Research Article

Upper limb muscle activation during sports video gaming of persons with spinal cord injury

Jeffrey P. Jaramillo, M. Elise Johanson, B. Jenny Kiratli

Spinal Cord Injury and Disorders Center, VA Palo Alto Health Care System, Palo Alto, California, USA

Objective: Video gaming as a therapeutic tool has largely been studied within the stroke population with some benefits reported in upper limb motor performance, balance, coordination, and cardiovascular status. To date, muscle activation of upper limb muscles in persons with spinal cord injuries (SCI) has not been studied during video game play. In this paper, we provide descriptive and comparative data for muscle activation and strength during gaming for players with tetraplegia and paraplegia, as well as, compare these results with data from traditional arm exercises (ie, biceps curl and shoulder press) with light weights which are commonly prescribed for a home program.

Participants: Fourteen individuals with chronic SCI (9 tetraplegia, 5 paraplegia).

Design: We measured upper limb muscle activation with surface electromyography (EMG) during Wii Sports video game play. Muscle activation was recorded from the playing arm during 4 selected games and normalized to a maximum voluntary contraction (MVC).

Outcome measures: Heart rate and upper limb motion were recorded simultaneously with EMG. Wilcoxon signed rank tests were used to analyze differences in muscle activation between participants with paraplegia versus tetraplegia and compare gaming with traditional arm exercises with light weights. A Friedman 2-way analysis of variance identified key muscle groups active during game play.

Results: Overall muscle activation across the games was not different between those with paraplegia and tetraplegia. Heart rate during video game play for tennis and boxing were on average 10 to 20 beats/minute above resting heart rate. The magnitude of EMG was relatively greater for traditional arm exercises with light weights compared with game play.

Conclusion: The selected Wii games were able to elicit upper extremity muscle activation and elevated heart rates for individuals with SCI that may be used to target therapeutic outcomes.

Keywords: Paraplegia, Tetraplegia, Video games, EMG, Upper limb, Exercise

Introduction

Video gaming represents an appealing strategy to encourage individuals with physical disabilities to perform large amplitude upper limb movements that can mimic the movements associated with actual sports. Participation in virtual games produces high volumes of repetitive movements¹, requires the player to grade the level of force to accomplish tasks successfully, and incorporates visual and auditory feedback which are all considered to be key ingredients important for motor learning.^{2,3} Thus, these features may be applied to strengthen residual motor resources in persons with

paralysis after spinal cord injury (SCI) and could be used in training paradigms to teach new movement strategies to accomplish tasks. Despite a dearth of evidence of clear physical benefits from the use of virtual reality/gaming to enhance upper extremity motor performance, it remains an alluring adjunct to therapy for many clinicians. Video gaming has the potential advantage over traditional exercises of producing a high level of repetitions as well as complex, integrated movements to enhance motor skills and increase adherence to exercise regimens which could drive recovery and maintenance of function.^{4,5}

Nintendo's Wii video games have largely been studied within the post-stroke population. The reported benefits include increased upper limb motor performance, balance, coordination, and cardiovascular

Correspondence to: Jeffrey P. Jaramillo, DPT, SCI/D Research Lab Manager, Spinal Cord Injury Center (640/128), VA Palo Alto Health Care System, 3801 Miranda Avenue, Palo Alto, CA 94304, USA; Ph: 650-493-5000, ext 62286, Fx: 650-496-2523. Email: jeffrey.jaramillo@va.gov

improvements.^{5–10} A few studies in both the adolescent and geriatric non-disabled populations have shown reduction in pain as well as improved upper extremity active range of motion.^{11,12} Other studies with post-stroke participants report limited or no benefits for upper extremity function while using Wii video games.^{10,13,14} There is a lack of information to what degree upper limb musculature is recruited for video gaming activities in general. To our knowledge there is no evidence of how muscle activation compares between video gaming and commonly prescribed resisted exercises with light hand weights, which are therapeutically prescribed for home exercise programs. Only two published studies have reported the benefits of video gaming for persons with chronic SCI in which positive effects on energy expenditure, gait, balance, and quality of life were reported.^{15,16} However, despite the reported improvements from gaming, there is no published information regarding its effects on muscle activation after SCI or in other populations with upper extremity paresis. Knowledge of the muscle activation patterns associated with specific games will assist therapists in choosing games that target patient-specific goals toward improving upper limb function.

We conducted a study with individuals who have chronic SCI using the Nintendo Wii video gaming system. The purpose of the study was to identify key muscle groups of the upper limb associated with selected games for persons with paraplegia and tetraplegia. Our primary aim was to explore if inherent weaknesses in grip and upper extremity musculature for persons with tetraplegia would show patterns of marked compensatory muscle activation during gaming tasks. A second aim was to explore how muscle activation would compare between gaming and common arm exercises performed with light weights. Heart rate measures were included to assess the effects of exercise in response to a gaming session. Here we report results from single session play of four Wii sport games: Bowling, Golf, Tennis, Boxing.

Methods

Protocol

Participants with SCI were recruited for this study of video gaming using the Wii gaming system (Nintendo of America Inc., Redmond, Washington, USA). Training was provided in a laboratory setting to instruct participants how to play four video games (bowling, golf, tennis, and boxing). While instruction was provided on how to use the controller and play each game successfully (e.g. when to release the controller button to time releasing a bowling ball), participants were not

coached on how to move their arms to accomplish game play tasks and were allowed to explore and develop their own motor plans for successfully accomplishing gaming tasks. For those who were unable to grip the controller, accommodation was made by ace-wrapping the controller to the hand to insure safety and ability to hold onto the controller during gaming.

A 90 minute training session to familiarize the person with each video game was followed by a separate 90 minute data collection session during which participants played the four games in a randomized order (determined by an Excel random number generator). Each individual was provided with breaks and each game was played on average of 10 minutes. Dynamic measurements of muscle activation, upper limb motion and heart rate were recorded simultaneously. Each person also performed a commonly prescribed arm curl and shoulder press exercise with a 1.36 kg weight.

Participants

Fourteen individuals (3 females, 11 males) with SCI (9 tetraplegia, 5 paraplegia) with a range of A to D ratings on the American Spinal Injury Association Impairment scale (AIS) participated in the study. The mean age of the group was 50.4 years (SD = 14.2) and the time since injury averaged 16.7 years (SD = 11.6). Demographic characteristics are presented in Table 1.

Strength testing

Strength of the playing arm was evaluated during the data collection session via manual muscle testing against gravity with a handheld dynamometer (Lafayette Manual Muscle Tester Model 01165, S.I.

Table 1 Participant demographics.

Injury Level	AIS	Sex	Age (years)	Duration (years)
<i>Paraplegia (n = 5)</i>				
T3	C	M	64	9
T6	A	M	65	12
T6/9	B	F	32	12
T10/11	A	M	47	6
T12	B	M	58	39
<i>Tetraplegia (n = 9)</i>				
C4/5 *	B	M	37	11
C5/6*	A	F	55	39
C6*	A	M	47	23
C6*	A	M	66	6
C6	B	M	21	2
C6/7	A	M	47	18
C6/7	A	M	66	27
C7	D	F	38	18
C7	B	M	63	12

*Ace wrap was used to secure game controller in hand.
AIS, American spinal injury association impairment scale; T, thoracic; C, cervical; F, female; M, male.

Instruments, Hilton, SA, Australia). Participants were tested while seated in their own wheelchairs utilizing muscle break tests and standardized muscle testing positions. Strength (kg) was recorded during shoulder flexion, extension, abduction, internal and external rotation; during elbow flexion and extension; and during wrist flexion and extension. Three manual break tests were performed for each muscle group and the results averaged for each person (Table 2).

Electromyography (EMG)

Muscle activity was measured on the playing arm using surface EMG (Motion Lab Systems, Baton Rouge, LA, USA). Raw EMG was recorded as participants performed each of four Wii Sports games: bowling, golf, tennis and boxing as well as the arm curl and shoulder press movements. EMG was recorded for six muscles including anterior deltoid, medial deltoid, biceps brachii, triceps (lateral head), wrist flexors (flexor carpi radialis), and wrist extensors (extensor carpi radialis longus and brevis). Surface electrodes, spaced 17 mm apart, were placed on each target muscle, pre-amplified at the skin surface, and sampled at 2000Hz. EMG was recorded with a fourth-order Butterworth band-pass filter from 10 to 500 Hz. EMG signals were expressed as a percentage of the maximum voluntary contraction (MVC). MVCs were obtained by manually resisting the maximal voluntary movement for each muscle group for each participant. Three maximally resisted movements were averaged to obtain the MVC of each muscle group for each participant. Processing was performed offline and the MVCs were used to normalize EMG signals for each muscle group to allow comparisons across participants.

A custom Matlab program was used for post-processing all EMG data (Mathworks, Natick, MA, USA). The program identified the peak EMG for 0.5 second for each muscle during the flexion phase and the extension phase during game play. The root mean square

value of the 0.5 sec period was calculated and expressed as a percent of MVC. Fifteen representative signals from each muscle group for each peak extension and flexion cycle from three separate trials were averaged. Signals were obtained during 5 minutes of representative game play for each sport.

Motion capture

Upper limb movements were recorded using an electromagnetic motion capture system during the performance of each game (Motion Monitor with Ascension Flock of Birds, Innovative Sports Training, Inc, Chicago IL, USA). EMG was recorded simultaneously with motion capture data. Four markers were used to make a digital model of the playing arm. Marker placement included dorsal hand, mid dorsal forearm, mid lateral upper arm, and sternum. The motion of the shoulder in peak flexion/extension was used as an event marker to define one repetition of arm motion and to identify the flexion phase and the extension phase. Peak flexion and extension phases were defined from the anatomical neutral position of the arm resting next to the trunk (Fig. 1). EMG and motion data were recorded together during play with a heart rate monitor.

All participants were fitted with a Polartm heart rate monitor (Polar Electro Inc., Model H10, Lake Success, NY, USA). A resting baseline heart rate was established for 2 minutes prior to gaming. Heart rate was then continuously monitored during game play with a chest strap fitted with 2 electrodes. Heart rate

Table 2 Strength profiles of upper extremity muscle groups.

Testing position	Paraplegia Mean (sd)	Tetraplegia Mean (sd)
Shoulder Flexion	8.08 (1.73)	6.66 (2.31)
Shoulder Abduction	10.01 (3.53)	8.2 (1.92)
Shoulder External Rotation	10.55 (2.77)	*7.45 (2.72)
Shoulder Internal Rotation	15.87 (4.58)	12.36 (5.31)
Elbow Flexion	17.95 (3.94)	**14.86 (3.22)
Elbow Extension	14.15 (2.16)	*4.45 (4.43)
Wrist Flexion	10.79 (3.02)	*3.59 (2.59)
Wrist Extension	10.54 (2.45)	*4.81 (3.39)

*P < 0.001; **P < 0.05 denotes differences between groups. Strength measured in Kilograms. sd, standard deviation.

Figure 1 The motion occurring at the shoulder during a repetition of game play was used to define an extension phase (A) and a flexion phase (B) for each game. The flexion phase and extension phase defined one repetition that was repeated during game play (average of 10 minutes). EMG from each muscle group was sampled at the time of peak shoulder flexion and at the time of peak shoulder extension (independent of the other joint motions). These data were used to quantify EMG amplitude, normalizing to MVC.

was recorded at five second intervals at the end of each 30 second bout of motion capture. Data were downloaded after the session and averaged over a 5-minute representative time period recorded during the performance of each game.

Data analysis

Differences between EMG activity recorded from participants with paraplegia and tetraplegia for each muscle, for game activity versus two arm exercises with hand weights, and for pre-game strength testing between groups were calculated using Wilcoxon signed rank tests ($P < 0.01$). A Friedman two-way analysis of variance (for repeated measures) was used to compare the combined activity (from all games) across the six muscles. The amplitude of normalized muscle activation within each game was ranked for the flexion and extension phases to identify the key muscle group for each game. Descriptive statistics were reported for heart rate before and after the gaming sessions (Table 3).

Results

Upper extremity strength

Strength testing revealed higher muscle forces, on average, across all eight muscle group movements for participants with paraplegia compared to those with tetraplegia (Table 2). Shoulder external rotation, elbow flexion and extension and wrist flexion and extension strength were significantly higher for the group with paraplegia ($P < 0.05$).

Heart rate

Heart rate recorded during video game play showed that both the games of tennis and boxing were on average 10 to 20 beats/minute above resting heart rate (Table 3). In contrast, bowling and golf resulted in less than 10 beats/minute increase above resting for both groups.

Comparison of muscle activation between paraplegia and tetraplegia

There were significant differences in the magnitude of the EMG recorded from the group with paraplegia

compared to the group with tetraplegia. EMG activity was higher in those with paraplegia during the flexion phase for the biceps during bowling ($P = 0.0124$) and boxing ($P = 0.0056$) when compared to those with tetraplegia (Fig. 2). EMG activity was higher in tetraplegia during the extension phase including; for the anterior deltoid ($P = 0.0025$) during bowling, wrist extensors during golf play ($P = 0.0053$), wrist flexors during bowling ($P = 0.0240$) and during boxing ($P = 0.0410$), when compared to paraplegia. Levels of EMG activity were not significantly different between paraplegia and tetraplegia during flexion for the remaining muscles tested (anterior and medial deltoid, triceps, wrist flexors and extensors) across all games. Similarly, there were no significant differences between the groups for the extension phase across games for the medial deltoid, biceps or triceps.

Key muscle group activation during gaming

The magnitudes of EMG recorded in the upper extremity muscles during the four selected Wii sports games were in the range of 16 to 52% of MVC during the flexion phase for the group with paraplegia and 17.5 to 58.9% MVC for the group with tetraplegia (Fig. 2). Magnitudes of EMG were in the range of 7 to 47% of MVC during the extension phase for paraplegia and 12 to 41% for tetraplegia.

There were significant differences between the combined activation levels for each muscle group across all four games during both flexion and extension phases ($P < .05$). During the flexion phase, the anterior deltoid and wrist extensors were activated at a greater level for boxing and bowling in both groups compared to the other muscles ($X^2_r = 14.4$, $df = 5$, $n = 4$, $P < 0.05$). During the extension phase, EMG activation was greatest for the wrist extensors in both groups across all games ($X^2_r = 14.1$, $df = 5$, $n = 4$, $P < 0.05$).

The six muscles were ranked in order of magnitude for each game separately (Fig. 3). This ranking allows a better visualization of which muscles were activated the most across different sports. The anterior deltoid and wrist extensors were activated at higher levels during the flexion phase across most sports for both paraplegia and tetraplegia. The wrist extensors were also activated heavily for extension phase movement across all sports for both groups. For example, the sports of bowling, golf, and tennis activated the triceps better than boxing during the extension phase for those with tetraplegia. In this way one can use the table to select games to therapeutically target muscle activation.

Table 3 Heart rate during Wii video game play.

Game	Paraplegia Mean (sd)	Tetraplegia Mean (sd)
Resting	72.2 (15.2)	70.0 (9.9)
Bowling	77.4 (13.6)	75.9 (10.4)
Golf	77.0 (13.3)	74.6 (10.9)
Tennis	*81.9 (12.1)	*79.2 (10.2)
Boxing	*93.3 (15.0)	*91.4 (13.6)

* $P < 0.05$ denotes different than resting heart rate.
Heart rate expressed in beats/minute.

Figure 2 Normalized Electromyography (EMG) activation during game playing of four sports: bowling, golf, tennis, and boxing. EMG data are expressed as percent of maximal voluntary contraction (MVC) for each muscle group in the flexion phase (left side graphs) and extension phase (right side graphs). Mean EMG is shown separately for participants with paraplegia (grey bar) and tetraplegia (black bar). Differences between groups are noted as statistically significant with $p < 0.01$ and marked with an asterisk (*).

Wii video gaming vs. commonly prescribed arm exercise with hand weights

The magnitude of EMG for two prime mover muscles (anterior deltoid and biceps) while performing

commonly prescribed resisted exercises (shoulder press and arm curl) that targeted these muscles were compared to the activation level during the four Wii sports games (Table 4). Mean normalized EMG for the

A.

Task	Flexion Phase					
Paraplegia	Anterior deltoid	Medial deltoid	Biceps	Triceps	Wrist extensors	Wrist flexors
Bowling						
Golf						
Tennis						
Boxing						
Tetraplegia	Anterior deltoid	Medial deltoid	Biceps	Triceps	Wrist extensors	Wrist flexors
Bowling						
Golf						
Tennis						
Boxing						

B.

Task	Extension Phase					
Paraplegia	Anterior deltoid	Medial deltoid	Biceps	Triceps	Wrist extensors	Wrist flexors
Bowling						
Golf						
Tennis						
Boxing						
Tetraplegia	Anterior deltoid	Medial deltoid	Biceps	Triceps	Wrist extensors	Wrist flexors
Bowling						
Golf						
Tennis						
Boxing						

Key

Color	Rank	% EMG
	1	higher
	2	
	3	
	4	
	5	
	6	lower

Figure 3 Muscle activation ranked within each game during the flexion (A) and extension (B) phases for both groups. Each muscle is color coded based on its ranked activation level for each game. Muscles were ranked 1 (highest) thru 6 (lowest) based on level of activation for each sport. Ranking was done for both flexion and extension phases of arm movement.

anterior deltoid during the shoulder press was significantly greater ($P < 0.01$) compared to the activity recorded during any of the four Wii sports games for those with paraplegia. For tetraplegia, mean normalized EMG from the anterior deltoid recorded during the shoulder press was significantly greater for golf and tennis but not for bowling or boxing ($P < 0.001$).

Mean normalized EMG for the biceps (44.7%) during the arm curl for those with paraplegia was significantly greater than that recorded during golf (32.7%) and tennis (26.2%) but not bowling (39.5%) or boxing (37.0%). For the group with tetraplegia, the biceps EMG recorded during the arm curl was higher for bowling, tennis, and boxing, but not golf ($P < 0.001$) (Table 4).

Table 4 Comparison of EMG activation between Wii sports games and two commonly prescribed resisted exercises.

Muscle	Group	Traditional exercises		Wii sports games			
		Arm curl	Shoulder press	Bowling	Golf	Tennis	Boxing
Anterior deltoid % MVC Mean/range	Paraplegia	NA	68.4 (53.9 - 82.9)	*52.6 (37.0 - 68.2)	*29.0 (18.2 - 39.8)	*44.4 (25.9 - 62.8)	*51.2 (34.9 - 67.5)
	Tetraplegia	NA	57.6 (44.4 - 70.8)	58.9 (47.9 - 69.9)	*38.1 (27.8 - 48.4)	*36.5 (26.9 - 46.1)	55.9 (48.6 - 63.2)
Biceps % MVC Mean/range	Paraplegia	44.7 (26.0 - 63.3)	NA	39.5 (25.7 - 53.4)	*32.7 (22.9 - 42.4)	*26.2 (17.6-34.9)	37.0 (24.7 - 49.3)
	Tetraplegia	34.8 (24.9 - 44.7)	NA	*22.2 (15.5 - 22.2)	31.3 (23.2 - 39.3)	*23.6 (14.9 - 32.3)	*17.5 (11.5 - 23.6)

*P < 0.001; Significant differences are reported between the commonly prescribed resisted exercises and Wii sports games for the prime mover muscles (anterior deltoid and biceps). NA, not applicable (Values were reported only for the prime mover for each exercise).

Discussion

The similarity of muscle activation patterns between groups suggests one could utilize any of the sports to target muscle activation in the upper limb for persons with either paraplegia or tetraplegia. Further, we found that bowling and boxing produced the highest levels of muscle activation (Table 4). Other studies^{15,17} have reported the best Wii sports for energy expenditure were tennis and boxing which corresponds to the elevated heart rates and higher levels of muscle recruitment seen in our study. The similarity between muscle activation for each sport between paraplegia and tetraplegia indicates that movement patterns in the upper limb were also similar between groups. We suggest that movement patterns of the shoulder, elbow and wrist may change over time as participants gain more experience with each game. For example, with experience, they may learn they can “cheat” by using more wrist actions to accomplish movements because the controller will respond to small amplitude movements to complete tasks. That is, serving a tennis ball can be accomplished by flicking the controller upward rather than performing full arm flexion mimicking how a traditional tennis serve is done in the “real world” sport activity. By learning to cheat the system, players could shift to smaller amplitude movements and from proximal muscle usage toward biased distal muscle usage to minimize energy expenditure and still score points. However, all participants in our study chose to play the selected sports with larger amplitude movements to simulate what they perceived to be good form. Their perceptions of how to play came from either playing the real sport previously or watching as a spectator. This concept is supported by other work which has indicated that people play games the way they have observed the real sports should be played.¹⁸ Rehabilitation professionals could discourage cheating and encourage maximum

benefit by suggesting adaptive approaches such as manually pivoting the wheelchair while playing tennis to increase whole body movement and maintain larger amplitude movements. Incorporating a variety of games that require different motor patterns might be another strategy to encourage a full range of movements.

One difference observed between groups was the lower activation of the biceps muscle during bowling and boxing for the tetraplegia group during the flexion phase of game play. Successful play during these sports necessarily involves motion at the elbow. For individuals with tetraplegia, elbow extension strength is typically weak (Table 2) thus the ability to prevent excessive flexion with a strong antagonist such as the triceps is compromised. It is noted that a strategy to control joint posture during play may be to voluntarily lower the agonist activation (i.e. biceps) in the presence of a weak antagonist (i.e. triceps).

During the extension phase, there were several muscles with significantly higher activation levels in the group with tetraplegia. These differences are most likely based on the weaker motor resources inherent in persons with tetraplegia, especially in the distal musculature. For example, higher activation level for the wrist extensors in the tetraplegic group, specifically for the sport of golf, was most likely a function of utilizing their stronger wrist extensors as a strategy to manipulate the golf club head rather than their weaker wrist flexors. This movement pattern was also anecdotally observed. We interpreted the increased activity of the wrist flexors for the games of bowling and boxing as an attempt to grip the controller tighter for these large amplitude and rapid movements. We postulate that the anterior deltoid was higher for persons with tetraplegia during the bowling extension cycle as a means to maintain more proximal control of the shoulder joint.

The triceps was substantially active in both groups and there were no significant differences in activation between paraplegia and tetraplegia despite the differences in strength between groups. This difference highlights the importance of recognizing that strength and muscle activation should always be considered separately. The higher activation of the biceps during arm flexion cycles for bowling and boxing for those with paraplegia compared with tetraplegia is most likely due to weaker triceps which in turn inhibits activation of the flexors (biceps) for breaking during these large amplitude arm flexion cycles. It is important to note that while the inherently weaker triceps could be effectively recruited during sports like tennis and boxing, the normalized activation level of the triceps in persons with tetraplegia may not be representative of the actual force produced during contraction. The activation level may be due to higher firing rates of fewer motor units.¹⁹ A weaker muscle may be subject to fatigue from highly repetitive actions which could lead to potential overuse and emergent compensatory movements to complete the video sport tasks.

Ranking the level of recruitment for all six muscles revealed that the anterior deltoid and wrist extensors were activated the most for all four sports games for persons with tetraplegia indicating these muscles were primarily being used to complete all the gaming tasks. Similarly, the anterior deltoid and wrist extensors were primarily recruited for playing boxing and bowling for the paraplegic group, however the medial deltoid was employed more for tennis and the triceps more for golf tasks. These differences most likely represent the availability of stronger resources to accomplish game tasks for those with paraplegia.

Comparison of the Wii sports tasks to two commonly prescribed exercises performed with wrist weights indicated muscle activation was higher in the muscles that were the prime movers for each of traditional exercises. This would be expected as the wrist weight was heavier than the game controller. However, the overall difference of activation levels across all the muscles that were monitored was similar in overall magnitude between the Wii gaming and the two commonly prescribed resisted arm exercises. That is, if the goal of therapy is to increase selected muscle strength, conventional strengthening exercises may produce the best outcome. Another option would be to add weights to the gaming arm to increase the resistance to play which may achieve an equal or better strength result. However, applying weights should be done cautiously as this potentially could both create compensatory movement strategies and increase the strain and

chance of overuse injury. The advantage of gaming would be to facilitate upper limb coordinated movement by activating both agonists and antagonists in coordinated movement patterns. It is important to recognize that movements may dictate different levels of muscle activation as people play faster or slower based on task requirements and physical ability. Further we suggest that gaming may offer a more engaging option and thus adherence may be higher resulting in a better therapeutic outcome.

Muscle activation levels and strategies may change as an individual's skill levels increase and or the video gaming system offers picking player status (beginner to advanced) both which in turn makes the play more challenging. Additionally, as the player's avatar (Wii Mii) gains in ranking to "Champ" status, the level of play becomes more difficult which often requires more rapid movement and skill which could change muscle recruitment levels. Conversely recruitment could also be less with increased play time as movement requirements could become more fluid and less extraneous movements and effort may become more limited.

Using video gaming such as the Nintendo Wii as an adjunct with conventional therapy for targeting muscle activation in persons with neurologic conditions is an appealing technique. It has advantages over traditional exercise with hand weights because of the demands placed on the upper extremities to produce dynamic movements that are complex and require mediating forces to accomplish the sports tasks. Whether this muscle activation can help produce strength gains and or improve functional movements in persons with neurological conditions needs further investigation. Studies in the stroke population have had mixed results in using virtual reality that have demonstrated actual functional improvement in the upper extremities.^{9,12,13} Understanding muscle activation during video gaming can help guide rehabilitation specialists towards targeting therapeutic interventions with specific gaming tasks.

Study limitations

This was a limited study to explore muscle activation patterns, and so the small number of participants (N = 14) is not adequate to generalize the findings to a larger SCI population. Additional study is needed to capture the range of responses that would be expected due to the intrinsic heterogeneity with a larger sample. We recognize that although participants were familiarized on how to play the games, muscle activation was only recorded on a single session and may change with greater playing time and increasing experience. Also,

standardizing the traditional exercises with a 1.6 kg weight, rather than determining weight per each individual, may have produced under recruitment of muscles specifically in the tetraplegic group.

Conclusion

In this study, the playing of Wii video sports games produced meaningful magnitudes of EMG in the upper extremity muscles of the spinal cord injured participants. There were only a few differences observed between muscle activation between players with paraplegia and tetraplegia despite differences in available motor resources. While EMG magnitude was greater for commonly prescribed arm exercises with light weights, this difference might be mitigated if weights were applied during video game play. These findings may be relevant towards designing therapeutic exercise programs that integrate video gaming which can readily be deployed in the home and may help to facilitate functional movement outcomes as well as contribute to enhanced cardiovascular training. Based on our findings, future studies should look at adjunctively integrating video games for chronic SCI individuals to enhance muscle activation and cardiopulmonary training with traditional training paradigms.

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