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Kinematic Variables in Operating a Computer Game Controller

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Abstract: Operating a computer game controller involves intensive and prolonged finger motions and sustained gripping. Four broad sources of stress on the hands are recognized in such a gaming activity: rapid repetitive finger motions, sharp bending of joints, forceful exertions, and sustained gripping. The cumulative effects are manifested as cumulative trauma disorders of the hand, such as tendinitis, tenosynovitis, deQuervain's disease, and epicondylitis – referred to as 'Nintenditis' by the general public. This study describes a method that captures and analyzes kinematic variables of the fingers (joint angle, velocity, and acceleration) in operating a game controller for two different gaming methods. No study on gamimg, other than this one, has analyzed kinematic variables before. Such analysis requires specialized equipment for capturing small rapid angular motions of the fingers. The Vicon 460 motion capture system, adapted for very small motions, comprising six cameras (Vicon Motion Systems, 2002), was used to perform (hand) motion capture. The kinematic variables for the metacarpophalangeal (MCP) and the interphalangeal (IP) joints of the index finger and thumb were measured by the Vicon system and modelled in Visual 3D. Joint motion data were collected from thirteen reflective markers (three on thumb, four on index finger, three on hand and three on wrist area), each of approximately of 4 mm diameter, placed on the right hand of participants. Vicon camera positions and foci were selected by trial and error until a steady and reliable image with all thirteen markers was clearly captured. Flexion-extension and abduction-adduction motions of the two joints in the thumb (the metacarpophlangeal , MCP; and the interphalangeal, PIP1) and three joints in the index finger (metacarpophalangeal, MCP2; proximal interphalangeal, PIP2; and distal interphalangeal, DIP2) were measured. The results showed that very high velocities and accelerations were achieved for flexion-extension motions of the interphalangeal joints of the thumb but sharp bending occurred for the flexion of the index finger. Lateral finger motions (abduction-aduction) were less deviated and slower for both types of games. Differences in joint kinematics are also analyzed for the two different methods – one involving a predetermined sequence of motions and the other, a natural free sequence.

Keywords: Video gaming, joint angle, joint velocity, joint acceleration, electromyography (EMG), interphalangeal joint, metacarpophalangeal joint.

1. Introduction

Playing video games with hand held electronic devices has proven to be very popular as a form of entertainment throughout the world, particularly among young adults. It has been reported that 58% of the US population play video games and 51% of the households have at least one gaming console (Entertainment Software Association, 2013). According to Lenhart et al. (2008), 81% of game players are between the ages 18 and 29 years. Demographic and epidemiological data also suggest that more than 15 % of an eight-hour workday is spent on gaming with small hand held devices, among college students (Berolo et al., 2011). Holding a small electronic device and pressing keys may seem harmless to the body, but scientific evidence suggests otherwise, especially when the activities are highly repetitive and prolonged. Such activities are reflected in the operation of a computer game controller. They involves intensive and prolonged finger motions and sustained hand forces for gripping and stabilizing the controller. Four broad sources of stress on the hands are recognized in such a gaming activity: rapid repetitive finger motions, sharp bending of joints, forces from muscular exertions, and sustained gripping. The harmful cumulative effects of these stresses are manifested as cumulative trauma disorders of the hand, such as tendinitis, tenosynovitis, deQuervain's disease, and epicondylitis (Tanaka et al., 2001; Moore, 1997). Popular terms such as 'Nintenditis' Brasington (1990), 'Wiitis' (Bonis, 2007; Nett 2009) and "PlayStation thumb" (Karim, 2005) have been coined in references to these cumulative trauma disorders from video game playing.

Published research on the effects of gaming on the health of gamers have dealt almost exclusively with the physiological (energy expenditure), psychological, psychosocial and demographic aspects of video gaming. Studies include measurement of facial muscle eletromyography, heartbeat, and skin conduction for investigating enjoyment levels (Ravaja et al., 2004); estimating energy expenditure (Maddison et al., 2007; Graves et al., 2008; and Wang, 2006); and measuring psychological and psychosocial stress levels (Hossini et al., 2011; Cole and Griffith, 2007; and Hussain et al., 2009). However, not much has been written on the kinematic aspects of video gaming, which is characterized by highly repetitive finger motions. An understanding of the causes of the physical stresses on the hand and fingers also an understanding of the associated muscular contractions and motions of the fingers.

Motion intensive activities by people may be defined by angular motion, velocity and acceleration of the joints or segments of the body, and with muscular forces, may be considered to be indicators of the level of strain, or the body's response to the stress, due to the demands of the activity (playing video games)**.** The present study aims to evaluate joint motion characteristics from video game playing.

Kinematics of rapidly moving fingers have been studied in non-gaming activities, such as using computer keyboards, small mobile phones, and musical instruments by several researchers. Joint angles, velocity, acceleration, and translational movement of the wrist, when using a computer keyboard, were studied by Baker et al. (2007) in an effort to understand the risks for musculoskeletal problems of the hand; muscle activation and joint angular displacement, when striking keys on a computer keyboard, by Kuo et al. (2006); the relationship between velocity of typing and other kinematic variables, by Angelaki et al. (1997); the kinematic variables of the fingers and hands of expert piano players, by Furuya et al. (2011); and the joint angle trajectories of the hand for fast tempo piano playing, by Goeble and Palmer (2013). Goeble and Palmer concluded, from their study, that the metacarpophalangeal joints contributed more than other joints to fingertip striking motion.

2. Methods

2.1 Objectives

The objectives of this study were to:
(i) Identify, measure, and analyze kinematic (joint motion) variables (angular displacement, velocity, and acceleration) of the index finger and thumb of the dominant hand, while playing a video game in two different protocols
(ii) To compare the kinematics between the two protocols of video gaming
(iii) To compare the kinematics among seven finger joint motions used in video gaming

2.2 Participants

Ten student participants, eight male (mean age 27.5 ± 4.2 years) and two females (mean age 27± 3 years) were recruited for the study by an advertisement on a university campus. They were all acquainted the game controller used in the study. Permission was granted by the University's Institutional Review Board to conduct he study.

2.3 Task description

The task was to play a video game called Facebreaker (Electronic Arts, CA, 2008), on a Sony PlayStation III (PSIII) gaming console. The game was chosen for it's simplicity, with a limited number of boxing motions, A specific sequence of boxing moves was established to standardize the task. Participants sat comfortably on a chair and played according to two game protocols, a sequenced protocol and a natural protocol. A predetermined sequence in button pressing was carefully chosen for the sequenced protocol in which all buttons were pressed. In the natural protocol, the gamer played the game as it should be played, normally, without any predetermined moves. All subjects practiced both protocols before data gathering was started to eliminate or minimize learning effects.

2.4 Joints and muscles of the hand

Reflective markers were placed on the appropriate positions of the hand and fingers to facilitate measurement of the motion of the finger joints. Since space on the hand and fingers was limited for the markers, only the thumb and index fingers were investigated. These two fingers were used predominantly for operating the game controller. Flexion-extension (f-e) and abduction-adduction (ab-ad) motions were measured on the following joints:

Metacarpophalangeal joint flexion-extension of the thumb (MCP1 f-e)
Metacarpophalangeal joint abduction-adduction of the thumb (MCP1 ab-db)
Interphalangeal joint flexion-extension of the thumb (PIP1 f-e)
Metacarpophalangeal joint flexion-extension of the index finger (MCP2 f-e)
Metacarpophalangeal joint abduction-adduction of the index finger (MCP ab-db)
Proximal interphalangeal joint flexion-extension of the index finger (PIP2 f-e)
Distal interphalangeal joint flexion-extension of the index finger (PIP2 f-e)

2.5 Hand preparation and data collection

The right hand was first shaved of hair and cleaned, by wiping with with alcohol, before attaching the reflective markers. Thirteen reflective markers of 4 mm diameter were then placed on that hand (three on thumb, four on index finger, three on hand, and three on wrist). Video data was collected on a VICON system at a rate of 60 Hz, and video frames were reconstructed in *workstation* software to model the marker movements in 3-D space. The motion data obtained from workstation software was modelled in Visual 3D software version 6.0. A static trial was performed by each participant, to establish a baseline to identify positions of the markers in order to construct hand segments in visual 3D. The X, Y and Z directions were defined as follows: the transverse plane of the body was the (x,y) plane, coronal plane was the (y,z) and sagittal plane was the (x,z) plane.

2.6 The kinematic variables

Inverse kinematics principles (C-Motion Research Biomechanics, "Inverse Kinematics", 2014) were used to calculate Euler angles of each segment with respect to X, Y and Z axes. Joint velocity (deg/s) was derived by differentiating the displacement angle with respect to time of movement; and joint acceleration, by differentiating the velocity with respect to time. Two types of averages were calculated:
(i) *Overall Average – the* average of a kinematic variable across all frames of an individual subject's data was first calculated, and the result was then averaged across all subjects, for each of the 14 task-joint combinations (2x7).
(ii) Maximal average: The maximum of a kinematic variable across all frames of an individual subject's data was first calculated, and the result was then averaged across all subjects, for each of the 14 task-joint combinations (2x7)

3. Results and Discussion

In all cases of joint motions, for both gaming methods, the kinematic variable (angular displacement, velocity, or acceleration) values were vastly different between the maximal and overall averages, as expected. Direct comparisons of variable values among joint motions would be more meaningful when made within each type of average. The velocity and acceleration values reached very large values for some joints; the range for each joint action is shown below:
Overall angular displacement – 8.7 to 41.6 deg
Overall angular velocity – 8.1 to 25.0 deg/s
Overall angular acceleration – 98.1 to 404.4 deg/s^2
Maximal angular displacement – 20.1 to 89.1 deg
Maximal angular velocity – 78.5 to 460.9 deg/s
Maximal angular acceleration – 1510.2 to 49.76 deg/s^2
Between the two gaming methods, there were observable differences in angular displacement, velocity, and acceleration, for the various joints, but most of the differences were not statistically significant ($p>0.05$). The two-sample Wilcoxon-Mann-Whitney test (Wilcoxon, 1945; Mann and Whitney, 1947) showed that there were five statistically significant differences in joint angular displacement, one in velocity, and none in acceleration (Table 1). The joints that showed statistical differences were:
Overall average flexion-extension angle at IP1 (p=.0196)
Maximal average flexion extension angle at MCP1 (p=0.0041)
Maximal average abduction- adduction angle at MCP1 (P= 0.0375)
Maximal average flexion-extension angle at MCP2 (p=0.0375)
Maximal average flexion-extension angle at PIP2 (p=0.0375)
Maximal average velocity of flexion-extension at MCP1 (p=0.044).

Table 1. Angular displacements and velocities significantly different between sequenced and natural game protocols

Joint action	Sequential Gaming	Natural Gaming
Maximal Average Angle (deg)		
MCP1 f-e	65.7	22.8
MCP1 ab-ad	43.4	29.3
MCP2 f-e	30.7	24.5
PIP2 f-e	89.1	53.5
Overall Average Angle(deg)		
IP1 f-e	27.3	41.6
Maximal Average Velocity (deg/s)		
MCP1 f-e	160.2	106.8

Of the five angles, four were maximal averages and the other, an overall average. Five were for flexion-extension motions (associated with gripping). The maximal average angles of the metacarpophalangeal joint of both the thumb and index fingers were significantly different between the two gaming methods, reflecting the difference in hand gripping of game controller for the two games. The natural gaming task seems to be more strenuous, based on the kinematic data, though most of the kinematic variable values were not significantly different between the two gaming methods.

A higher maximum velocity for flexion-extension was achieved at the MCP1 joint for natural gaming compared to sequential gaming ($p<0.05$), indicating greater finger activity for natural gaming compared to sequential gaming. In sequential gaming, cautious and slower movements of the fingers were made to maintain the predetermined sequence of key pressing. Strike rates (button pressing) were also very high -- 4.5 strikes per second for natural gaming, and 2.65 strikes per second for sequential gaming.

No data was available in the published literature for video gaming kinematics to make direct comparisons with the results in this study. However, there is a limited amount of kinematic data for other tasks -- single thumb key press texting (Gustaffson et al., 2010), typing on keyboards (Baker et al., 2007), and single thumb typing on touch screen phones using a claw grip (Hogg, 2010). The data from Baker et. al (2007) showed much smaller velocity and acceleration values with the little finger (48°/s and 776.5°/s^2 compared to 271.56°/s and 5463.9°/s^2) than the data in present study.

Considering the number of strikes per unit time found in this study, it is not surprising that repetitive motion traumas, mentioned in the Introduction section of this paper afflict gamers who play for prolonged periods of time, and no one knows how may finger motion repetitions are tolerable per unit time. It seems that a few improvements in the game controller may help in decreasing the susceptibility to CTD's of the hand: making the side buttons larger to reduce the pressure on the finger from the tapping force; increasing the touch sensitivity of the buttons so that less finger force and smaller velocity and acceleration of finger movements are required; better distribution of the keys to other parts of the controller to use the other fingers more. It is acknowledged that these recommendations would compete with other design features, such as aesthetics, which may not produce the best function and safest game controller.

4. Conclusions

The results of this study showed that very high velocities and accelerations were achieved for flexion-extension motions of the interphalangeal joints of the thumb but sharp bending occurred for the flexion of the index finger. Lateral finger motions (abduction-aduction) were less deviated and slower for both types of games. These extreme motion characteristics may predispose regular gamers to cumulative trauma disorders in the hand. The data from this study were from a controlled laboratory study and may not necessarily correspond perfectly to how people actually play the game. It is not known how differently other games are played, but the results of the study should provide a starting point in the analysis of finger motions in using hand held devices that require repetitive finger motions

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