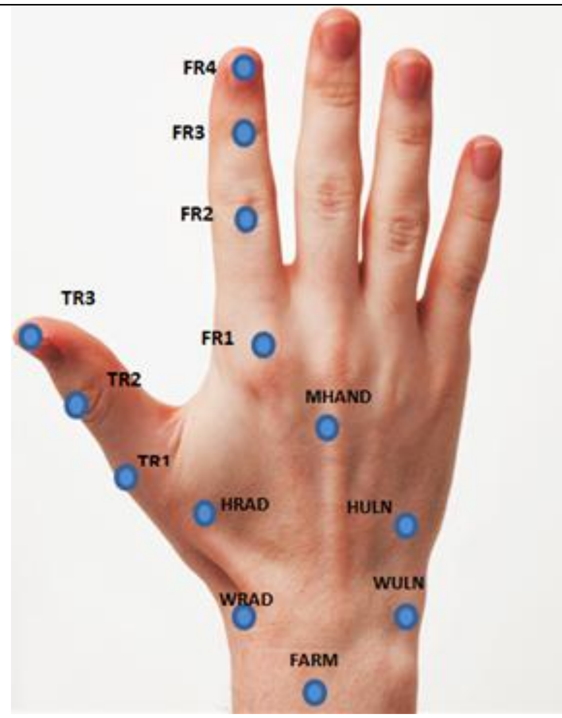



**TABLE 3:** Symbols and Positions of Markers On Hand.

Video data was collected on the VICON system at a rate of 60 Hz. The video frames were reconstructed in *workstation* software to model the marker movements in 3-D space. The first few frames of each video were cut off until all thirteen markers were visible in the reconstructed data. Each marker in each frame was identified, and *Woltering* filter routine was used in the software to fill gaps.

### 2.4 Modelling Joint Motions in 3-D

2.4.1 Direction of Movement

Standard biomechanical directions were followed for finger flexion/extension and abduction/adduction. When a button was pressed, the joints of the finger were flexed; and, when the finger moves away from the button, the joints were extended. Finger abduction/adduction was taken as movement away from/toward the midline of the hand.

2.4.2 Modelling Thumb and Index Finger in Visual 3D

The motion data obtained from workstation software was modelled in Visual 3D software version 6.0. A static trial recorded for each subject served as the baseline to identify positions of the markers in order to construct hand segments in visual 3D. The following hand segments were constructed to model movements of index finger and thumb (Figure 4): thumb base, thumb12, thumb23, finger12, finger23 and finger34, palm triangle and wrist triangle. Thumb base was a segment that simply connected the MCP1 joint to the hand. Thumb12 connected MCP1 and PIP 1 joints, and thumb 23 represented the distal phalanx joint of the thumb. Similarly, finger12 joined MCP2 and PIP2, finger23 joined PIP2 and DIP2, and finger 34 represented the distal phalanx of the index finger. The palm triangle segment represented the dorsal plane of the palm in general.

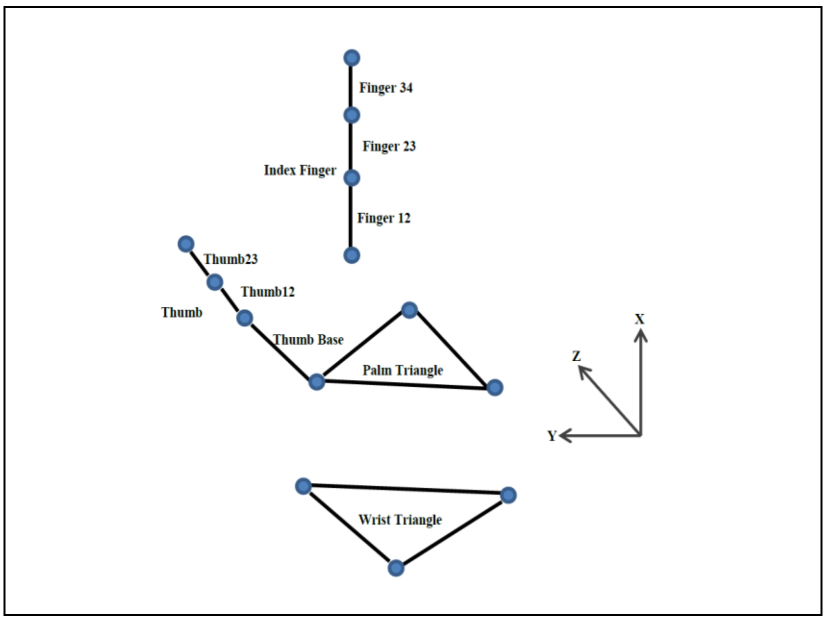



**FIGURE 4:** Hand Segments and Axes as Modelled In Visual 3D.

Each segment had its own local coordinate system. The coordinate systems were kept as aligned together as possible. The X, Y and Z directions were defined as follows: the transverse plane of the body was on (x,y) plane, coronal plane was on (y,z) and sagittal plane was on (x,z) plane.

2.4.3 Joint Angle, Velocity and Acceleration

Inverse kinematics principles [26] were used to calculate Euler angles of each segment with respect to X, Y and Z axes. The joint angle definitions in terms of location, reference segment, Euler axes, and segment in motion are summarized in Table 4. The X Euler angles represent flexion-extension, and Y Euler angles represent abduction-adduction of the finger. For both flexion-extension and abduction- adduction joint angles, the study focused on the magnitude rather than the direction (positive/negative) of angular movement. Consequently, the absolute values of the joint angles were used for analyses.

| Joint and motion | Joint angle abbreviation | Euler axis | Reference Segment | Motion Segment |
|---|---|---|---|---|
| Metacarpophalangeal joint of the thumb, flexion-extension | MCP1 f-e | X | Thumb base | Thumb 12 |
| Metacarpophalangeal joint of the thumb, abduction-adduction | MCP1 ab-ad | Y | Thumb base | Thumb 12 |
| Interphalangeal joint of the thumb, flexion-extension | IP1f-e | X | Thumb 12 | Thumb 23 |
| Metacarpophalangeal joint of the index finger, flexion-extension | MCP2 f-e | X | Palm | Finger 12 |
| Metacarpophalangeal joint of the index finger, abduction-adduction | MCP2 ab-ad | Y | Palm | Finger 12 |
| Proximal interphalangeal joint of the index finger, flexion-extension | PIP2 f-e | X | Finger 12 | Finger 23 |
| Distal interphalangeal joint of the index finger, flexion-extension | DIP2 f-e | X | Finger 23 | Finger 34 |

**TABLE 4:** Joint Angle Definitions.

Joint velocities (degrees/s) and accelerations (degrees/$s^2$) were computed by differentiating the angles and velocities respectively with respect to time (of movement). Two types of averages were derived, for each task:

a) *Overall Average:* For each combination of task and joint (2x7 or 14), the average value of a joint motion variable (angle, velocity or acceleration) was calculated across all the frames of data, for each subject. The result was then averaged across subjects, to yield the overall average (or the average of the averages).
b) *Maximal Average:* For each combination of task and joint, the maximum value of a joint motion variable was obtained across all the frames of data, for each subject. The result was then averaged across subjects to obtain the maximal average of the angle, velocity or acceleration (or average of the maxima).

### 2.5 EMG Variables
Raw EMG signals obtained from workstation software were processed in Visual software. The raw EMG signals were rectified to get a unidirectional view. The rectified data was then low-pass filtered using Butterworth filter of 6 Hz cutoff frequency to produce a consistent and comprehendible EMG pattern.

The EMG patterns found for all the tasks were not similar. In some cases, the tasks required a “burst” of muscle activity at some frames, while other frames indicated a relatively small amount of muscle effort. For some tasks, however, there was no discernable “burst” of activity. To be consistent with our video data analysis, the method of Lay et al. [27] was adopted, with some modifications. EMG signals were collected at 1080 Hz, while the video data was taken at 60 Hz. Therefore, 18 frames of EMG data were produced for each frame of video data. The average value of EMG signals, for each of these 18 frames, was first calculated (average EMG per frame, $M_f$). The overall average EMG ($M_a$) for each task was found by: $M_a = (\sum M_f)$ / number of video frames in the task.

To get an idea about the muscle effort expended in the sections where an EMG "burst" was found, another average EMG value, "burst average", $M_b$ was calculated; it was defined as: $M_b = (\sum M_f$, where $M_f > M_a)$/ (number of video frames where $M_f > M_a$).

Figure 5. shows the average (Ma) and burst average ($M_b$) amplitudes of EMG for a subject while performing the sequential video gaming task.

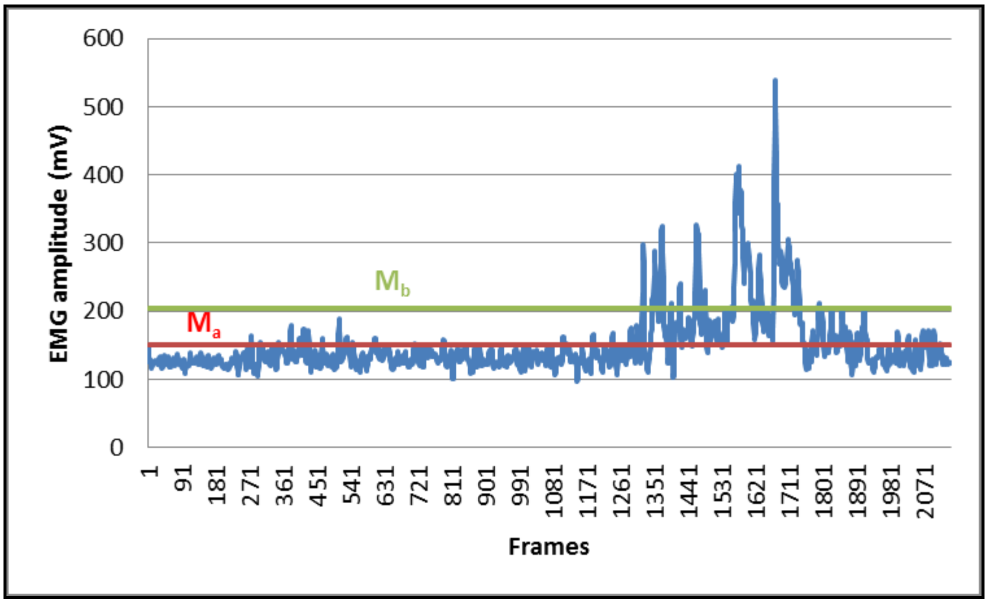



**FIGURE 5:** EMG Average Amplitude Calculation.

Thus, the EMG "burst to average ratio", $M_b/M_a$ is a representation of the higher-than-average muscular efforts required for the task.

## 3. RESULTS AND DISCUSSION

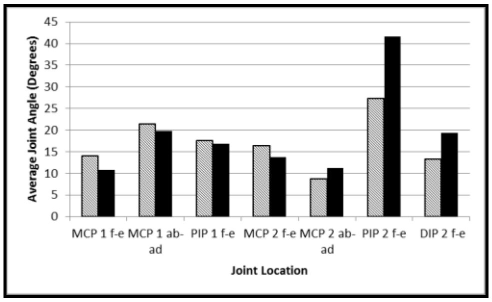
Summary data for the kinematic (joint angle, velocity and acceleration) and EMG variables for the gaming tasks are presented in Table 5. These variables represent the body's responses to the task demands from gaming, and are taken to be measures of strain. For the kinematic variables, the overall average and maximal average for each of the seven joint actions are presented. The overall average is an indication of the general strain from the tasks, while the maximal average is an indication of the most intense strain. For the muscle activity data, average EMG burst activity and Burst-to-Average ratio of the muscles are also stated. The two-sample Wilcoxon-Mann-Whitney test ([28], [29]) was performed to test the difference between natural and sequential gaming for the kinematic variables.

| Measures of Strain | Location on body | Sequential | Natural |
|---|---|---|---|
| Overall Ave. Angle (deg) | MCP 1 f-e | 13.97 | 10.87 |
| | MCP 1 ab-ad | 21.38 | 19.85 |
| | PIP 1 f-e | 17.56 | 16.91 |
| | MCP 2 f-e | 16.35 | 13.75 |
| | MCP 2 ab-ad | 8.69 | 11.2 |
| | **PIP 2 f-e*** | 27.25 | 41.61 |
| | DIP 2 f-e | 13.3 | 19.28 |
| Overall Ave. Velocity | MCP 1 f-e | 16.68 | 13.01 |
| | MCP 1 ab-ad | 12.2 | 11.28 |
| | PIP 1 f-e | 21.25 | 24.96 |
| | MCP 2 f-e | 8.13 | 11.81 |
| | MCP 2 ab-ad | 7.63 | 10.44 |
| | PIP 2 f-e | 10.26 | 15.95 |
| | DIP 2 f-e | 13.77 | 14.75 |
| Overall Ave. Acceleration | MCP 1 f-e | 210.34 | 192.27 |
| | MCP 1 ab-ad | 147.95 | 153.4 |
| | PIP 1 f-e | 255.86 | 404.42 |
| | MCP 2 f-e | 115.99 | 180.07 |
| | MCP 2 ab-ad | 98.09 | 138.61 |
| | PIP 2 f-e | 139.14 | 270.8 |
| | DIP 2 f-e | 172.71 | 230.4 |
| Maximal Ave. Angle (deg) | **MCP 1 f-e*** | 65.71 | 22.83 |
| | **MCP 1 ab-ad*** | 43.35 | 29.33 |
| | PIP 1 f-e | 40.59 | 32.28 |
| | **MCP 2 f-e*** | 30.71 | 24.48 |
| | MCP 2 ab-ad | 20.14 | 19.69 |
| | **PIP 2 f-e*** | 89.08 | 53.48 |
| | DIP 2 f-e | 45.53 | 53.78 |
| Maximal Ave. Velocity (deg/s) | **MCP 1 f-e*** | 160.19 | 106.8 |
| | MCP 1 ab-ad | 123.37 | 122.45 |
| | PIP 1 f-e | 161.92 | 271.56 |
| | MCP 2 f-e | 140.32 | 116.52 |
| | MCP 2 ab-ad | 78.5 | 113.97 |
| | PIP 2 f-e | 111.12 | 214.55 |
| | DIP 2 f-e | 460.94 | 178.15 |
| Maximal Average Accelerations (deg/s$^2$) | MCP 1 f-e | 2905.05 | 2177.98 |
| | MCP 1 ab-ad | 2447.48 | 2093.67 |
| | PIP 1 f-e | 2818.36 | 4976.26 |
| | MCP 2 f-e | 3031.58 | 2665.01 |
| | MCP 2 ab-ad | 1510.17 | 2352.55 |
| | PIP 2 f-e | 2412.38 | 4054.71 |
| | DIP 2 f-e | 2652.83 | 5463.9 |
| EMG Average Burst | **First Dorsal** | 401.23 | 676.28 |
| EMG Burst to Average | **First Dorsal** | 1.49 | 1.37 |
| EMG Average Burst | Extensor Digitorum | 844.14 | 1392.26 |
| EMG Burst to Average | Extensor Digitorum | 1.92 | 1.79 |

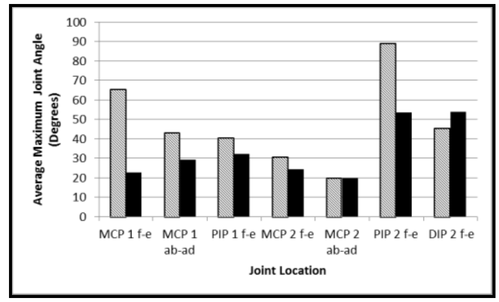
**TABLE 5:** Joint Kinematics and EMG activity for Sequential and Natural Gaming. (Significant difference indicated by *).

### 3.1 Comparison of Joint Actions

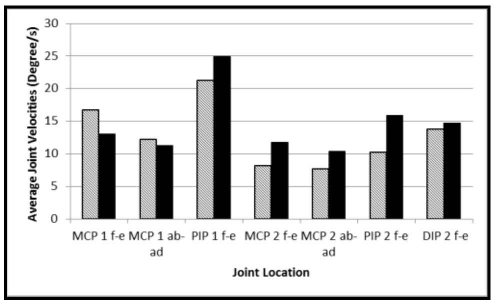
Figure 6 (a-f) gives a graphical comparison of the joint actions. The solid bars represent the natural gaming task, and patterned bars represent the sequential gaming task.



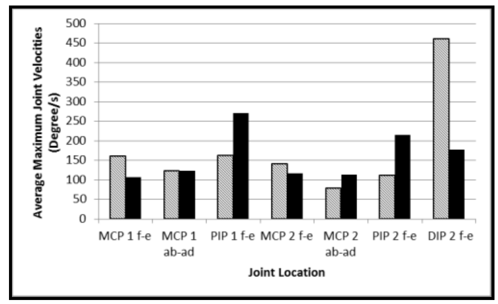

a. Overall average joint angle (deg)



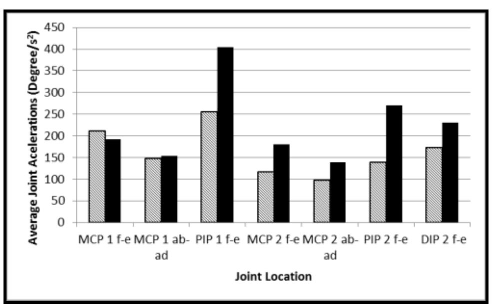

d. Maximal average joint angle (deg)



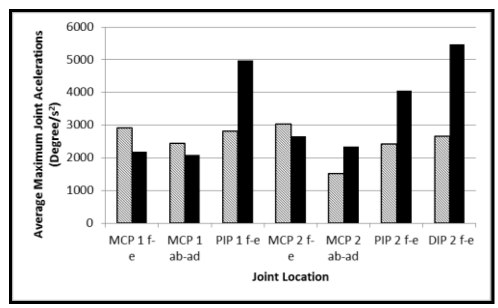

b. Overall average joint velocity (deg/s)




e. Maximal average joint velocity deg/s)




c. Overall average joint acceleration (deg/$s^2$)




f. Maximal average joint acceleration (deg/$s^2$)

Natural Gaming    Sequential

**FIGURE 6:** Average and maximal joint kinematic variables for gaming tasks.

The magnitude differences between average and maximal values are extremely large; the height of the bars may be compared within any of the six joint motions.

3.1.1 Angular Displacement

In all cases of joint motions, for both of the gaming methods, the kinematic variable (angular displacement, velocity, or acceleration) values were vastly different between the maximal and overall averages, as expected (Table 5). Direct comparisons of variable value magnitudes among joint motions would, therefore, be more meaningful when made within each type of average.

For both the overall and the maximal averages, the proximal joint of the index finger (PIP2 f-e)) made a greater angular displacement than any other joint (27.25 $^o$ and 41.61$^o$ , respectively, for flexion-extension). This is most likely because the flexion-extension joint motion is required for operating (pressing) the side buttons of the game controller and maintaining a proper grip on it. For the overall average, the difference between natural and sequential gaming was non-significant for all joint displacements (p>0.05), except flexion-extension of the proximal interphalangeal joint of the index finger (PIP2 f-e; p=0.129), mentioned above. For the maximal averages, four of the seven joints had a significant difference between the two gaming methods (p<0.05): PIP2 f-e , MCP1 f-e, MCP1 ab-db, and MCP2 f-e (p = 0.0041 to 0.0375); and in all four cases, the sequential game produced the greater angular displacements (Table 5).

There was a gaming effect for the significant PIP2 f-e joint displacement, mentioned above; that is: for the overall average, the angle was greater for natural gaming but, for the maximal average, the angle was greater for sequential gaming (Table 5 and Figure 6). The angle of the PIP2 joint defines the gripping of the controller, to a large extent, and can be attributed solely to the design of the gaming console. The larger overall average angle for natural gaming, compared to sequential gaming, was due to longer periods of gripping the controller snugly (greater knuckle bending) with the middle and distal finger segments wrapped around the upper corners of the controller, and to the sharp unplanned finger presses. The larger maximal angle for sequential gaming, on the other hand, was due to the need for more caution and better stabilization of the controller, to allow for more precision and speed in tapping the keys throughout the gaming period

3.1.2 Angular Velocity
There was no significant difference in the overall average velocity (p>0.05) between games for any of the seven joint motions, and there was only one for the maximal average (MCP1 f-e ;160.2 deg/s for sequential vs 106.8 deg/s for natural gaming; p=0.04).

For the overall average, the highest velocity was achieved by the IP1 f-e (interphalangeal joint of the thumb, flexion-extension, 24.96 deg/s); and, for the maximal average, the highest was by the DIP2 f-e (distal interphalangeal joint of the index finger, flexion-extension, 460.94 deg/s ). Both cases confirm fast movements of the distal segments of the fingers for tapping the keys.

Over the course of the sequential gaming task, there were two particular occasions when the side-buttons were pressed in conjunction with a top-button. Although the PIP2 joint achieved the greatest angular displacements (for average and maximal averages), it's velocity and acceleration was relatively low compared to those of IP1 and DIP2 joints (Figure 6).

A gaming effect was also observed for joint velocity -- the highest velocity for the overall average was with the thumb (IP1) and the highest for the maximal average was with the index finger (DIP2), both for flexion-extension. This most likely reflects different finger motion demands for the two gaming methods.

For the overall average, most of the joint velocities were slower for sequential gaming, suggesting more cautious movements of the fingers to maintain precision in executing the predetermined sequence of key pressing. For the maximal average, the velocity for flexion-extension of DIP2 was much larger for sequential than natural gaming, which is difficult to explain.

3.1.3 Angular Acceleration
In general, very high joint accelerations were achieved for both games and, in most cases, the joints that achieved the higher velocities were the ones that achieved correspondingly higher accelerations (the IP1 f-e, PIP2 f-e, and DIP2 f-e). One notable exception was DIP2 f-e, which had a greater velocity for sequential gaming, but a greater acceleration for natural gaming. Most of the joint accelerations were greater for natural gaming, and for the distal finger segment of each finger, in flexion-extension. However, there was no significant difference between two

games for any joint acceleration, for either the overall or maximal average. For both types of average, noticeable differences occurred for (thumb) IP1 f-e (2818 vs 4976.3 deg/s$^2$), (index finger) PIP2 f-e (2412.4 vs 5463.9 deg/s$^2$) and DIP2 f-e (2652.8 vd 5463.9 deg/s$^2$). The tendency for natural gaming to have higher accelerations than sequential gaming suggests a tendency for gamers to move the fingers as fast as possible and, (thus) exert greater forces (effects of accelerations) on the buttons when the gaming actions were not predetermined.

3.1.4 Abduction-adduction Motions

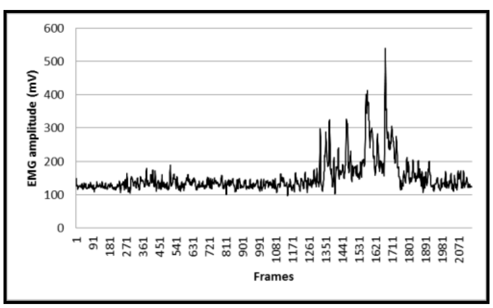
In general, abduction-adduction motions were associated with smaller angular displacements, velocities, and accelerations than flexion-extension motions. Abduction-adduction motions were required more for joystick and side button operations than for tapping forces, due to the nature of the game and the physical design of the controller; and moving the position of the finger tip over the keys (abduction-adduction) was less stressful than tapping the keys (flexion-extension).

3.1.5 Strike Rates

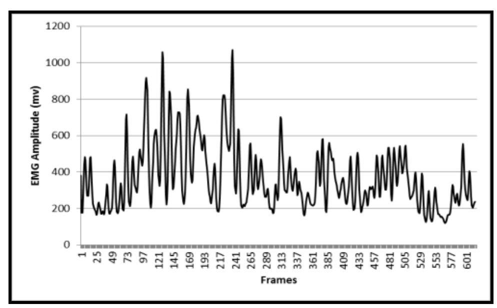
The video data analysis showed that the strike rate (on the keys) was much greater for natural gaming (4.5 strikes per second) than for sequential gaming (2.65 strikes per second), with statistical significance at p=0.0008. This was as expected since the natural gaming involved uninhibited pressing of keys to win a game.

### 3.2 Comparison of EMG Muscle Activities

For the sequential gaming task, a burst of muscle activity was found in most of the cases near the end of the activity, usually around 65-80% of the completion time. This was the case for both the FDI and ED muscles. For the natural gaming task, the burst patterns were not consistent, and many bursts were found in the same activity. This was, perhaps, because the natural gaming task was performed at will, so the patterns were not uniform across subjects.
FIGURE 7 shows a typical EMG pattern (filtered, rectified) for sequential gaming and a sample EMG pattern for natural gaming.




a. Sequential Gaming.




b. Natural Gaming.

**FIGURE 7:** EMG patterns for a subject's ED muscle for gaming activity.

For the FDI muscle, a higher *average* burst activity was achieved in natural gaming, but the ratio of burst to average overall activity was higher for sequential gaming. This makes sense because during sequential gaming, the first few movements were slow, and most of the subjects performed the task cautiously. Towards the end of the task, there was side button and joystick movements, which needed significant abduction-adduction of fingers, triggering FDI muscle activity.

Similar to FDI muscle, ED muscle also exhibited greater *average* burst activity for natural gaming, and EMG burst-to-average ratio was also higher for sequential gaming. This is mainly due to the fact that, in natural setting, buttons were vigorously pressed at a higher strike rate. Therefore, both the muscles were used more for natural gaming. For both gaming tasks, the ED muscle showed higher average burst activity, which indicates higher-flexion extension activity, particularly, extension of the proximal phalanges of the index finger. This is in agreement with the findings from joint kinematic analysis.

EMG average burst activity (p=0.0029) and burst to average ratio (p=0.0243) at the FDI muscle were the only EMG variables that showed a statically significant difference between the two gaming techniques; and the greater EMG activity of the FDI muscle for natural gaming, compared to sequential gaming, reflects the more vigorous use of the controller for pressing side buttons as the index finger moved from one button to the next.

The EMG average burst activities of extensor digitorum (ED) showed a wide range across the gaming tasks, ranging from 844 mV (for sequential gaming) to 1392 mV (for natural gaming). On the other hand, the average EMG burst activities for first dorsal interosseous (FDI) muscle had a narrower range, 401 mV (for sequential gaming) to 676 mV (for natural gaming).

### 3.3 Finger Joint Kinematics In Comparable Activities

As mentioned earlier, no description of finger kinematics was found in the existing literature for video gaming activities. However, there is a limited amount of kinematic data for other tasks -- single thumb key press texting [30], typing on keyboards [19], and single thumb typing on touch screen phones using a claw grip [31]. The only pattern that is evident is the relatively small angle for the metacarpophalangeal joint of the thumb, flexion-extension (MCP1 f-e), compared to other joint displacements. There are great variations in the joint angle displacements among these studies, characteristic of the nature of the activities or tasks, with none beyond 42 deg average. Further comparisons may be spurious. The data from [19] also show smaller velocity and acceleration values with the little finger ($48^o$/s and $776.5^0/s^2$ compared to $271.56^o$/s and $5463.9^o/s^2$ in the present study).

### 3.4 Product Design and Usage

As can be seen in Figure 8, the index finger wraps around the gaming console at the PIP2 joint (knuckle of the index finger) for pressing the side control buttons (arrows a and b). While this PIP2 joint (knuckle of the index finger) mostly contributed to gripping and controlling the game controller to press the buttons, the DIP2 joint tapped the buttons vigorously, as evidenced by its high velocities and accelerations.

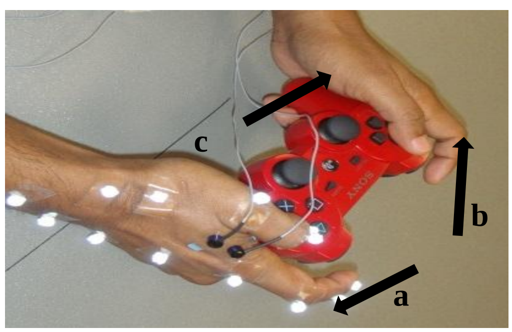



**FIGURE 8:** Finger Position On The Gaming Console.

Thumb abduction-adduction (MCP1 joint) was relatively slow, and did not attain as large displacement as other joints. This was because the position of the top-surface buttons and the joysticks on the gaming console were close and required only slight abduction-adduction motions. The workload severity of the thumb was defined by the repetitiveness of its motions, in addition to the angular displacement, velocity or acceleration. The rate of pressing on buttons was very high.

Of great concern about the game controller is the contouring at the PIP joint of the index finger, and the extremely high velocities and accelerations of joint motions. Highly repetitive loading can significantly damage the articular cartilage tissues, and once damaged, they are very difficult to repair [32]. Torsional, compressive and shearing loading result as forces are applied across finger joints, at each repetition of finger contact with the controller. The average strike rate on buttons in the gaming was 4.5 strikes per minute for natural gaming and 2.65 for sequential gaming. Using Berolo et al's [3] average usage time of small devices per day (73 min), these numbers translate into 19,926 and 11,734 strikes (repetitions) per day. It is well known from theoretical stress-frequency relationship in exercise science, that the higher the repetition level, the lower should be the stress experienced by any structural part of the body to avoid risk of injury. Combined with very high velocities and accelerations, highly repetitive movements of fingers would likely lead to damage to repetitive strain injuries. In the long run, damage of the articular cartilage is likely to occur, resulting in irreversible ailments.

Recommendations for improvements in the design or operation of a game controller are not easy to come by. The thrill and enjoyment of games come typically from the extremes of the activities involved and the intensity of competition generated between players (people) or between person and machine. High repetition and fast motions are characteristic of such activities. Changes in design of equipment or method of playing that may minimize a cumulative strain problem may reduce enjoyment or satisfaction, and generate less demand for the game on the market. However, the results of this study point to a few changes that may mitigate the severity or incidence of repetitive strain injury:

i. The side buttons may be made larger so that a larger surface area of the index finger is involved in pressing it, thereby reducing the mechanical pressure (force/area) on the fingers
ii. A greater touch-sensitivity of the buttons on the controller should reduce the finger force for activation (as indicated by the accelerations of the distal joints of the thumb and index finger.
iii. A greater distribution of the buttons around on the controller should enable the use of other parts of the palm, such as the thenar eminence and other fingers.
iv. Reducing repetition of finger presses, by having a button perform more than one function, should reduce the musculoskeletal severity of the activity.

## 4. LIMITATIONS AND FUTURE WORK

One of the limitations of our study is that the tasks were performed in a laboratory setting. We have tried to replicate the tasks as close to real life as possible, but in real life, many other postures may be adopted for these tasks. The video gaming task was performed in a sitting posture with arms and hands placed on a table. But in real living rooms, the posture may be quite different. Future studies should include assessment of these tasks in natural settings as they occur. Also, epidemiological information can be incorporated with the current data to find out the specific reasons for musculoskeletal symptoms by looking at trends in their occurrences. Future studies may also include age-wise segments of population. Gaming consoles and video games come in numerous varieties. We limited our study to one device type (one gaming console, one video game, and one controller). Studies can be extended to include other device and game types.

Also, we have limited our focus on only two fingers: the thumb and the index finger. While the other fingers were not actively involved in performing the tasks in our study, postural strain may have occurred, due to prolonged constrained grasping at other finger joins as well. Obtaining subjective opinions from subjects regarding the difficulty or discomfort of tasks may provide useful information, which can be incorporated in future studies.

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